Appendix D
Urban Stormwater Economics

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A Comparative Cost-Benefit Study of Site Technologies & Strategies for the City of Toronto

Pierre Bélanger

Executive Summary

Over the next 25 years, the City of Toronto will spend $1 billion dollars on the management of stormwater and wastewater systems that service the 5.5 million people spread across the Greater Toronto Area. Dependent on an infrastructure of curbs, gutters and underground pipes underlying a region of 600 square kilometres, the stormwater system that currently supports the city is being put into question by the pressure of an urban population expected to reach almost 8 million by 2025. Evidenced by increasing flood incidents, combined sewer overflows, equipment decay, operational breakdowns, rising maintenance costs, beach closures and groundwater depletion, the capacity of the 26-billion dollar water utility is reaching a tipping point, both economically and ecologically.

How then can we re-structure the current stormwater system to exploit the dynamic forces of rain events, snow melts and storms while promoting growth and development of cold climate cities?

Re-questioning the predominance of centralized infrastructure in North America, this report provides an introduction to the technologies and the systems associated with contemporary stormwater conservation and their potential effects on the city as an urban landscape. At the center of this watershed moment, are strategies of bioretention and infiltration that simply rely on the ground as a living ecological resource. Using the Toronto Green Development Standard as a baseline, examples of conventional and contemporary water management from across North America are compared to better understand the costs and benefits of stormwater practices. A growing body of evidence emerging from the past decade is demonstrating that end-of-pipe systems of conveyance and control have reached a point of diminishing returns, and that decentralized systems of water conservation offer distinct alternatives to traditional engineering. From permeable surfaces to forest ravines, the spectrum of contemporary conservation practices bear considerable potential for achieving economies of scale across different sectors of the urban economy. When factoring the total lifecycle of stormwater infrastructure, the long term advantages of tactical water conservation simply grow beyond individual sites and expand over time, with foreseeable impacts on the structure of the city as well as the urban life it supports.

Realigning and combining issues related to water, transportation and energy systems, downstream effects of stormwater conservation further demonstrate the critical agency of that landscape planning and landscape management hold at the regional watershed level. If groundwater replenishment, energy conservation, carbon sinking and air quality are the denominators of long term conservation and robust urban development, then the future of big cities on the coastline of the Great Lakes necessarily starts with the landscape and infrastructure of its water.

Objective & Scope

This document provides a comparative cost-benefit study of different technologies used in the management of urban stormwater. Using the technologies and practices listed in the *Toronto Green Development Standard* (January 2007)[1], the report reviews and synthesizes proposed practices and their impacts. The main objective is to substantiate the economic value of contemporary stormwater strategies while the ulterior objective argues for the understanding of the added value of ecological integration of these strategies within the urban context of the Greater Toronto Area through design.

This study is set within the context of Toronto as a metropolitan area in the Great Lakes Region, a geographic region with over 35 million inhabitants formed by the combined watersheds of Lake Ontario, Erie, Huron, Michigan and Superior. Other cities in this watershed region include Chicago, Detroit, Cleveland, Buffalo, Windsor, Sudbury and Hamilton to name a few. From a regional perspective, several areas of the Greater Toronto Area along the lakeshore are currently enlisted as part of the 43 Areas of Concern (AOC) in the Great Lakes, areas - mostly former harbours and ports - designated as severely degraded from port activities, contaminated industrial effluents and wastewater discharges.[2] As a result, the city of Toronto has developed a $1 billion *Wet Weather Flow Management Program*[3] that will be implemented over the next 25 years to improve the quality of its waters. From a North American perspective, the City of Toronto is unique given the current traction of multi-billion dollar public works spread across more than 1000 hectares of contaminated land along Toronto's waterfront.[4] Furthermore, The City of Toronto currently estimates that a storm water utility to cover the cost of stormwater management across its land area would require over a billion dollars in capital expenses and $233 million in operating expenses for the next 25 years.

From a global perspective, the general attitude of Torontonians, and Canadians at large, to water conservation is paramount to the understanding of this report. Facts about Canada's water pricing and consumptive behaviour for example, present an interesting, albeit paradoxical, contradiction. According to the World Water Commission, Canadians pay the smallest amount for fresh drinking water than any other country in the world ($0.31/m^3 in Canada compared to $2.16/m^3 in Germany) and they are the largest consumer of fresh water in the world (335 litres per day per capita in Canada compared to 135 litres per capita in Israel). Though inconclusive, this evidence suggests that despite all commonly held assumptions and good intentions, Canadians do not really seem to care about water conservation.

Across the Canadian landscape, there are a few other important facts about water usage and water flow as primers to this report:

- In 2001, Canadians used an average of 335 litres of water each day.
- A mere 10% of home water supply is used in the kitchen and as drinking water.
- About 65% of home water use occurs in our bathrooms, with toilets being the single greatest water consumer.
- Indoor water use peaks twice a day year-round, in the mornings and evenings.
- The biggest peaks during the year occur in the summer, when about half to three quarters of all municipally treated water is sprayed onto lawns.

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1 *Toronto Green Development Standard* (January 2007): www.toronto.ca/planning/greendevelopment.htm

2 Sierra Legal, "US, Canadian cities fouling the Great Lakes with raw sewage - Sewage Report Card reveals Great Lakes cities not making the grade" (November 29, 2006) www.ecojustice.ca/media-centre/media-release-files/bgr.great.lakes.sewage.nov.2006.pdf

3 See *Wet Weather Flow Management Master Plan* (WWFMMP): www.toronto.ca/involved/projects/archived/wwfmmp_archive/index.htm

4 With its size and geography in the Great Lakes, Chicago figures prominently as a comparative benchmark for the City of Toronto in the cost-benefit analysis of stormwater strategies. Over the past decade, the zealous initiative of Mayor Richard Daley has lifted Chicago to become a leader in urban landscape redevelopment throughout North America.

- As a community grows, the water use grows even faster because the diversity of water uses increases with size.
- By 1999, Canadian water use rose to 343 litres per person per day, enough water to fill 91,000 rail tanks cars every day or 7.9 billion litres per day if we factor the entire population of the country.[5]
- In 1999, a full 44% of Canadian residences served by municipal water systems were not metered. Also, 55% of Canadians faced residential water use charges that discouraged water conservation. These water pricing structures confirm that water use was 70% higher when consumers face flat monthly rates rather than volume-based rates.

The lack of full-cost pricing and conservation-oriented pricing structures has also contributed significantly to an imbalance between the demand and supply for water infrastructure. According to the *National Round Table on the Environment and Economy*, unmet water and wastewater infrastructure needs in Canada were between $38 and $49 billion in 1996, and capital costs for the following 20 years would be in the order of $70 to $90 billion.[6] At the same time, only 50% of the cost of maintaining and operating water infrastructure was actually being met through cost recovery from users of the systems. In summary, the combination of low levels of residential water metering, conservation-discouraging pricing structures and lack of real price increases in key rates has led to substantially increased residential water use levels in 1999 and will continue to erode municipalities' ability to finance needed infrastructure.

The regional, national and global landscape of water usage and conservation serves as a legitimate context to introduce a cost-benefit analysis of stormwater strategies in the Greater Toronto Area. Using studies from cold weather climates across North America, as well as precedents of stormwater technologies from across the US and Canada, this report provides facts, estimates and extrapolations about the costs of stormwater strategies. The report also evaluates the importance of including downstream benefits when assessing contemporary stormwater strategies, placed against a backdrop of contemporary perceptions, behaviours, attitudes and practices of water usage and wastage.

[5] High rates of consumption are explained by the absence of appropriate price checks and signals.
[6] In the conclusion of a report titled *The State of Municipal Wastewater Effluents in Canada* (2001), Environment Canada stated that: "Municipal wastewater effluents remain one of the most common contributors to a variety of local water pollution problems in many parts of the country. Beach closures, restrictions on shellfish harvesting, and degraded aquatic habitats that support fewer species are the most obvious of these problems, but the presence of persistent, bio-accumulative substances in municipal wastewater may also be contributing to other problems on a wider scale that may not immediately be apparent. To remedy these problems and to diminish the overall impact of municipal wastewater effluents on the environment, Canadians need to devote more effort and resources to wastewater management and the improvement of our wastewater treatment capabilities. In the first instance, this means bringing wastewater treatment to areas that do not at present have such facilities and improving existing facilities where they are not providing an adequate level of treatment. In many older communities, however, the reduction or elimination of CSOs is the most pressing priority, and in virtually every part of the country, better management of stormwater is essential. While the improvement of treatment facilities will play an important role in achieving these objectives, it is also important to look beyond end-of-pipe controls and implement other solutions, such as water conservation and metering or urban planning arrangements that provide better management of surface runoff. Not only will these measures lessen the impact of municipal wastewater effluents on the environment, but they will also reduce the cost of the impact." (Ottawa, ON: Minister of Public Works and Government Services Canada, 2001): p.51.

Exclusions & Disclaimers
This study is solely focused on the cost benefit ratio of urban site technologies related to the management of urban stormwater for newly constructed multi-family residential developments, condominiums, commercial developments and industrial properties.[7] While the study does discuss in part the implication and the importance of soft management strategies (pricing, policy, education), the study focuses primarily on structural methods of stormwater management in cold climates (retention basins, infiltration trenches, permeable pavements, compact development). The study excludes the cost benefits of technologies related to 1) retrofits of existing properties, 2) disconnected downspouts, rain gardens and other vegetated treatment systems for single family residences, 3) the treatment of agricultural and industrial effluents. While the subject of water usage and waste water effluent is vitally important to the discussion on stormwater management, the scope of the report is limited to stormwater management strategies. Nevertheless, it is important to stress that wastewater discharge is categorically the most important factor in the water quality of the Great Lakes today.[8]

In the case where conservation of existing biophysical or geophysical resources is involved, this study attempts to define the economic value and quantify the downstream benefits of many pre-existing hydrological systems such as creeks, streams, ponds, rivers, wetlands, and lakes, components of the urban hydrological system that cannot be dissociated from site-based technologies or sectoral stormwater systems. Consideration and valuation of these pre-existing resources as a form of capital is paramount to this report. Albeit subjective and complex, the evaluation of existing resources relies on accurate quantitative information to fully account for their impacts and benefits, a task that is further complicated by the scale and magnitude of dynamic systems. Ducks Unlimited Canada, a national, private, non-profit organization dedicated to the conservation of wetlands across the country, outlines the complexity of valuing existing biophysical resources in contrast to conventional assets:

> "Valuing natural capital is straightforward when the good or service has a market value (e.g. fish, timber). However, in many cases, hydrological goods or services of interest do not have a market value. In these situations their value can be calculated using a non-market valuation technique that calculates the cost society would incur if the good or service were lost. Converting our natural landscapes may be economically inefficient in the long term. By destroying natural capital, we are forced to find substitutes for the services they once provided. The substitutes for natural capital can be much more expensive to duplicate and operate than those provided by nature. Also, there are many goods and services only natural capital can provide. There are no substitutes [which] humans can create. As with other forms of capital, the value of natural capital can be depreciated. Each time we lose another hectare of natural land, we are depreciating our asset base and losing the goods and services that they once provided. Destruction and degradation of natural capital occurs continually. We may only recognize the loss of important ecosystems once they are gone – a loss that is often irreversible."[9]

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[7] For an in-depth cost-benefit analysis of retrofit measures at the urban level, see "Climate & Urban Stormwater Infrastructure in Canada: Context & Case Studies" (Report 2003-1) by W. Edgar Watt, D. Waters and R. McLean (Kingston: Queen's University Hydrology Research Group, 2003).
[8] As a result of combined sewer overflow, Toronto discharged 9 billion litres of wastewater in Lake Ontario in 2004. In comparison, Chicago does not discharge any wastewater into the Great Lakes Basin at all since most it is diverted into the Mississippi River. Dr. Elaine MacDonald delivers a stinging indictment of wastewater systems in Great Lakes cities at large in "A Peek at Green Strategies for Combined Sewer Overflows", *Ecojustice, formerly the Sierra Legal Defence Fund* (November 14, 2007). For an excellent account of the importance wastewater discharge in the Great Lakes, see "The State of Municipal Wastewater Effluents in Canada (1999)" by Environment Canada.
[9] See "Natural Capital and Ecological Goods & Services" in *Ducks Unlimited Canada, Natural Values: Linking The Environment To The Economy*, www.ducks.ca/conserve/wetland_values/conserve.html

In 2007, *t*he United Nations further confirmed this perspective by simply stating that:

> "Many services are degraded precisely because they are free to use but costly to provide."[10]

Combined with the cost benefit of constructed systems, the value of pre-existing systems is therefore enlisted as part of the scope of this report, since conventional forms of engineering and site development have neglected to incorporate the valuation of pre-existing ecologies as a capital resource system or as an essential urban infrastructure. Consequently, this report addresses the need to attribute value to the undervalued good and services of existing pre-development resources and ecological systems with contemporary stormwater strategies in order to engage a cogent discourse on the future of urban landscape.

About the Literature

Considerable literature currently exists on the subject of stormwater strategies using different methods of analysis in different geographic conditions spread across different climatic regions. The flood of information that is currently inundating the practice of stormwater management is at first glance, overwhelming and confusing. From the literature, the use of different terms and expressions such as "low impact development", "LID", "Smart Growth", "green development", "green infrastructure" "conservation design", "best management practices", "BMPs",[11] "soft landscaping", is widely used in different disciplinary circles such as planning, urban design and civil engineering, but they remain vague and poorly defined. This report does not seek to re-define these terms nor does it intend to invent new ones. Instead, this report purposely uses simple and basic principles grounded in the technical, spatial and ecological concepts that are applicable to any layperson or professional practitioner interested in the cost and benefits of urban stormwater management. A glossary is also provided at the end of the document for additional information and clarification.

Throughout this report, several reference documents, books, publications and articles were used to define, compare and evaluate the validity of findings from different studies. Due to the emergence of sophisticated environmental metrics which are providing new ways to measure urban environments, the literature on the subject of urban stormwater strategies that is constantly being revised, updated and improved. At best, the following report should be considered a synthesis and a generalization of these findings in order to meet the main objective of substantiating the costs and benefits of emerging standards in contemporary technologies for stormwater management.

In addition to the literature cited throughout the report and the reference documents listed in the bibliography, the following books have been consulted as the basic references for the definition of site technologies and design practices involving stormwater management:

Nicholas T. Dines & Charles W. Harris, *Time-Saver Standards for Landscape Architecture* (Washington, DC: McGraw Hill Text, 1997)

Michael Hough, *Cities and Natural Process: A Basis for Sustainability* (New York: Routledge, 1995)

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[10] See *Food and Agriculture Organization of the United Nations, The State of Food and Agriculture 2007: Paying Farmers for Environmental Services*, www.fao.org/docrep/010/a1200e/a1200e00.htm (accessed January 7, 2008)

[11] Best management practices and the principles of low impact development need to be considered in relationship to the basic principles of landscape ecology and site engineering that were established several decades ago. See *Landscape Ecology: Principles & Applications* by Richard T. T. Forman and Michel Godron (New York: John Wiley & Sons, 1986) and *Site Engineering for Landscape Architects* by Steven Strom and Kurt Nathan (New York: John Wiley & Sons, 1998).

For the purposes of cost-benefit evaluation and comparison, the following documents are used as main references:

> Center for Watershed Protection, “The Economics of Watershed Protection”, *Watershed Protection Techniques* Vol. 2 No.4: 469-481, and, *The Economics of Stormwater Treatment: An Update.* Technical Note #90, *Watershed Protection Techniques* Vol. 2 No.4: 395-499.
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> Christopher Kloss and Crystal Calarusse, *Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows (*NRDC, June 2006).
>
> National Resources Defence Council, *Stormwater Strategies: Community Responses to Runoff Pollution* (NRDC, May 1999).
>
> Conservation Research Institute, *Changing Cost Perceptions: An Analysis of Conservation Development*, Illinois Conservation Foundation & Chicago Wilderness (February, 2005).
>
> John B. Braden and Douglas M. Johnston, “Downstream Economic Benefits from Storm-Water Management”, *Journal of Water Resources Planning and Management* (November/December 2004): 498-505.

For the design and implementation of stormwater strategies and hydrological systems, the following books were used as main references:

> Steven Strom and Kurt Nathan*, Site Engineering for Landscape Architects* by (New York: John Wiley & Sons, 1998).
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> Deb Caraco and Richard Claytor, *Stormwater Best Management Practices Design: Supplement for Cold Climates* (US EPA Office of Wetlands, Oceans & Watersheds and US EPA Region 5, December 1997).
>
> Richard T. T. Forman, Wenche E. Dramstad and James D. Olson, *Landscape Ecology Principles in Landscape Architecture and Land-Use Planning* (Cambridge, MA: Harvard University, 1996)

From the onset of the research, it is important to confirm that the concepts and technologies presented in this report have been in use in one way or another over the past century and, continue to be commonly used in the interdisciplinary field of Landscape Architecture; a practice involving the planning, the design and the management of urban hydrology in relationship to urban land use and public space.[12] Furthermore, it is important to stress that these concepts and technologies are rooted in the basic principles of landscape ecology and site engineering; mainstays of the professional education, research and practice of Landscape Architects. As a result of the growing importance of stormwater management and water conservation at large, the field of Landscape Architecture has garnered considerable recognition during the past two decades throughout North America as the choice discipline in the management of water resources in relation to urban and regional development.

[12] For an introduction to the history and theory of Landscape Architecture, see *Design on the Land: The Development of Landscape Architecture* by Norman T. Newton (Cambridge, Belknap Press, 1971), and *Site Planning* by Kevin Lynch (Cambridge: MIT Press, 1984).

Introduction: The Challenge of Stormwater Management

The urban infrastructure in place in Canada today, and for the foreseeable future, reflects the approaches to managing urban stormwater over the last 100 years. This approach has relied on the underlying notion that stormwater, like solid waste, is a nuisance and that it should be disposed of as quickly as possible. Furthermore, the approach and the infrastructure in place today is likely to be utilized for the next decade or more because of the current inertia in urban water resources policy and management.[13]

From a national perspective, there is a great deal of inaction towards water usage and conservation policy in Canada. The history of municipal stormwater management has been dominated by the engineering of so-called efficient drainage systems to protect people and property[14], a history that cannot be dissociated from the chronology of past floods and storms across Canada and the United States.[15] Over the past decade however, with increasing forms of urbanization across North America, the impacts of conventional, specialized approaches to stormwater engineering (intended to collect, concentrate, convey, centralize and control) have had serious impacts on urban groundwater, watercourses and regional watersheds. These impacts have been well documented and include the following major effects:

1. The greater imperviousness that comes with urbanization results in higher volumes of stormwater runoff and higher peak flows in receiving streams, leading to increased flooding and streambank erosion.
2. During rainfall events, urban pollutants from streets, parking lots, and yards are washed off and deposited in streams and rivers, degrading water quality.
3. Increased imperviousness reduces the infiltration of rainwater, resulting in a reduction of base flow (dry weather flow) in streams and rivers.

These impacts can potentially threaten property and infrastructure, significantly impair aquatic habitat, and limit the recreational potential of local rivers and streams - all of which can lead to large expenditures to mitigate damage after the fact. These are referred to as the externalities of stormwater infrastructure or the downstream effects, and they play an extremely important and essential part in any discussion on the costs of stormwater strategies.

In recent decades, however, recognition of the need to protect the hydrological and ecological systems of watercourses has led to significant changes in how municipalities plan and practice stormwater management. The evidence points towards a tipping point in the conventional engineering of stormwater systems, whereas conventional methods and practice are reaching a point of diminishing returns: lifecycle costs now indicate that the cost of replacement of existing end-of-pipe infrastructure far exceeds the cost of alternative at-source stormwater strategies. Rapid urbanization, coupled with the succession of floods and storms that hit the Province of Ontario since Hurricane Hazel in 1954 have led up to the emergence, and explosion of conservation-based practices and new site technologies. Of no coincidence is it that the Toronto and Region Conservation Authority was concurrently given birth in 1957, some three years after Hurricane Hazel swept through the City of Toronto.

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[13] See W. Edgar Watt, D. Waters and R. McLean, "Climate Change and Urban Stormwater Infrastructure in Canada: Context and Case Studies" (Report 2003-1) Toronto-Niagara Region Study on Atmospheric Change, Canadian Climate Impacts & Adaptation Research Network, www.c-ciarn.ca

14 For a comprehensive account of the see "Urban Drainage Systems: Evolution of Problems" in Barry J. Adams and Fabian Papa, *Urban Stormwater Management Planning with Analytical Probabilistic Models* (New York: John Wiliey & Sons, 2000): pp.1-18.

[15] The history of drainage and stormwater engineering can also be told through the history of flood control as the result of responses to floods and storms in the Lake Ontario region such as Hurricane Hazel in 1954. See "The Evolution of Flood Control", http://www.hurricanehazel.ca/. Of considerable importance is the birth of the Toronto & Region Conservation Authority (www.trca.ca) in 1957 immediately following the reconstruction efforts in the wake of Hurricane Hazel.

Evolving stormwater management practices now reflect a more equitable approach that considers the protection of existing biophysical systems and associated fish habitat, as well as people and property. Stormwater management practices have evolved based on the growing scientific understanding of how rivers and streams function, the use of integrated planning processes, and improved technologies to mitigate the consequences of urbanization. From a systems perspective, it is now widely understood and recognized that drainage and flooding concerns cannot be managed separately from the receiving watercourses. How stormwater management infrastructure is planned for, designed, implemented and maintained is ultimately reflected in the health and performance of local streams, rivers and groundwaters.

The essential challenge of stormwater management today is how to balance the needs of urban environments with the needs of fish habitat while ensuring cost-effectiveness over long and short terms.. Put otherwise, how can the maintenance of roads and basements that don't flood be combined with the imperative for healthy streams and rivers that support diverse aquatic communities, This rather tall order is being addressed in jurisdictions across North America as municipalities struggle with the challenge of meeting increasingly stringent legislative requirements, growing citizen demands for environmental protection, continuing growth pressures, increasing scrutiny with respect to the effectiveness of current stormwater management efforts, and the reality of limited financial resources. The City of Toronto faces these same challenges.

Addressing these ongoing demands requires an integrated, strategic approach because they cannot effectively be dealt with on an individual, piece-meal or short-term basis. The City of Toronto's stormwater runoff strategy in its *Wet Weather Flow Management Master Plan* is driven by the need to address these significant challenges and provide a road map forward.

Stormwater is currently considered a cost and burden to the developer (development costs), the homeowner (flooding, pumping, moisture), and the municipality (flooding, erosion, water quality, habitat degradation) as opposed to being viewed as a resource. This report aims to determine the value of contemporary stormwater strategies that are outlined in the *Toronto Green Development Standard* in relationship to their costs, benefits, and downstream effects. To accomplish this, the report establishes a series of parameters to assess these strategies and their useful applications. Where possible, the report will attempt to compare systems from a variety of measures and methods found throughout the literature. However, it remains imperative to understand how difficult they are to evaluate, let alone compare since stormwater systems involve multiple components, multiple costs, multiple stakeholders, multiple jurisdictions, and multiple watersheds over periods of time.[16]

Because of the current emphasis on the quality of receiving waters in the design and selection of urban drainage/stormwater management systems, it is appropriate to briefly review the environmental problems caused by wet-weather pollution and examples of solutions implemented by Canadian municipalities.[17] The following table categorizes environmental problems caused by wet-weather pollution according to the distance of the problem area from the source of runoff, i.e. where the rainfall hits the ground surface or where the snow and ice melt. The types of problem and treatment obviously vary from category to category. It should also be noted that the perceived importance of an individual problem, and therefore its solution, varies across Canada because of differences in climate, type and size of

[16]The evaluation of cost benefits has traditionally relied on the use of anticipated rent values as a proxy for the benefits from a planning perspective. A more contemporary approach to cost-benefit involves the comparison of the cost-benefits of traditionally engineered systems versus the design of integrated urban systems. This report privileges the second approach using a systems-wide approach rather than sectoral approach that is all too common in urban infrastructure planning.

[17] See W.E. Watt, J. Marsalek, and B.C. Anderson, "Stormwater Pond Perceptions vs. Realities: a Case Study", *Sustaining Water Resources in the 21st Century*, Proceedings, 105-122.

receiving waters, regulatory environment, historical context of pollution abatement, and resource constraints. The problems and solutions summarized in the following table are considered to be traditional problems and solutions that would apply throughout Canada.

Table 1 Examples of problems and solutions to wet-weather pollution

Area/ infrastructure	Example Problems	Example Solutions
Individual lot	▪ accumulation of runoff (surface ponding) and flooding	▪ grading of lots and driveways to eliminate ponding ▪ BMPs include lot-level source controls, biofiltration by swales and filter strips, local infiltration facilities (wells, trenches, perforated pipes and drainage structures), stormwater inlets, and water quality inlets
Gutters, ditches and storm sewers	▪ excessive maintenance in older sewer systems that remain operable well beyond the design life	▪ repair or replace with a new sewer
Combined sewers	▪ combined sanitary and storm sewer overflows (CSOs) (common in downstream sections of sewer systems in many Canadian municipalities)	▪ reduction of stormwater flows ▪ long-term programs of separating combined sewers ▪ construction of storage facilities (oversized pipes or tanks, off-line underground storage tanks or in the receiving waters) ▪ treatment of combined sewer flows (in central sanitary treatment plant or special satellite plants)
Urban creeks and streams	▪ flooding ▪ increased erosion and sedimentation ▪ degradation of water quality	▪ no action (accept the problem as a cost of urbanization) ▪ installation of localized erosion control measures ▪ channel modification including lining the entire cross section with concrete or other erosion-resistant material (in severe cases) ▪ retrofit and community-level BMPs including infiltration facilities, stormwater ponds, constructed wetlands, and extended detention basins
Urban lakes	▪ degradation of water quality (e.g., thermal loading, fecal bacteria contamination and associated beach closures) ▪ gradual infilling with contaminated sediments	▪ periodic removal and disposal of bottom sediments ▪ BMPs in the contributing watershed to reduce sediment and other contaminant loadings ▪ community-level BMPs as described for urban creeks and streams
Watershed	▪ flooding, erosion and degradation of water quality	▪ watershed-wide planning that protects specific features and resources, supports land use decisions, improves source control BMPs, and assists in BMP siting
General	▪ all of the above	▪ policies and source controls including public education, planning management, material use, exposure and disposal controls, spill prevention and cleanup, and prevention/elimination of illegal dumping and connections

Sources: Camp Dresser and McKee *et al.* 1993, Marsalek *et al.* 1993, Marsalek 1999, Urbonas 1994.

Costs, Considerations & Downstream Effects of Urban Stormwater Management[18] [19]

There are three ways to deal with stormwater in terms of its location in the urban watershed: at the source, or throughout the conveyance system, or at the end-of-pipe. This report deals with the comparison between the conventional end-of-pipe stormwater engineering such as curb, gutter or sewers and contemporary source control systems such as permeables surfaces, green roofs or bioswales, that bear the potential of greatly contributing to a reduction in the cost of stormwater flow management.

Few studies if any, compare costs across the whole continuum of alternatives due to the different assumptions and different parameters. What complicates the comparison between different stormwater management methods are the differential units of measure and the downstream effects. The first factor involves the measurement units that are not easily comparable and in regions that are not easily compatible such as the acre-foot of detention storage in Florida from a report by the US Environmental Protection Agency (US EPA) cannot be easily compared with the cost of a linear metre of bioswale in Ontario). The second factor affecting the complexity in comparative work involves the effects of different systems. A centralized combined sewer system that conveys stormwater and sanitary wastewater within a designated municipal area, is difficult to compare with a decentralized system of infiltration and bioretention strategies spread across an entire watershed. Despite these apparent difficulties, the comprehensive evaluation of the costs and benefits of stormwater strategies cannot be made without the full consideration of their benefits and downstream effects in comparison to conventional approaches to stormwater infrastructure.

The distinction between conventional methods and innovative measures in the management of stormwater flow - a difference that is not explicitly expressed in common literature - is therefore paramount and necessary. These differences stem largely from different purposes and different perceptions. Conventional water engineering as it has been practiced over the past century, treats stormwater as a nuisance or waste, a generic and undifferentiated fluid which needs to be disposed of as quickly as possible, as allowed by regulation. The objective of conventional infrastructure is to temporarily store stormwater, move it off-site and into the local watershed in accordance with the acceptable discharge rate.

Landscape strategies on the other hand, often involving water infiltration technologies and water conservation measures, manage stormwater as a resource, as close to the source as possible. Often referred to as "source controls", these strategies either restore, mimic or improve upon pre-development hydrologic patterns to enable stormwater infiltration into the ground and evapotranspiration into the atmosphere. Using biomass, topography and hydrology, landscape strategies usually entail the design and synergy of several measures by incorporating different technologies throughout a site to considerably decrease and even eliminate the need for conventional detention or retention facilities. As an alternative technique, bioretention for example relies on plans for added efficiency with the multiple functions of retention, infiltration, transpiration and cleansing. Bioretention areas are usually designed as part of a system that incorporates bioswales, permeable surfaces, green roofs, woodlands and other areas to slow down, cleanse, infiltrate and evapotranspire stormwater.

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[18] Values presented throughout this report are estimates based on a synthesis of previous studies, in which a number of valuation methods were used. Where possible, original source materials and references are provided. Unless otherwise noted, the present value of costs and benefits is calculated.

[19] Economic analysis plays a significant role in setting environmental standards or evaluating environmental policies. However, economic considerations are not the only factor relevant to policy decision-making. Cost-benefit analysis and other economic tests should not replace statutory requirements, environmental science, spatial planning and design or, common sense. For an in-depth discussion of the limitations inherent to cost-benefit analysis of stormwater management, see "Uses and Abuses of Economic Analysis in Setting Stormwater Regulations" by Dr. Frank Ackerman, Global Development and Environment Institute, Tufts University, December 2002. Website: http://ase.tufts.edu/gdae/policy_research/AckermanStormwaterDec02.pdf (accessed January 26, 2008)

Centralized & Decentralized Infrastructure. Traditional approaches to stormwater management involve conveying runoff off-site to receiving waters, to a combined sewer system, or to a regional facility that treats runoff from multiple sites. This centralized approach to stormwater engineering typically includes hard and impervious infrastructure, such as curbs, gutters, piping and pavements. Decentralized approaches to stormwater management[20] in contrast, are designed to use biophysical drainage features or vegetal surfaces for runoff conveyance, infiltration, retention and treatment. In terms of costs, these source controls and infiltration techniques, coupled with landscape management, can significantly reduce the amount of materials needed for paving roads and driveways and for installing curbs and gutters. Landscape planning can also be used to reduce the total amount of impervious surface, which results in reduced road and driveway lengths and reduced costs. Other structural techniques, such as grassed swales, can be used to infiltrate roadway runoff and eliminate or reduce the need for curbs and gutters, thereby reducing infrastructure costs. Also, by infiltrating or evaporating runoff, these alternative techniques can reduce the size and cost of flood-control structures. More research is needed however to determine the optimal combination of alternative techniques and detention practices for flood control.

Downstream Effects. The following table shows the conventional costs associated with the implementation of capital programs for stormwater management. However, the assessment of these technologies including stormwater ponds, constructed wetlands, infiltration areas and swale systems does not account for the systems-wide impacts, the externalities or the benefits of structural stormwater strategies such as groundwater recharge, pollutant removal, erosion prevention and control. From this table, alternative stormwater practices may appear to be more expensive than conventional forms of stormwater drainage or engineering, to the point where they can be at first glance, perceived as infrastructural luxuries.

Conventional Assessment of Stormwater Programs without Factoring Total Downstream Benefits[21]		
Program Level	*Cost/Acre/Year*	*Typical Program Features*
Incidental	\$15- \$30	Reactive incidental maintenance and regulation as part of other programs.
Minimum	\$30- \$60	Plus: right-of-way maintenance, better regulation and inspection, more staff, and erosion control.
Moderate	\$60- \$90	Plus: additional maintenance programs and levels of service, better regulation and inspection, some planning, minor capital programs, and general upgrade of capabilities.
Advanced	\$90- \$150	Plus: maintenance (of some sort) of the whole system, master planning, regional treatment, some water quality, data collection, multi-objective planning, strong control of development and other programs, and utility funding.
Exceptional	Over \$150	Plus: stormwater quality, advanced flood control, advanced levels of service for maintenance, aesthetics become more important, and public programs.

[20] The term "LID" or "Low Impact Development", is one of many used to describe the practices and ideologies employed to provide advanced stormwater management. However labeled or branded, these practices rely on the design of topographic, hydrological and vegetal strategies to effectively manage and filter stormwater runoff as a connected regional landscape. For purposes of this report, the term "landscape strategies" is employed throughout to designate contemporary methods involving separation, infiltration, evaporation, cleaning of stormwater in the ground as key operative functions that include the use of techniques such as permeable surfaces and bioretention areas that are described later in the section
[21] Table adapted from Elizabeth Treadway and Andrew L. Reese, *Financial Strategies for Stormwater Management*, *APWA Reporter* (February 2000).

Land Area. Another factor to consider when comparing costs between conventional and contemporary strategies is the amount of land required to implement a structural management practice. Both practices require areas of land but in general, conventional curb-and-gutter practices require more land in addition to individual lots and other community areas, whereas bioretention areas and swales can be incorporated into the landscape of rooftops, back yards, rights of-way, roadside verges, backlands, in or adjacent to parking lots. The land that would have been set aside for ponds or wetlands can, in many cases be used for additional housing units, potentially yielding greater profits.[22]

Maintenance. Differences in maintenance requirements need to be considered when comparing costs. According to a 1999 US EPA report, maintenance costs for retention basins and constructed wetlands were estimated at 3 to 6 percent of construction costs, whereas maintenance costs for swales and bioretention practices were estimated to be 5 to 7 percent of construction costs. However, much of the maintenance for bioretention areas and swales can be accomplished as part of routine landscape maintenance and does not require specialized equipment. Wetland and pond maintenance, on the other hand, involves heavy equipment to remove accumulated sediment, oils, trash, and vegetation in forebays and open ponds. The following table provides a comparative breakdown of maintenance regimes and effective longevity of landscape strategies.

Comparison of Capital and Maintenance Costs for Landscape Strategies

Strategies	*Capital Costs*	*O&M*	*Maintenance*	*Effective Life*
Infiltration Trench	Moderate to High	Moderate	Sediment Debris Removal	5-10
Infiltration Basin	Moderate	Moderate	Mowing	5-10
Bioretention	Moderate	Low	Mowing Plant Replacement	5-20
Detention Ponds	Moderate	Low	Annual Inspection	20-50
Wetlands	Moderate to High	Moderate	Annual Inspection Plant Replacement	20-50
Bioswales	Low	Low	Mowing	5-20
Filter Strips	Low	Low	Mowing	20-50
Porous Pavements	Low	Moderate	Semi-Annual Vacuum Cleaning	15-20
Green Roofs	High	Moderate	Plant Replacement	20-25

Risk Avoidance. While the costs associated with managing storm water seem large, the cost of mismanaging stormwater is much larger. When centralized city-based stormwater systems are overwhelmed, flooding can cause serious damage to roads, infrastructure and homes. On October 15, 1954, Hurricane Hazel was one of the first major storm events to hit the City of Toronto and surrounding region with 110 kilometers per hour (68 mph) winds and 285 millimetres (11.23) of rain in 48 hours. Fromm the more than 300 million tons of water that fell during the storm washing out bridges and roads, to the 4,000 families that

[22] A more detailed discussion on the subject of land requirements can be found in the Center for Watershed Protection, "The Economics of Stormwater Treatment: An Update" Technical Note #90, *Watershed Protection Techniques* Vol. 2 No.4: 395-499.

were left homeless in Southern Ontario, the total cost of the destruction from the storm event was valued $100 million, about $1 billion today.[23]

More recently for example, a single heavy storm event in August 2005 resulted in the wash-out of a major arterial road, damaging three other roads, and a wastewater plant down-stream. This single rain event cost the City of Toronto an estimated $34 million, including $6 million for the immediate repair of Finch Avenue, $9 million for surrounding parks, and over 1,600 over-time staff hours. The environmental clean-up cost to mitigate the effects of a broken sewer main that ruptured during the storm (releasing raw sewage into a nearby stream at 7 cubic meters per second) incurred additional costs. The Insurance Bureau of Canada estimates over $400 million was paid out to private citizens to cover flood damage to basements from this storm. The cost of damage from this single rain event was astronomical. By pushing the stormwater system past its capacity, it is anticipated that these events will only become more common.

Exacerbating these risks, aging infrastructure and increased development with impermeable areas bring increased chances of sewer backups, overflows and flood damage. Combined sewer overflows in Toronto for example, also represent a serious economic cost. Storage facilities or a new trunk sewer to contain these overflows is estimated to cost with a range of $5 million to $15 million. Beach closures from high bacteria counts associated with these overflows may be even more costly in the long run. The economic benefit to the Toronto business community from just three fewer days of beach closure is estimated at $750,000. Furthermore, the cost of wet basements from sewer back-ups and watermain breaks within Toronto is currently borne by homeowners. The City of Toronto estimates that $5.5 million to $50 million would be required annually to fund no-fault insurance, just to cover damages and clean-up costs for basement flooding related to these causes. This cost would rise substantially without replacement of the current crumbling infrastructure.

Finally, it must also be mentioned that the use of infiltration techniques might not always result in lower project costs given the current landscape of environmental legislation and lack of fiscal incentives. For example, costs might be higher because of the costs of plant material, site preparation, soil amendments, underdrains and connections to municipal stormwater systems, and increased project management at the site level without taking in to account the downstream effects of source controls. This report aims to show that, by including the long term life cycle costs and the invisible downstream effects, how the design of landscape strategies can provide significant cost savings and higher performance when evaluating different types of developments.

[23] Canadian Hurricane Centre, “Remembering Hurricane Hazel (1954)” http://www.atl.ec.gc.ca/weather/hurricane/hazel/en/index.html and Toronto & Region Conservation Authority, “About Hurricane Hazel” http://www.hurricanehazel.ca/

Site Technologies: Cost-Benefits & Downstream Effects[24]
There is a considerable range of stormwater management strategies currently being developed as a result of the pressure on conventional, centralized infrastructure. The following section describes a selection of individual site technologies based on their costs and net benefits. A brief description of each site technology and its intended applications is provided for comparative purposes given the wide array of definitions currently used across the literature. According to Strom and Nathan, authors of *Site Engineering for Landscape Architects*, "it cannot be stressed enough that all stormwater management practices must be *site, region,* and *climate specific."*[25] Therefore, it is important to understand that the design, the selection, the engineering and the benefits of stormwater technologies also take full account of these conditions and for the purposes of this study, cold-climate practices are the focus here.

A discussion of the aggregated or combined benefits of these technologies, when used in combination, follows in the next section on "Downstream Effects".

Range of Contemporary Stormwater Management Technologies	
Infiltration & Retention Technologies*	Proprietary or Patent Technologies
Green Roofs Permeable Surfaces Bio-Swales Filter Strips Rain Gardens Bioretention Systems Constructed Wetlands Infiltration Basins & Trenches Detentions Basins Retention Ponds (Wet Ponds) *Technologies addressed in this report	Hydrodynamic Separator Systems Filtrations Systems (inline filters, catchbasin inserts) Underground Stormwater Storage Tanks Sediment Containment Devices

While infiltration & retention technologies are specifically addressed throughout this report, the implications of strategic design and planning are discussed in the concluding sections of this report. A full discussion of the spectrum of contemporary stormwater management technologies can be found in the following reference publications:

> Bruce K. Ferguson, *Stormwater Infiltration* (Boca Raton, FL: CRC Press, 1994)
>
> Richard Field & Daniel Sullivan, *Wet-Weather Flow in the Urban Watershed: Technology and Management* (Boca Raton, FL: CRC Press, 2003).

The primary objective of this section is to layout a basic comparison of different technologies and different approaches from an economic perspective. Equally as important, the secondary objective is to define the added value and added performance provided by contemporary technologies when considered, either spatially and ecologically, from a landscape perspective.

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[24] One of the most comprehensive documents on the life-cycle costs and economic spin-offs of contemporary strategies is "Downstream Economic Benefits from Storm-Water Management" by John B. Braden and Douglas M. Johnston, in *Journal of Water Resources Planning and Management*, American Society of Civil Engineers (November 2004).
[25] Steven Strom and Kurt Nathan, *Site Engineering for Landscape Architects* (New York: John Wiley & Sons, 1998): p.131.

Green Roofs

Toronto is home to more than 100 green roofs. To evaluate the benefits of greatly expanded use of green roofs in the city, a study was conducted in 2004 by a team of researchers at Ryerson University. According to the City of Toronto, the study "indicated that widespread implementation of green roofs in Toronto would provide significant economic benefits to the City, particularly in the areas of stormwater management and reducing the urban heat island (and the energy use associated therewith)."[26]

Comparative Table of the Effects of Conventional Flat Roofs and Green Roofs in Urban Areas	
Conventional Flat Roof	*Green Roof*
- Concentrates pollutants into waterways, where they cannot be completely broken down	- Reduced stormwater flows into separate storm and combined sewer systems
- Increased air pollution due to the intensification of the heat island effect - Reduced indoor comfort	- Improved air quality
- Accelerated deterioration of roofing materials, increased roof maintenance costs, and high levels of roofing waste sent to landfills	- Mitigation of urban heat island effects
- Higher peak electricity demand, raised electricity production costs, and a potentially overburdened power grid ; -Increased cooling energy use and higher utility bills	- Reduced energy consumption

Of the many benefits of green roofs reported in this study, "the ones that had the most quantifiable monetary value based on currently available research data are: benefit from stormwater flow reduction including impact on combined sewer overflow (CSO), improvement in air quality, reduction in direct energy use, and reduction in urban heat island effect."[27]

The following table presents a summary of the municipal level environmental benefits of green roof implementation in the City of Toronto, assuming green roof coverage of approximately 5,000 hectares:

Breakdown of Capital Cost & Maintenance Savings From Green Roof Development in Toronto[28]		
Benefit Category	*Initial Cost Savings*	*Annual Cost Savings*
Stormwater	$118,000,000	-
Combined Sewer Overflow (CSO)	$46,600,000	$750,000
Air Quality	-	$2,500,000
Building Energy	$68,700,000	$21,560,000
Urban Heat Island	$79,800,000	$12,320,000
Total	$313,100,000	$37,130,000

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[26] See City of Toronto "Green Roofs: Study Findings" (http://www.toronto.ca/greenroofs/findings.htm (accessed December 6, 2007)

[27] Banting, H. Doshi, J. Li, P. Missios, A. Au, B.A. Currie, and M. Verrati, *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto* (Toronto, ON: City of Toronto and Ontario Centres of Excellence—Earth and Environmental Technologies, 2005), www.toronto.ca/greenroofs/pdf/fullreport103105.pdf (accessed December 6, 2007).

[28] *Ibid.*, p.59.

In the aggregate, greening 6% of Toronto's roofs would cost about $36 million over 10 years and would retain almost 1 billion gallons of stormwater annually resulting in more than $100 million in stormwater capital cost savings, $40 million in combine sewer overflow (CSO) capital cost savings and $650,000 in CSO annual cost savings.[29] The cost of installing the green roofs would be largely borne by private building owners and developers; the cost to Toronto would consist of the cost of promoting and overseeing the program and would be minimal. Costs for green roof installations in Canada have averaged $6 to $7 per square foot. The smallest green roof included in the study, at 3,750 square feet, would cost between $22,000 and $27,000. The total cost to install 12,000 acres of green roofs would be $3 billion to $3.7 billion. Although the modeled total costs exceed the monetary benefits, the costs would be spread across numerous private entities.

In another study conducted by the U.S. EPA titled *Cool Roofs*[30], it was noted that if 90% of the dark-colored roofs in the United States were simply converted to highly reflectant, light colored surfaces, with high reflectivity and high thermal emittance, metropolitan scale savings in cold weather climates like Chicago would yield 10 US Dollars per 100 sq.m. of roof area in energy consumption for air conditioned buildings.[31] Applying this potential saving to the City of Toronto's 5000 hectares of flat roofs exceeding $350m^2$ (large commercial retail buildings for example) would yield total annual savings of over 5 million dollars in energy consumption. The Urban Heat Island group also estimated that by 2015, the full-scale implementation of reflective surfaces in combination with the use of vegetal systems will save the nation about 4 billion US dollars annually in reduced cooling energy demand.[32]

Equally important, although more difficult to quantify, are the additional benefits associated with green roof development including the provision of rooftop amenity space, overall aesthetic improvement and amenity space, local food production,[33] [34] health improvements[35] and real estate values[36] when compared to conventional roofing materials.

[29] D. Banting, H. Doshi, J. Li, P. Missios, A. Au, B.A. Currie, and M. Verrati, *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto* (Toronto, ON: City of Toronto and Ontario Centres of Excellence—Earth and Environmental Technologies, 2005), www.toronto.ca/greenroofs/pdf/fullreport103105.pdf (accessed December 16, 2005).
[30] See *Cool Roofs:* www.epa.gov/hiri/strategies/coolroofs.html
[31] See *Chicago - Energy Analysis:* www.epa.gov/hiri/pilot/chic_energysavings.html. It is also worth noting that the City of Chicago's energy code requires that roof installations on most commercial, low-sloped air conditioned buildings have an initial solar reflectance greater than or equal to 0.25 to help reduce the urban heat island effect.
[32] This estimate accounts and corrects for a potential heating-energy penalty during the winter season. See Lawrence Berkeley National Laboratory - Urban Heat Island Group: http://eetd.lbl.gov/HeatIsland/CoolRoofs/
[33] See Robin Kortright , "Evaluating the Potential of Green Roof Agriculture" (Trent University October 2001) www.cityfarmer.org/greenpotential.html
[34] The Fairmont Waterfront Hotel in Vancouver used to grow herbs, flowers, and vegetables on its accessible roof, saving its kitchen an estimated $30,000 a year in food purchasing and processing costs. www.designroofing.ca/services/green_roof.htm (accessed January 13, 2008)
[35] See *Private & Public Benefits of Green Roofs*: www.greenroofs.org/index.php?option=com_content&task=view&id=26&Itemid=40
[36] See CMHC's *Green Roof: A Resource Manual for Municipal Policy Makers:* http://commons.bcit.ca/greenroof/download/Resource_Manual.pdf

Permeable Surfaces

Impervious surfaces represent the greatest single most important contributing factor to stormwater runoff, peak flow discharge and water quality degradation in urban areas.[37] Various studies acknowledge that a 10% impervious land cover usually results in the impairment of fish ecosystems with noticeable effects on downstream fish populations, a critical indicator of water quality and is referred to as the stream impact threshold.[38] In a study on the urban pattern and land cover variation in the Greater Toronto Area, a range of 35 to 95% of the surface area of the city was impervious.[39] Using estimates from the Centre for Watershed Protection on the urban landsape of North America regarding the percentage of impervious land cover we can estimate that as much as 65% of the total impervious surfaces in the GTA consists of streets, parking lots and driveways.

The Impervious Surface Budget[40]		
Land Cover	*Land Uses*	*Coverage*
Structures	Offices, Stores, Patios, Houses	35%
Transportation	Parking Lots, Roads, Driveways, Sidewalks	65%

By now, the effects of impervious surfaces are well known and well documented. The following table summarizes those effects telescopically, from the site level to the watershed level:

Comparative Table of the Effects of Impervious and Pervious Surfaces in Urban Areas	
Impervious Surfaces (conventional pavement coverings such as asphalt and concrete)	*Pervious Surfaces* (alternative surface systems such as aggregates, modular blocks, and porous pavements)
- Removes water from site	- Recharges local aquifers and groundwater
- Promotes flooding	- Reduces flooding and downstream erosion
- Requires expensive stormwater infrastructure	- Reduces need for expensive stormwater infrastructure
- Concentrates pollutants into waterways, where they cannot be completely broken down	- Large surface area allows pollutants to break down and degrade over time
- Contributes indirectly to the destruction of riparian habitat	- Contributes indirectly to healthy riparian habitat

Reducing the amount of impervious cover is therefore one of the single most effective ways of reducing the pressure of stormwater overloading of existing sewer systems as well as an effective way of reducing long term costs of urban development and stormwater infrastructure for municipalities and developers. Impervious cover can be minimized in two ways: the first is through the use of permeable surface materials by specification and the second is by adopting land conservation strategies by design.

[37] Elizabeth Brabec, Stacey Schulte and Paul L. Richards, "Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning", *Journal of Planning Literature*, Vol. 16 No. 4 (2002): 499-514

[38] For a comprehensive assessment of different case studies across North America, see Oak Ridges Moraine Conservation Plan, "Subwatersheds (Impervious Surfaces)", Draft Technical Paper # 13 (Ottawa, ON: Ministry of the Environment, June 2005) https://ozone.scholarsportal.info/bitstream/1873/2727/1/254446.pdf

[39] Tenley Conway & Jason Hackworth, Urban Pattern And Land Cover Variation In The Greater Toronto Area, *The Canadian Geographer / Le Géographe Canadien* Vol.51 No.1 (2007): 43–57.

[40] Figures generalized from Chester Arnold Jr. and James C. Gibbons. "Impervious Surface Coverage; The Emergence of a Key Environmental Indicator" *Journal of the American Planning Association*, Vol. 62 Issue 2 (Spring 1996).

The first method for minimizing impervious cover and encouraging stormwater infiltration is the use and implementation of permeable pavements in lieu of impervious surfaces such as asphalt and concrete. Over the past three decades, significant technologies have been developed including porous asphalt, porous concrete, open-cell systems and open-joint interlocking block pavers to name a few. Typical applications include parking lots, sidewalk, laneways, firelanes and local residential streets.

Costs for porous asphalt are approximately 10% to 15% higher than those for regular asphalt; porous concrete is about 25% more expensive than regular concrete. Requirements for site preparation or the use of specialized equipment may also increase these costs. The use of modular paving stones can be up to four times as expensive as either regular asphalt or concrete. However, the higher costs of installation of porous pavements are offset to some extent by the elimination of curbs, gutters, and storm drains. In some cases, this effect can lower the overall cost for a project.

Another method for minimizing impervious cover and encouraging stormwater infiltration involves site design practices and land conservation strategies that layout narrower or shorter roads, smaller parking lots, shorter driveways and smaller turnarounds. These design techniques make both economic and environmental sense. Infrastructure - roads, sidewalks, storm sewers, utilities - normally constitute over half the total cost of subdivision development. Whenever site conditions permit, a substantial percentage (60 to 90%) of the total annual runoff of the urban stormwater can be diverted to surrounding soil and disposed of on site throughout a combination of infiltration and retention systems. This effectively contributes to groundwater recharge and low flow augmentation of base flow in streams.

In addition to these direct cost savings, developers can realize indirect savings. Costs for stormwater treatment and conveyance are a direct function of the amount of impervious cover. For each unit of impervious cover that is reduced, a developer can expect a proportionately smaller cost for stormwater treatment.[41] Current state and local requirements for erosion and sediment control often do increase the cost of development. On a typical site, the cost to install and maintain erosion and sediment control can average $800 to $1,500 per cleared acre per year, depending on the duration of construction and the site conditions.[42]

The following table provides a breakdown of the general benefits from a reduction in the effective impervious area, i.e. the hard surface area that is directly connected to municipal drainage systems. As shown below, the benefits are multi-dimensional when considered at the regional watershed level:

[41] See Tom Schueler, “The Economics of Watershed Protection”, *Watershed Protection Techniques* Vol. 2 No.4: 469-481.
[42] See R. Paterson, M. Luger, R. Burby, E. Kaiser, H. Malcom, and A. Beard, “Costs and Benefits of Urban Erosion and Sediment Control - The North Carolina Experience,” *Environmental Management* Vol.17 No.2 (1993):167-178, and Suburban Maryland Building Industry Association (SMBIA) Unpublished data on the unit cost of residential subdivision development in Suburban, Maryland (1990).

Breakdown of the Benefits from a Reduction in the Effective Impervious Area[43]	
Runoff Volumes	Research shows that pavers can significantly reduce runoff volumes, thereby reducing the erosive power of stormwater entering creeks and inter tidal areas. This helps to protect backwater refuges, brings less sediment to spawning areas, prevents down cutting of streams and loss of bank stability.
Pollutant Removal	Long term research on permeable pavers shows their effective removal of pollutants such as total suspended solids, total phosphorous, total nitrogen, chemical oxygen demand, zinc, motor oil, and copper. In the void spaces, naturally occurring micro-organisms break down hydrocarbons and metals adhere.
Groundwater Recharge	In areas with suitable soils, permeable pavements allow stormwater to enter the sub-soils, replicating the natural hydrological cycle by allowing for groundwater recharge and moderating the fluctuations of flows in watercourses.
Heat Pollution	Porous pavement can help lower high runoff water temperatures commonly associated with impervious surfaces. Stormwater pools on the surface of conventional pavement, where it is heated by the sun and the hot pavement surface. By rapidly infiltrating rainfall, porous pavement reduces the water's exposure to sun and heat. Cool stream water is essential for the health of many aquatic organisms, including trout and salmon.
Infrastructure Performance	Using permeable pavement surfaces reduces the amount of Effective Impervious Area (EIA), in an existing development. Reduction of EIA improves the performance of existing on-site cleansing, infiltration and storage facilities, which thus process less stormwater flow.
Infrastructure Footprint	A reduction in EIA can help reduce the size of the on-site stormwater storage technique required in many municipalities, potentially freeing up land surface for other more valuable uses.
Longevity/Maintenance	While there is little historical evidence, many concrete paver manufacturers claim their product will last 50 years or more. In comparison, asphalt parking lots last a far shorter time, especially in freeze/thaw climates. Frequent crack filling and overlaying, some re-striping and at least one reconstruction, would be required within a 50-year span.

Although the use of permeable pavements remains an emerging practice,[44] maintenance required on a permeable concrete paver system is claimed, depending upon the source, to be from minimal to onerous. Maintenance consists of re-striping and occasional cleaning of the aggregate within the pore area by vacuum truck. The latter of which needs to performed only on a case-by-case basis, depending on how the pavement is performing.[45] [46]

[43] Largely understated, another added benefit is noise reduction from the use of porous asphalt with optimized textures. Research on the effects of porous asphalt on several streets an highways in Europe is summarized in "Effects of Porous Overlays on Noise" in Bruce K. Ferguson, *Porous Pavements* (New York: Taylor & Francis, 2005): p.499-500. See also "Silence: Noise Abatement Strategies" (Sixth Framework Programme of the European Commission) http://www.silence-ip.org/

[44] For definitive information on the uses, costs and benefits of permeable pavements, refer to Bruce K. Ferguson's *Porous Pavements* (New York: Taylor & Francis, 2005). Bruce Ferguson is a Landscape Architect who has specialized in environmental management of watersheds for 25 years.

[45] A good example of porous asphalt maintenance at a large is the case of use of permeable pavements on highways in Sweden and Denmark where roads are subject to frost heaving during the winter and are cleaned with vacuum trucks during the Spring. See Mikas Scholz and Piotr Grabowiecki, "Review of Permeable Pavement Systems" in *Building & Environment*, Volume 42, Issue 11 (November 2007): 3830-3836.

The cost-benefit of the use of porous pavement as an alternative for asphalt on parking lots or for concrete on sidewalks must be compared to the full cost of the full stormwater management paving system. For example, while the nomimal cost of asphalt paving is lower than porous pavement, the actual cost of the impervious paving from a system perspective that includes the costs for drains, reinforced concrete pipes, catch basins, outfalls and stormwater connects are included, an asphalt or conventional concrete stormwater management paving system costs between $9.50 and $11.50 per square foot, compared to a permeable paving stormwater management system at $4.50 to $6.50 a square foot.[47] In addition to this, most municipal stormwater utilities and stormwater management departments impose taxes or fees based on impervious coverage. The savings associated with the use of permeable pavements are considered to be even greater when pervious paving systems are calculated for their stormwater storage; if designed properly, they can also eliminate the requirement for retention ponds.

Comparative Table of the Costs[48] & Savings of Impervious and Pervious Surfaces in Urban Areas[49]			
Pavement Type	*Infiltration Rates (mm/hour)[50]*	*Construction Costs (per ft²)*	*Infrastructure Costs (per ft²)[51]*
Asphalt	0.00015 to 15.25	$0.50 - $1.00	$9.50 - $11.50
Modular Interlocking Concrete Block Pavers	235	$5.00 - $10.00	$3.50 - $6.50
Grass or Gravel filled Grid Systems Pavers	1000	$1.50 - $5.75	$2.50 - $4.50
Porous Concrete / Porous Asphalt	20,000	$2.50 - $6.50	$4.50 - $6.50
Potential Net Savings			**$3.00 -$4.50**

According to this table, porous asphalt for example costs about 10% more than non-porous, yet it helps total costs decrease by 30% at favorable sites wen considering the downstream benefits of reduced infrastructure. So when all the factors are considered together as a system, permeable pavements become extremely cost-effective, as report by agencies by the Low Impact Development Centre amd the US EPA. In two often cited reports of permeable

[46] A longstanding case study of maintenance-related issues with permeable pavements is the use of porous asphalt at demonstration project at Walden Pond State since 1977. See "Porous Pavement: Pavement That Leaks" by A. Richard Miller (1989):www.millermicro.com/porpave.html (accessed February 17, 2008)
[47] Based on cost information posted on the LID Urban Design tools Permebale Paver section: www.lid-stormwater.net/permpaver_costs.htm
[48] Based on cost information posted on the LID Urban Design Tools Permeable Paver section: www.lid-stormwater.net/permpaver_costs.htm
[49] In comparison, an interesting tool for understanding the cost of stormwater utility associated with the surface of impervious area is the City of Manitowic's automated Stormwater Utility Charge Calculator: http://www.manitowoc.org/dept_storm_utility.html
[50] Adapted from "Surface Infiltration Rates under Saturated Conditions" in Burce Ferguson, *Porous Pavements* (New York: Taylor & Francis, 2005): p.125.
[51] The infrastructure costs for both systems, impervious and permeable, includes drains, reinforced concrete pipes, catch basins, outfalls and stomrsewer connections.

pavement tests in Ontario and Washington,[52] comparative results show the following relationships:

1. The use of permeable pavement systems dramatically reduces surface runoff volume and attenuated the peak discharge.

2. Although there were significant structural differences between the systems, the hydrologic benefits were consistent.

3. Storm characteristics and weather conditions influenced the hydrologic responses of the systems. Furthermore, permeable pavement can reduce freezing, salt use and associated road wear.

4. Permeable pavement system types vary widely in cost and are more expensive than typical asphalt pavements. Cost comparisons between permeable pavement installations and conventional ponds or underground vaults are limited. However, the elimination of conventional systems and reduced life cycle and maintenance costs can result in significant cost savings over the long term.

5. A significant contribution of permeable pavements is the ability to reduce *effective impervious area*, which has a direct connection with downstream drainage systems. This strategy of hydrologic and hydraulic disconnectivity can be used to control runoff timing, reduce runoff volume, and provide water quality benefits.

Given the demonstrated and proven benefits of permeable pavements compared to conventional impervious surfaces, coupled with the backlog of 300 million dollars in road repair alone in the City of Toronto, it is therefore surprising that there are no established standards or policies for the use of permeable pavements in the *2007 Toronto Green Development Standard* nor Environment Canada's *2007 Infraguide - Best Practice Reports on Storm & Wastewater* or *Roads & Sidewalks* do not currently.

In comparison, the city of Chicago currently has a policy in place using permeable pavements in the retrofit of streets, alleys and parking lots. [53]Using data from the Chicago Green Alley Program,[54] if the City of Toronto's 3000 kilometers of laneways were converted from asphalt to permeable pavements, the net benefits would range between $27 million and $40.5 million in stormwater infrastructure cost savings.[55]

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[52] Tim Van Seters, *Performance Evaluation of Permeable Pavement and a Bioretention Swale*, *Seneca College, King City, Ontario* (Toronto & Region Conservation Authority, May 2007) and Center for Urban Water Resources Management, *Field Evaluation of Permeable Pavements for Stormwater Management Olympia*, *Washington*, Factsheet EPA-841-B-00-005B (US EPA, October 2000).
[53] Susan Saulny, "In Miles of Alleys, Chicago Finds Its Next Environmental Frontier", *The New York Times*, November 26, 2007 www.nytimes.com/2007/11/26/us/26chicago.html (accessed January 14, 2008)
[54] Chicago Department of Transportation, *The Chicago Green Alley Handbook: An Action Guide to Create a Greener, Environmentally Sustainable Chicago* (2007). The City of Vancouver has developed a similar initiative called the *BC Country Lanes Demonstration Project*: www.tc.gc.ca/programs/Environment/utsp/greeninglocaltransportation.htm
[55] Calculations assume 3000 kilometers of laneways (2000 miles), 3 meters in width, factored by savings of $30.00 to $45.00 per square meter of porous asphalt. From another perspective, a total of 86 million dollars in equivalent stormwater infrastructure costs can be tallied when considered the estimated 1 million cubic meter storage capacity of these laneways using a factor $85.00/cubic meter of water stored.

Bioretention Areas

There is a considerable range of bioretention methods that have been made possible through increasing research in the areas of groundwater retention and infiltration. The most common technologies include bioswales and constructed wetlands. While there are considerable variations that are possible, each one provides a basic understanding of their mechanism. Most often designed as off-line treatment system, bioretention areas are intended to reduce reliance on centralized sewer systems as well as reduce dependence of detention ponds which are comparatively more expensive to build and maintain over the long term.

Bio-Swales. Also known as infiltration swales, biofilters, grass swales, or in-line bioretention, bioswales are low lying, linear pieces of land that are designed as vegetated channels to reduce stormwater runoff by maximizing flow residence time, and filter pollutants by infiltration. Bioswales usually consist in a long linear drainage courses with gently sloped sides (less than 6%) and filled with vegetation, compost and/or riprap. There are some design variations of the bioswale, but they are all are considered improvements on traditional drainage ditches which are conventionally designed to convey rather than delay and retain. Each type of swale incorporates modified geometry and other design features to allow it to treat and convey stormwater runoff differently. A typical swale bottom is flat in cross section, 600 to 2400 mm wide, with a 1-2% longitudinal slope, or dished between weirs on steeper slopes. Bioswale side slopes are usually no more than 3:1, horizontal to vertical. Even where soils have very poor hydraulic conductivity (around 1 mm/h), a 4 m swale/trench can reduce the volume of runoff from a typical local road to about 25% of total rainfall.

Due to their linear configuration, a common application for bio-swales is around parking lots, where substantial impervious paving collect automotive pollution that are flushed into sewers by rain. As a type of filter, bioswales wrap around the parking lot and treats the runoff before releasing it to the watershed or storm sewer. Bioswales are particularly well suited along highways, building edges and parking lots. Although retrofits are part of the scope of this report, bioswales provide an excellent retrofit strategy for roadside drainage ditches. [56] One of the best examples of roadway retrofit is the Seattle Edge Alternative (SEA) project in Appendix A. By design however, they are extremely flexible in order to accommodate different site conditions. They can be designed as one of a series of stormwater strategies or as part of a treatment train, for instance, conveying water to a detention pond and receiving water from filter strips.

[56] This information is based on a factsheet on filterstrips by the US EPA in "Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring" www.fhwa.dot.gov/environment/ultraurb/3fs11.htm

Comparative Cost Breakdown of Conventional Pipe System & Swale Systems[57]		
Site Application	*Type of System*	
	Pipe System	*Swale System*
New construction	$79/metre ($24/foot)	$17/metre ($5/foot)
Retrofit	$106/metre ($32/foot)	$59/metre ($18/foot)

According to the US EPA, bioswales are relatively low cost stormwater techniques, ranging between $2.50/m^2 ($0.25/ft^2) to $5.00/m^2 ($0.50/ft^2).[58] Their costs vary according to the price and availability of lands for a given development site. Usually where land prices are generally less than $9.70/m^2, bioswales are more viable. However, if swale alternatives can be accommodated within existing landscaping requirements, i.e. without the additional purchase of land, the cost of land is irrelevant. Although swales are extremely flexible as stormwater technologies given their linearity, their use can sometimes be limited in ultra-urban settings due to space availability.

The following table demonstrates a simple comparative cost breakdown of a conventional concrete ditch and a contemporary use of bioswale, resulting in a 2 to 3 times cost factor:

Comparative Cost Breakdown between Concrete Ditch and Bioswale		
Application	*Unit*	*Cost & Range*
Earth/Concrete Ditch	$/m	36.00-75.00
Bioswale	$/m	12.00 - 15.00

Cost Breakdown for a Bioswale over 25 years												
Item	*Required Cost per Year (2005 Dollars)*											
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*...*	*25*
Installation*	10,000												
Mowing		100	100	100	100	100	100	100	100	100	100		
Reseeding-Replanting		100	100	100	100	100	100	100	100	100	100		
Remove & Replace													10,000
Total Cost	10,000	200	200	200	200	200	200	200	200	200	200		10,000
Annualized Cost	$600 / year												

*Land acquisition and Developer Cost not included. Not included in annualized cost

The table above provides the capital installation and annual maintenance costs for a bioswale, using a surface area of 80m^2 (900 ft^2) to treat runoff from 0.2 hectares (1/2 acre) of impervious acre is comprised of both the installation cost and annualized costs. These cost calculations were based upon a bioswale with a surface area of 900 ft^2. The bioswale is

[57] These costs do not account for land acquisition. Values are adapted from Backstrom et al. "Resources Utilization Analysis: A Comparison of Different Stomrwater Transport Systems. *Proceedings from the 8th Internaitonal Conference on Urban Stormwater Drainage. August 30-Sept3, 1999. Sydney Australia edited by I.B. Jolifee and J.E. Ball International Association on water Quality, Institute of Engineers Australia, The International Association for Hydraulic Research. P.1327*

[58] According to the US EPA National Pollutant Discharge Elimination System (NPDES): http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=75

assumed to have a lifespan of 25 years, at which point it will be removed and replaced. The literature holds a significant degree of agreement that the use of swales for stormwater flow conveyance is cheaper than pipe systems, by some claims as much as 80 percent.

In comparison, filter strips cost approximately 2000$/ acre or $5000 per hectare for establishment of an area by hydro-seeding.[59] Although filter strips are not designed to attenuate peak stormwater flows, they can be an effective measure of water quality. Good indicators include a dense vegetal cover, long flow length, and low gradient to provide the most efficient removal rates.

When used in combination, the design of bioretention areas and some innovative stormwater technologies, are often less expensive to construct than enclosed storm drain systems, while providing better environmental results. Liptan and Kinsella-Brown (1996) documented residential and commercial case studies where the use of bioretention and swales reduced the size and cost of conventional storm drains needed to meet local drainage and stormwater management requirements. The more natural drainage system eliminated the need for costly manholes, pipes, trenches and catch basins, while removing pollutants at the same time. Total reported savings for the three projects ranged from $10,000 to $200,000.

Constructed Wetlands. In the context of stormwater runoff, constructed wetlands are shallow pools developed specifically for the treatment of stormwater that create growing conditions suitable for wetland plants. Constructed wetlands differ from other artificial wetlands in that they are not intended to, nor should they, replace all of the functions of natural wetlands. Rather, they are designed to provide water quality benefits by minimizing point source and nonpoint source pollution prior to its entry into streams, natural wetlands, and other receiving waters.

Constructed wetlands serve three main purposes: to capture stormwater to prevent flooding, to detain and slow the rate of runoff to reduce stream channel erosion and habitat degradation; and to capture and hold sediment and other pollutants that are present in runoff.[60]

Like bioswales, the cost of implementing a constructed wetland varies depending on its size and the site conditions. In general, larger constructed wetlands involve higher construction, installation, maintenance, and waste disposal costs. Some sources suggest that constructed wetlands, for the storm and/or waste water they treat are relatively inexpensive, with the costs of a constructed wetland intended to serve a cluster of houses similar to installing a conventional septic system.

Several estimates of the costs of constructed wetlands have been published:[3]

> *A. Construction Costs*: Using data from municipal systems, Kadlec (1995) cites construction costs from 18 North American surface flow wetlands ranging from $6,000 to $300,000 per hectare (1994), with a mean of $100,000. Reed et al. (1994) cited a range of $100,000 to $240,000 per hectare for the same type of system.

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[59] *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring Fact Sheet - Filter Strips* www.fhwa.dot.gov/environment/ultraurb/3fs11.htm (Schueler, 1987)

[60] There are two common types of ponds: wet ponds and dry ponds. Wet Ponds (retention ponds) are storm water control structures that provide both retention and treatment of contaminated storm water runoff. A wet pond consists of a permanent pool of water into which stormwater runoff is directed. Runoff from each rain event is detained and treated in the pond until it is displaced by runoff from the next storm. By capturing and retaining runoff during storm events, wet detention ponds control both storm water quantity and quality. Dry Ponds (detention ponds) are designed to capture and slowly release runoff water for a period of 72 hours or less after a precipitation event. Dry ponds do not treat the storm water and are typically constructed in areas where flood control is the greatest concern.

B. Operations and Maintenance Costs: Once established, the operation and maintenance costs for constructed wetlands can be lower than for alternative treatment options, generally less than $1,500/ha/year (Kadlec, 1995), including the cost of pumping, mechanical maintenance, and pest control.

An important and essential factor in the value of constructed wetlands in cold climates is that the first flush volume of stormwater in early Spring has been found to contain 80% to 90% of annual pollution due to the accumulation of sediments, salts and other solids during the winter months.[61] The snow-melt season is therefore a considerable design consideration in the selection, configuration, implementation and evaluation of a constructed wetland.

Wetlands are a relatively inexpensive stormwater practice.[62] Construction cost data for wetlands are rare, but one simplifying assumption is that they are typically about 25% more expensive than stormwater ponds of an equivalent volume. Using this assumption, an equation developed by Brown and Schueler (1997) to estimate the cost of wet ponds can be modified to estimate the cost of stormwater wetlands using the equation:

$$C = 30.6V^{0.705}$$

where:

C = Construction, Design and Permitting Cost
V = Wetland Volume needed to control the 10-year storm (cubic feet)

Using this equation, typical construction costs are:

Cost Breakdown for Constructed Wetlands	
1 acre-foot facility	$ 57,100
10 acre-foot facility	$ 289,000
100 acre-foot facility	$ 1,470,000

Based on these cost differences, the selection and benefits of bioretention areas should considered the size and configuration of site in relationship to existing hydrological systems. From a real estate perspective, the drawback with constructed wetlands is that they consume about 3% to 5% of the land that drains to them, which is relatively high compared with other stormwater management practices. In areas where land value is high, this may make wetlands an unfeasible option. For wetlands, the annual cost of routine maintenance is typically estimated at about 3% to 5% of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Wetlands are long-lived facilities, typically longer than 20 years before any maintenance is required. Thus, the initial investment into these systems may be spread over a relatively long period.

[61] See *Stormwater Engineering Group, North Carolina State University College of Agriculture & Life Sciences* http://www.bae.ncsu.edu/stormwater/pubs.htm#reports (accessed February 27, 2008)
[62] As pointed out in the Ontario Ministry of the Environment's Manual Stormwater Management Practices (OMOE, 1994), stormwater ponds should be considered treatment facilities and not a replacement for natural wetlands.

In addition to their hydrological functions, constructed wetlands – including wet ponds and retention basins - are visually appealing which bears the potential of increasing nearby property values. Results from the Center for Watershed Protection study suggest that "pond frontage" property can increase the selling price of new properties by about 10%. Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25% when located near a wet pond. It is anticipated that well-designed wetlands, which incorporate additional aesthetic features, would have the same benefit.[63]

A major concern in the cost-benefits of constructed wetlands and other bioretention areas is mosquito proliferation, especially when so many wet and dry ponds are in place and continue to be installed in urban areas across North America. Many ponds are not properly maintained, particularly in cases where they are installed in subdivisions and other developments where the entity responsible for long-term maintenance is not clearly defined once the construction is complete. However, if inspected regularly and maintained properly, ponds can effectively reduce flooding and remove pollutants without allowing proliferation of large mosquito populations.[64]

The best way to reduce potential mosquito breeding habitat is to reduce reliance on stormwater ponds for runoff control altogether. Alternative technologies, such as rain gardens, bioinfiltration areas, bioswales, that slow down water and help it infiltrate without extended periods of ponding are proving successful. These techniques are not only minimizing but are also eliminating the need for stormwater ponds and significantly reducing the pond size requirements. However, management care must be taken to ensure that these alternative controls drain all standing water as designed over the years.

Another, extremely successful effort in reducing the need for stormwater ponds is the use of porous pavement and bioinfiltration areas to reduce overall impervious surface cover. Couple with porous materials, the design of narrower streets, sidewalk-less communities, and elimination of cul-de-sacs are just a few of the ways that some communities are beginning to reduce the need for conventional stormwater controls.

Maintenance. Stormwater practices must be maintained, and that cost burden usually falls on landowners or local government. Over a 20 to 25 year period, the full cost to maintain a stormwater practice is roughly equal to its initial construction costs.[65] Few property owners and homeowner associations are fully aware of the magnitude of stormwater maintenance costs, and most fail to regularly perform routine and non-routine maintenance tasks. It is likely that performance and longevity of many stormwater practices will decline without adequate maintenance. Therefore, local governments need to evaluate how the future maintenance bill will be paid and who will pay it.

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[63] See Stormwater Center, Stormwater Management Fact Sheet, http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Wetland/Wetland.htm
[64] US EPA, "Do Stormwater Retention Ponds Contribute to Mosquito Problems?" Issue 71, Technical Notes, http://notes.tetratech-ffx.com/newsnotes.nsf/0/143f7fa99c3ea25485256d0100618bc9?OpenDocument
[65] Wiegand *et al.,* 1986.

Breakdown of Maintenance Activities and Frequencies per Type of Stormwater Strategy		
Type	*Maintenance Activity*	*Rate/Frequency*
Bioswale	Mowing	Monthly, seasonal
	Litter Control	Annually
	Surface Rototill	As required (infrequent)
	Silt Removal	Every 3 years (or when silt build reaches 25% of design volume)
Wet Pond	Mowing banks	Monthly, seasonal
	Outlet/inlet inspection	After storm events
	Removing vegetation from outlet	Varies
	Forebay dredging	0-3 times over pond life
Stormwater Wetland	Harvest/replanting of wetland biomass	0-1 times over wetland life
	Outlet/inlet inspection	After storm events
	Removing vegetation from outlet	Varies
	Forebay dredging	1-3 times over pond life
Bio-retention Area	Pruning shrubs and trees	1-2 times annually
	Mowing	Monthly, seasonal
	Weeding	1-2 times annually
	Re-mulching	Annually
	Replanting shrubs	Every 7-10 years
	Removing sediment accumulation	1-2 times over practice life
	Underdrain inspection	Annually
Sand Filter	Dredging sedimentation chamber	1-3 times annually
	Removing built up debris in chamber	2-3 times (Year 1) Annually, thereafter
	Outlet inspection	Annually
	Underdrain inspection	Annually
Filter Strips	Erosion Control	1-2 times (Year 1)
	Mowing & Trimming	2-3 times annually
	Regrading and Reseeding	Every 5 years
	Replanting	Every 5 years

Conservation Tactics

It is virtually impossible to calculate the cost-benefit of site-based stormwater strategies without including the value of onsite or offsite systems (streams, rivers, wetlands, forests, lakes) to which they are connected, and whose value have traditionally been externalized from the cost of site development. As part of a series of other tactical measures in the protection of existing part of watershed systems, land conservation forms an influential part of an overall index of measures that include land use planning, aquatic buffer designations, improved site design, stormwater technologies, and management programs that are discussed throughout this report.

In association with constructed systems, the securement and acquisition of existing lands bear considerable impact on the evaluation and the integration of stormwater management systems. Through legislative protection and added value through rehabilitation, lands such as wetlands, riparian areas and forests are existing watershed features become critical for durable water resource management.[66] As a system, they are proven to prevent soil erosion, filter and store, create and preserve open spaces, and reduce the impacts of floods downstream.

Critical to the economic analysis of stormwater technologies is the valuation of existing resources in order to fully account for the biocapital of urban areas such as in the City of Toronto, and how it can change the bottom line for regional authorities, developers, landowners and residents. As estimates, the following values provide a context for the conservation of wetlands and forests as part of a global ecological context upon which urban areas are reliant. These values are only estimates of the value of what is considered the services rendered by ecosystems throughout the world. What remains important is the understanding of the value of these resources as "intrinsic capital"[67] that can establish a new balance sheet when accounting for the full cost and full opportunity of development. In general, it is widely recognized that their value will increase exponentially as they become scarcer.

Average Annual Global Value of Ecological Services[68]	
Biome	*Total Value / Hectare / Year*
Marine (Oceans, Estuaries, Reefs)	$577,000,000,000
Forests	$969,000,000,000
Grass/Rangelands	$232,000,000,000
Wetlands	$14,785,000,000,000
Lakes/Rivers	$8,498,000,000,000
Cropland	$92,000,000,000

Placed against this background of global ecological value, the following pages explore the economics of watershed protection and the tactics of conservation to shed light on their intrinsic value as existing biocapital.[69]

[66] An excellent resource on the valuation of ecological systems as an infrastructure is Lucy Emerton and Elroy Bos, "Value: Counting Ecosystems as Water Infrastructure" (Gland, Switzerland: International Union for Conservation of Natural Resources, 2004).
[67] Intrinsic capital, or biocapital, should be differentiated from resource capital of, for example, ore as a mineral resource for the steel industry, or trees for the wood industry.
[68] Values are in 1994 US dollars. The values do not incorporate the 'infrastructure' value of ecosystems, leading to an underestimation of the total value according to Costanza *et al.* "The value of the world's ecosystem services and natural capital" *Nature* 387 (1997): 253-260.
[69] The failure to account for the current value of ecological resources such as wetlands and forests as assets, is a failure of universal and global proportions that needs to be revisited and realigned immediately. In critical need of restructuring, the field of economics currently bears two main flaws at the macro-economic level that explain

Wetlands, Riparian Zones & Buffer Areas. More than 90 percent of Toronto's original wetlands have been drained and developed, initially for agriculture, then for industrial and more recently for residential uses. This condition is not isolated to the Greater Toronto Area but is rather common in the Great lakes Region as a result of the urbanization along the shorelines of all five lakes including the St' Lawrence River Region.

Although the definition for wetlands greatly vary, a wetland can be understood as dynamic land that is seasonally or permanently covered by shallow water, as well as land where the water table is close to or at the surface. In either case, the presence of abundant water leads to the formation of hydric soils and favours the dominance of either hydrophytic (water tolerant) plants. These unique areas represent a combination of terrestrial and aquatic characteristics, and are further categorized by type as marsh, swamp, fen and bog. From a perspective of biodiversity, wetlands are often the most biologically diverse of all ecosystems on the planet. Riparian areas, in turn, are the adjacent borderlands including the stream bank and adjoining floodplain, which is distinguishable from upland areas in terms of vegetation, soils, and topography. Wetlands, and their associated riparian zones, are integral to the life cycle of many aquatic organisms, contain a high percentage of rare flora and fauna of a watershed and are extremely sensitive to disturbance caused by urban and biodynamic processes.

From an ecological and economic perspective, the effects of wetlands loss is therefore significant. This section deals with the costs and benefits associated with the valuation of existing of wetlands or their rehabilitation. Like constructed wetlands or other built stormwater technologies in urban areas, wetlands form part of an extremely complex ecological system that is extremely difficult to quantify and evaluate from an economic perspective. From a conservation perspective, this task becomes extremely difficult given the scale and magnitude of pre-existing systems that are often much more sophisticated hydraulically and ecologically.

Given the complexity in defining the value of wetlands as biocapital particular level of complexity, a series of relevant publications on the subject of wetland economics were consulted beforehand and are especially worth listing establishing from the onset given:

> Luke M Brander, Ramond JGM Florax, Jan E. Vermaat, "The Empirics of Wetland Valuation: A Comprehensive Summary and a Meta-Analysis of the Literature" *Environmental & Resource Economics* Vol. 33, no. 2 (February 2006): pp. 223-250.
>
> Barbara Heidenreich, "Full Cost Accounting. Valuing Natural Areas and Open Space"*, Stewardship and Conservation in Canada Conference,* July 6-8, Corner Brook, Newfoundland, 2006.
>
> M. Bardecki, "Wetlands and Economics: an Annotated Review of the Literature, 1988-1998", Environment Canada, Ontario Region, 1998.

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current conditions: first, it results from a "failure of the world market" on the one hand, in its inability to account for natural resources (see the discussion on the flawed idiom in economics, "ceteris paribus", meaning "all other things being equal", in Ekkehart Schlicht, *Isolation and Aggregation in Economics*, New York: Springer-Verlag, 1985) and, the "tragedy of the commons" on the other, in the inability of the current land tenure system to account for the collective services of complex ecological systems (see Garrett Hardin, "The Tragedy of the Commons", *Science*, Vol. 162, No. 3859, December 13, 1968, pp. 1243-1248). Paul Krugman, one of the most respected economists in the world discusses the implications of these two shortcomings in his acclaimed book *Economics* (New York: Worth Publishers, 2005).

International Lake Ontario & St. Lawrence River Study, *Valuating Wetland Benefits compared with Economic Benefits and Losses* (April 27, 2006), http://www.losl.org/reports/20060427_wetlandvalue_e.html#s3

The following tables break down the benefits and costs associated with these biodynamic processes in order to further discuss their relevance to urban stormwater management.

Breakdown of the Benefits of Wetlands & Riparian Zones[70]	
Stormwater Runoff	Wetlands function like giant natural sponges, retaining and absorbing water during rain events. During dry periods they slowly release water. Water that flows through a wetland tends to slow down, allowing suspended solids to settle out of the water. Some aquatic plants are also able to filter out some dissolved elements in water resulting in a cleaner outflow.
Flood Control	Wetlands can store large volumes of water. Conversely, when wetlands are drained, converted or filled in, the probability of a rainfall event causing flooding and floodwater damage increases significantly.
Water Filtration	Wetlands help neutralize a number of different contaminants. They can remove nutrients like phosphorus and nitrogen from water that flows into lakes, streams, rivers and groundwater.
Groundwater Recharge	If wetlands are removed, groundwater levels will be reduced. Wetlands constructed on highly porous soils can release up to 150,000 litres/hectare into the groundwater on a daily basis.
Contaminant Removal & Retention	Often referred to as aqua-remediation, wetlands can remove or retain a variety of different pollutants including nitrogen and phosphorus (agricultural and residential fertilizers), sediment (road and channel runoff), coliforms (wastewater) and pesticides. Riparian areas contribute greatly to trapping sediment.
Buffers	Buffers provide a critical right of way for streams during large floods and storms. When buffers surround the entire 100-year floodplain, they are an extremely cost-effective form of flood damage avoidance for both communities and individual property owners. As an example, a national study. of 10 programs that diverted development away from flood-prone areas found that land next to protected floodplains had increased in value by an average of $10,427 per acre.[71]
Habitat Biodiversity	Wetlands provide habitat for over 600 species of wildlife – including more than one-third of Canada's species at risk. In 2003, the value of wetlands to Canadians was estimated at $20 billion annually.[72] In 2004, migratory bird hunting contributed $91.7 million to the Canadian economy. [73] In another report by Ducks Unlimited, Coastal wetlands provide life support for oysters valued at between $54- $6,337/acre/year.[74]
Real Estate Value	Wetland frontage increases the value of adjacent property. For example, housing prices were found to be 32% higher if they were located next to a greenbelt buffer in Colorado (Correl *et al*., 1978). Nationally, buffers were thought to have a positive or neutral impact on adjacent property values in 32 out of 39 communities surveyed (Schueler, 1995). [75]
Regional Economy	Shoreline or coastal wetland areas contribute to local economies through recreation, fishing and flood protection. Various economists have calculated that each acre of coastal wetland contributes from $800 to $9,000 to the local economy (Kirby, 1993). A shoreline or creek buffer can create many market and non-market benefits for a community, particularly if they are managed as a greenway or part of a large regional network.
Carbon Storage	The value of the carbon storage services provided by the wetlands in Canada's boreal forest wetlands has been estimated at $349 billion while other ecological goods and services such as biodiversity, flood control and water filtering have been valued at another $80.4 billion.[76]

[70] Based on information from Ducks Unlimited Canada, Environment Canada and the US Environmental Protection Agency. See also USEPA, "Economic Benefits of Wetlands", http://www.epa.gov/OWOW/wetlands/facts/fact4.html
[71] Mark R. Correll, Jane H. Lillydahl and Larry D. Singell, 1978. "The Effects of Greenbelts on Residential Property Values: Some Findings on the Political Economy of Open Space." *Land Economics* 54 (2) and K. Kirby, "Wetlands Not Wastelands." *Scenic America Technical Information Series* Vol.1 No.5 (1993): 1-8, and Thomas Schueler, *Site Planning for Urban Stream Protection.* Center for Watershed Protection. Silver Spring, MD: Metropolitan Washington Council of Governments, 1995.
[72] L. Campbell and C. D. A. Rubec. "Wetland Stewardship: New Directions. Final report of the conference on Canadian Wetlands Stewardship". Report No. 03-3 (1993).
[73] Government of Canada, "Regulations Amending the Migratory Birds Regulations" *Canada Gazette* Vol. 139, No. 52 (2005).
[74] N. Olewiler, *The Value of Natural Capital in Settled Areas of Canada* (Ducks Unlimited Canada and the Nature Conservancy of Canada, 2004).
[75] In a comparison of home prices in Minnesota, sale prices were nearly one-third higher for homes that had a view of a stormwater wetland compared to homes without any "waterfront" influence. Indeed, the homes near the stormwater wetland sold for prices that were nearly identical to those homes bordering a high quality urban lake (Clean Water Partnership, 1997).
[76] M. Anielski, and S. Wilson, *Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems* (Canadian Boreal Initiative and The Pembina Institute, 2005).

Summary of Freshwater Wetland Services & Values[77]		
Study	*Services*	*Reported Values in Acres/ Year (in $US, 2006 value)*
Woodword and Wiu (values are not additive since in any one example, studies primarily providing one service type also provide other services)	Flood	$595
	Quality	$632
	Quantity	$192
	Recreational fishing	$541
	Commercial fishing	$1,179
	Bird Hunting	$106
	Bird Watching	$1,836
	Amenity	$5
	Habitat	$464
	Storm	$359
Kazmierczak	Habitat and species protection	$287
Costanza et al	Habitat/Refugia	$235
	Recreation	$263
	Total ecosystem services	$10,482
Arreola	Preserve/restore total services	$956
Breunig	Total ecosystem services	$17,307
Olewiler	Total ecosystem services (Low)	$4,217
	Total ecosystem services (High)	$17,712

According to the International Joint Commission, in a study of the value of wetlands in Lake Ontario,[78] the table above estimates the benefit values of wetlands in the range of $200-$500 per year per acre for the habitat services provided by wetlands, although there is substantial uncertainty associated with attempts to apply these estimates to Lake Ontario. Using these indicators of a single service, and allowing some value for the habitat provided now, without counting other possible benefits (such as recreation benefits)[79] from improved

[77] This table is by no means exhaustive, nor does it present all the benefits of wetlands. For a greater discussion, see International Lake Ontario & St. Lawrence River Study, *Valuating Wetland Benefits compared with Economic Benefits and Losses* (April 27, 2006), http://www.losl.org/reports/20060427_wetlandvalue_e.html#s4

[78] Like other existing biophysical systems, the economic value and benefits of wetlands is difficult to assess and is sometimes only made possible through the economic evaluation of reconstruction costs. For a comprehensive breakdown of the geo-economic value of wetlands in the Lake Ontario region, see International Lake Ontario & St. Lawrence River Study, *Valuating Wetland Benefits compared with Economic Benefits and Losses* (April 27, 2006), http://www.losl.org/reports/20060427_wetlandvalue_e.html#s3. See also Environment Canada, "Putting an Economic Value on Wetlands - Concepts, Methods and Considerations" Great Lakes Fact Sheet, http://www.on.ec.gc.ca/wildlife/factsheets/fs_wetlands-e.html

[79] As a point in comparison, the Long Point wetland complex is a 3200-hectare in size located along a 40 kilometre peninsula in Southwestern Ontario along Lake Erie. Featuring a national wildlife area and a provincial park on the peninsula, along a major waterfowl migration route called the Atlantic flyway. Like the Leslie Street Spit in Toronto, Long Point is one of the most significant stops on the continent for birds each spring and autumn. According to Environment Canada, annual recreational uses alone have been estimated to $215,906. For more information on the big business of conservation, see Howard Youth, "Cashing in on Conservation - economic benefits of wildlife

wetlands, current wetland improvements, valued at an average annual cost per acre of about $2,900, might produce between $0.6 and $3 million per year in annual benefits. There are however, according to the International Joint Commission, “caveats on both sides of this value; economists warn that these are costs, not benefits, and biologists warn that constructed wetlands are generally thought to be less valuable than natural wetlands.” [80]

From a Canadian perspective, there are a considerable number of studies that have put the annual value of the compounded goods and services generated by one hectare of wetlands, at between $5,792 and $24,330. The gamut of these values include the full gamut of habitat (including fish, shellfish, waterfowl, mammal and reptile), water supply, erosion, wind, wave barrier, storm control, flood mitigation, and recreational opportunities. As a comparison, if the approximately 40,000 hectares of Lower Fraser Valley wetlands in Western Canada were valued at the lowest estimate, its annual value would be $231.7 million. [81]

Most relevant to the City of Toronto, is the example of a wetlands acquisition project in Boston, Massachusetts, where the U.S. Army Corps of Engineers, the Commonwealth of Massachusetts and local governments acquired 8,500 acres (3,400 hectares) of wetlands in the Charles River basin to serve as a natural valley storage area for floodwaters. The cost of acquiring the wetlands was $10 million, while the cost of the alternative approach - constructing dams and levees - would have been $100 million (as cited in Kusler and Larson 1993).[82] Roughly assuming that for every 1 acre (0.4 hectare), wetlands can store a volume of over 6,000 cubic meters of stormwater, the total capacity of these wetlands is over 51 million cubic meters of water. Put otherwise, the total economic value of avoided stormwater infrastructure, at $2.50 per cubic foot (87.50/m^3) is about 4.5 billion dollars. [83]

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watching” National Wildlife, August-Sept, 2001 by http://findarticles.com/p/articles/mi_m1169/is_2001_August-Sept/ai_76817705

[80] Environment Canada, “Putting an Economic Value on Wetlands - Concepts, Methods and Considerations” *Great Lakes Fact Sheet*, http://www.on.ec.gc.ca/wildlife/factsheets/fs_wetlands-e.html (accessed January 18, 2008)

[81] N. Olewiler, *The Value of Natural Capital in Settled Areas of Canada* (Ducks Unlimited Canada and the Nature Conservancy of Canada, 2004).

[82] J. Kusler and L. Larson, Beyond the Ark: A new approach to U.S. floodplain management. Environment Vol. 35 No.5 (1993): 6-16.

[83] Another important distinction to be made in the political landscape of conservation in North America is that “mitigation banking”, a method of compensation which plays a key role in wetland conservation in the United States, is not part of Canadian conservation policy. Mitigation banking is the creation, restoration or enhancement of wetlands that will be sold or exchanged to compensate for future wetland losses incurred as a result of development. Typically, the wetlands are designated as a bank and the value of the wetlands in the bank is quantified and assigned credits, which can be sold or "withdrawn" to compensate for losses from specific future development actions.

Urban Forest Cover. Toronto has an urban forest coverage of approximately 17% to 20% of its total land area, counting the full collection of trees and shrubs in a city, including those in parks, on streets, in ravines, and on private properties in front and backyards. The City of Toronto currently maintains over 500,000 street trees on city property, and restricts the removal of trees on private property that account for more than 7 million trees across the Greater Toronto Area. According to a report by Natural Resources Canada, the value Toronto's urban forest cover as a financial asset and environmental resource, based on an average value of $700 per tree set by the Council of Tree and Landscape Appraisers in 1992, is over $16 billion.[84] [85]

The value and benefits of a single mature tree in the urban forest is summarized in the following table:

Breakdown of the Economic Values of a Single Mature Tree in the Urban Forest[86]			
Benefit	*Rate*	*% Reduction*	*Economic Value*
Storm Water & Soil Erosion Control	1300 litres/rainfall	12-17%	$75.00
Air Pollution Control	50-100kg/year	-	$50.00
Energy Savings (Air Conditioning)	-	8-12%	$73.00
Wildlife Shelter	-	-	$75.00
Total Value in 1985 Dollars	-	-	$273.00
Total Value for 50 years*	**-**	**-**	**$57,151.00**

* Total value compounded at 5 per cent interest for 50 years.

According to Environment Canada and American Forests, a city should maintain a forest cover of 40% (with a potential for 60% to 80%) since urban forests bear considerable impact on urban landscape, especially on the hydrology and the climate of the city. According to the Canadian Forest Service and the Canadian Mortgage & Housing Corporation, urban forests play an important role in reducing stormwater runoff. Tree roots absorb the water while their leaves slow the impact of the rainfall thereby reducing the load on storm sewage systems.[87] The resultant reduction in flood size translates into less damage to life and property. One Canadian study measured the amount of rain intercepted, retained in the mulch layer, and running off or infiltrated based on a 25 mm rainfall. At a minimum, the results show that a considerable portion, about 25%, is intercepted. Another study in 1988 reported that stormwater decreased by 17% due to forest cover in a Utah development during a typical one-inch rainstorm.[88] According to the City of Regina, Saskatchewan, studies

[84] Ken Farr, "Evolving Urban Forest Concepts and Policies in Canada" (Natural Resources Canada) http://www.recherchepolitique.gc.ca/v6n4_art_09_e.html. See also Council of Tree and Landscape Appraisers, "Summary of Tree Valuation Based on CTLA Approach" (17 January 203) http://www.web.net/~fode/treescount/tc_E.pdf

[85] The majority of large trees in Toronto were planted around the 1920's and 30's, and these trees now have about 10 - 15 years left in their life expectancy. The City of Toronto maintains that new urban street trees only have a life expectancy of approximately 5 years due to the stresses of urban life including confined soil space, polluted runoff, low nutrients, and compacted soil.

[86] According to a 1985 study by the American Forestry Association (now called American Forests). Primary source unknown, cited from the City of Regina Department of Urban Forestry: www.regina.ca/trees/PDFs/Benefits.pdf

[87] A percentage of rainfall is intercepted by tree leaves or needles, and then evaporates or evapotranspirates afterwards. Rainfall that passes through the canopy usually falls on soil that is more pervious than it otherwise would be due to the influence of tree roots on soil. The actual runoff benefits are dependent on the species, canopy density, level of maintenance, and time of year.

[88] S. Hanson and R. Rowntree, "Influence of Urban Forest Cover on Radiation, Temperature, and Runoff in the Salt Lake Basin, Utah" in *Proceedings of Society of American Foresters 1985 National Convention* (July 28-31, 1988) Ft. Collins, CO. Bethesda, MD: Society of American Foresters: 412-415.

show that the urban forest can reduce stormwater runoff from 12 to 17 per cent. For a moderate sized community the estimated savings are approximately $600,000 annually.[89]

Breakdown of the Benefits of Urban Forests[90]	
Stormwater Runoff Reduction	According to the Canadian Mortgage & Housing Corporation, urban forests prevent runoff by intercepting rain in their canopy, on their bark, and later through infiltration. Studies show that increasing the amount of tree cover will reduce the amount of stormwater runoff. For example, an increase in tree cover from about 25% to 50% on a residential lot can reduce runoff from about 10% to 20%.[91] Another study completed in Toronto illustrates the effects of urban forests at a higher level, where the interception capability of trees is about 2 mm, or about 40% of an average rainfall event.
Stormwater Quality	As filters, urban forests help improve the quality of stormwater runoff. Tree roots intercept fertilizers and other pollutants flowing into watercourses through ground and surface runoff. Downstream, soil erosion and siltation of urban watercourses can be reduced and prevented by the placement of biomass (woody species) along the banks of watercourses and riparian zones. In addition to the filtering of rainwater through the soil, the roots of tree species and other plant species clean the water by assimilating, or absorbing, chemicals and heavy metals.[92]
Groundwater Recharge	Urban forests provide shade and lower surface temperatures on roads, walkways and other paved surfaces, reducing the heating of rainwater that runs across its surface. This minimizes the fast, hot and dirty impact of runoff pollution.
Air Quality	Due to its large surface area, the canopy cover of urban forests improves air quality.[93] Canopy cover can trap particulate pollutants, bind or dissolve gaseous pollutants particularly when wet, and can uptake gaseous pollutants (carbon monoxide, sulphur dioxide and the nitrogen oxides) during gas exchange at leaf stomatas. Besides directly absorbing or intercepting pollutants, trees can also influence the formation and build-up of ozone. For example, modelling of a June day in Atlanta, Georgia, indicates that reducing tree cover by 20% would increase maximum ozone concentrations from 123 to 140 parts per billion, mainly because of a 2°C temperature increase.[94]
Spatial & Visual Quality	The strategic location of urban forests and placement of trees can moderate wind speed at ground level and protect against the sun's harmful ultra-violet rays. Effective windbreaks can reduce heating costs by 10 to 25 per cent in winter. In summer, properly located trees can reduce air conditioning costs up to 50 per cent. As a source of civic pride, urban forests also impart a distinctive character to an urban area and enrich the ecological identity of the region. As the city's population continues to age there will be an ever-increasing demand for more passive recreational opportunities in the form of forested parks and other green spaces.
Noise Pollution	Trees help reduce the negative effects of noise pollution. Noise directly effects the quality of life in the city. Tree planting can be used to diminish the psychological effects of noise pollution by visually eliminating the source. Effective noise barriers can be created when trees are planted in combination with earth berms and specialty fencing.

[89] See The City of Regina Department of Urban Forestry: www.regina.ca/trees/PDFs/Benefits.pdf

[90] This table is based on a wide range of literature including one of the most comprehensive documents on the cost-benefits of urban forests in cities titled "Quantifying Urban Forest Structure, Function, And Value: The Chicago Urban Forest Climate Project" by E. Gregory McPherson, David. Nowak, Gordon Heisler, Sue Grimmond, Catherine Souch, Rich Grant and Rowan Rowntree in *Urban Ecosystems* Vol.1 No.1 (March 1997): 49–61.

[91] See "Trees: the Oldest New Thing in Stormwater Treatment? – How much do tree canopies affect runoff volume" by Janis Keating, in *Stormwater* - Feature Section (February 2003) http://www.forester.net/sw_0203_trees.html

[92] The process of chemical and heavy metal uptake by plants is called *phytoremediation*. For more information on the benefits of phytoremediation, see "A Citizen's Guide to Phytoremediation", published by the US Environmental Protection Agency: www.clu-in.org/download/citizens/citphyto.pdf

[93] The Ontario Medical Association estimates that air pollution induced illness costs the Province of Ontario $1 billion a year. See Ontario Medical Association, "The Illness Costs of Air Pollution in Ontario: A Summary of Finding (Toronto, 2000) www.oma.org/phealth/icap.htm#forecast. See also L.D. Pengelly and J. Sommerfreund, "Air Pollution-Related Burden of Illness in Toronto: 2004 Update", *Technical Report* (Toronto: Environmental Protection Office, March 2004).

[94] Research by the Chicago Urban Forest Climate Project is investigating the magnitude of vegetative emissions of volatile organic compounds (a precursor of ozone) and air temperature reductions caused by trees to determine how these factors influence ozone formation in the Chicago area. See C.A. Cardelino, C.A. & W.L. Chameides, "Natural hydrocarbons, urbanization and urban ozone" in *J. Geophys. Res.*, 95 D9 (1990): 13971 - 13979.

Heat Pollution	Urban forests reduce temperature and heating costs because of heat-absorbing surfaces and land clearing, urban areas generate higher temperatures than the surrounding rural areas. Tree canopies can help to diffuse the effect of heat islands by providing shade and evapotranspiration. In addition, forest cover reduces heating costs during the winter, help protect houses from rain, heat and wind, reducing energy use. Providing shade for lawns and gardens, forest cover also reduces water irrigation needs in summer.
Cooling & Warming Effects	By absorbing a high percentage of sunlight due to the low reflectivity of a tree's dark surfaces, urban forests warm the surface of urban areas during the winter. This warming effect, or reduced albedo, is large where evergreen forests shade snow cover, which is highly reflective. Urban forest also cool urban areas through evapotranspiration by adding water vapor to the atmosphere and over time increases protective cloud cover.
Real Estate Value	Studies indicate that trees alone can enhance the marketability of a home adding 5%, up to 10% to its market value. The economic return to the City in the form of property, sales and taxes can therefore be substantial.
Carbon Sequestration[95]	As carbon sinks, urban forests play a critical role in offsetting the increase in production of carbon dioxide and other greenhouse gas emissions. Through the process of photosynthesis they convert carbon dioxide into oxygen. An average tree captures nearly half a ton of carbon dioxide over the first thirty years of its life. For the 7 million trees in the City of Toronto, a total 3.5 million tons of carbon dioxide can be stored, representing 8.74 million dollars stored. Furthermore, researchers have found that tree-lined streets had up to 70 per cent less pollution in summer, and significantly less in winter as compared to streets without trees. Increasing the amount of forest cover can therefore potentially slow the accumulation of atmospheric CO_2, so long as the trees are healthy and growing vigorously. Furthermore, urban forests offer the double benefit of direct carbon absorption and reduction of the CO_2 produced by fossil fuel power plants through energy conservation from properly located trees. According to United States Department of Agriculture Forest Service in Chicago, there is a considerable effect of planting ten million urban trees annually in the United States, between 1991 and 2000 over a 50-year period. In the year 2040, these trees would have stored 85 million tonnes and prevented the production of another 315 million tonnes of carbon, a 4:1 carbon avoided to stored ratio.
Energy Conservation	The amount of energy required to heat and cool buildings depends on their thermophysical properties, occupant behaviour and local climate. By modifying local climate, urban forests can increase or decrease building energy use. Measured and simulated energy reductions caused by vegetation around individual buildings generally range from 5% to 15% for heating and 5% to 50% percent for cooling. The aggregate effects of neighbourhood trees on air temperature and wind speed are just as important as more localized shading effects.[96] [97] Furthermore, projections from computer simulations indicate that 100 million mature trees in United States cities (3 trees for every 2 homes) could reduce annual energy use by 30 billion kWh (25800 million kcal), saving about 2 billion USD in energy costs. Avoided investment in new power supplies and an estimated 9 million tonnes (8,165 million kg) annual reduction in carbon dioxide emissions from existing power plants could augment these savings considerably. Even when the costs of planting, watering and maintaining trees are considered, tree-planting is a more cost-effective energy and carbon dioxide conservation strategy than many other fuel-saving measures.[98] [99] [100]

The description of the benefits of urban forest conservation and management should include its potential for carbon sequestration. According to the Canadian Forest Service, trees

[95] See Roger A. Sedjo, R. Neil Sampson, *Economics of Carbon Sequestration in Forestry* (CRC Press, 1997).
[96] G.M. Heisler, "Energy savings with trees" in *J. Arboriculture* Vol.12 (1986): 113-125.
[97] E.G. McPherson, L.P. Herrington & G. Heisler "Impacts of vegetation on residential heating and cooling. *Energy and Buildings* 12 (1988): 41-51.
[98] J. Huang, H. Akbari, H. Taha, & A. Rosenfeld, "The potential of vegetation in reducing summer cooling loads in residential buildings" in *J. Clim. Appl. Meteorol*. Vol. 26 (1988).
[99] See also "Urban Forest Section" in the *Toronto Homeowner's Guide to Rainfall*: http://www.riversides.org/rainguide/riversides_hgr.php?cat=2&page=54&subpage=93
[100] More than 75 percent of Chicago households use electricity for air-conditioning during the summer. According to Chicago Urban Forest Climate Project (CUFCP), initial computer simulations indicate that three 7.6 m trees around a well-insulated new home would reduce annual heating and cooling costs by 8 percent (96.00 USD) compared to those without. Annual savings created per tree would be broken down as follows: reduced cooling requirements in summer as a result of shade (37%); reduced cooling requirements in summer as a result of evapotranspiration and lowered air temperature (42%); reduced heating requirements in winter as a result of lowered wind speeds (21%).See D.J. Nowak and E.G. McPherson, "Quantifying the Impact of Trees: The Chicago Urban Forest Climate Project" in *Unasylva* No. 73 (1993).

are a valuable tool in the fight against climate change, as researchers at the Canadian Shelterbelt Centre have discovered. Their work in the field of agro-forestry[101], has determined how much carbon is fixed in a variety of tree species. Their findings bear considerable impact for urban forests given the parallels that can be drawn between the linearity of shelterbelts and the linearity of city street plantings. For example, their results prove that shelterbelts (windbreaks) are extremely useful in altering micro-climates, wind conditions, sequestering greenhouse gases. More specifically, the table below shows the potential for carbon sequestration according to different tree species.

Breakdown of Carbon Sequestration Potential of Urban Forest Tree Species[102]

Species	*Sequestration Qty per tree (kg)*	*Sequestration Qty per shelterbelt (tonnes/km)*
Poplar (*Populus* spp.)	266	106 tonnes
Green Ash (*Fraxinus* spp.)	63	41
White Spruce (*Picea* spp.)	143	26
Caragana (*Fabaceae* spp.)	39	26

As a system, urban forests are a valuable and vital part of the infrastructure of cities especially in the management of stormwater flow. Urban forests intercept rain, absorb water, and considerably slow down runoff. Using a study from American Forests on the structure of urban landscapes, the following table presents a quantitative evaluation of urban forests in relationship to urban areas across North America.

[101] Agro-forestry is a contemporary agricultural approach of using the interactive benefits from combining trees and shrubs with crops and/or livestock. It combines agriculture and forestry technologies to create more integrated, diverse, productive, profitable, healthy and robust land-use systems. See *Prairie Farm Rehabilitation Administration* - PFRA Shelterbelt Centre http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1186517615847&lang=e

[102] Shelterbelt spacing according to the Canadian Forest Service. These figures don't include the amount of carbon that will become sequestered in the trees roots, which may equal roughly 50 to 75 per cent of these amounts. These figures corroborate the findings of the American Forestry Association that found that in just one year, a mature tree absorbs over 11 kilograms (26 pounds) of carbon dioxide, cleaning up the equivalent air pollution of a car driven 18,000 kilometres (11,300 miles). The same tree also provides enough oxygen for a family of four to breathe during an entire year.

Avoided Stormwater-Construction Costs attributed to Urban Forests[103]			
Urban Area	*Savings from Urban Forests in one-time Stormwater construction costs*[104]	*Total Size of Study Area*	*Percentage Forest Cover*[105]
Houston, Texas	$1.33 billion	160,000 ha (395,000 acres)	30.0%
Atlanta, Georgia	$2.36 billion	314,000 ha (775,000 acres)	29%
Vancouver, Washington/ Portland-Eugene, Oregon	$20.2 billion	2.83 million ha (7 million acres)	25%
Washington D.C. Metro Area	$440 million	164,700 ha (43,000 acres)	21%
Delaware Valley region/Philadelphia	$5.9 billion	0.97 million ha (2.4 million acres)	20-29%
Mecklenburg County, North Carolina	$1.87 billion	142,000 ha (351,000 acres)	53%
Fayetteville, Arkansas	$92 million	12,000 ha (29,000 acres)	27%
Canton-Akron, Ohio	$414 million	395,000 ha (975,000 acres)	20.5%
Detroit, Michigan	$382 million	36,000 ha (88,855 acres)	31%
Chesapeake Bay Region, Charlottesville-Harrisburg, Virginia	$1.08 billion	0.61 million ha (1.5 million acres)	21%-26%
Buffalo-Lackawanna, New York	$35.5 million	13,200 ha (32,600 sq. miles)	12%
Greater Toronto Area	*$3.5 billion*	*590,363 ha (1,458,000 acres)*	*20%*
Greater Toronto Area (Projection)	*$7 billion*[106]	*590,363 ha (1,458,000 acres)*	*40%*

Tabulating the entire canopy cover in the Greater Toronto Area (GTA), i.e. 20% of the total land area of 5,903 square kilometers,[107] there are over 1,180 square kilometers (or 118,000

[103] As measured by the American Forest's CITY Green Model (2000-2006), reproduced in ECONorthwest, "The Economics of Low Impact Development: A Literature Review" (November 2007): p.24.
[104] Amounts are based on an average range of $2.00 to $5.00 per cubic foot for construction costs to build equivalent retention facilities.
[105] Total Number of Trees & Percentage of Total Land Area are estimates compiled from data and statistics from American Forests' Urban Ecosystem Analysis: www.americanforests.org/resources/rea/
[106] Projected values for Toronto assume that 1 hectare of urban forest can store a minimum of 350 cubic meters of water (5000 cu.ft./acre) and that the equivalent cost of stormwater construction is $85.00 per cubic meter ($2.50/cu.ft.). Considered as conservative estimates, the values are based on an average of storage volume capacity and equivalent stormwater construction costs for cities in the Great Lakes Region and across North America, according to the American Forests' Urban Ecosystem Analysis: www.americanforests.org/resources/rea/

hectares) of urban forests that cover the city including the ravines, the urban parks, and the streets. This urban forest coverage represents a 2.95 billion dollar asset in avoided stormwater costs for the handling of over 41 million cubic meters of water annually. Handling and absorbing a total volume of 3.5 million tons of carbon dioxide over the next 30 years, a doubling of the urban forest cover from 20% to 40% would therefore result in a 20% to 30% reduction in stormwater flow, representing a total savings of 7 billion dollars in additional stormwater infrastructure costs annually.[108]

Technological Performance. In addition to individual methods of assessing the value of site technologies, another method exists in the comparison of the volume of stormwater managed for a given or fixed dollar investment This section on individual site technologies,. In a recent study for the New York Department of Environmental Protection in 2007, *Riverkeep* created such an evaluation for the evaluation of different stormwater technologies, and their performance. The table below breaks down the volume of stormwater managed for each 1000 dollars invested.

Volume of Stormwater Managed per $1,000 Invested[109]	
Technology	*Litres (Gallons)*
Conventional Storage Tanks	9,000 (2,400)
Green Streets	56,000 (14,800)
Urban Forests*	50,000 (13,170)
Green Roofs	3,000 (810)
Rain Barrels	34,000 (9,000)

*The original table denotes street trees

The table demonstrates how the management performance of simple strategies such as green streets (modeled on Portland's Street Edge Alternative Project mentioned in Appendix B) and street trees greatly increases with considerably less technology investment than with green roofs and conventional storage tanks. From a macro-economic perspective, this performance assessment also suggests the importance of a multi-site approach or regional strategy that includes basic urban infrastructure such as roads and forests – resources that already compose 75 to 90% of the urban landscape - as part of a systematic infrastructure to control stormwater runoff at the source, in the most direct way possible. This broader view is discussed in greater depth at the end of the report in the section titled *Beyond Site: Landscape Planning, Design & Management*. The next section provides an in-depth compari-

[107] According to Statistics Canada, the census metropolitan area of Toronto in 2006 included over 5 million people living in a land area just under 6,000 square kilometers: http://www12.statcan.ca/english/census06/data/popdwell/Table.cfm?T=201&S=3&O=D&RPP=150

[108] It is worth noting that the City of Toronto's expenditure on urban forestry is merely $6.20/year per capita. According to the City of Toronto's *Our Common Grounds* Report, the budget for Toronto's urban forestry in Toronto is far less than what is needed. City staff is reportedly managing four times the land with half the resources that were used in 1990. In the same period, cities across the United States, particularly Chicago, invested heavily in green assets. Even smaller cities in the US spend more on urban forestry than Toronto: Detroit spends $13.00 US per capita; Milwaukee spends $15.13 US per capita; Minneapolis spends $18.21 US per capita. This evidence suggests that in order to increase the cover of urban forests throughout the GTA, the City of Toronto needs to at least double the current level of investment in urban forestry practices. In order to offset these costs, the City of Toronto should consider assessing the costs, benefits and services that urban forests provide in stormwater flow management and avoided infrastructure costs.

[109] Adapted from M. Plumb and B. Seggos, "Sustainable Raindrops: Cleaning New York Harbor by Greening the Urban Landscape" *Riverkeeper.* Website: http://riverkeeper.org/special/Sustainable_Raindrops_FINAL_2007-03-15.pdf

son of different development scenarios that make use of these different technologies for high density residential, commercial and industrial sites.

Comparative Development Scenarios[110]

Using several examples from the the literature, the following section synthesizes a series of climate-specific scenarios for development for the purposes of comparing conventional and landscape-based approaches to site design. From several sources including the Environment Canada and the US Environmental Protection Agency[111], this section quantifies the following main objectives of landscape strategies:

1. Minimization: the reduction of the parking footprint by way of shared parking, making the best use of on-street parking and pricing strategies.
2. Conservation: landscape design features, such as forest preservation, riparian buffer and streambank setbacks.
3. Water Harvesting: water storage and harvesting through cisterns and rooftop containers.
4. Infiltration Measures: other strategies to handle or infiltrate water on development and redevelopment sites such as the use of permeable surfaces, structural soils, bioretention areas and biofiltration strategies.

In one of the most cited examples of comparative runoff calculations and cost benefits of alternative stormwater management, the Conservation Research Institute, *Changing Cost Perceptions: An Analysis of Conservation Development*, Illinois Conservation Foundation & Chicago Wilderness (February, 2005) provides the following cost savings breakdown for residential, institutional and commercial sites:

Comparison of Runoff Controlled & Cost Savings for Conventional and Contemporary Landscape Strategies[112]

Prototypical Site	Runoff Storage (acre-feet)		Net Cost or Savings
	Conventional	Landscape	
Medium Density Residential	1.3	2.5	$476,406
Elementary School	0.6	1.6	$(48,478)
High Density Residential	0.25	0.45	$25,094
Commercial	0.98	2.9	$(9,772)

[110] An excellent study performed on the subject of the comparative cost-benefits of urban development using best management practices is the "Blackberry Creek Watershed Alternative Futures Fiscal Impact Study" prepared by the Center for Governmental Studies (Kane County, Illinois) in 2004. The study provides comparative scenarios of conventional development versus conservation development with considerable graphic material that discuss the spatial ramifications of landscape development as well as the ecological and the economic benefits and limitations of each method.

[111] An excellent case study on this subject is an EPA supported project for the the City of Emeryville (California) in the development of *Stormwater Guidelines for Green, Dense Redevelopment* (December, 2005). Emeryville, which is a suburb of San Francisco, has worked for over a decade on reclaiming, remediating and redeveloping the many brownfields within its borders. These efforts sparked a successful economic rebound. The city did not stop there, and decided to harness the redevelopment for better environmental outcomes, in particular that related to stormwater runoff. The city faced several challenges, including a high water table, clay soils, and few absorbent natural areas among the existing and redeveloped industrial sites.
http://www.ci.emeryville.ca.us/planning/pdf/stormwater_guidelines.pdf

[112] To convert from an acre foot to cubic feet, multiply by 43,560 (the number of cubic feet in an acre-foot. Information reproduced from K. Brewer, and H. Fisher "*Successfully Developing a Low-Impact Design Ordinance*." Presented at the Low Impact Development 2004 Conference in College Park, Maryland. Prince George's County, MD and the Anacostia Watershed Toxics Alliance. September 21-23.
http://www.mwcog.org/environment/LIDconference/downloads/Final LID Conference Program_091504.pdf

Value of the Difference in Runoff Storage provided by Landscape Strategies[113]					
Site Example	*Runoff Storage (acre-feet)*			*Runoff Storage Difference (cubic-feet)*	*Value of Difference in Runoff Storage ($2/cf)*
	Conventional	*LID*	*Difference*		
Medium Density Residential	1.3	2.5	1.2	52,272	$104,544
Elementary School	0.6	1.6	1	43,560	$87,120
High Density Residential	0.25	0.4 5	0.2	8,712	$17,424
Commercial	0.98	2.9	1.92	83,635	$167,270

In a 1998 study,[114] the Center for Watershed Protection used four actual development sites to compare conventional and innovative design techniques. The four short case studies are reproduced here as examples of intelligent practice that factor the economics of good design with downstream economic benefits.

Medium Density Residential Land Use Comparison. The first comparison was between two medium residential site plans for the same site (a typical Virginia Piedmont site) with the same number of units (108). One is a conventional design with uniform lots, wide streets, and a dry extended detention facility. The other is an innovative open space design that incorporates clustering, avoidance of natural features, buffering, shorter and narrower streets, bioretention with a wet extended detention pond, and minimization of turf and other features. The result showed a conservation benefit of about $300,000 (20%).

Cost Comparison between Conventional Application and Innovative Site Design for a Medium Density Residential Comparison		
Costs	*Conventional Application*	*Innovative Design*
Infrastructure	1,390,198	992,780
Stormwater Technologies	149,100	245,020
Afforestation	-	951
Total	1,539,298	1,238,751
Savings		$300,547 (20%)

Retail Land Use Comparison. Retail designs were also compared for a site with two large retail stores, another retail space, a gas station, and a bank. The conventional retail center is a strip development, with large paved parking areas. The innovative alternatives preserve open space and reduce impervious cover, with fewer parking spaces, pervious overflow areas, and building positioned to reduce walking distances.

[113] Brewer and Fisher, 2004.
[114] The Center for Waterhsed Protection, "Nutrient Loading from Conventional and Innovative Site Development" (July 1998).

Cost Comparison between Conventional Application and Innovative Site Design for a Retail Comparison		
Costs	*Conventional Application*	*Innovative Design*
Infrastructure	708,764	643,452
Stormwater Technologies	72,000	100,556
Afforestation	2,388	2,263
Total	782,452	746,270
Savings		$36,182 (5%)

Commercial Land Use Comparison. Designs for a commercial office park were also compared. Again, the site was typical for the Chesapeake Bay watershed: 12.2 acres with two five-story buildings covering 1.37 acres. The conventional building was surrounded by parking, with almost no open space, and two stormwater detention ponds. The design moved buildings closer to the road, reduced the parking space ratio and the number of spaces because of nearby transit. Overflow parking was designed with porous paving. Bioretention and dry swales were used in combination with a water retention pond.

Cost Comparison between Conventional Application and Innovative Site Design for a Commercial Comparison		
Costs	*Conventional Application*	*Innovative Design*
Infrastructure	856,242	631,164
Stormwater Technologies	88,441	153,859
Afforestation	4,217	3,409
Total	948,900	788,432
Savings		$160,469 (17%)

The previous examples would probably save even more than indicated, because the comparisons did not included grading erosion and sediment control costs, which are anticipated to be less for conservation and source control approaches. [115]

[115] In some circumstances, structural stormwater strategies can offset the costs associated with regulatory requirements for stormwater control. In urban redevelopment projects where land is not likely to be available for large stormwater management practices, developers can employ site-dispersed technologies in sidewalk areas (permeable surfaces), in courtyards (retention basins), on rooftops (greenroofs), in parking lots (bio-swales), and in other small outdoor spaces (cisterns), thereby avoiding the fees that some municipalities charge when stormwater mitigation requirements cannot otherwise be met. In addition, stormwater utilities often provide credits for installing stormwater infiltration technologies.

Name	Effective Area Served (Acres)	Indications (Restrictions and Strengths)	Cost Function (Q in ft^3)	Soil Permeability Ranges (minimum infiltration rate inches/hour)	Slope restriction (yes/no)
Wet Pond (Retention Pond)	>15	Large space requirement, high sediment input potentially problematic, has thermal impacts, depth limit	$C=6.1Q^{0.75}$ (<100,000 c.f. storage) $C=34Q^{0.64}$ (>100,000 c.f. storage)	Loamy Sand to Clay (>2.4)	No
Infiltration Basin	>5 <25	Cannot be near bedrock or foundations, uses more space than trench, can handle high sediment input	$C=15.3Q^{0.69}$	Sand to Loam (<.55)	Maybe
Extended Detention Pond	>15	Large space consumption, may not handle high sediment input	$C=10.7Q^{0.69}$	Sand to Sandy Clay (<.04)	No
Porous Pavement	<10	Has many restrictions (depth, slope, space, proximity to foundations/bedrock)	C=4Q	Sand to Loam (<.55)	Yes
Infiltration Trench	<10	Cannot be near bedrock or foundations, needs little space, can handle high sediment input	$C=157Q^{0.63}$	Sand to Loam (<.55)	Yes
Filter Strip/ Sand Filter	<10	Use in residential properties precludes other uses.	$C=26.6Q^{0.64}$	Various	Yes
Grassed Swales	<10	Small scale. Reserved here for Residential properties.	C=4.94Q	Various	No

Comparative Use of Structural Stormwater Technologies
From Field, R., Scott D. Struck, Anthony N. Tafuri, Michale A. Ports, Michael Clar, shirley Clark. Bety Rushton (eds.), *BMP Technology in Urban Watersheds: Current and Future Directions* (Reston, Virginia: American Society of Civil Engineers, 2006).

Based on experience across the United States and Canada, this table describes unit costs associated with the level of service provided by typical stormwater technologies. In consideration of the total cost associated with stormwater programs, components include: administration and financial management, operations and maintenance, regulation and enforcement, engineering and planning, capital investment, water quality, public involvement and education, technology, and other miscellaneous activities. For advanced stormwater programs, the three biggest cost items are: operations and maintenance, capital investment, and water quality. The cost of managing stormwater can usually be quantified in terms of cost per developed acre/hectare per year. From the current literature, all stormwater strategies with very few exceptions, displayed economies of scale when designed in series and significant differences can be found in the annual costs per acres treated when comparing different stormwater retention techniques and strategies.

Cost Comparison for Conventional Design versus Water Conservation Design			
Case Study	*Conventional Engineering*	*Conservation Design*	*Savings*
6-Acre Commercial Parking Lot	Landscape Medians designed to shed runoff.	Landscape medians re-designed as swales to accept runoff and filter pollutants. Eliminated manholes, pipes, trench-ing and catch basins.	$78,000
2-Acre Light Industrial Site	Site built with mounded me-dians and landscapes, catch basins, curb and gutter to convey runoff into city storm drain system.	Water quality site plan included bioswales and depressions instead of mounds, regarding to drain pavement into bioswales, reduction of catch basins, roof con-figuration to drain into bioswale, native vegeta-tion.	>$10,000, (despite higher excavation costs.
Residential Community (Village Homes)	Conventional approach with curb ad gutter, piping and catch basins.	Meandering vegetated swales feeding into a city detention pond.	$800/unit
2-Acre Office & Parking Garage	Inlet and pipes.	Landscape swales.	$0 (equal cost)
3.2 Acre Office & Parking Lot	Catch basins and pipes.	Reduced piping and catch basins, conversion of landscapes to swales.	$24,000 or 71%
2.2 Acre Educational Facil-ity	Piping, catch basins and mounded landscape.	Swales with minimal piping and catch basins.	$21,000 or 68%
0.2 Acre Residential Devel-opment with Four Row Houses	Soakage trench with catch basin and piping to city storm drain.	Smaller trench and catch basin in front, adding landscape filtration area in rear of lot.	$4,000 Or 44%
5 Acre Residential Devel-opment, 31 homes with 3 acres of riparian area	Significant piping and some bioswales.	Open channel bioswales replacing piping for con-veyance.	$21,000 ($680/unit, 27%)
1 Acre parking lot	Lot sloping to drain to catch basin an pipe to an on-site infiltration drywell. $10,000 added costs.	Drainage to perimeter landscapes designed to accept water and allow infiltration. No added costs.	$10,000 or 100%

Cost Savings
Associated with the Implementation of Stormwater Strategies in Residential Developments[116]

Location	*Description*	*Cost Savings*
Meadow on the Hylebos Residential Subdivision Pierce County, WA	9-acre development reduced street width, added swale drainage system, rain gardens, and a sloped bio-terrace to slowly release stormwater to a creek. Stormwater pondreduced by 2/3, compared to conventional plan. (Zickler 2004)	LID cost 9% less than conventional
Somerset Community Residential Subdivision Prince George's Co., MD	80-acre development included rain gardens on each lot and a swale drainage system. Eliminated a stormwater pond and gained six extra lots. (NAHB Research Center Inc. 2003)	$916,382 $4,604 per lot
Pembroke Woods Residential Subdivision Frederick County, MD	43-acre, 70-lot development reduced street width, eliminated sidewalks, curb and gutter, and 2 stormwaterponds, and added swale drainage system, natural buffers, and filter strips. (Clar 2004; Lehner et al. 2001)	$420,000 $6,000 per lot
Madera Community Residential Subdivision Gainesville, FL	44-acre, 80-lot development used natural drainage depressions in forested areas for infiltration instead of new stormwater ponds. (PATH 2005)	$40,000 $500 per lot
Prairie Crossing Residential Subdivision Grayslake, IL	667-acre, 362-lot development clustered houses reducing infrastructure needs, and eliminated the need for a conventional stormwater system by building a natural drainage system using swales, constructed wetlands, and a central lake. (Lehner et al. 2001; Conservation Research Institute 2005)	$1,375,000-$2,700,000 $3,798-$7,458 per lot
SEA Street Retrofit Residential Street retrofit Seattle, WA	1-block retrofit narrowed street width, installed swales and rain gardens. (Tilley 2003)	$40,000
Gap Creek Residential Subdivision Sherwood, AK	130-acre, 72-lot development reduced street width, and preserved natural topography and drainage networks. (U.S. EPA 2005; Lehner et al. 2001; NAHB Research Center Inc. 2003)	$200,021 $4,819 per lot
Poplar Street Apartments Residential complex Aberdeen, NC	270-unit apartment complex eliminated curb and gutter stormwater system, replacing it with bioretention areas and swales. (U.S. EPA 2005)	$175,000
Kensington Estates* Residential Subdivision Pierce County, WA	24-acre, 103-lot hypothetical development reduced street width, used porous pavement, vegetated depressions on each lot, reduced stormwater pond size. (CH2MHill 2001; U.S. EPA 2005)	$86,800 $843 per lot[b]
Garden Valley* Residential Subdivision Pierce County, WA	10-acre, 34-lot hypothetical development reduced street width, used porous paving techniques, added swales between lots, and a central infiltration depression. (CH2MHill 2001)	$60,000 $1,765 per lot[b]
Circle C Ranch Residential Subdivision Austin, TX	Development employed filter strips and bioretention strips to slow and filter runoff before it reached a natural stream. (EPA 2005)	$185,000 $1,250 per lot
Woodland Reserve* Residential Development Lexana, KS	Reduced land clearing, reduced impervious surfaces, and added native plantings. (Beezhold 2006)	$118,420

[116] Published US dollar values reported according to period of study listed in sources. This information is adapted from ECONorthwest, "The Economics of Low Impact Development: A Literature Review" (November 2007): p.26-27.

The Trails* Multi-Family Residential Lexana, KS	Reduced land clearing, reduced impervious surfaces, and added native plantings. (Beezhold 2006)	$89,043
Medium Density Residential* Stafford County, VA	45-acre, 108-lot clustered development, reduced curb and gutter, storm sewer, paving, and stormwater pond size. (Center for Watershed Protection 1998b)	$300,547 $2,783 per lot[b]
Low Density Residential* Wicomico County, MD	24-acre, 8-lot development eliminated curb and gutter, reduced paving, storm drain, and reforestation needs. Eliminated stormwater pond and replaced with bioretention and bioswales. (Center for Watershed Protection 1998b)	$17,123 $2,140 per lot[b]

* Hypothetical cost-benefit project, not actually constructed

Cost Savings **Associated with the Implementation of Stormwater Strategies in Commercial Developments**[117]		
Location	*Description*	*Cost Savings*
Parking Lot Retrofit Largo, MD	One-half acre of impervious surface. Stormwater directed to central bioretention island. (U.S. EPA 2005)	$10,500 -$15,000
Old Farm Shopping Center* Frederick, MD	9.3-acre site redesigned to reduce impervious surfaces, added bioretention islands, filter strips, and infiltration trenches. (Zielinski 2000)	$36,230 $3,986 per acre
270 Corporate Office Park* Germantown, MD	12.8-acre site redesigned to eliminate pipe and pond stormwater system, reduce impervious surface, added bioretention islands, swales, and grid pavers. (Zielinski 2000)	$27,900 $2,180 per acreb
OMSI Parking Lot Portland, OR	6-acre parking lot incorporated bioswales into the design, and reduced piping and catch basin infrastructure. (Liptan and Brown 1996)	$78,000 $13,000 per acre
Light Industrial Parking Lot* Portland, OR	2-acre site incorporated bioswales into the design, and reduced piping and catch basin infrastructure. (Liptan and Brown 1996)	$11,247 $5,623 per acre
Office Warehouse* Lexana, KS	Reduced impervious surfaces, reduced storm sewer and catch basins, reduced land cost, added bioswales and native plantings. (Beezhold 2006)	$317,483
Retail Shopping Center*	9-acre shopping development reduced parking lot area, added porous pavers, clustered retail spaces, added infiltration trench, bioretention and a sand filter, reduced curb and gutter and stormwater system, and eliminated nfiltration basin. (Center for Watershed Protection 1998b)	$36,182 $4,020 per acre
Commercial Office Park*	13-acre development reduced impervious surfaces, reduced stormwater ponds and added bioretention and swales. (Center for Watershed Protection 1998b)	$160,468 $12,344 per acre
Tellabs Corporate Campus Naperville, IL	55-acre site developed into office space minimized site grading and preserved natural topography, eliminated storm sewer pipe and added bioswales. (Conservation Research Institute 2005)	$564,473 $10,263 per acre
Vancouver Island Technology Park Redevelopment Saanich, British Columbia	Constructed wetlands, grassy swales and open channels, rather than piping to control stormwater. Also used amended soils, native plantings, shallow stormwater ponds within forested areas, and permeable surfaces on parking lots. (Tilley 2003)	$530,000

* Hypothetical cost-benefit project, not actually constructed

[117] Published US dollar values reported according to period of study listed in sources. This information is adapted from ECONorthwest, “The Economics of Low Impact Development: A Literature Review” (November 2007): p.28-29.

Urban Stormwater Strategies - Life Cycle Benefits & Added Value[118]			
Strategy	***Tool***	***Benefits***	***References***
Land Use Planning	*Land Use Regulations*	- 10-17% increase in real estate land value - 25% increase in vacant land value - Increased Tax base	Beaton, 1998.
Land Conservation	*Open Space Conservation Plans*	- Attracts new businesses to areas that retain open space, rural landscape and recreational opportunities	National Park Service, 1992.
	Forest Conservation on Residential and Commercial Sites	- 6-15% increase in property value - Net Increase in the rate of sale and lease - Increase in residential property tax base - Reduction in irritating noise level & screening of adjacent land use	Morales, 1980. Weyerheauser, 1989. Anderson & Cordell, 1982. Nelson, 1985
	Tree Cover Conservation	- 20 to 25% residential energy savings (compared to homes with cleared land) - 17% decrease in urban stormwater loading during a typical one-inch rainfall	American Forest Association Henson & Rowntree, 1988.
	Coastal Wetland Conservation	- Economic return of $8000-9000 per wetland acre to local economy through recreation, fishing, and flood protection	Kirby, 1993.
Aquatic Buffers	*Shoreline/Creek Buffer (greenbelt system)*	- 31% to 33% increase in residential property value -Noticeable reduction in number of drainage complaints due to decrease in shoreline erosion due to buffers - Each mile of buffer protects 12 acres of habitat along shorelines and 25 acres of habitat along creeks. - 60% of suburban residents in the vicinity of protected buffers have a willingness to pay a premium for their residential property - Increase of $33 to $900 per metre of shoreline property from a 1 metre increase in water clarity - Aggregate increase of $3.3 million to $5.4 million of additional tax revenue per year from lands adjacent to a greenbelt or greenway.	Correl *et al,* 1978. Schueler, 1995. Adams, 1994. Flink and Searns, 1993. Chesapeake Bay Foundation, 1996a. Michael *et al,* 1996.
	Floodplain Setback/Protection	- $10,427 per acre in creae in property value for lands adjacent and setback from floodplain	Burby, 1998.
	Stream Restoration	- 13% increase in property value of residential land adjacent to restored stream compared to land next to unrestored water courses	Streiner & Loomis, 1996

[118] Data for this table was tallied from the cost-benefits listed in Center for Watershed Protection, "The Economics of Watershed Protection", *Watershed Protection Techniques* Vol. 2 No.4: 469-481.

	Wilderness Buffers	- Savings of $270 to $640 per acre from reduced maintenance costs for corporate land owners when compared to highly maintained and manicured lands.	Wildlife Habitat International, 1992.
Site Planning & Stormwater Design	*Permeable Surfaces, Retention Areas & Inflitration Zones*	- 10% to 33% (upwards to 50%) reduction in the capital cost of subdivision development by reduction of length of underground stormwater infrastructure '- Conservation or reservation of 40% to 80% of total development site area for permanent, public open space - 32% premium increase in property value for property in cluster development adjacent to open space compared to low-density subdivisions. - 12% faster appreciation rate of property value in cluster development compared to a typical subdivision over a period of 20 years. - One acre lot in cluster development has same market value as a conventional subdivision lot with one to five acre lots - 35% to 60% reduction in site preparation, grading costs and erosion control costs associated with typical subdivision development that usually costs up to $5000 per acre. - 15% of site area reserved for passive or active recreation with immeasurable benefits for increased pedestrian mobility and spatial quality - 10% to 15% reduction in site impervious cover (depending on the lot size and layout) resulting in the savings of $2000 to $5000 per acre in conventional stormwater infrastructure.	NAHB, 1986. Maryland Office of Planning, 1989. Schueler, 1995. Lacey and Arendt, 1990. Legg Mason, 1990. Arendt, 1994.

Beyond Site: The Economic Value of Landscape Planning, Design & Management
While there are a considerable number of technologies that can address at source or combined benefits at the site scale, it is widely recognized that the cost-benefit ratio of urban stormwater technologies greatly increases over space and over time.

The literature confirms that the largest cost savings across all built-site conditions are mainly derived from site preparation, stormwater management, site paving and sidewalk. More specifically, there are two conservation-based design strategies appear to have the most direct and significant influence on cost savings: compact site design or clustering, and stormwater flow management systems. For example, the configuration of low impact developments and the incorporation of best management practices stormwater management can lead to the following effects:

1. *Capital Cost Reduction*: innovative design can save 10% to 33% in capital cost of subdivision development through the reduction in the length of conventional pipe infrastructure needed to serve development.[119]

2. Reduction in Site Preparation & Grading: innovative design can reduce the need to clear and grade 35 to 60% of total site area. Since the total cost to clear, grade and install erosion control practices can range up to $5,000 per acre, reduced clearing can be a significant cost savings to builders.[120]

3. *Public Open Space Creation*: 40 to 80% of total site area in permanent public open space can be maintained and managed as open space, which often increases the future value of residential property in comparison to low-density subdivisions. This premium has ranged from five to 32% in communities in the Northeastern United States. In Massachusetts, cluster developments were found to appreciate 12% faster than conventional subdivisions over a 20-year period (Lacey and Arendt, 1990). In Howard County, Maryland, a cluster development with an average lot size of one acre had the same market value as a conventional subdivision with one to five acre lots.[121]

4. *Open Space Programming*: innovative design can reserve up to 15% of the site for active or passive recreation. When carefully designed, the recreation space can promote better pedestrian movement, a stronger sense of community space and a park-like setting. Numerous studies have confirmed that developments situated near trails or parks sell for a higher price than more distant homes.

5. *Avoided Stormwater Construction Costs*: the cost of designing and constructing stormwater practices can be very substantial. The most recent cost study indicates the cost of treating the quality and quantity of stormwater runoff ranges from $2,000 to $50,000 per impervious acre. The construction costs do not include cost of land used for stormwater. Stormwater practice costs are greatest for small development sites (less than acres), but drop rapidly at larger sites. In general, about a third of every dollar spent on stormwater practice construction is used for quality control, with the rest devoted for flood control.

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[119] NAHB, 1986; Maryland Office of Planning, 1989; Schueler, 1995).
[120] Schueler, 1995. The Center for Watershed Protection computes net development savings of over $600,000 for this 490-acre cluster development (or about 50% lower costs than the conventional scenario). These large savings in development infrastructure including engineering, sewage and water, and road construction costs certainly contribute to a better bottom line. In addition, Arendt (1994) maintains that open space units sell both more rapidly and at a premium, thus increasing cash flow which is always a prime concern to the developer. See The Economics of Watershed Protection. *Feature article from Watershed Protection Techniques.* 2(4): 469-481.
[121] Legg Mason, 1990.

6. *Development Cost Compensation*: Provides a developer some "compensation" for lots that would otherwise have been lost due to wetland, floodplain or other requirements. This, in turn, reduces the pressure to encroach on stream buffers and natural areas.

7. *Real Estate Market Value:* stormwater management can also be beneficial for developers, since stormwater ponds and wetlands create a waterfront effect. For example, the U.S. EPA analyzed in 1995 twenty real estate studies across the U.S. and found that developers could charge a per lot premium of up to $10,000 for homes situated next to well-designed stormwater ponds and wetlands. In addition, EPA found that office parks and apartments next to well-designed stormwater practices could be leased or rented at a considerable premium (and often at a much faster rate). The cost-benefit of open space alone has been documented to yield considerable impact on the value of real estate. In a study by Economic Research Associates, it was found that urban open spaces, i.e. parks in the vicinity of urban developments, considerably impact the value of nearby properties from 5% to 15%.[122] [123]

8. *Permeable Surface Cover*: Reducing the amount of impervious cover created by subdivisions and parking lots at developments can lead to savings for municipalities and developers. Impervious cover can be minimized by modifying local subdivision codes to allow narrower or shorter roads, smaller parking lots, shorter driveways and smaller turnarounds. These tools make both economic and environmental sense. Infrastructure—roads, sidewalks, storm sewers, utilities, street trees—normally constitute over half the total cost of subdivision development.[124] Using innovative design, site impervious cover from 10 to 50% (depending on the original lot size and layout), thereby lowering the costs for both stormwater conveyance and treatment. This cost savings can be considerable, as the cost to treat the quality and quantity of stormwater from a single impervious acre can range from $2,000 to $50,000. In addition, the ample open spaces within a more compact development provide a greater range of locations for more cost-effective stormwater runoff practices.[125] [126]

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[122] One of the earliest studies on the tri-lateral relationship between open space, property value and tax revenue was completed by Frederick Law Olmsted over a century ago, who looked at increased tax receipts for properties surrounding Central Park. From 1856 to 1873, he tracked the value of property immediately adjacent to Central Park in order to justify the $13 million spent on its creation. He found that over the 17-year period there was a $209 million increase in the value of the property impacted by the park." See American Planning Association (Chicago ILL). "How Cities Use Parks for Economic Development" City Parks Forum Briefing Papers #3, 2002. Another good example of research on the benefits of open space design was performed by Tom Fox in a study titled "Urban Open Space: An Investment that Pays" (New York, New York: The Neighborhood Open Space Coalition, 1990. Conclusions from these studies point towards the fact that proximity to high quality urban space leads to rental premium 10 to 40% higher premiums, and that housing prices can be 5% to 20% higher. See ERA Issue Paper "Real Estate Impacts of Urban Parks", Economics Research Associates, 1991).

[123] Not all stormwater practices provide a premium however. For example, Dinovo (1995) surveyed the preferences of Illinois residents about living or locating next to dry ponds, and found most residents would not pay a premium to live next to a dry pond, and in some cases expected to pay less for such a lot. The study confirmed that wet ponds command a considerable premium and they even scored higher than natural areas, golf courses, and parks in some location decisions.

[124] See "The Economics of Watershed Protection", *feature article from Watershed Protection Techniques.* 2(4): 469-481.

[125] Some indication of the potential savings associated with "open space" or cluster development are shown in the Remlik Hall Farm example produced by Land Ethics, Inc. for the Chesapeake Bay Foundation (1996b). Cost estimates were derived for two development scenarios that result in equivalent yield to the developer. In the conventional scenario, the farm is subdivided into 84 large-lot units, whereas in the open space scenario 52 higher-end units are located on smaller lots in three clusters. Over 85% of the site is retained in open space, as farmland, forest or wetland.

[126] Besides providing shade and beauty, a mature oak tree consumes nearly 500 gallons a week from the ground, a significant factor where high rainfall is the norm. Permeable paving preserves and protects tree assets, while per-

9. *Infrastructure Capacity & Longevity*: another added yet less visible benefit of urban stormwater management using structural best management practices involves the added capacity of sanitary sewer and combines sewer outfalls during peak periods. While estimates of the benefits from off-loading of sanitary sewer results in reduced capacity for future development or prolonged life is difficult to estimate, the American Forests Organization uses a $2.00 to $5.00 per cubic foot measurements in equivalent avoided stormwater costs.

Technologies to Systems. The overall amalgamation of the cost benefits of innovative approaches to stormwater management and to the design of new sites, either multi-residential, commercial or industrial, suggests that considerable benefits can be gained from a multi-site approach that incorporates the costs of infrastructure costs at the urban level while factoring the important downstream effects at the regional level.[127] In addition to the data from the long term evaluation and effect of site technologies,[128] this observation calls for a bioregional approach to the development of cities as urban landscapes, in contrast to individual site development. While there are a number of contemporary forms of development that are gaining importance such as Low Impact Development, Smart Growth or Green Infrastructure, the research suggests that basic principles of landscape ecology be incorporated into the planning, the design and the management of urban landscapes and urban infrastructures,[129] especially when considering new forms of development on the periphery of large urban areas or in the redevelopment of existing abandoned inner city areas typical of some North American cities.

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mitting developers to maximize land use. Pervious concrete permits water to run through it, and offers a small amount of detention as well, when the ground reaches field capacity.

[127] Site-based savings are limited by to the size and location of a particular site in ultra-urban settings. See The Center for Watershed Protection, "The Economics of Watershed Protection: An Update" (Article 68, Technical Note #90) *Watershed Protection Techniques.* 2(4): 395-499. Site-based savings can also be limited in large-scale, big box, commercial developments. Ironically, one of the most straightforward, comprehensive testing of stormwater strategies is currently being performed by Wal-Mart in the U.S. Several experiments are currently being selected, tested, eliminated and explained using innovative building materials as well as site technologies www.walmartstores.com/GlobalWMStoresWeb/navigate.do?catg=654

[128] Long term monitoring and cost-benefit analysis is currenty being done by the US EPA in a comprehensive international database of best management practices: http://www.bmpdatabase.org/

[129] See "Creating a Multifunctional Landscape & Infrastructure" in *Low Impact Development Design Strategies: An Integrated Design Approach* (Prince George's County, Maryland: Department of Environmental Resources, June 1999): 2-5.

Summary of Benefits of Landscape Strategies for Stormwater Management[130]	
Benefit	*Sampling of References*
Higher Property Values Increased sales, Higher Sale & resale Prices, Shorter time on market, etc.	Schueler & Holland; trust for Public Land; Haughland; Brabec, 1992, Gilroy; Ewiing; Center for Watershed Protection 1995; Farnsworth; Emmerling-Dinovo, 1995; Lacey & Arendt; USEPA.
Increased Tourism & Recreation	Trust for Public Land; Gilroy; Brabec & Kirby.
Increased Tax Revenue	Trust for Public Land; Brabec, 1992
Downstream Economic Benefits (reduced flood damages, treatment costs, increased property values, etc.)	Braden & Johnston; Braden, Johnston & Price; Price Center for Open Space Design Fact Sheet; trust for Public Land; Gilroy.
Land Reclamation Space released back to developer for additional returns	Prince George's County.
Reduced needs for infrastructure project bonding	Prince George's County.

Public Works. At the urban level, the cost-benefits are even greater. Drawing from the example of another study in Portland, Oregon,[131] several additional cost benefits can be attained when public works are incorporated as part of site-based stormwater management strategies, at the commercial, industrial or residential level. The public sector realizes additional benefits through smaller bridges, culverts, and other drainage infrastructure and through increased aquifer recharge. Cities and industries may avoid costly upgrades to waste water treatment facilities if low flows increase. It is difficult to generalize about the economic value of the latter effects.

[130] Table adapted from Conservation Research Institute, "Changing Cost Perceptions: An Analysis of Conservation Development", Illinois Conservation Foundation & Chicago Wilderness (February, 2005).
[131] T. Liptan & C.K. Brown, "A Cost Comparison of Conventional & Water Quality-Based Stormwater Designs" (City of Portland, Oregon: Bureau of Environmental Services, 1996).

Table 2. Synthesis of Economic Values of Downstream Effects

	Economic valuation studies			
Effects category	Source	Methodology/application	Estimate ($ 2001)	Categorical synthesis
Reduced flood damage	FEMA (2003)	Average flood insurance premium/nationwide	5%–6% of property value	≤2% of value for properties receiving partial mitigation; 2–5% of value for removal from 100-year floodplain
	Streiner and Loomis (1995)	Hedonic property valuation/California urban stream restoration projects	3%–5% of property value[a]	
	Chivers (2001)	Hedonic property valuation/Flood exposure in Boulder, CO	Ephemeral effect on improved properties	
Smaller public drainage infrastructure	None	Construction and operation costs	None	Unquantified, but probably significant
Reduced sedimentation	Paterson et al. (1993)	Benefits transfer/nationwide Contingent valuation/Phase I construction site rule in NC	$317M–$3.6B/year $14–$28/household/yr	0.2–0.4% of property value, all households; more for waterside properties
		Abatement cost/Phase I construction site rules in NC	$453/treated ha/yr[b]	
Reduced pollution treatment	Sample et al. (2003) Schueler (1987)	Cost functions/best management practice costs for stormwater treatment	Site specific	Site specific
	None	Cost functions for point source effluent treatment	Industry specific	Industry specific
Improved water quality	Steinnes (1992)	Hedonic property valuation/incremental improvements in lake clarity affecting vacant lakefront lots in MN	5% increase in vacant lakefront property value/0.3 m increase in visibility	Inclusive of reduced sedimentation, 0.2%0.4% of average property value for *all* households in a watershed, including: 5% for *undeveloped waterside* properties; 10–15% for *waterside residential* properties
	Michael et al. (1996)	Hedonic property valuation/reduced turbidity in ME lakes	10–15% increase in lakefront residential property value/1 m increase in visibility	
	Brox et al. (2003)	Contingent valuation/restoration of river to provincial water quality standards in Ontario urbanizing area	$7.23/mo/household, equivalent to 0.2% of average family income	
	Loomis et al. (2000)	Contingent valuation/restoration of wastewater dilution, natural purification through streamside vegetation and wetlands, erosion control, and improved habitat for fish and wildlife in the South Plate River, CO	$ 276/yr/household, equivalent to 3% of median house value in CO	
	Leggett and Bockstael (2000)	Hedonic property valuation/impacts of reducing fecal coliform counts in Chesapeake Bay to meet state standards	6% of average property value for the 7% of all properties that are close to waters with excessive coliform (equivalent to 0.4% of all property values in MD study area)	
	Carson and Mitchell (1993)	Contingent valuation/incremental improvements to achieve Clean Water Act use classifications nationwide	$278–$378/yr/household, equivalent to 0.6%–0.8% of U.S. median annual household income and 4–6% of U.S. median house value	
Improved biological integrity and Aesthetics	Streiner and Loomis (1995) and Loomis et al. (2000)	See descriptions above	See descriptions above	See above
Increased ground-water recharge	*Use value* None	Price of potable water	Depends on years to availability and local prices	Site specific
	In-situ value NRC (1997)	N/A	Depends on aquifer structure	

[a]Includes reduced flood exposure, stream bank stabilization and revegetation, debris removal, improvements in fish habitat, additional buffer land around stream corridor, and aesthetic, educational and recreational features.

[b]Costs amortized over 20 years.

In one of the most comprehensive synthesis of economic benefits published to date[132], the downstream effects of stormwater management – especially when incorporated with public works - bear considerable value at the urban scale, over long periods of time. The table above presents those findings leading to a greater discussion on the value of landscape planning, design and management in the following section.

[132] See John B. Braden and Douglas M. Johnston, "Dowstream Economic Benefits from Storm-Water Management" in *Journal of Water Resources Planning and Management*, American Society of Civil Engineers (November 2004).

Zoning Strategies & Regional Watershed Considerations. The value of landscape planning, design and management greatly increases with scale, through geography and time. Given that the Toronto Green Development Standard only addresses property level transformation, considerable benefits can be gained from a district-based, urban-based or regionally-based approach to the design of stormwater infrastructure in combination with other systems.[133]

Like conventional stormwater engineering, there is a point of diminishing returns at which the design and maintenance of site technologies no longer affords economic returns or benefits. Although the literature on this subject is scarce, the current climate of technological and structural change seems to suggest that alternative approaches need to be developed and studied on the future of urban stormwater management. In addition to the cost-benefits of specific structural methods such as site technologies and site design, the management of stormwater runoff can also be handled through non-structural methods with the use of alternative zoning strategies.

Non structural management practices bear a considerable impact on the economy when considered at the scale of the watershed. More attention also needs to be given to practices such as 1) zoning, ordinances and local regulations, 2) industrial storm water regulation revisions and 3) effluent limitations on construction sites and other sources.[134]

Conventional, Euclidean zoning[135] requirements are intended to regulate the use, the density and geometry of development, specifying roadway widths, parking and drainage requirements; and defining natural resource protection areas. Landscape planning process recognizes that in most instances, innovative stormwater strategies or water conservation approaches need to meet local zoning requirements. However, typical conventional zoning regulations are often inflexible and restrict development options regarding certain site planning parameters. Consequently, local planning agencies that wish to optimize the environmental and economic benefits provided by alternative measures should consider employing environmentally adaptive, flexible zoning options that facilitate the use of contemporary site technologies.

Landscape planning and design strategies employ a number of flexible zoning options to meet the environmental and financial objectives of development without impeding growth. The use of these options provides added environmental responsibility to the zoning and subdivision process over and above what conventional zoning can achieve. Alternative zoning options, such as those summarized below, include overlay districts, performance zoning, impervious overlay zoning, and watershed-based zoning to allow for the introduction of innovative development, site layout, and design techniques.

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[133] Charles J. Fausold and Robert J. Lilieholm, *The Economic Value of Open Space: A Review and Synthesis*, Lincoln Institute of Land Policy Research Paper, WP96CF1, 1996.
[134] For an excellent reference on the benefits and returns of stormwater strategies over a total 100 year life cycle for a single family residential dwelling, consult the Green Value Stormwater Calculator created by Center for Neighborhood Technology: http://greenvalues.cnt.org/calculator
[135] For a comprehensive definition of zoning regulations and their effects on the shape of the North American landscape, see American Planning Association, *Planning and Urban Design Standards* (New York: John Wiley &Sons, 2006) and Chris Duerkesen, "Saving the World Through Zoning" (January 2008).

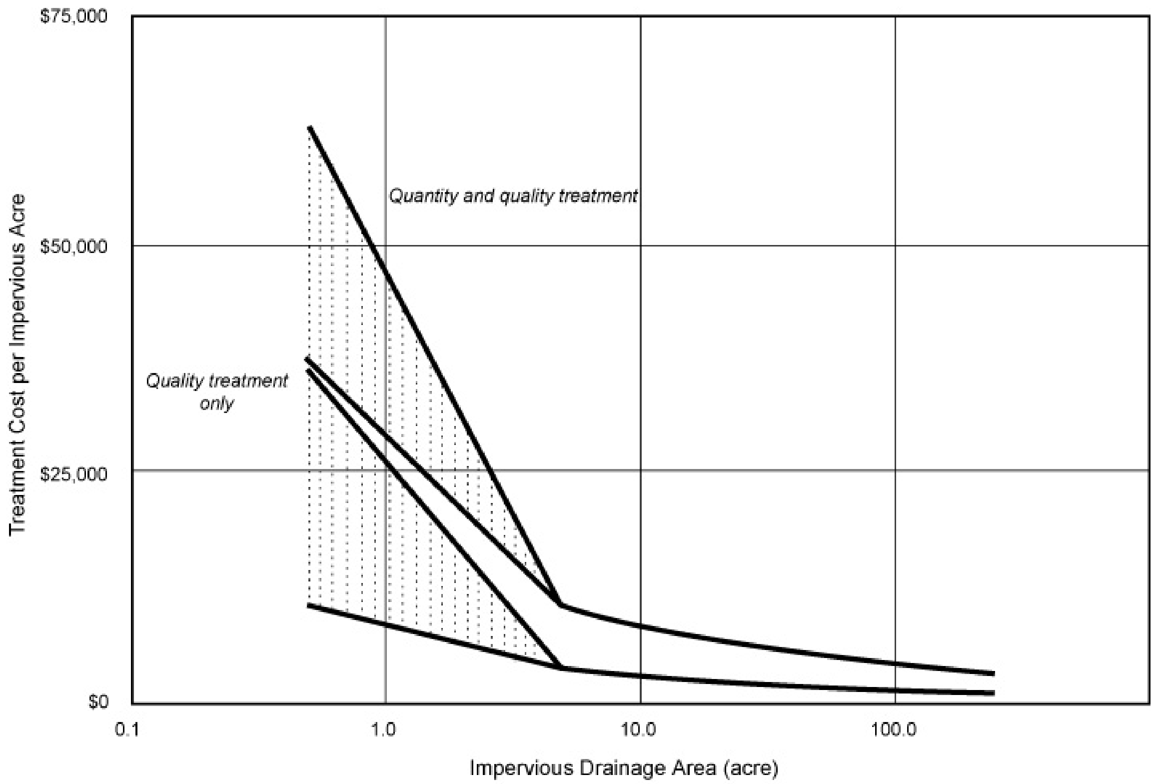
Alternative Zoning Strategies & Landscape Planning Techniques	
Strategy	*Techniques & Measures*
Overlay Zoning	Superimposition of additional regulatory standards, specifying permitted uses that are otherwise restricted, or applying specific development criteria onto existing zoning provisions.
Performance Zoning .	Flexible zoning based on a set of objectives designed to ensure a minimum level of performance within a given zoning district such as providing a certain open space ratio, an impervious area target, stormwater runoff quality and quantity criteria or a desirable density.
Incentive Zoning	Give-and-take provision to compromise on existing zoning restrictions to allow for more flexibility to provide environmental protection (such as FAR bonuses).
Impervious Overlay Zoning	Restrictions placed on subdivision layout options or any other development, based on total site imperviousness limits.
Watershed-Based Zoning	Combination of the above principles to meet a pre-determined watershed capacity, goal or objective. This technique is the foundation of a land use planning process using subwatershed boundaries as the basis for future land use decisions.

In addition to these techniques and principles, there are several other types of alternative zoning strategies such as urban growth boundaries, large-lot zoning, infill standards, and transfer of development rights. One of the most interest zoning innovations has been enacted by the City of Tumwater (Washington) involving a "Zero Effect Drainage Discharge" design standard. The standards encourage developers to achieve "zero effective impervious surface"[136]. The ordinance provides provisions for deviations from standard development regulations that include the following criteria:[137]

1. The standards recommend that at least 65% of the native forested conditions be retained over the site; that the forest is used to buffer impervious surfaces and is not clustered on the site or segregated from impervious surfaces.
2. Underlying zoning density be maintained.
3. Local access streets (ADT less than 200) are allowed to be constructed as one lane, 13-foot roadways for looped road sections with additional 3-foot shoulders on each side; or two lane, two-way, 20-foot wide for dead end and cul-de-sac road sections.
4. Curbs may be omitted.
5. Road rights-of-way include forested buffer of 50 feet minimum. All roads, turn-outs for emergency vehicles, on-street parking stalls and driveways shall be constructed with impervious surfaces.

In addition to the common sense principles of watershed zoning, policy and legislation, considerable research needs to be undertaken to lay out the cost-benefit of alternative zoning strategies in order for planning agencies, especially at the municipal and provincial level, to fully harness the long term returns from landscape planning and management in the future.

[136] Zero Effective Impervious Surface is defined as impervious surface reduction to a small fraction of that resulting from traditional site development techniques such that traditional drainage collection systems are not necessary.
[137] This criteria is adapted from *Low Impact Development Design Strategies: An Integrated Design Approach* (Prince George's County, Maryland: Department of Environmental Resources, June 1999).



Generalized Relationship between Unit Stormwater Management Cost and Size of Site. The cost of providing quantity and quality control dramatically falls when development sites are larger, due to the flexibility of systems design and economies of scale achieved.[138]

[138] Center for Watershed Protection, "The Economics of Watershed Protection", Watershed Protection Techniques Vol. 2 No.4: 469-481 and The Economics of Stormwater Treatment: An Update. Technical Note #90, *Watershed Protection Techniques* Vol. 2 No.4: 395-499.

A Comparative Example of Alternative CSO Control Scenarios: New York City - Toronto
In its June 2007 long term plan submission to the Department of Environmental Conservation for New York City, the New York Department of Environmental Protection is likely to propose $2.1 billion in end-of-pipe projects to control combined sewer overflows, or CSOs, As of the date of this publication, some of these projects are already contracted and under construction. The following scenario compares how $2.1 billion could be spread across three different alternatives:

1. 100 percent end-of-pipe,
2. 50 percent end-of-pipe and 50 percent source control,
3. 100 percent source control.

The exercise is basic, but it explores the potential costs and benefits of variations in end-of-pipe and source control commitments. Each example corresponds with a column in the chart below.[139]

	Example 1: Proposed LTCP (100% End-of-Pipe)	*Example 2: 50% End-of-Pipe and 50% Source Control*	*Example 3: 100% Source Control*
Installation Cost	$2.1 billion	$2.1 billion	$2.1 billion
Gallons Captured per Year	5.1 billion gallons	6.1 billion gallons	7.2 billion gallons
Cost of Treating Captured Stormwater per Year[140]	$1.41 million	$0.68 million	None
Air Quality Effects (Not including CO2)[141]	Water treatment adds 37.8 tons of air pollution via energy consumption per year	Water treatment adds 18.9 tons. Trees remove 25 tons. (Net reduction 6.1 tons.)	Trees remove 60 tons of air pollution. Cooling decreases summer smog.
Carbon Dioxide Effects[142]	6,481 tons created by water treatment energy consumption	3,240 tons created by water treatment energy consumption. Trees remove 145 tons. (Net addition of 3,095 tons)	Trees remove 340 tons.
Additional Street Trees[143]	None	150,000	300,000
Additional Water Collecting Green Streets[144]	None	2,133	4,266

[139] This comparative scenario is adapted and reproduced from Plumb, M. and B. Seggos. 2007. *Sustainable Raindrops: Cleaning New York Harbor by Greening the Urban Landscape* (Riverkeeper, 2007) http://riverkeeper.org/special/Sustainable_Raindrops_FINAL_2007-03-15.pdf (accessed October 31, 2007).
[140] The cost only reflects electricity costs as explained in detail in Note 130. (5.1 billion gallons * 1.49 * 10-6 MWh/gallon * 1000kWh/MWh * $0.186 per kWhr = $1.41 million).
[141] Air pollution from electricity production for water treatment. Tree air pollution reductions are detailed in note 134. Note that while energy production pollution is widely distributed, air quality improvements are localized to NYC.
[142] 25 year-old northeast maple-beech-birch average 2.52 lbs of CO2 uptake per year. 25 year-old northeast white and red pines average 14 lbs of CO2 uptake per year. Tufts Climate Initiative at http://www.tufts.edu/tie/tci/sequestration.htm. Calculations assume: 2.52 lbs of CO2 per tree per year; no CO2 benefits from greenstreets or green roofs.
[143] Assume $1,000 per street tree (see note 70). 50% solution includes 150,000 street trees ($150 million; 1.9 billion gallons per year) and 275 sq. ft. of porous pavement surrounding 105,148 street trees ($240 million; 428 million gallons per year; assuming $8.30 per square foot – see note 78). 100% solution includes 300,000 stree trees ($300 million; 3.9 billion gallons per year) and 275 sq ft of porous pavement surrounding 210,296 street trees ($480 million; 857 million gallons per year). $8.30 per sq ft is a conservative cost for porous concrete sidewalk, which can cost as little as $2.50 per sq ft. Stormwater estimate conservatively assumes no additional street trees in Greenstreets. However, most existing Greenstreets include street trees.

Additional Green Roofs[145]	None	175 million square feet	350 million square feet
Electricity Cost Savings	None	Hundreds of thousands to millions of dollars.	$67 million per year152
Property Value Benefits	None	3% - 20% increase in property values.	
Other Benefits	None	Reducing stress, enhancing productivity, and attracting customer, decreased violent crime, decreased property crime, and increased social interaction.	

Comparative Summary of Benefits & Limitations	
Comparative Scenario	*Summary of Benefits & Limitations*
Example 1 *100% End-Of-Pipe*	The end-of-pipe projects at the core of the DEP's plans would capture and treat 5.1 billion gallons of CSO at a total cost of about $2.1 billion dollars. This end-of-pipe approach will produce no ancillary benefits.
Example 2 *50% End-Of-Pipe &* *50% Source Control*	Alternatively, the City could halve the scope of the end-of-pipe controls and invest the other half ($1.05 billion) in source controls. This alternative could capture and treat over 6.1 billion gallons of stormwater by installing 2,133 greenstreets, 87.5 million square feet of new green roof, 87.5 million square feet of retrofit green roof, planting 150,000 street trees and installing 275 square feet of permeable pavement sidewalk around 105,148 street trees. This alternative would also include significant additional benefits for the City beyond stormwater control.
Example 3 *100% Source Control*	Another alternative might be to invest the entire $2.1 billion in source controls. This alternative could capture and treat over 7.2 billion gallons of stormwater. This alternative would include 4,266 green streets, 175 million square feet of new green roof, 175 million square feet of retrofit green roof, planting 300,000 street trees and installing 275 square feet of permeable pavement sidewalk around 210,296 street trees.

The New York City example is extremely relevant and highly applicable to the City of Toronto for two major reasons: 1) both cities share the same stormwater engineering system premised on end-of-pipe treatments, and 2) their capital budget/infrastructure maintenance ratio is comparable. Furthermore, the City of Toronto estimates that a storm water utility to cover the cost of stormwater management would require over a billion dollars in capital expenses and $233 million in operating expenses for the next 25 years. By using a 50% ratio of comparison, the New York City scenario brings relevance to the cost benefits of conventional and innovative approaches to stormwater engineering in the City of Toronto.

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[144] Assume 500 sq ft Green Streets built at the same cost per square foot as the $75,000 Green Street on W 110 and Amsterdam (or $46,875 per Green Street). 50% solution of 2,133 stormwater collecting Green Streets would reduce runoff by 264 million gallons per year. 100% solution of 4,266 stormwater collecting Green Streets would reduce runoff by 528 million gallons per year. Most Green Streets can be built for less. Using the assumptions explained in note 63, a 500 sq ft Green Street would cost $8,334. Also, assume all Green Streets are new. This conservative estimate does not include the significant cost savings available by simply retrofitting the over 2,000 existing Green Streets to collect stormwater.

[145] Assume new green roof incentive cost $0.40 per square foot ($6.40 for a new green roof - $6.00 for a new non green roof). Assume traditional roof retrofit as green roof incentive cost $6.00 per square foot ($9.00 green roof retrofit - $3.00 traditional roof retrofit). Using the low end of the green roof cost scale is consistent with the extensive green roofs used to determine 23% reduction in runoff. 50% solution includes $35 million of incentive toward 87.5 million sq ft of new green roof and $525 million of incentive toward retrofit of 87.5 million sq ft of traditional roof to new green roof. The resulting 175 million sq.ft. of green roof will reduce runoff by 909 million gallons per year. 100% solution includes $70 million of incentive toward 175 million sq.ft. of new green roof and $1050 million of incentive toward retrofit of 175 million sq ft of traditional roof to new green roof. The resulting 350 million sq ft of green roof will reduce runoff by 1.8 billion gallons per year.

Conclusions & Future Directions
The costs associated with contemporary urban stormwater strategies cannot therefore be judged without the context of benefits, and the literature cited throughout this report discusses numerous benefits of conservation development, which are not necessarily shared with conventional tools. A partial list of the additional selling points for developers, communities and municipalities:[146]

1. Downstream economic benefits (reduced flooding damages, treatment costs, increased property values, etc.).
2. Land released back to the developer for additional returns.
3. Reduced needs for infrastructure project bonding.
4. Higher property values (increased sales, higher sale/resale prices, shorter on-market time).
5. Increased tax revenue.
6. Increased tourism and recreation.

Simply by minimizing impervious cover, builders can therefore realize significant cost savings. Some of the typical savings include the following:

- $1,100 for each parking space that is eliminated in a commercial parking lot, with a lifetime savings in the range of $5,000-$7,000 per space when future parking lot maintenance is considered
- $150 for each linear foot of road that is shortened (pavement, curb and gutter, and storm sewer)
- $25 to $50 for each linear foot of roadway that is narrowed
- $10 for each linear foot of sidewalk that is eliminated.

The literature consistently raised examples of how conservation development methods can save money in both construction and maintenance, from the broad metropolitan scale down to the site level, and further down to a comparison of specific stormwater technologies. This is a summary of conclusions from the literature:

1. Green roofs are currently more expensive to install than standard roofs. Yet costs are highly variable and going down. Green roofs also have significant cost advantages when looking at life-cycle costs.
2. At the site level, significant cost savings can be achieved from clustering, including costs for clearing and grading, stormwater and transportation infrastructure, and utilities.
3. Installation costs can be between $4,400 and $8,850 cheaper per acre for natural landscaping than for turf grass approaches.
4. Better site design can reduce paving costs.
5. While conventional paving materials are less expensive then conservation alternatives, porous materials can help total development costs go down, sometimes as much as 30%, by reducing conveyance and detention needs.
6. Swale conveyance is cheaper than pipe systems, by some claims as much as 80%.
7. Maintenance cost savings range between $3,950 and $4,583 per acre per year over ten years for native landscaping approaches over turf grass approaches.
8. The literature is not clear enough to resolve the cost differences between discrete detention and retention tools by themselves.

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[146] Financing of stormwater strategies remains a critical factor in the proactive development of contemporary methods. An excellent guide of case studies on the financing of stormwater management programs is *Financing Stormwater Management Programs - Choices and Options*:
http://water.nstl.gov.cn/MirrorResources/2537/index.html and *The 2003 Stormwater Management Planning And Design Manual* http://www.ene.gov.on.ca/gp/4329e_5.htm

9. Costs of retention or detention cannot be examined in isolation, but must instead be analyzed in combination with conveyance costs, at which point conservation methods generally have a cost advantage.
10. Several specific conservation tools can actually have multiple positive economic effects by themselves, both directly and indirectly.
11. Despite commonlyhld assumptions, infiltration strategis and water conservation measures, incomebination with landscapeplanningmethods, usually require less space, when fully accounted for, than traditional end-of-pipe infrastructure
12. Public infrastructure costs are higher when a development is built within the context of urban sprawl, as compared to compact growth patterns that conserve land.
13. There is a correlation between density, land pattern and the effectiveness of structural stormwater strategies. Challenging conventional wisdom, low rise urban development - common to the peripheral areas across the Greater Toronto Area and many other urban centres across North America - may in fact offer the most advantageous and flexible forms of land patterns in order to effectively decentralize stormwater system and implement management strategies using infiltration and retention at their source.[147]

Perhaps the most significant theme gleaned from the literature is that, by combining multiple technologies, such as clustering and permeable surfaces, bio-swales, and other practices, deeper cost savings can be achieved from the resulting opportunities to downsize the infrastructure. This fact suggests that a dualized approach to the design of infrastructure - where techniques are designed together yielding multiple functions that can be doubled within a single system - the individual benefits of specific tools cannot be separated from the overall benefits of a complete site design, whereby the cumulative economic benefits of the site design can be impressive. Across the case studies examined here, landscape strategies and water conservation practices saved an average of 36% over conventional practices.

Furthermore, research suggests that the design of stormwater infrastructure can and should be combined with other systems, such as pedestrian and cycling infrastructure and open space networks. From an economic, ecological and spatial perspective, the combination of linear systems such as bio-swales adjacent to pedestrian walkways or bicycle lanes, or the combination of infiltration trenches with roadway medians, are feasible alternatives to conventional, specialized forms of engineering and planning. Overall, this synthetic approach suggests a dualization of public infrastructure[148] - where economic, ecological and spatial goals are combined – melding the objectives of stormwater management with the challenge of mass transportation systems, and metropolitan open space networks by design.

Finally, it is important to remember that the synthesis of stormwater management infrastructures using urban landscape strategies is of global importance. With over 60% of the world's population living in cities according to the United Nations by 2020, the reclamation of stormwater as a resource is - despite its invisibility - critically important to the future of urban areas given that over 30% of the world's freshwater supply is contained in the ground.[149]

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[147] For a comprehensive account of the counter discourse on suburban sprawl, see Robert Bruegman's *Sprawl: A Compact History* (Chicago, IL: University of Chicago Press, 2005).
[148] Due to the complexity of urban ecological systems, LEED currently does not address strategies that include urban forest cover, resource conservation, or hybrid stormwater infrastructures.
[149] Groundwater makes up 30.9% of the world's fresh water supply. Lakes and rivers only make up 0.4%, while the rest is locked up in the snow and ice (68.7%). Put together, the freshwater supply on the planet represents only 2.5% of the total water supply on the planet. The remaining 97,5% is saline.

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Acronyms

BMP – Best Management Practice
CCS – City Car Share
CEQA – California Environmental Quality Act
EPA – United States Environmental Protection Agency
MS4 – Municipal Separate Storm Sewer System
NEPA – National Environmental Policy Act
NPDES – National Pollutant Discharge Elimination System
NRDC – Natural Resources Defense Council
TDM – Transportation Demand Management
CFS - Cubic feet per second.

Glossary

Aquatic Bench or Safety Shelf - A bench, usually 4-feet to 5-feet wide, that is constructed around the inside perimeter of a permanent pool and that ranges in depth from zero to 12 inches. Normally vegetated with emergent plants, the bench augments pollutant removal, provides habitat, conceals trash and changes in water level, and enhances safety.

Bank Full Flood - The storm water generated by the 1.5-year storm.

Bare-Root Stock – Plants used as a component of vegetation for open detention basins and retention basins that are received with very little, if any, soil around the roots and are generally wrapped in Hessian cloth or plastic to prevent the roots from drying out.

Base Flow – The portion of stream flow that is not runoff and results from seepage of water from the ground into a channel over time. The primary source of running water in a stream during dry weather.

Best Management Practice (BMP), nonstructural – Strategies implemented to control stormwater runoff that focus on pollution prevention, such as alternative site design, education, and good housekeeping measures.

Best Management Practice (BMP), structural – Engineered devices implemented to control, treat, or prevent stormwater runoff.

Biochemical oxygen demand – Depletion of dissolved oxygen in water caused by decomposition of chemical or biologic matter.

Bio-filtration – The use of vegetation such as grasses and wetland plants to filter and treat sormwater runoff as it is conveyed through an open channel or swale, or collects in an infiltration basin (see Bio-retention).

Biological Diversity – The concept of multiple species or organisms living together in balance with their environment and each other.

Bio-retention – The use of vegetation in retention areas designed to allow infiltration of runoff into the ground. The plants provide additional pollutant removal and filtering functions.

Borings - Cylindrical samples of a soil profile used to determine soil properties.

Buffer Strip - A zone that is used for filtering direct storm water and storm water runoff into a storm water management system and for providing maintenance access to a storm water management system.

Catch Basin – A unit that is installed to capture and retain debris, particulate matter, or other solid materials, but allows stormwater to "flow through" to its discharge location

Check Dam - A crushed rock or earthen structure used in vegetated swales to reduce water velocities, promote sediment deposition, and enhance infiltration.

Closed Conduit - An enclosed conveyance designed to carry storm water runoff such that the surface of the water is not exposed to the atmosphere, including without limitation storm sewers, culverts, closed County drains, and pipes.

Construction Activity - A human-made activity, including without limitation, clearing, grading, excavating, construction and paving, that results in an earth change or disturbance in the existing cover or topography of land, including any modification or alteration of a site or the "footprint" of a building that results in an earth change or disturbance in the existing cover or topography of land.

Conveyance - Any structure or other means of safely conveying storm water or storm water runoff within a storm water management system, including without limitation a watercourse, closed conduit, culvert, or bridge.

Culvert - A structure, including supports, built to carry a feature over a surface water or watercourse, with a clear span of less than 20 feet measured along the center of the feature being carried.

Design Storm - A rainfall event of specified size and return interval that is used to calculate the runoff volume and peak flow rate that must be handled by a storm water management system.

Design Water Level - The water surface elevation in a detention system at which the storage volume in the system (above the permanent pool water level, if any) equals the required flood control storage volume.

Detention – The storage and slow release of stormwater following a precipitation event by means of an excavated pond, enclosed depression, or tank. Detention is used for both pollutant removal, stormwater storage, and peak flow reduction. Both wet and dry detention methods can be applied.

Detention System – A component of a storm water management system, either aboveground or belowground, that detains storm water and storm water runoff. Detention systems may include, without limitation, open detention basins and underground detention systems.

Detention Time - The amount of time that a volume of water will be detained in a detention system.

Drainage Area - The entire upstream land area from which storm water runoff drains to a particular location, including any off-site drainage area.

Drip Irrigation – irrigation via a perforated device (i.e. hose) that allows for a slow watering method with reduced evaporation and runoff losses

Easement - A legal right, granted by a property owner to another person, allowing that person to make limited use of the property involved for a specific purpose.

Edge Zone - The area within an open detention basin or retention basin between the permanent pool water surface elevation and the bank full elevation.

Evapotranspiration – The loss of water to the atmosphere through the combined processes of evaporation and transpiration, the process by which plants release water they have absorbed into the atmosphere.

Emergency Spillway - A depression in the embankment of an open detention basin or retention basin that is used to pass flows in excess of the overflow structure capacity.

Fill - Earth or other substances that are added to land to change its contour.

Filter Fabric - Textile of relatively small mesh or pore size that is used 1) to allow water to pass through while keeping sediment out (permeable), or 2) to prevent both runoff and sediment from passing through (impermeable).

Filter Strip – Grassed Strips situated along roads or parking areas that remove pollutants from runoff as it passes through, allowing some infiltration, and reductions of velocity.

First Flush - Storm water runoff that occurs during the early stages of a storm as a result of the washing effect of storm water runoff on pollutants that have accumulated on the surface of the drainage area.

Floodplain – Can be either a natural feature or statistically derived area adjacent to a stream or river where water from the stream or river overflows its banks at some frequency during extreme storm events.

Flow Restrictor - A structure, feature, or device in a detention system or pretreatment system that is used to restrict the discharge from the system for specified design storm(s).

Forebay - A component of a storm water management system that is comprised of a surface water that is used as a pretreatment system.

Freeboard - The vertical distance from the design water level to the top of the embankment of an open detention basin or retention basin.

Green Roof – A contained space over a building that is covered, partially or entirely, with living plants.

Groundwater – Water that flows below the ground surface through saturated soil, glacial deposits or rock.

Hydraulic – Referring to water

Hydrograph - A graph showing variation in the water depth or discharge in a watercourse or closed conduit over time.

Hydrology – The science addressing the properties, distribution, and circulation of water across the landscape, through the ground, and in the atmosphere.

Impervious surface – A surface that cannot be penetrated by water such as pavement, rock, or a rooftop and thereby prevents infiltration and generates runoff.

Imperviousness – the percentage of impervious cover within a defined area.

Infiltration - The rate of absorption of water into the ground, usually expressed in terms of millimetres or inches per hour.

Intergraded Pesticide Management (IPM) – An environmentally sensitive approach to pest management (not elimination) that uses the last toxic control method – a sustainable approach to managing pests by combining biological, cultural, physical and chemical tools.

Loading – Term used in conjunction with sediment and hydraulic to describe excessive amounts of (of term that is described)

Manhole - A structure that allows access into a closed conduit or other underground component of a storm water management system.

Manning's Formula - A technique for estimating the hydraulic capacity of a closed conduit, watercourse, or other means of conveyance of storm water and storm water runoff.

Manning's Roughness Coefficient ("n") - A coefficient used in Manning's Formula to describe the resistance to flow due to the roughness of a conveyance.

Manufactured Treatment System - A component of a storm water management system that consists of a manmade device or structure that is used as a pretreatment system.

Metered Detention and Discharge – A system where stormwater is collected in a cistern pond and then slowly released into the landscape beds or the storm drain in the following hours at the rate that allows for better filtration and is less taxing to the overall community storm drain.

National Pollutant Discharge Elimination System (NPDES) – A provision of the Clean Water Act that prohibits discharge of pollutants into waters of the United States unless a special permit is issued by the EPA, a state, or (where delegated) a tribal government or and Indian reservation.

Naturescaping – An alternative landscaping technique that incorporates native plants and creates beneficial wildlife habitat – also conserves water and energy, reduces soil/water pollution.

Oil/Water Separator – A unit that is installed "in line" to a wastewater discharge pipe which is devised to capture petroleum derived materials that float on water

Open Detention Basin - A component of a storm water management system that is comprised of a surface water that is used as a detention system.

Outfall – The point of discharge from a river, pipe, drain, etc. to a receiving body of water.

Outflow Rate - The rate of discharge in volume per unit time.

Peak discharge – The greatest volume of stream flow occurring during a storm event.

Peak Flow Rate - The maximum instantaneous rate of flow at a particular location within a storm water management system, usually in reference to a specific design storm event.

Permanent Pool - A pool in an open detention system or forebay that provides additional removal of pollutants through settling and biological uptake.

Permit Office - The Permit Office of the Wayne County Department of Public Services, Engineering Division.

Pesticides – Products that are toxic and used to kill pests – can be classified as insecticides, herbicides rondenticides, biocides, aquacides.

Plug – Plants used as a component of vegetation for open detention basins and retention basins that are raised as individual plants, each in a small container about the size of an ice cube.

Pollutant - Any substance introduced into the environment that may adversely affect the public health, safety, welfare, or the environment, or the usefulness of a resource.

Polluted runoff – Rainwater or snowmelt that picks up pollutants and sediments as it runs off roads, highways, parking lots, lawns, agricultural lands, logging areas, mining sites, septic sytems, and other land-use activities that can generate pollutants.

Pond Zone - The area within an open detention basin or retention basin where the permanent water depths range from 0 to 3 ft deep.

Ponding Area – In bioretention areas, the area where excess storm water runoff is temporarily stored prior to infiltration into the ground.

Porous pavement and pavers – Alternatives to conventional asphalt that utilize a variety of porous media, often supported by a structural matrix, concrete grid, or modular pavement, which allow water to percolate through to a sub-base for gradual infiltration.

Pretreatment System – A structure, feature, or appurtenance, or combination thereof, either aboveground or below ground, that is used as a component of a storm water management system to remove incoming pollutants from storm water and storm water runoff. Pretreatment systems may include, without limitation, forebays, manufactured treatment systems, and bioretention areas.

Publicly Owned Treatment Works (POTW) – a municipal wastewater treatment plan

Rational Method Formula - A technique for estimating peak flow rates at a particular location within a storm water management system, based on the rainfall intensity, watershed time of concentration, and a runoff coefficient.

Regulated Construction Activity - Construction activity that is subject to the provisions of the Ordinance or a rule promulgated pursuant to the Ordinance

Regulated Wetland - Any wetland protected by federal, state, or local laws or regulations.

Retention or Retain - The temporary storage of storm water and storm water runoff to provide gravity settling of pollutants and to promote infiltration into the soil, rather than to discharge the storm water or storm water runoff to a surface water or closed conduit.

Retention Basin - A component of a storm water management system that is comprised of a surface water that retains storm water and storm water runoff.

Retrofit – The creation or modification of a stormwater management practice, usually in a developed area, that improves or combines treatment with existing stormwater infrastructure.

Return Interval - The average expected time interval between events of some kind.

Riprap - A combination of large stone, cobbles, and boulders used to line watercourses, stabilize banks, reduce runoff velocities, or filter out sediment.

Runoff – Water from rainfall, snowmelt, or otherwise discharged that flows across the ground surface instead of infiltrating the ground.

Runoff Coefficient - The ratio of the volume of storm water runoff from a given drainage area over a given time period, to the total volume of precipitation that falls on the same drainage area over the same time period.

Sanitary sewer system – Underground pipes that carry only domestic or industrial wastewater to a sewage treatment plant or receiving water.

Scupper – an opening (in a bridge deck) to allow water drainage – it does not capture debris, particulate matter, or other solid materials

Sediment – Small particles of matter that settle to the bottom of a body of water

Sedimentation – A solid-liquid separation process utilizing gravitational settling to remove soil or rock particles from the water column.

Silt – Material consisting of mineral soil particles ranging in diameter from 0.02 millimeters to 0.002 millimeters

Siltation – A solid- liquid separation process utilizing gravitational settling to remove fine-grained soil or rock particles from the water column.

Storm sewer system – A system of pipes and channels that carry stormwater runoff from the surfaces of building, paved surfaces and the land to discharge areas.

Stormwater – rainwater runoff or snow melt waters- these waters can interact with different types of materials, transporting contaminants to surface waters (i.e. streams, creeks, rivers). Water derived from a storm event or conveyed through a storm sewer system.

Storm Water Runoff - The excess portion of precipitation that does not infiltrate the ground, but "runs off" and reaches a conveyance, surface water, or watercourse.

Surface water – Water that flows across the land surface, in channels, or is contained in depressions on the land surface (e.g. runoff, ponds, lakes, rivers and streams).

Swale – A natural or human-made open depression or wide, shallow ditch that intermittently contains or conveys runoff. Swales can be equipped with an underdrain or other man-made drainage device and can be used as a BMP to detain and filter runoff.

Time of Concentration - The time duration (typically in minutes) that is required for storm water runoff from the most remote area of the watershed to reach a given location in a storm water management system.

Total Suspended Solids - Particles or other solid material suspended in storm water or storm water runoff. “Total suspended solids” is commonly expressed in concentration (mg/l).

Toxicity – The relative degree of being poisonous

Underdrain - One or more underground pipes installed beneath bioretention areas, terraced side slopes, or other structures to facilitate conveyance of storm water runoff from beneath the structure to another part of the storm water management system.

Underground Detention System - One or more underground pipes and/or other structures that are utilized as a detention system.

Upland Zone – The area within an open detention basin or retention basin between the bank full elevation to the 100-year flood elevation and beyond.

Urban runoff – Runoff derived from urban or suburban land-uses that is distinguished from agricultural or industrial runoff sources.

Watercourse - An open conduit, either naturally or artificially created, that periodically or continuously conveys water, including without limitation rivers, streams, vegetated swales, open channels, and open County drains.

Water (hydrological) cycle – The flow and distribution of water from the sky, to the Earth’s surface, through various routes on or in the Earth, and back to the atmosphere. The main components are precipitation, infiltration, surface runoff, evapotranspiration, channel and depression storage, and groundwater.

Water table – The level underground below which the ground is wholly saturated with water.

Watershed – The land area, or catchment, that contributes water to a specific waterbody. All the rain or snow that falls within this area flows to the waterbodies as surface runoff, in tributary streams or as groundwater.

Weir - A structure that extends across the width of a surface water, watercourse or closed conduit and is used to impound or restrict the flow of water.

Wetted Perimeter –The length of the perimeter of a watercourse or closed conduit cross-section that is submerged and thereby causes resistance to flow.

Xeriscaping – An alternative landscaping technique that conserves water and protects the environment

Zero input, low input (lawns) – have minimal need for care (i.e. addition of fertilizers/pesticides, water, etc.)