Stormwater Markets: Concepts and applications

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Carleton University

Andrea Bassi
Andrés Cuéllar
Georg Pallaske
Laurin Wuennenberg

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Head Office

111 Lombard Avenue, Suite 325
Winnipeg, Manitoba
Canada R3B 0T4

Tel: +1 (204) 958-7700
Website: www.iisd.org
Twitter: @IISD_news

Carleton Centre for Community Innovation Carleton University

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Head Office

Carleton University
2104 Dunton Tower
1125 Colonel By Drive
Ottawa, ON K1S 5B6

Tel: +1 613.520.2600 ex 5792
Website: carleton.ca/3ci/

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Written by Andrea Bassi, Andrés Cuéllar, Georg Pallaske and Laurin Wuennenberg

Table of Contents

1.0 INTRODUCTION: STORMWATER RUNOFF, CAUSES AND IMPLICATIONS

Stormwater runoff refers to water that is not absorbed by soil (because the surface is saturated or sealed), and flows on impermeable land cover, such as roads. The saturation point of surface areas depends on the soil type, landscape, evapotranspiration and biodiversity of the area. In natural settings, the surface is usually permeable and absorbs large amounts water due to high levels of shallow and deep infiltration. Consequently, only a small percentage of precipitation exceeds the absorption capacity (Figure 1) (Saraswat, Kumar, & Mishra, 2016). Urban areas show a very different pattern, primarily due to the higher share of impermeable surface (e.g., roads, sidewalks, parking spaces, housing properties) which results in inhibited infiltration, interrupted hydrological cycles, and thus significantly higher surface runoff volumes and peak flows (Barbosa, Fernandes, & David, 2012).

Together with the growth of impermeable surface and precipitation, stormwater runoff is caused by the limited capacity and efficiency of installed water management infrastructure. Urban conditions cause stormwater to reach receiving streams and sewage systems quickly and in large volumes, resulting in higher peak flows (Parikh, Taylor, Hoagland, Thurston, & Shuster, 2005). This is a relevant issue especially for older cities that are often equipped with combined sewage systems. These systems collect sewage and stormwater and channel it to wastewater treatment facilities. During heavy precipitation events, these systems do not have sufficient capacity to handle the excess water (and resulting overflow) or need to discharge the mixed water directly into streams and rivers, causing pollution and further negative environmental impacts for these water bodies (Sustainable Prosperity, 2016).

Excess amounts of stormwater cause millions of dollars in damage to existing physical infrastructure and properties every year, and pose a threat to environmental quality and hence human health (AECOM, 2013; Saraswat, Kumar, & Mishra, 2016; Sustainable Prosperity, 2016).

Short-term interventions are normally designed and implemented to improve and expand infrastructure. On the other hand, a long-lasting solution would require addressing both stormwater and water management infrastructure. This is expected to reduce infrastructure costs, avoid stormwater damage and improve both human and environmental quality. It is in fact the primary goal of decision makers to balance the needs for economic growth, social empowerment and environmental preservation with the financial stability of public administrations (Philadelphia Water Department [PWD], 2011; AECOM, 2013; Sustainable Prosperity, 2016).

Finding solutions to the stormwater problem is critical. Urban areas are rapidly expanding, climate variability is increasing, and social and environmental impacts are becoming more difficult to anticipate and more expensive to fix. In addition, funds are simply not available from the public sector to meet the increasing needs for capital and operation and maintenance (O&M) costs of water management infrastructure. Further challenges emerge from the many and varied (and often conflicting) expectations of local stakeholders and the fact that stormwater management is at the intersection of federal and local legislative and policy frameworks (PWD, 2011; Department of Energy and the Environment [DOEE], 2013; CH2M HILL, 2014; Sustainable Prosperity, 2016).

This paper provides an overview of the technology and financing options available to address the problem and better plan for stormwater management. Specifically, the analysis focuses on the creation of stormwater markets, an instrument that holds considerable promise to attract private investment and to safeguard long-term funding for implementing comprehensive mitigation measures.

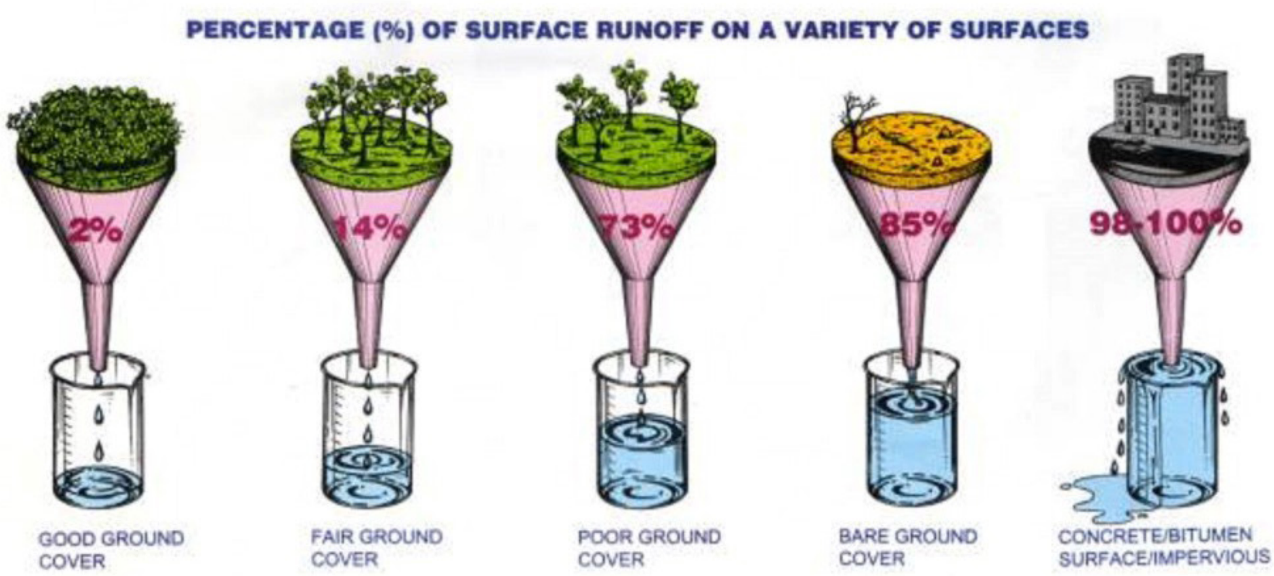

Figure 1. Percentage of runoff on a variety of surfaces

Source: © State of New South Wales Department of Premier and Cabinet. For current information go to www.nsw.gov.au.

2.0 GRAY AND GREEN INFRASTRUCTURE OPTIONS FOR STORMWATER MANAGEMENT

Stormwater infrastructure can be classified as engineered (or gray) infrastructure and green infrastructure. Gray infrastructure includes engineered elements such as piped drainage and engineered water treatment systems (Marsalek & Schreier, 2009). Green infrastructure (GI) refers to natural and/or man-made elements that provide, improve or restore ecological and hydrological functions and processes to manage wet weather impacts (Sustainable Prosperity, 2016).

Engineered infrastructure measures can serve at different scales (property, neighbourhood, city, watershed level) for different stormwater management purposes. These include source-control measures (pollution prevention), abatement measures that either reduce the quantity of stormwater runoff and/or improve the water quality of stormwater runoff through pre-treatment, and end-of-pipe measures that deal with the negative consequences of stormwater. Gray stormwater infrastructure serves to channel stormwater away from private properties toward waterbodies and centralized water treatment facilities. Gray infrastructure is often characterized as end-of-pipe measures and are mostly installed at the municipal level (Marsalek & Schreier, 2009).

Most of the currently installed stormwater management systems consist of gray infrastructure components, including pipes, pumps and culverts (Canadian Water Network [CWN], 2015; Sustainable Prosperity, 2016). Gray infrastructure contributes to the management of stormwater in urban areas, but does not necessarily support the mitigation of stormwater peak flow. In recent years, GI components are increasingly being incentivized in recognition of their beneficial effects in absorbing large quantities of stormwater through the increase of permeable surface and hence reducing peak flow as well (Environmental Protection Agency [EPA], 2014a). A variety of cities are revising their stormwater management (and billing) system in order to boost its resilience toward future (PWD, 2011; AECOM, 2013; CH2M HILL, 2014; City of Philadelphia, 2017; Sustainable Prosperity, 2016).

More specifically, GI in the context of stormwater comprises natural and/or man-made elements that provide, improve or restore ecological and hydrological functions and processes to manage wet weather impacts (Sustainable Prosperity, 2016). According to the U.S. Environmental Protection Agency, green infrastructure "uses vegetation, soils, and natural processes to manage water and create healthier urban environments" (EPA, 2014b). Other terms in the literature that are commonly used to refer to GI are low-impact development, rainwater management or natural stormwater management (Sustainable Prosperity, 2016).

GI reduces the volume of stormwater (e.g., by decreasing the impermeability of sites and allowing infiltration) and prevents, or at least reduces, the risk of pollution from remaining runoff (e.g., by reducing the level of pollutants through filtering and treatment processes) (PWD, 2011; EPA, 2015a). The implementation of GI for stormwater abatement and pollution prevention is increasingly featured in the literature on stormwater in urban environments (EPA, 2014a; EPA, 2015a; Sustainable Prosperity, 2016; Brown & Sanneman, 2017). Large volumes of pollution from stormwater, which are normally transported to urban water bodies by the so-called "first flush," is partially retained by GI components (EPA, 2015a). GI measures hence actively contribute to flood mitigation by reducing and decelerating stormwater peak discharges (Sustainable Prosperity, 2016).

Different types of GI measures have a varying degree of effectiveness depending on the level of exposure of a given area to stormwater (EPA, 2015a) (Table 1). At the same time, the costs for implementing GI measures can vary depending on property conditions, including current level of impermeability, parcel size, soil type, and slope. The costs (dollars per square foot of impermeable area managed) tend to be inversely related to the parcel size of a property—the costs per unit decrease as the parcel size increases. Consequently, the cost-effectiveness of GI varies based on property attributes (Valderrama, et al., 2013). Several studies provide evidence that both, i) the replacement of gray infrastructure with GI components, and ii) the combined implementation of gray and green stormwater infrastructure generate cost savings, especially from a lifecycle perspective (Sustainable Prosperity, 2016).

Beyond the direct effect of improved stormwater management, GI measures facilitate multiple economic (avoided water treatment and cleanup costs from flooding events, utilization of harvested rainwater, increased property values), social (more aesthetically pleasing inner cities and private properties, green jobs) and environmental benefits (recharged groundwater, better air quality, improved biodiversity) to urban environments and communities (Sustainable Prosperity, 2016). In addition, the implementation of GI helps create a knowledge base among community members and increases their appreciation of stormwater management and improved hydrological cycles (PWD, 2011; Water Environment Federation [WEF], 2015). Such positive externalities provide additional reasons for cities to foster GI and consider its implementation from a holistic urban management perspective.

Table 1. Green Infrastructure measures for stormwater management, partly based on EPA, 2015a.

Green Infrastructure Measure	Stormwater Impact*	Description of Application for Stormwater Runoff Management	Benefits	Costs
Green roofs	Both	Green roofs usually consist of four layers: waterproof membrane, drainage layer, growing medium, and vegetative cover layer.	Reduction of total annual runoff from a building envelope by 60 to 70 per cent, and support of hydrological cycles in urban areas.	USD 30–40 per ft²
Downspout disconnection	Quantity	Disconnection between various impermeable areas.	Reduction of runoff volume and instead facilitation of on- or near-site retention through rainwater harvesting or infiltration. Further benefits can be generated from utilizing harvested water.	Costs associated with installation of new runoff retention solutions
Rainwater Harvesting (barrels, cisterns)	Quantity	Capture of runoff generated from impermeable areas in a storage facility (wide range of sizes available). Two common types: Shared and integrated rainwater harvesting systems.	Reduction of runoff volume.	USD 2–5 per gallon captured (≈ USD 2–5 per ft² of IA)
Raingardens/ bioretention facilities	Both	Relatively small, ground-level spaces consisting of a mixture of sand, vegetation and organic filter media to treat polluted runoff.	Capture and treatment of runoff, provision of enhanced water quality and infiltration into surrounding soils or underground detention.	USD 3–4 per ft² of IA
Bioswales	Both	Narrow, below-ground-level sloped drainage areas with grass or vegetation. These can continue over long distances. Located next to roads and walking paths, at roadway medians, shoulders and parking lots.	Provision of runoff conveyance and water quality treatment through slow draining, filtering and infiltration. Filtering media can be used under the bioswale for added pollutant removal efficacy.	USD 1–2 per ft² of IA

Green Infrastructure Measure	Stormwater Impact*	Description of Application for Stormwater Runoff Management	Benefits	Costs
Planter boxes (stormwater/ infiltration planters)	Both	Bio-infiltration-based structures with vertical walls. Located in transportation corridors or parking areas.	Capture and retention of urban runoff generated on sidewalks and roadways or capture of runoff from downspout disconnection efforts. Planters can exfiltrate directly to underlying soils or can be tied into drainage infrastructure.	USD 3.80–7.70 per ft^2 of IA
Permeable pavements	Quantity	Different types: porous asphalt, permeable concrete, permeable pavers, open-matrix pavement.	Enablement of water to soak through paved areas.	USD 5–7 per ft^2 of IA
Detention and retention ponds/basins & Constructed wetlands	Both	Relatively large, natural ponds to collect rainwater. Detention ponds stay dry during times of no rainfall whereas retention ponds hold a constant amount of water.	Large storage spaces to prevent flooding during times of intense rainfall, infiltration of water into the aquifer. Additional benefits: habitat for animals and plants.	N/A
Urban tree canopy	Both	Trees can be planted on private and public properties. This is a long-term measure.	Among others, trees reduce and slow stormwater by intercepting precipitation, they provide water treatment and mitigate negative impacts such as erosion.	N/A
Land conservation	Both	Protection of natural open spaces and sensitive areas within and adjacent to urban areas, such as riparian areas, wetlands and steep hillsides. Land conservation measures take place on a neighbourhood or city scale.	These areas reduce the volume of stormwater runoff and fulfill significant filtration functions.	N/A

3.0 MEASURING THE COST OF INACTION AND THE BENEFITS OF INTERVENTIONS

Before answering the question of how to measure the benefits of stormwater management, it is necessary to understand what the economic implications of stormwater runoff are, and hence how much a community should be willing to pay to solve the problem.

Stormwater runoff can have many unexpected impacts, resulting in extrabudgetary expenditure for the public sector as well as economic losses for the private sector and households. Some of these costs are direct, such as floods leading to infrastructure damage (e.g., to roads, buildings). Some others are indirect, such as increased water pollution leading to hypoxic events and fish death, which in turn may affect fisheries (recreational and commercial), tourism and real estate value (Saraswat, Kumar, & Mishra, 2016). Addressing the problem also requires considerable funding, especially when considering that the most negative impacts of stormwater runoff are peak flows (or extreme events) which reach beyond the capacity of water (and wastewater) management infrastructure. In fact, water contamination primarily takes place during the initial phase of a stormwater event, also known as first flush, where the highest concentrations of pollutants are transported toward water systems. The composition of stormwater is different from regular domestic wastewater, as the former often contains significant amounts of heavy metals and toxic substances (Table 2), posing additional challenges for existing wastewater treatment facilities. The severity of water pollution depends on the quality and flow velocity of stormwater, which itself depends on local conditions such as types and extent of polluting substances present in affected locations (e.g., anthropogenic activities and land use in residential areas vs. industrial zones) and climatic conditions. Additionally, characteristics of sewage systems, such as combined sewer systems (CSS), and water supply systems as well as the volume and quality of the affected water influence the degree of pollution caused by stormwater (Barbosa, Fernandes, & David, 2012). Since advancements are being made to reduce water pollution from point sources in many countries, it is now recognized that non-point sources such as stormwater are the primary contributor to pollution of receiving waters (Lee, Swamikannu, Radulescu, Kim, & Stenstrom, 2007).

Table 2. Characterization of stormwater pollutants

Pollutant group	Measurement parameter	Sources	Comments
Solids (suspended solids, or SS)	TSS	Pavement wear; construction sites or rehabilitation works; atmospheric fallout; anthropogenic wastes, etc.	60-80% of SS in stormwater could be less than 30 mm diameter. Other sewer solids are present in combined sewer overflow (CSO). Solids also accumulate within the sewer system and may be discharged at different times. Heavy metals and PAHs are bonded to the smaller particles (e.g., 100–250 mm).
Heavy metals	Cu, Zn, Cd, Pb, Ni and Cr	Vehicles parts and components; tire wear; fuel and lubricating oils; traffic signs and road metallic structures. Industries may also be an important source of heavy metals.	They are relevant because of toxic effects. Generally, the focus is on copper (Cu), zinc (Zn); cadmium (Cd) and lead (Pb). The incidence of Pb is minor in countries using unleaded gasoline.
Biodegradable organic matter	BOD5 and COD	Vegetation (leaves and logs) and animals such as dogs, cats and birds (either fecal contributions or dead bodies).	Organic matter (o.m.) from stormwater is less biodegradable (dominated by plant material), therefore is also less problematic for the environment than the o.m. from CSO.
Organic micropollutants	They are numerous, and include PAHs, PCBs, MTBEs, endocrine-disrupting chemicals	e.g., PAH: incomplete fossil fuel combustion; abrasion of tire and asphalt pavement, etc. Phthalate esters: urban construction plastic materials.	Presently, a large number of compounds (over 650 identified) are discharged in trace concentrations and sometimes there is no accurate chemical determination method available for them.
Pathogenic microorganisms	e.g., Total coliforms; Escherichia coli	Contributions from cats, dogs and birds.	Stormwater sources are much different than domestic wastewater contribution in the case of CSOs.
Nutrients	Nitrogen and phosphorous (e.g., total Kjeldahl N; NO_2+NO_3; total-P; soluble-P)	Fertilizers and atmospheric fallout.	Nutrients can cause not only eutrophication problems but also water discoloration, odours, toxic releases and overgrowth of plants.

Source: Barbosa, Fernandes, & David, 2012.

The next sections outline the potential benefits emerging from the adoption of best stormwater management practices (BSMPs). The content is primarily based on Braden and Johnston (2002). Further, we provide an overview of mechanisms and instruments available to estimate stormwater-related benefits and to determine an adequate financing structure for stormwater management.

3.1 Floods and Related Socioeconomic Impacts

The benefits of BSMPs result from the mitigation of damages of flooding events. The cost of floods is generally measured as the cost of repairs and cleaning of the properties and areas affected. Flood insurance is an example of a mitigation practice. The insurance premium comprises the willingness to pay for avoided flooding costs, and determines coverage in case of a flood.

Stormwater management infrastructure anticipates that infrastructure improvements will protect public and private property against flooding damages. The main purpose of investing in infrastructure is to avoid damages that are economically higher than the investment itself. At the same time, the implementation of mitigation measures increases or maintains the property value of affected properties, as the economic risk of flooding is (partially) mitigated.

3.2 Public Drainage Infrastructure

Efficient stormwater management infrastructure helps reduce infrastructure investments in the public drainage system. Public infrastructure is designed to support peak sewer flows. The implementation of stormwater management infrastructure reduces the peak flow requirement. Costs decline as the pipe's diameters would be smaller, without losing system efficiency.

3.3 Water Pollution Treatment

Additional benefits from efficient stormwater infrastructure are realized through a reduction in total runoff volume. Lower runoff volumes enter the public drainage system, which implies reduced water flow to be processed by wastewater treatment facilities. The avoided treatment costs (capital, energy and material savings) are direct benefits from a reduction of stormwater runoff.

3.4 Erosion and Sedimentation

Excessive runoff generates soil erosion and releases pollutants into the sewer system and water streams. The implementation of BSMPs reduces runoff into the sewer system and hence the amount of sediments and pollutants carried into the system. Lower sediment and pollutant loads increase water mobility and contribute to a reduction in operations and maintenance costs, both for public waterways (e.g., channels, sewers) and wastewater treatment facilities (energy for sediment and pollution removal). BSMPs also improves the well-being of the community, as residents and tourist would enjoy clearer waters (reduced water turbidity) in coastal areas. Improved water quality also raises the value of property close to streams or coastlines.

3.5 Water Quality

On its way to the sewer or water bodies, surface runoff collects many contaminants that are mixed with other substances inside the public sewer system. This hampers the water treatment process and increases the costs of wastewater treatment. Stormwater infrastructure reduces the volume of runoff that goes into the sewer system. Surface waters are collected by stormwater infrastructure, rather than being released into the sewer system. Consequently, pollutants bond to soil particles, or are changed by microorganisms in the soil. In both cases, the water quality entering the system is improved.

4.0 STORMWATER MANAGEMENT AND GOVERNANCE

There are many approaches to addressing stormwater runoff, starting from strategic and political decisions, to source-control measures and end-of-pipe measures (Barbosa, Fernandes, & David, 2012). In many cities, end-of-pipe measures in form of centralized, large-scale facilities have been constructed to handle high volumes of stormwater runoff in case of severe storm events. This is because decentralized solutions on private properties could not sufficiently address the volume of runoff expected, especially due to the expansion of impermeable surfaces. However, new GI measures provide additional options for more integrated approaches to stormwater management, which include preventive and source-control measures to reduce runoff volumes and runoff speed, as well as to curb water pollution through natural filtration (Saraswat, Kumar, & Mishra, 2016).

Available public green spaces are insufficient to mitigate the increase of stormwater runoff in urban areas. Furthermore, centralized infrastructure is costly and has proven ineffective in managing the initial phase of a stormwater event (first flush). As a result, it is now important to implement stormwater control measures on private properties as well (CH2M HILL, 2014). This would reduce runoff through improved water infiltration, lessen the need for expanding water management infrastructure and lower environmental degradation and resulting health impacts. Thus, people in residential, commercial and industrial areas are more frequently being requested to invest in stormwater control measures (Dennehy, 2013).

However, this is not an easy—or welcome—process. While private investment into management and technology measures is necessary, its benefits would primarily be collective, and no single economic actor accrues enough benefits to justify such an investment. The result is a social dilemma: a tendency toward collective inaction and a desire for so-called "freeloading" arises (Carlson, Barreteau, Kirshen, & Foltz, 2015). Because individual property owners will only consider their personal benefits when making investment decisions, there will be an investment gap that undermines the achievement of sufficient levels of stormwater management from a municipal perspective. Therefore, public intervention is required to incentivize investments into GI measures and/or raise funds for higher public expenditures. Available intervention instruments comprise command-and-control regulations, fiscal policies or the creation of a stormwater market. The latter option could potentially attract higher volumes of private investments.

The following sections provides a general overview of stormwater governance mechanisms that regulatory bodies can use to incentivize private property owners to implement measures to mitigate stormwater runoff.

4.1 Command-and-Control Regulations

A traditional state-centred approach to address stormwater issues is to introduce command-and-control regulations that mandate that individuals achieve uniform (technology or pollution) standards (e.g., all property owners must have a rainwater harvest facility and install green roofs). However, such approaches are often inefficient, since it is difficult to customize them to account for differences in implementation at the plot level and they are expensive to monitor. On the other hand, for point source pollution, they would guarantee reaching targets at the city/urban level if well planned and effectively implemented. Since stormwater runoff is a non-point source of pollution, command-and-control regulations are considered less effective and thus are not discussed further in this report

4.2 Economic Instruments

Economic instruments include fiscal instruments (such as taxes and fees) and market-based instruments, such as allowance trading. In general, economic instruments are outcome-focused and set monetary incentives for property owners to implement measures against stormwater runoff, while not mandating the implementation of any particular measures.

Property owners may choose between investing into the implementation of measures (with or without incentives) or paying a fee for not implementing them. Rational decision making will determine their decision, by considering upfront and maintenance costs for physical measures and the benefits over time (avoided taxes/fees, additional income from sold allowances, and additional environmental benefits on private property). Transaction costs for the regulatory body will be incurred when designing and implementing the instrument (based on given stormwater conditions and desired targets) and monitoring property owner compliance (accurate implementation of measures and/or correct payment of taxes/fees/allowance prices). In terms of effectiveness, while taxes or fees do not guarantee the achievement of stated targets, the establishment of a market would both stimulate investments through supply and demand (rather than with public incentives) and guarantee outcomes (due to a predetermined cap).

5.0 DEVELOPMENT OF STORMWATER MARKETS

The implementation of stormwater management technologies, especially through the establishment of a market mechanism, is a process that involves a detailed analysis of how costs, benefits and responsibilities can be equally distributed between the utility/regulator and the members of the community (e.g., households and the private sector). Because the costs of implementation usually exceed the financial capabilities of the utility/regulator, it is important to design an inclusive policy or market mechanism that allocates costs in a fair manner between governments, property owners and developers. In this context it is essential to identify the costs on which local governments could save (social, economic and environmental) and, (1) in the case of fiscal policies, plan for incentives in the same amount as the avoided costs (so as to develop a revenue-neutral mechanism) and then estimate the amount of investment that should be sustained by land and property owners, and (2) in the case of a market mechanism, implement a market that determines an allowance price that matches the economy-wide benefits to be accrued through private investments.

The next sections present the main activities involved in designing an equitable stormwater market.

5.1 Financing Instruments

Geographical location, landscape design, and the permeability of the materials used on a property are factors that determine the level of stormwater runoff (in combination with the severity and intensity of rainfall). This indicates that stormwater runoff charges need to consider several variables for the development of a socially and economically fair and equitable approach to stormwater management.

5.1.1 Price Instruments

Price instruments are designed to be applied either (1) as a fee or tax or (2) an incentive or subsidy, and are applied to control stormwater runoff levels (Parikh, Taylor, Hoagland, Thurston, & Shuster, 2005). Among the former are the polluter-pay fee (or Pigouvian tax) and stormwater user fees and charges; among the latter are fee reductions and subsidies, insurance premium discounts and land development project support.

The **Pigouvian tax** is a price-based instrument designed to minimize the negative impacts generated by an individual (or organization) on the environment. It is intended to persuade the producer of pollution or runoff by taxing the impacts (pollution/runoff) it delivers to the system. The higher the stormwater-related impacts, the higher the tax to be paid (Thurston, 2006). It is, in short, a polluter-pay tax.

Stormwater user fees are applied to property owners. Fees must be fair, reasonable, and should be charged according to the service provided. For stormwater regulation purposes, fees are calculated according to an estimated level of runoff delivered to the sewer system and the impermeable surface area of the property. Credits or fee reductions could be granted by the utility/regulator as incentives after the BSMP implementation. A credit system is applied in many cities in the United States to commercial and residential properties. Table 3 provides examples of implemented credit systems in five American cities. Different fee reductions could be applied according to the level of runoff estimated by the utility/regulator after visiting the location.

Table 3. Examples of credit options

	Utility	Eligible users	Basis for credit	Maximum credit	Typical credit
1	Gainesville, FL	Non-residential properties	Volume of onsite detention	100% of base fee	15–35%
2	Louisville-Jefferson. County KY	Commercial properties	Onsite detention of peak flows	82%	Varies with degree of control
3	Charlotte, NC	Commercial, industrial, institutional, multifamily, residential, and homeowner associations	1. Peak discharge 2. Total runoff volume 3. Annual pollutant loading reduction	1. 50% 2. 25% 3. 25%	Varies with degree of control
4	Austin, TX	Commercial properties	Onsite detention; inspection	50%	50%
5	Bellevue, WA	All properties	Onsite detention; intensity of development	Reduction of one rate (intensity of development) class	Varies

Source: Parikh, Taylor, Hoagland, Thurston, & Shuster, 2005.

To determine a fair fee for each property, additional analysis must be applied. According to Parikh et al. (2005, p. 176),

> [the]hydrological model underlying the price mechanism must focus not only on the amount of impervious surfaces, but also an evaluation of landscape factors, extant development, existing stormwater and sewer infrastructure, and inventory of pipe breaks and other losses, and other information to better understand how the watershed drains. It is also important to incorporate the effect of spatial and transboundary relationships between adjacent parcels on stormwater runoff.

Fees can then be determined once the desired level of runoff reduction in the system and the level of runoff reduction per property are identified.

Fee reductions (credits/rebates/discounts). The utility/regulator could also offer credits for the construction or improvement of properties to reduce runoff. These could be rebates or tax reductions on the utility services provided. Usually, benefits are offered to non-residential locations, as they have bigger areas where BSMPs implementation could give better results. Stormwater volume, peak flow reductions, or improved water quality, may offer a maximum reduction of up to 50 per cent to 75 per cent of the fees (Brown & Sanneman, 2017).

Subsidies are used in some communities to sponsor the use of BSMPs. Cities that use them include Austin, Texas, where the installation of rainwater harvesting systems is subsidized up to USD 500. In Prince George, Maryland, the county will subsidize residential properties up to USD 4,000 and commercial properties with up to USD 20,000 for the construction of rain barrels, permeable pavement or rain gardens (Brown & Sanneman, 2017).

Insurance Premium Discounts are offered by insurance companies to those clients who decide to use BSMPs on their properties. These incentives, reduce the risk of flooding in flood-prone areas.

Land Development Project Support. Despite not being a financial incentive, land development project support is useful to the utility/regulator to promote the implementation of BSMPs. Usually, local regulations stimulate technology adoption that could support reaching desired runoff reduction. Developers may be interested in green infrastructure construction or projects that employ BSMPs on their designs, but existing regulations may obstruct their execution, or the regulatory staff may lack the technical knowledge required to review and approve the development. To overcome those barriers, special technical analysis to speed up the licensing process can be employed by local agencies if the project is valuable for runoff reduction purposes.

Stormwater runoff charges and incentives could also be determined based on the average cost of managing the runoff levels delivered to the sewer system by each property. The incentive given by the utility/regulator is the opportunity to reduce the runoff charge by the implementation of BSMPs on the property. On the other hand, different properties have different BSMP implementation costs, which may not be apparent to the utility/regulator. One example is when improvements would change the use of the land/surface on the property, adding a cost opportunity to the upgrade.

5.1.2 Quantity-Based Instruments

Quantity-based instruments are based on a maximum amount (allowance) of runoff that each property could deliver to the sewer system. Through the use of allowances, the utility/regulator generates a trading environment where the most economical investments would be made first. Allowances would be purchased in locations where costs are higher, and investments are not economical, such as urban centres with a high amount (or share) of impermeable area.

The operation of stormwater markets is based on the level of runoff that the sewer system can accommodate. This cap is divided into allowances between each property according to their runoff level. For example, a property that makes extensive use of impermeable materials (e.g., cement pavement) will generate higher runoff levels than a property that uses gravel. Allowances initially equal the current amount of runoff, and reductions are then determined based on the difference between current (based on impermeable area by property) and desired (based on stormwater infrastructure capacity) runoff. The market value of allowances is ultimately determined by the cost and efficiency of the solution (e.g., GI) implemented at any given location.

Specifically, if property runoff levels are lower than the allowance, the difference could be credited to the property owner and traded in a market to monetize the benefits created for the community. Conversely, if a land owner fails to comply with the desired runoff level, they will have to purchase allowances. Further, if overall reductions are not sufficient to lower runoff to the desired level, the price of allowances will increase. This mechanism provides economic incentives to property owners, both those who can reduce runoff easily (and can sell allowances) and to those who face higher implementation costs (and can buy allowances). The trading of allowances could be done directly between property owners or through a clearinghouse service that allows for the creation of a market price based on supply and demand. The opportunity to generate revenues through selling excess allowances in a well-implemented market can attract further private investment (even from investors who are not property owners in the covered region).

Since the runoff reduction potential is difficult to identify, the adoption of a BSMP could be used as a measure of the potential reduction of runoff in each property. To avoid the uncertainty that the use of different BSMPs could generate, the use of trading ratios is often applied. A trading ratio is a grading system that assesses the relative improvement that each BSMP provides compared to the status quo. Each BSMP could in fact be associated with a certain ratio of runoff reduction that could be exchanged for goods or benefits according to the regulation.

The effectiveness of the allowance market is affected by the extent to which legal support is provided, and by the design of the regulatory system that a local government is embedded in. Property owners will find economic incentives valuable and worth pursuing—and will thus implement BSMPs—only if the market is supported by clear laws, and only if these do not affect the right of citizens and landowners. In this respect, the creation of a national market (or a national scheme that could be used to harmonize local efforts) and/or the presence of a stormwater allowance bank, could go a long way to assisting local governments with technical tasks and processes and facilitate the implementation of a stormwater market in their jurisdiction. In fact, a national framework could reduce process inefficiencies, making the implementation of local markets faster and easier.

5.2 Implementation Options

There are several options to consider for the creation of a stormwater market. The most common are credit trading and a mitigation bank. Various additional mechanisms can be used to create incentives for investments in stormwater management, even if these are not designed to create an open market. Examples include in-lieu fees, permittee-responsible mitigation (offsets) and layering economic instruments.

Credit Trading. Stormwater retention credits are a common option for the trading of allowances. One example is Washington D.C.'s specific credit for property developers. Since projects are required by the municipality to meet a 1.2-inch runoff retention standard, developers are allowed to buy credits when their projects do not comply with the limit. Credits are sold and purchased among developers or redevelopers, based on their capacity to meet the program's limits. A similar program is used by Chattanooga, Tennessee, where limits are determined between a range of 1 to 1.6 inches according to location. The generation of revenues through selling credits helps establish a secondary market to attract private investment to finance more substantive stormwater management measures.

Mitigation bank. In the context of a mitigation bank program, a site or a set of sites dedicated exclusively to ecological functions, such as flow retention and pollutant reduction, are established. The purpose of the bank is to sell the credits obtained from the ecological functions to buyers that could use them to compensate the impact of developments at other locations. Private investment can be attracted by the establishment of ecological sites while generating revenues through selling generated credits to the mitigation bank. The programs developed by the Maryland State Highway Administration in 1992 and Delaware Department of Transportation in 1999 provide an example of mitigation banking. In both cases, the transportation department developed an agreement with the state environmental regulatory agency in addition to using existing policy guidance (Brown & Sanneman, 2017).

Social Impact Bonds. Social Impact Bonds (SIBs) represent innovative financing mechanisms aiming at mobilizing private capital investors to supplement public investment. A distinctive feature of this kind of public-private partnership is that the investors are only repaid if the desired social outcomes are achieved (EPA, 2017). Based on the SIB model, Washington D.C. has issued the first Environmental Impact Bond (EIB), an outcome-based initiative incorporating "Pay for Success" elements, in September 2016. The 30-year tax-exempt municipal bond (with a mandatory tender in year five) foresees payments by either the municipal water utility or investors based on predetermined performance requirements. More information on D.C.'s EIB is provided in the case study section.

In-Lieu Fees. In-lieu fee programs are designed to allow developers that are not able to meet the runoff regulation requirements, to pay a fee for the expected runoff volume that their projects could generate. These fees are used by governments for the construction of runoff mitigation facilities like the ones implemented in Park Ridge, Illinois; Aspen, Colorado; and San Antonio, Texas.

Permittee-Responsible Mitigation (Offsets). Also known as payment for performance (P4P), the offset or voluntary action compensation is implemented after benefits are accrued (regardless of the main focus of the intervention). San Diego is planning to implement a program to enhance regulatory flexibility for the development of property projects that comply with surface water runoff quality treatment and channel protection requirements. By implementing this program, the city is promoting property developments in its jurisdiction while simultaneously incentivizing the improvement of water quality.

Layering Economic Instruments. A combination of instruments can be used to stimulate investment and compliance. Chattanooga uses credit trading and the in-lieu fee option. San Diego is considering a program that provides developers the option to use offsite investments, in-lieu fees or credit transactions to promote its runoff reduction program; and Maryland allows for developers to meet pollutant-reduction requirements through a combination of onsite treatment, paying into a fee-in-lieu fund, purchasing credits or offsite remediation.

5.3 Allowances as a Trigger for Private Investment

The estimation (ex-ante) and realization (ex-post) of GI benefits can play a key role in attracting private investment for mitigating stormwater runoff (EPA, 2014a). Property owners are already negatively affected by stormwater-related damages, which could be mitigated by GI interventions. As a result, GI can avoid costs for both the private and the public sector, as described earlier, including from direct and indirect potential impacts. For example, while flood control is not the primary objective of GI, any solutions that increase permeability will increase rainwater uptake and reduce the overall risk of runoff and damage to assets (EPA, 2015b). Specific examples include the replacement of asphalt with mixed pavement for the parking lots of large companies, or the use of GI to reduce water speed in the proximity of power utilities (e.g., especially in proximity to rivers).

On the other hand, stormwater-related damage is the result of a series of events (e.g., heavy rainfall and ground permeability), as well as location. As a result, not all the actors that can mitigate stormwater runoff are directly or indirectly impacted by it. It is therefore essential that incentives facilitate private investments in interventions that, possibly as a secondary synergy if not as a primary goal, support stormwater management. The implementation of an allowance trading system serves this purpose, allowing many and varied actors to be rewarded if they contribute to solving the problem. The Stormwater Retention Credit trading system developed by Washington D.C. (Sustainable Prosperity, 2016; DOEE, 2017b), which is described in more detail in Section 6 of this report, is currently spearheading the discussions around the development of incentive schemes at the city level.

5.4 Improving Efficiency Through Economies of Scale

While most of the discussion about stormwater management and mitigation generally focusses on the city or neighbourhood level, a watershed or sub-watershed approach could be a way to increase stormwater mitigation effectiveness and to attract more private investments.

Stormwater runoff management, and especially managing peak flow runoff volumes, can have both causes and impacts that reach beyond the scale of a single urban area. The importance of stormwater management at the watershed level is recognized as a great challenge of modern water pollution control, as it is a principal contributor to water quality impairment of waterbodies (EPA, 1995; U.S. NRC, 2008).

The National Academy of Sciences (2017) proposes a watershed-based approach for stormwater mitigation, especially for runoff that results from roads and highways in urban and ultra-urban areas. Watershed-based stormwater management is expected to yield significant efficiency gains by implementing a structure (e.g., allowance mechanisms) that covers several locations at once. In fact, the infrastructure required (e.g., equipment for the trading platform, monitoring and assessment of GI implementation and performance, capacity building for audits) is likely to cost approximately the same when designed and implemented for one or more urban areas. Also, a larger market would increase the number of transactions, coordinated by a multi-level governance system to optimize the allocation of private investments as well as their direct outcomes and co-benefits.

In conclusion, to enhance the attractiveness for private investment there must be a clear connection between investments in stormwater management infrastructure and expected benefits. If the impacts of stormwater runoff (e.g., high concentration of pollutants, leading to algae growth and increased risk of hypoxic events in waterbodies) is visible in lakes and coastal areas where there is a confluence of various streams, or where the main river has many tributaries, taking a watershed or sub-watershed approach would be the only way to effectively monitor the performance of investments, and to assign credits (and financial rewards) to those who have invested.

5.5 Challenges

As indicated earlier, the effectiveness of instruments utilized to reduce runoff is a result of technical characteristics, implementation effectiveness and the supporting legal framework. New policy implementation takes time, and its success is usually determined by (a) the impact of technology and (b) the perception/satisfaction of citizens.

Further, the success of an incentive-based policy is generally determined by the buy-in of local economic actors. If the incentive is not enough to trigger the investment required, the reduction in stormwater runoff will not be enough to offset the constraints of existing infrastructure. As a result, the local government will be faced with the costs of providing incentives and the need to invest in the expansion of infrastructure. This scenario would put considerable pressure on public finances, possibly resulting in additional taxes to cover a growing budget deficit). It is critically important that the full range of benefits, for all economic actors, is fairly distributed and fully covers the initial investment required, future maintenance and any potential opportunity cost. Complementary interventions could be designed and implemented, such as direct technical assistance, highlighting positive impacts on property values and safety (e.g., flood protection).

Another possible issue relating to the perceived attractiveness of stormwater management interventions is tax management. It is not effective to promote incentives for BSMP implementation if these incentives will be taxed by authorities as income. Coordination between local governments and the tax authority is key for the success of the policy. In 2015, two federal legislators of the United States and 32 other signatories sent a letter requesting that the IRS not consider rebates associated with BSMPs adoption as taxable income. They suggested instead that the IRS should establish parity with energy efficiency rebates, which currently enjoy non-taxable status. (Brown & Sanneman, 2017).

In addition, there are several technical challenges to consider (Brown & Sanneman, 2017):

a) The development of a trading or mitigation framework requires specialized skills that many communities may not have access to or are unable to fund;
b) A market tends to work more efficiently as it grows bigger (with more buyers and sellers), which is a challenge for stormwater management as the problem is confined to a relatively small geographical area;
c) Difficulties in identifying clear units of trade (e.g., m3 of runoff, or pollution e.g., kg of nitrogen), which is critical in the case of stormwater because of the variability of precipitation; and
d) The extent to which credits are permanent or time-bound (permanent credits require protection in perpetuity, which limits options for future development and/or reduces flexibility around how the site can be used in the future) (Brown & Sanneman, 2017).

6.0 CASE STUDIES

Several attempts to develop stormwater markets have been launched during the last decade (PWD, 2011; CH2M HILL, 2014; CWN, 2015; DOEE, 2017a; Sustainable Prosperity, 2016). This section provides an overview of five case studies (Table 4), with emphasis on the type of policy used, whether a market was created and the current as well as potential long-term outcomes of such programs.

Table 4. Overview of stormwater case studies

Location	Results	Market	Policies in use	Financing mechanism	Main focus
Washington D.C.	• **Trade volume:** 2016: 24,972 stormwater retention credits (SRCs) (value USD 46,284) 2017: 64,000 SRCs (value USD 133,000) expected • SRC price range: USD 1.85–USD 2.27 • Expected average sales price for 2017 is USD 2.10 per SRC.	Yes	Runoff-based fee Stormwater Runoff Credits	• Grants & Rebates • Stormwater fee credits • Green Infrastructure incentive programs • Environmental Impact Bond	• Green infrastructure development • Compliance with national legislations • SRC trading • Decentralized amount of permeable surface throughout the city • Integration with local and national programs
Philadelphia	• Number of jobs: 430 • FTE Turnover: USD 146,8mn • Economic impact: USD 57mn • Tax revenues: USD 860,000	No	Runoff-based fee Stormwater discounts (credits)	• Grants & Rebates • Stormwater fee credits • Green Infrastructure incentive programs	• Green infrastructure • Integration with local and national programs
Lancaster	• Avoided investment: USD 120mn (gray infrastructure) • Benefits from energy: USD 2.4 mn. Benefits from air quality: USD 1 mn. • TClimate change benefits: USD 0.75 mn	No	Runoff-based fee Stormwater discounts (credits)	• Grants & Rebates • Stormwater fee credits	• Green infrastructure development • Gray infrastructure maintenance • Close cost recovery gap for SW utility • Integration with local and national programs
Mississauga	No results available	No	Runoff-based fee Stormwater discounts (credits)	• Grants & Rebates • Stormwater fee credits	• Gray infrastructure • Close cost recovery gap for SW utility• Integration with local and national programs
Halifax	No results available	No	Runoff-based fee	• Grants & Rebates • Stormwater fee credits • Debt strategy	• Integrated asset management • Close cost recovery gap for SW utility • Integration with local and national programs

6.1 Washington D.C.

Background

The Anacostia River in Washington D.C. is one of the most polluted rivers in the United States, with billions of gallons of untreated combined sewer overflow (CSO) and stormwater being discharged into the river every year. Stormwater management in Washington D.C. is controlled by DC Water and the Department of Energy and the Environment (DOEE). To acquire its US EPA National Pollutant Discharge Elimination System permit, in 2004, DC Water was required to prepare a LTCP, outlining a strategy to reduce CSOs and sustainably manage stormwater. The LCTP was approved in 2004, and renamed the Clean Rivers Project (CRP) in 2010 (Sustainable Prosperity, 2016).

Washington D.C.'s initial approach to stormwater management was the construction of three tunnels, with an insignificant portion of GI investment. Initially, the CRP foresaw a rain barrel distribution program and a USD 3 million budget for GI retrofits. Further work of the DOEE resulted in the implementation of several GI incentive programs, covering green roofs, rain barrels, rain gardens and permeable pavements. These additional efforts resulted in a comprehensive GI support program and policy tool to facilitate the implementation of GI, as the program supports GI at many levels (Sustainable Prosperity, 2016).

Main Stormwater Management Features

Stormwater Retention Credits

In 2013, Washington D.C. updated its performance standards on stormwater retention requirements on site for new major developments (5,000+ ft^2) and created a private market for trading stormwater retention credits (SRCs). New projects are required to retain on site at least 50 per cent of the water anticipated from a 0.8 to 1.2-inch storm. In case of a shortcoming, the remaining volume can be "retained" by purchasing SRCs from a private market or by paying a fee to the DOEE. SRCs are obtained by providing excess retention volume and complying with the city's eligibility requirements for SRCs. The eligibility requirements are well documented in the DOEE's published guidebook on stormwater retention, which also provides support in finding the stormwater management best practices (DOEE, 2013).

Washington D.C. implemented a stormwater credit trading program to provide flexibility to project developers and to stimulate GI investments by private home owners. By rendering stormwater retention location-independent, SRCs provide the opportunity to spread GI projects all over the D.C. area. In fact, retention benefits are estimated to be bigger if GI is spread over the city, instead of being concentrated in the downtown core (Sustainable Prosperity, 2016).

SRC owners trade their credits in an open market to other parties that need them to fulfill the regulatory requirements for retaining stormwater (DOEE, 2017b). Each SRC has a unique serial number, and their trade, transfer and use are overseen by the DOEE. The one-year lifespan of an SRC begins with its use, which implies that SRCs can be banked for future use without expiration (DOEE, 2013). The DOEE provides a calculator spreadsheet to calculate whether the retention capacity on site complies with the retention volume eligibility requirements.

Environmental Impact Bond

In addition to its SRC programme, D.C. is the first city to issue an Environmental Impact Bond (EIB) to attract private funds for investments in GI components. Based on the model of Social Impact Bonds, the EIB is a 30-year tax exempt municipal bond with a mandatory tender after five years. A USD 3.3 million performance-based provision is, depending on the success or failure of the project, to be paid by DC Water to investors or by investors to DC Water (EPA, 2017). The performance of the project will be assessed over a 12-month period beginning no later than three months after project completion.

The performance tier, outcome ranges and contingent payment are summarized in Table 4.

Table 4. Overview of D.C.'s Environmental Impact Bond performance tiers (Goldman Sachs, 2017)

Performance Tier	Outcome Ranges	Contingent payment
1	Runoff Reduction > 41.3%	DC Water will make an Outcome Payment to Investors of $3.3 million.
2	18.6% <= Runoff Reduction <= 41.3%	No contingent payment due.
3	Runoff Reduction < 18.6%	Investors will make Risk Share Payment to DC Water of $3.3 million.

The outcome range reflects the expectation that a successful implementation will result in performance tier 2. If project performs above expectations, DC Water will make an additional Outcome Payment to the investors. In case of underperformance, Investors will make a Risk Share Payment to DC Water, which DC Water would withhold from the principal and interest it would otherwise be obliged to pay on the tender date (EPA, 2017; Goldman Sachs, 2017).

The performance-based nature of the EIB provides benefits for DC Water and investors. The main benefit for DC Water is that the Risk Share Payment allows for recouping part of the investment and potentially using it to remediate the performance failure (EPA, 2017; Goldman Sachs, 2017). The key benefit for investors is that key risks such as financing risk, construction risk and regulatory risk are allocated to DC Water. Table 5 provides an overview of risk allocation between the water utility, DC Water, and the investors, Goldman Sachs and the Calvert Foundation.

Table 5. Risk allocation between DC Water and Investors in the Environmental Impact Bond (EPA, 2017)

Risk Category	Risk Allocation	Description
Performance of Green Infrastructure	Goldman/ Calvert	DC Water has effectively hedged performance risk. The Risk Share and Outcome Payments offset the project underperforming or exceeding expectations, respectively. The Risk Share Payment provides DC Water with additional resources to address performance deficiencies should project performance fall short of expectations. Because the Outcome Payment reflects outperformance, the additional payout has a positive cost benefit.
Market/Financing Risk	DC Water	DC Water retains the financing risk with the multi-modal financial structure. The scheduled reset in year five subjects DC Water to market conditions when the rate is reset. The multi-modal structure also hedges risk that the reset rate will be higher than the initial rate as DC Water determines future reset periods.
Counterparty Risk	Goldman/ Calvert	Offsets against principal and interest due on Mandatory Tender Date (MTD) assure payment of the potential Risk Share Payment and eliminates any counterparty risk that DC Water would otherwise have with respect to the Investors. For GS/Calvert the Outcome Payment is payable from Net System Revenues after all principal and interest payments due on senior and subordinated debts are paid. Investors take an extra degree of counterparty risk on DC Water for this payment given the additional subordination.
Construction Risk	DC Water	DC Water retains responsibility for designing, constructing and maintaining the project assets. GS/Calvert brought in experts to review the plan before agreeing to invest and do not make or receive any outcome or risk share payment until the project is completed thereby eliminating construction risk to the Investors.
Regulatory Risk	DC Water	Any changes in laws, rules, regulations, policy or guidance will be the responsibility of DC Water. GS/Calvert only need comply with standard private placement rules.
O&M and CapEx / Lifecycle Risk	DC Water	DC Water is responsible for Operating and Maintenance (O&M) for the life of the transaction.

Results

Since 2013, when the SRC program was launched, only four trades have taken place, but the volume increased in following years (Sustainable Prosperity, 2016). According to DOEE[1], in 2016 a total of 24,972 SRCs were traded, totalling USD 46,284.40. The average price per SRC was USD 1.85. For 2017, SRC trades are expected to increase to almost 64,000 SRCs, with an estimated worth of around USD 133,000. Between 2014 and 2017, SRC prices fluctuated between USD 1.85 (2016) and USD 2.27 (2014), and the expected average sales price for 2017 is USD 2.10 per SRC (DOEE, 2017a).

Replicability

Washington D.C.'s Stormwater Retention Credit Trading program was recognized by the C40 Cities Climate Leadership Group as "one of the world's most innovative climate programs."[2] The SRCT program introduces mechanisms that create a real market for stormwater. The Conservation Finance Network indicated in 2016 that the stormwater credit system could provide a blueprint for other cities that are trying to deal with their stormwater challenges (CFN, 2016).

[1] The current trade statistics can be accessed under https://octo.quickbase.com/up/bjkxxcfcp/g/rb7/eg/va/levels.html?sitelevel=1&pagerecord=167&userrole=Everyone%20on%20the%20Internet

[2] Full article available under https://doee.dc.gov/node/903872

According to the EPA (2017) and Goldman Sachs (2017), the EIB issued by DC Water represents an innovative financing instrument that can be used by utilities throughout the water sector. EIBs are both, replicable and scalable, allowing for customizing them for other communities that are in need of finances for managing stormwater runoff and water quality problems of CSOs.

6.2 Philadelphia

Background

In the 1990s, it became apparent that charging residents for stormwater services based on their water consumption was no longer fair and equitable. After convening a Citizens Advisory Council in 1996, a parcel-based fee assessment method was recommended, but not implemented due to the lack of the required technology. The parcel-based fee assessment method was implemented at a later stage for residential and non-residential properties in 2002 and 2010 respectively. In September 2009, the City of Philadelphia submitted the Combined Sewer Overflow (CSO) Long-Term Control Plan Update (LTCPU) to communicate how its vision and commitment for sustainable stormwater management grew out of its history (Sustainable Prosperity, 2016).

The Philadelphia Water Department (PWD) initiated the *Green City, Clean Waters* (GCCW) program in 2009. The program aims to improve Philadelphia's environmental performance through the development of city-wide green infrastructure. The PWD's analysis determined that a green stormwater infrastructure-based approach would fulfill all project requirements and maximize social, economic and environmental benefits within the most efficient time frame (PWD, 2011; WEF, 2015). Incremental implementation over a period of 25 years makes the program adaptable to changing conditions and uncertainty. In fact, it provides a "unique opportunity" to improve the declining quality of Philadelphia's built infrastructure and to generate benefits beyond the reduction of CSOs (WEF, 2015).

Main Stormwater Management Features

The GCCW includes a variety of tools to incentivize the use of green infrastructure, such as a green roof tax credit for businesses and entrepreneurs, zoning incentives for green roofs and the Rain Check rebate program, which provides stormwater management support for home owners (PWD, 2017; Sustainable Prosperity, 2016). To provide additional support, the Stormwater Management Incentives Program (SMIP) was launched in 2012. The SMIP is a green infrastructure subsidy program that provides grants to non-residential property owners who want to retrofit their properties to improve stormwater management. Due to the lack of measurable results, the PWD consulted SMIP users to evaluate potential shortcomings of the program. Subsequently, PWD revised the SMIP and launched the Green Acre Retrofit Program (GARP). The GARP provides grants to contractors and project manager capable of conducting stormwater retrofits across multiple sites on a large scale (City of Philadelphia [CoP], 2017; Sustainable Prosperity, 2016).

Results

According to a recently released report of the Sustainable Business Network of Greater Philadelphia, the implementation of the GCCW created a Green Stormwater Infrastructure (GSI) industry with annual turnover of at least USD 146.8 million and an economic impact of USD 57 million. The industry supports more than 430 jobs and generates USD 860,000 in tax revenues (Sustainable Prosperity, 2016).

Replicability

Philadelphia uses an impermeable area-based stormwater charge for residential and non-residential properties. Philadelphia's green development strategies recognize stormwater as an opportunity for development. Programs like the SMIP and the GARP provide excellent learning opportunities to other cities. A high degree of customization and substantial financial commitments would be necessary to replicate Philadelphia's approach. However, a market for stormwater was not created in the case of Philadelphia. On the other hand, the PWD's approach to stormwater management has contributed to the creation of a stormwater industry in the Philadelphia area. The Green City, Clean Waters (GCCW) initiative capitalizes on the socioeconomic and environmental benefits of green stormwater infrastructure and only considers gray infrastructure when necessary to meet water quality standards.

6.3 Lancaster, Pennsylvania

Background

In 2008, Lancaster prepared an update to its Long-Term Control Plan (LTCP) after the U.S. Environmental Protection Agency (EPA) requested information on how the city is planning to handle CSOs in the future. Historically, Lancaster has relied on the expansion of gray infrastructure (e.g., underground combined sewers, wastewater facilities) for stormwater management. In fact, the city upgraded pump stations and a biological nutrient reduction project between 2002 and 2012 (CH2M HILL, 2014).

The main goal of the project was the upgrade of Lancaster's urban infrastructure toward the uptake and adoption of green infrastructure (GI) options to manage runoff quantity and quality. Faced with increasing regulatory requirements and an anticipated cost recovery gap, Lancaster needed to develop a program that complies with active EPA legislation (e.g., The Clean Water Act, Total Maximum Daily Load) and is able to recover costs (CH2M HILL, 2014). The LTCP identifies opportunities for GI implementation over a 5-year and 25-year time period, which makes it adaptable to changing regulations and uncertainty (EPA, 2014a).

Main Stormwater Management Features

In 2012, Lancaster conducted several analyses on the implementation of an impermeable area-based stormwater fee system. With a four-tier system, the stormwater fee is calculated based on the stormwater runoff per property, whereby runoff depends on total impermeable surface and precipitation. Table 5 presents the four-tier impermeable area-based fee system of Lancaster.

Table 6. Proposed 4-tier rate structure for the city of Lancaster

Tier	Impermeable Area Range	Annual	Quarterly
1	<= 1,000 ft^2	USD 15.48	USD 3.87
2	> 1,000 ft^2 and <= 2,000 ft^2	USD 46.44	USD 11.61
3	> 2,000 ft^2 and <= 3,000 ft^2	USD 77.40	USD 19.35
4	> 3,000 ft^2*	USD 30.96 / 1,000 ft^2	USD 7.74 / 1,000 ft^2

Source: CH2M HILL, 2014.

CH2M HILL proposed to develop both, a credit and a rebate (or grant) program to support MS4 and CSO LTCP compliance. The rebate (or grant) program provides incentives by reducing upfront payments for stormwater infrastructure, especially for private homeowners. Deductible stormwater fee credits, on the other hand, provide a long-term incentive to investing in stormwater management due to an accumulation of savings (CH2M HILL, 2014).

Results

Initially, only a small range of the benefits resulting from reductions in runoff volume, sediment loads, and nutrient loads was quantified in the plan. A follow-up study conducted by the EPA estimates the total benefits over the 25-year implementation period. The EPA assumed that the benefits resulting from the implementation of the plan accrue proportionally over time. This approach implies that the full stream of benefits will be realized at the end of the 25 years (EPA, 2014a).

The long-term implementation of green infrastructure could reduce the average annual stormwater runoff by 1.05 billion gallons per year. Further, the implementation yields more than USD 120 million in savings from avoided gray infrastructure capital investment cost and generates nearly USD 5 million in annual benefits following the implementation period. Annual benefits considered are avoided operation and maintenance costs for gray infrastructure (USD 0.7 million) energy savings (USD 2.4 million), improvements in air quality (USD 1.0 million), and climate change benefits (0.8 million) (EPA, 2014a).

Replicability

Lancaster's approach to stormwater management recognizes GI as an opportunity to improve both, reductions in stormwater loads and compliance with legislative requirements. A rebates and grants program reduces upfront capital investments in GI, supported by a stormwater fee credit system that incentivizes the implementation of GI. The assessment of impermeable area, and the development of both a rebate and a credit system for local application should be replicable without major challenges.

6.4 Mississauga, Ontario, Canada

Background

Several years after implementing a stormwater fee, the City of Mississauga introduced a dedicated stormwater user fee in August 2011. A financing study in 2012 revealed that the program was underfunded and needed to be enhanced to meet current and future obligations (AECOM, 2013). The result was a new stormwater fee introduced at the beginning of 2016. This extra charge is dedicated to maintaining Mississauga's stormwater infrastructure and avoiding costly repairs in the future (City of Mississauga [CoM], 2016a). Mississauga's vision is to be a leader in the delivery and management of a safe and functional stormwater management system (CoM, 2017).

Main Stormwater Management Features

Mississauga's stormwater management relies heavily on gray infrastructure assets. A study found that the current stormwater management program in Mississauga included USD 1.7 billion in stormwater infrastructure assets, and annual payments of USD 14.6 million in capital investment and operations and maintenance costs (O&M). Despite the high level of annual capital investment, the study concluded that annual capital, renewal, and O&M costs would need to be close to USD 35 million annually for the stormwater program to be sustainable (AECOM, 2013; Sustainable Prosperity, 2016).

Various financing options were reviewed during the development of the stormwater programs. Among these financing options were i) property taxes (general fund tax; dedicated levy), ii) development-related charges and fees (development charges; cash-in-lieu), and iii) an impermeable-area-based stormwater rate. During the comparison of financing options, the stormwater charge was found to be the fairest and most equitable approach to stormwater billing, as it is based on the polluter-pays principle (AECOM, 2013; Sustainable Prosperity, 2016).

Mississauga's property owners pay an annual stormwater charge of USD 100 per billing unit (256m^2). Billing units represent the average hard surface area on a single detached residential property (CoM, 2017). The number of billing units per property is estimated using a GIS-based approach.

Table 6 shows the six-tier classification of properties in Mississauga.

Table 7. Proposed six-tier rate structure for Mississauga

Tier	Properties included*	Roofprint range (m^2)	Stormwater billing units	Annual charge (USD)
Smallest	Smallest 10%	26.7–99.0	0.5	50
Small	Next largest 40%	99.1–151.0	0.7	70
Medium	Next largest 30%	151.1–194.0	1.0	100
Large	Next largest 15%	194.1 –242.0	1.2	120
Largest	Largest 5%	242.1+	1.7	170
Green	Residential properties with IA < 26.7m^2 or roof print area < 26.7m^2	0 – 26.6	0.0	USD 0

**Per cent of all single-unit and separately owned homes*
Source: Sustainable Prosperity, 2016.

The Mississauga implemented a program that allows multi-residential and non-residential properties an opportunity to reduce the stormwater charge through the implementation of best practices (CoM, 2016a; CoM, 2016b; Sustainable Prosperity, 2016). Best practices are divided into peak flow reduction, water quality treatment, runoff volume reduction and pollution prevention (Sustainable Prosperity, 2016). A maximum credit percentage can be achieved for each of the five categories, with an overall maximum discount of 50 per cent. Stormwater credits are valid for five years and need to be renewed afterwards (CoM, 2016b).

Credit Schedule

Table 7. Credit schedule of Mississauga's stormwater program

Category	Evaluation Criteria	Total Credit (50% max)	
Peak Flow Reduction	Per cent reduction of the 100-year post-development flow to pre-development conditions of the site.	Up to 40%	Up to 50%
Water Quality Treatment	Per cent of site (hard surface) receiving water quality treatment consistent with provincial criteria for enhanced treatment.	Up to 10%	
Runoff Volume Reduction	Per cent capture of first 15 mm of rainfall during a single rainfall event.	Up to 15%	
Pollution Prevention	Develop and implement a pollution prevention plan.	Up to 5%	

Mississauga developed an online tool to help residents understand their stormwater fee. Property owners can enter their address to see a picture of their roof, obtain the digitized roof area (impermeable area), and the roof print area in use to calculate the charge (Sustainable Prosperity, 2016).

Results

Since Mississauga's stormwater program is relatively new, no results have been reported yet.

Replicability

Mississauga's stormwater charge can be replicated on any scale. The stormwater charge and the rebate schedule are commonly used instruments. A potential challenge is the technical know-how required to replicate the GIS-based determination of impermeable area by property. The classification of properties according to the six tiers needs to be customized to the local context to ensure fair and equitable fees for residential and non-residential property owners. Mississauga's approach to stormwater system is based on traditional financing instruments is not creating a stormwater market.

6.5 Halifax, Nova Scotia, Canada

Background

Halifax Water is the first regulated, integrated water, wastewater and stormwater utility in Canada. The Public Service Commission was formed in 1945 and is also known as the Halifax Regional Water Commission (HRWC) (HRWC, 2014; CWN, 2015). Halifax Water was charged with resolving water problems and repairing the water systems. In 2007, the Halifax Regional Municipality (HRM) transferred wastewater and stormwater assets to the HRWC. Initially, stormwater payments were funded as part of a wastewater charge (consumption-based), though the HRWC spent several years on the establishment of a stormwater-based pricing approach. In 2013, the first separate rates for stormwater service were established (HRWC, 2014). Asset management is critical to Halifax, with an emphasis on meeting user demands, promoting cost reductions and contributing to economic growth (CWN, 2015).

Halifax Water developed a five-year business plan (2013–14 to 2017–18), which is continuously updated (HRWC, 2014; CWN, 2015). Halifax water combines cost of service/rate design, an integrated resources plan, and debt strategies to sustain operations and enhance the development of funds for (storm)water management (CWN, 2015). Until 2008, Halifax was using mainly gray infrastructure-based stormwater management practices. During a HRCW workshop on water resources management in 2011, the development of green infrastructure was determined to be a top priority to reduce stormwater runoff loads (HRM, 2012).

Main Stormwater Management Features

Halifax has implemented a parcel-based system to calculate stormwater fees. The system distinguishes between stormwater from (impermeable) residential properties, non-residential properties and impermeable public areas (human right of way, or RoW), such as roads. The implementation of multiple integrated water management policies ensures the consideration of important factors, such as, among others, economic development, environmental impacts, impacts on human health, and income of various stakeholders (CWN, 2015).

Stormwater charges are determined based on precipitation and the impermeable area per property. Stormwater charges for public spaces like roads (e.g., RoW) are billed to the HRWC (CWN, 2015). In 2017, Halifax approved restructuring the stormwater billing system, which will likely lead to a reduction in discharge fees for almost 90 per cent of Halifax's residents (Withers, 2017). The HRWC established a four-tier system for residential homeowners, determining the stormwater discharge fees based on impermeable surface per property. Table 8 provides an overview of Halifax's tiered system:

Table 8. Proposed four-tier rate structure for Lancaster

Tier	Impermeable area range	Annual	Quarterly
1	<= 50m^2	USD 00.00	USD 00.00
2	> 50m^2 and <= 200m^2	USD 14.00	USD 3.50
3	> 200m^2 and <= 400m^2	USD 27.00	USD 6.75
4	> 400m^2	USD 54.00	USD 13.50

Source: Withers, 2017,

Results

The establishment and maintenance of an integrated water management system benefits Halifax in multiple ways. Stormwater peak runoff is reduced by rainwater utilization systems, which lower the total stormwater load and help mitigate floods. Further, ponds, wetlands and green corridors mitigate stormwater loads and provide a buffer system which reduces the sediment loads of stormwater, and hence mitigates water pollution (CWN, 2015). Another benefit of the establishment of an independent water management unit is that it has the authority to implement policies and regulations applicable to the private and the public sector alike.

Replicability

Halifax Water was Canada's first regulated, integrated water, wastewater and stormwater utility. 60 years of experience in establishing and running the water management unit can now be easily replicated, especially thanks to the latest expansion of the approach to green infrastructure and stormwater charges. The establishment of an integrated water management unit may be the most challenging task, due to potential restructuring requirements of existing governance mechanisms. On the other hand, the development and implementation of integrated water management policies, potentially using a participatory approach (HRM, 2012), can be replicated and customized to any local context.

7.0 CONCLUSIONS

Stormwater surges resulting from the increasing impermeability of surface areas in urban centres pose an increasing threat to properties and environment, as they often exceed the capacity of the installed water management infrastructure. Costs are on the rise, both due to infrastructure damage and human and environmental health. Two distinct trends are causing the growth of stormwater-related cost: (1) the increase in population and consequent impermeable surfaces and (2) the higher variability of rainfall, combined with an increase of extreme events.

A conventional approach would require investments in centralized gray infrastructure. On the other hand, capital costs are very high, and "first flush" events—which cause most of the damage and carry most of the pollution—are normally not addressed by this type of intervention. Instead of targeting the management of stormwater runoff, green infrastructure aims to increase surface infiltration and lower the amount of stormwater at the source. This would reduce the need for investments in gray infrastructure, given that runoff (and its concentration of pollutants) would be lower.

Green infrastructure requires interventions by land and property owners, representing a decentralized approach to stormwater management. While investments would take place primarily on private property, the benefits of such interventions would be felt by many. As a result, the economics of the investment (centralized costs and decentralized benefits) have not made these interventions very popular in the past.

Policy support is needed, in the form of incentives (for investments) and disincentives (for stormwater runoff and pollution) to stimulate investments. This implies an important role for the public sector, which is not the sole beneficiary of such investments. As a result, stormwater markets have emerged to trigger private investment. These represent a quantity-based approach, with a set number of allowances, normally declining over time. The fact that these allowances can be traded, and hence have an economic value, would stimulate investments by land and property owners.

Several examples can be found worldwide, and primarily in developed and heavily urbanized areas. The vast majority of cases are examples of policy implementation (either individual policies or a portfolio of options), but the implementation of stormwater markets is also on the rise. Available options include credit trading and the creation of a mitigation bank. Various additional mechanisms can be used to create incentives for investments in stormwater management, even if these are not designed to create an open market. Examples include in-lieu fees, permittee-responsible mitigation (offsets) and a combination of policy instruments.

Despite holding promise, stormwater markets are not easy to implement. Their effectiveness is a result of the technical characteristics of the solution utilized, the success of implementation and the presence of a supporting legal framework. Further, the success of an incentive-based policy is generally determined by the buy-in of the local economic actors. If the incentive is not enough to trigger the investment required, the reduction in stormwater runoff will not be enough to offset the constraints of existing infrastructure. Finally, there are several technical challenges to consider, including the need for specialized skills (which may not be available locally), the efficiency of the market (proportional to the number of buyers and sellers), and the identification of clear and measurable units of trade (e.g., m3 of runoff), and, last but not least, the extent to which credits are permanent or time-bound.

The opportunities emerging from the establishment of stormwater markets are considerable, especially when considering the potential social, economic and environmental impacts. To obtain such benefits, and in light of the design and implementation challenges identified, a customized approach is required. This would ensure that the market is designed to create synergies with existing legal frameworks, and generate enough buy-in to work effectively for a variety of economic actors, a key requirement to reach scale.

References

AECOM. (2013). Stormwater financing study. AECOM, in collaboration with the City of Mississauga. Retrieved from http://www7.mississauga.ca/Documents/TW/Environment/RPT_MississaugaStormwaterFinancingStudy_Apr2013_Final.pdf

Barbosa, A., Fernandes, J., & David, L. (2012). Key issues for sustainable urban stormwater management. Water Research, 46(20), pp. 6787–6798.

Braden, J., & Johnston, D. M. (2002). Downstream economic benefits from storm-water management. Journal of Water Resources Planning and Management, 130(6), 498–505.

Brown, S., & Sanneman, C. (2017). Working with the market: Economic instruments to support investment in green stormwater infrastructure. Retrieved from http://willamettepartnership.org/wp-content/uploads/2014/06/Econ-Instruments-for-Stormwater_2017-04-20.pdf

Beckley Sanitary Board. (2014). What is impervious surface. Retrieved from http://beckleysanitaryboard.org/impervious-surface/

Canadian Water Network (CWN). (2015). The examination of Halifax water application of integrated water, wastewater and stormwater infrastructure. http://www.creditvalleyca.ca/wp-content/uploads/2016/09/Appendix-L-The-Examination-of-Halifax-Waters-Application-of-Integrated-water-wastewater-stormwater-infras.pdf

Carlson, C., Barreteau, P., Kirshen, P., & Foltz, K. (2015). Storm water management as a public good provision problem: survey to understand perspectives of low-impact development for urban storm water management practices under climate change. Journal of Water Resources Planning and Management, American Society of Civil Engineers, 141(6).

Conservation Finance Network (CFN). (2016). Stormwater credits in D.C. could provide a blueprint for other cities. Retrieved from http://www.conservationfinancenetwork.org/2016/06/06/stormwater-credits-in-dc-could-provide-blueprint-for-other-cities

CH2M HILL. (2014). Stormwater management fee policy options and recommendations. Philadelphia: CH2M HILL. Retrieved from http://cityoflancasterpa.com/sites/default/files/documents/LNC_SWMF_Report_Final.pdf

City of Mississauga (CoM). (2016a). Stormwater program – 2016-2018 business plan & 2016 budget. Mississauga: City of Mississauga. Retrieved from http://www7.mississauga.ca/eCity/Budget/img/2016-2018-business-plan-2016-budget-1.3.pdf

City of Mississauga. (2016b). Stormwater fees and charges by-law 135-12. Mississauga: City of Mississauga.

City of Mississauga. (2017a). Stormwater – 2017-2020 business plan & 2017 budget. Mississauga: City of Mississauga. Retrieved from http://www7.mississauga.ca/eCity/Budget/img/2017/2017-2020-Business-Plan-and-2017-Budget.pdf

City of Mississauga. (2017b). Understanding your stormwater charge. Mississauga: City of Mississauga. Retrieved from http://www7.mississauga.ca/Departments/Marketing/stormwater/stormwater-charge/img/understanding_swc_2.4.pdf

City of Philadelphia (CoP). (2017). Stormwater grants. Retrieved from http://www.phila.gov/water/wu/stormwater/Pages/Grants.aspx

Dennehy, C. (2013). Confronting stormwater challenges. Worldwater Stormwater Management, 1(1). Retrieved from https://www.o2env.com/wp-content/uploads/2014/01/Stormwater-Management_Stormwater-Management-Market-set-for-growth.pdf

Department of Energy & Environment. (DOEE). (2013). Stormwater management guidebook. Washington D.C.: Department of Energy and the Environment. Retrieved from https://doee.dc.gov/swguidebook

Department of Energy & Environment. (2017a). Stormwater database. Retrieved from https://octo.quickbase.com/up/bjkxxcfcp/g/rb7/eg/va/levels.html?sitelevel=1&pagerecord=167&userrole=Everyone%20on%20the%20Internet

Department of Energy & Environment. (2017b). Stormwater retention credit trading program. Retrieved from https://doee.dc.gov/src

Environmental Protection Agency (EPA). (1995). Watershed protection: A statewide approach. U.S. Environmental Protection Agency, Office of Water. Retrieved from https://www.epa.gov/sites/production/files/2015-06/documents/state_approach_1995.pdf

Environmental Protection Agency. (2014a). The economic benefits of green infrastructure – A case study of Lancaster, PA. U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/green-infrastructure/economic-benefits-green-infrastructure-case-study-lancaster-pa

Environmental Protection Agency. (2014b). Integrated municipal stormwater and wastewater plans. Philadelphia: U.S. Environmental Protection Agency.

Environmental Protection Agency. (2015a). Community based public private partnerships and alternative market-based tools for integrated green stormwater infrastructure – A guide for local governments. Philadelphia: U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/waterfinancecenter/community-based-public-private-partnerships

Environmental Protection Agency. (2015b). Flood loss avoidance benefits of green infrastructure for stormwater management. Washington D.C.: U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/sites/production/files/2016-05/documents/flood-avoidance-green-infrastructure-12-14-2015.pdf

Environmental Protection Agency. (2017). National Pollutant Discharge Elimination System (NPDES). Retrieved from https://www.epa.gov/npdes/about-npdes

Goldman Sachs. (2017). FACT SHEET: DC Water Environmental Impact Bond. Retrieved from http://www.goldmansachs.com/media-relations/press-releases/current/dc-water-environmental-impact-bond-fact-sheet.pdf

Halifax Regional Water Commission (HRWC). (2014). Halifax Water Five Year Business Plan 2015/16 to 2019/20. Halifax: Halifax Water. Retrieved from https://www.halifax.ca/sites/default/files/documents/home-property/water/2015_16HalifaxWaterBusPlan.pdf

Halifax Regional Water Commission. (2014). Stormwater billing – Lessons learned. Halifax: Halifax Regional Water Commission. Retrieved from http://www.livablecitiesforum.com/wp-content/uploads/2014/04/4Mackenzie_Stormwater-Billing-Lessons-Learned.pdf

HRM. (2012). HRM Protect our lakes workshop II. Retrieved from http://new.halifax.ca/boardscom/bwac/documents/Infoitem1CommunityPrioritiesforGreenInfrastructure.pdf&gws_rd=cr&dcr=0&ei=Y0TLWc7RH6eR6ATUt7ygCg#12

Lee, H., Swamikannu, X., Radulescu, D., Kim, S.-j., & Stenstrom, M. (2007). Design of stormwater monitoring programs. Water Research (41), pp. 4186–4196.

Marsalek, J., & Schreier, H. (2009). Innovation in stormwater management in Canada. Water Quality Research Journal of Canada.

National Cooperative Highway Research Program (NCHRP). (2017). A watershed approach to mitigating stormwater impacts. Washington D.C.: National Cooperative Highway Research Program, National Academy of Sciences.

Parikh, P., Taylor, M. A., Hoagland, T., Thurston, H., & Shuster, W. (2005). Application of market mechanisms and incentives to reduce stormwater runoff. An integrated hydrologic, economic and legal approach. Environmental Science & Policy, 8, 133–144.

Philadelphia Water Department (PWD). (2011). Amended green city clean waters. Philadelphia: Philadelphia Water Department.

Philadelphia Water Department. (2017). Rain Check. Philadelphia: Philadelphia Water Department. Retrieved from http://www.phillywatersheds.org/whats_in_it_for_you/residents/raincheck

Saraswat, C., Kumar, P., & Mishra, B. (2016). Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi and Tokyo. Environmental Science & Policy (64), pp. 101–117.

Sustainable Prosperity. (2016). New solutions for sustainable stormwater management in Canada. Sustainable Prosperity. Retrieved from http://institut.intelliprosperite.ca/sites/default/files/stormwaterreport.pdf

Taylor, W. (2013). White paper for stormwater management program effectiveness literature review. Seattle: Taylor Aquatic Science and Policy & Cardno TEC, Inc.

Thurston, H. W. (2006, March/April). Opportunity costs of residential best management practices for stormwater runoff control. Journal of Water Resources Planning and Management, 132(2), 89 - 86.

U.S. National Research Council (NRC). (2008). Urban stormwater management in the United States. Washington D.C.: United States National Research Council.

Valderrama, A., Levine, L., Bloomgarden, E., Bayon, R., Wachowicz, K., & Kaiser, C. (2013). Creating clean water cash flows–Developing private markets for green stormwater Infrastructure in Philadelphia. Natural Resources Defense Council, The Nature Conservancy, EKO Asset Management Partners. Retrieved from https://www.nrdc.org/sites/default/files/green-infrastructure-pa-report.pdf

Water Environment Federation (WEF). (2015). Rainfall to results—The future of storm water. Alexandria: Water Environment Federation Stormwater Institute. http://wefstormwaterinstitute.org/wp-content/uploads/2015/09/Rainfall-to-Results.pdf

Withers, P. (2017). Halifax stormwater charge going down for most. CBC News. http://www.cbc.ca/news/canada/nova-scotia/halifax-regional-water-commission-stormwater-bill-utility-review-board-1.4067691

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