A Methodology and Evaluation Tool for Comparing Post-construction Storm Water Best Management Practises

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This dissertation is substantially my own work and conforms to the Department of Engineering’s guidelines on plagiarism. Where reference has been made to other research, this is acknowledged in the text and bibliography.

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Abstract

Structural post-construction storm water Best Management Practices (BMP) are needed to address the pollutant load and increased volume of urban runoff. There are many management practices to choose from, and many factors to consider, in the selection of a BMP. This proposed BMP selection tool attempts to provide information concerning the technical, environmental, social, and economic aspects of each BMP so that the most appropriate BMP can be implemented. The tool is applied to two test cases to demonstrate its use. Ideally, this selection tool will provide a common tool for stakeholders to use in their discussion about the selection of the most appropriate BMP.

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Chapter 1. Introduction

I. The Problem

The amount of oil running off streets and driveways in the US and ultimately flowing into the ocean is estimated to be equivalent to the *Exxon Valdez* oil spill – 10.9 million gallons – every eight months. (NRC, 2002)

According to a National Academy of Sciences study, the amount of oil running off streets and driveways in the United States (U.S.) and ultimately flowing into the ocean is estimated to be equivalent to the *Exxon Valdez* oil spill – 10.9 million gallons – every eight months (NRC, 2002). Add the fact that sprawl development is consuming land at a rate of five or more times the rate of population growth in many coastal areas of the U.S. (POC, 2003). Then consider the fact that coastal marshes, which trap floodwaters, filter out pollutants, and serve as "nurseries" for wildlife, are disappearing at a rate of 20,000 acres per year (POC, 2003). In summary, the urban environment, which is growing at a rapid pace, causes significant water pollution; and meanwhile the environment's natural defences to this pollution are being reduced. These impacts on the environment are detrimental. Polluted water impacts drinking water supply and affects the whole food chain by contaminating fish eaten by people or other predators. Something must be done to reverse this trend.

There are two parts to the pollution problem:
- contaminants
- increased runoff volume

There are two parts to the pollution problem; the contaminants themselves, as well as the increased runoff volume caused by impervious surfaces. First, pollutants must be controlled at the source. This means preventing the contaminants from coming in contact with *storm water*[1] which transports the pollutants from the urban environment through the storm water conveyance system to creeks, streams, or lakes known as *surface water bodies*. Unfortunately, due to the dynamics of

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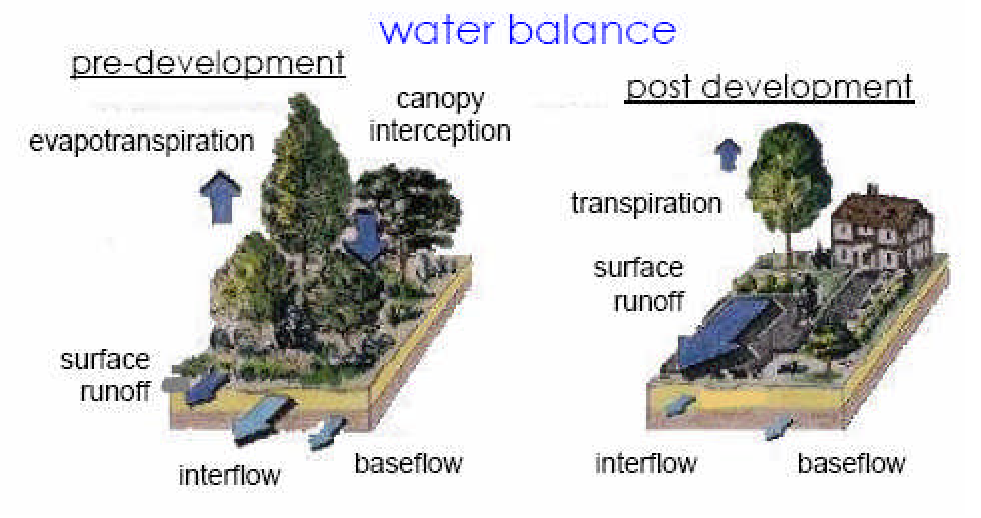
[1] defined for the purposes of this report as precipitation originated water such as rain water runoff or snow melt

the urban environment, source control does not prevent storm water runoff from being contaminated with pollutants, it only reduces or minimises the contamination. Sediment and chemical pollutant laden storm water that is discharged into surface water bodies reduce fish spawning habitat by filling the pores of the gravel beds with fine sediment. Sediment laden runoff also causes increased flooding when sediment is deposited in waterways, decreasing the carrying capacity. Aquatic biological diversity is decreased by the presence of chemical contaminants. Therefore, treatment of the runoff to remove pollutants is necessary.

The other part of the pollution problem is the increased volume of storm water runoff that results from impervious surfaces. On undeveloped land, rainfall is intercepted by vegetation, decreasing the impact of the water droplet and preventing erosion. The roots of the vegetation keep the soil porous so that water is easily absorbed into the soil to be evaporated or absorbed by plant roots. This is known as *evapotranspiration*. While there is some surface runoff, most of the water is infiltrated into the soil and either travels to surface water bodies in the shallow *interflow* or travels to groundwater through the deeper *baseflow* (Figure 1)(Bowles, G., 2002).



Copyright 2000, Center for Watershed Protection

Source: (Bowles, G., 2002)

Figure 1. A Comparison of Pre-development and Post-development Runoff Conditions.

As development spreads, porous vegetated areas are replaced by impervious pavement and buildings. Infiltration is limited by the impervious surfaces and interflow and baseflow are reduced. Most storm water is transported above ground as surface runoff, picking up pollutants and causing erosion as it flows to surface water bodies. The increased volume and velocity of the storm water runoff causes erosion within the streambed. The unnatural quantity and force of the water scours the banks and destroys riparian habitat. The hydraulic characteristics of surface water bodies receiving runoff from developed areas include higher peak flow rates. Since there is little opportunity for absorption of the rainfall, large quantities of rainwater runoff into creeks and streams immediately after a storm. Because the storm water cannot be absorbed into the soil and discharged by means of interflow into the stream at a steady rate, the peak flow rate of the stream is increased. Also, the frequency and duration of *bankfull* (flood stage) flows are increased in streams impacted by development. Small rain showers which in undeveloped conditions would not have resulted in runoff, cause flood stage flows after development (Bowles,G., 2002). In addition, downstream flooding is increased. Surface water bodies receiving runoff from developed areas also experience reduced base flow levels resulting from a decrease in interflow, which slowly recharges surface water bodies. For these reasons, control measures to reduce the volume of runoff and recharge groundwater flow are necessary.

II. Regulatory Response

Most existing urban drainage systems consist of underground pipe networks that are designed to transport storm water away from the developed area as quickly as possible. Traditionally, flood control measures have consisted of the capture and controlled release of peak flows. However, this approach to the management of urban drainage does not address pollutant removal and has, in many cases, worsened the aquatic habitat of natural channels downstream as a result of the unnatural quantities of flow (USEPA, 2006).

Although the U.S. Clean Water Act was amended by Congress in 1972 to prohibit the discharge of pollutants to waters of the United States through the National Pollutant Discharge Elimination System (NPDES), the prohibition only applied to *point* *sources*[2] such as municipal sewage and industrial process water. The NPDES program was successful in improving water quality; however, significant sources of water quality impairment still threatened surface water bodies. Runoff from agricultural and forestry operations as well as the urban environment were not regulated until 1987 when Congress again amended the Clean Water Act requiring the U.S. Environmental Protection Agency (EPA) to issue permits for storm water discharges (SWRCB, 2003; Rapid City, 2006).

The two-phase approach to urban storm water regulation considered storm water discharges from municipalities to be point sources of pollution. Phase I (promulgated on November 16, 1990) of the Federal Storm Water Regulations require *medium and large municipalities*[3] to develop a storm water management program. Phase II (promulgated on December 8, 1999) requires *small municipalities*[4] to develop storm water management programs. These programs, enforceable by the regulatory authority (State and Federal Government), must include the development and implementation of six measures that reduce storm water pollution. Evaluation and reporting of the progress of the measures is required (Rapid City, 2006). One of the six measures requires municipalities to address *post-construction*[5] storm water runoff from new and re-developments that disturb one or more acres. This includes the development of a strategy to implement a combination of structural and non-structural *Best Management Practices* (BMPs)[6], an ordinance to address post-construction runoff, and a program to ensure adequate long-term operation and maintenance of BMPs.

Best Management Practices (BMPs) are practices used to reduce the environmental impacts from a particular land use.

There are many post-construction storm water BMPs that are effective at reducing either the pollutant load or volume of runoff or, in some cases, both. However, these practices perform differently depending upon the climate, soil type, and topography of

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[2] pollution that can be traced back to a single origin or source such as a sewage treatment plant discharge (Rapid City, 2006)

[3] municipalities with a population of 100,000 or more (USEPA, 2006)

[4] municipalities located within an urbanised area with a population density of 1,000 people per square mile (USEPA, 2006)

[5] after construction is complete (USEPA, 2006)

[6] practices used to reduce the environmental impacts from a particular land use (USEPA, 2006)

their location. The U.S. EPA has created a *menu of BMPs* (USEPA, 2006) which lists the types of practices representative of those found to successfully achieve the post-construction measure requirements (Table 1).

III. Sustainable Drainage

Sustainable development, as defined in the 1987 Brundtland Report from the United Nations (UN), is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainable Development was the central theme of the UN Earth Summit at Rio de Janeiro in 1992, which called on governments to produce their own strategies for sustainable development. Urban areas place demands on the environment by using resources and producing waste. The built environment is therefore one area where the strategies of sustainable development should be put into practice. Conventional drainage systems focus on evacuating storm water from the urban environment but do not consider water resources or wildlife habitat (SUDS, 2004).

Sustainable drainage is a concept that includes long term environmental and social factors in decisions about drainage. It considers the quantity, quality, and value of storm water (SUDS, 2004).

Sustainable drainage considers the:
- quantity
- quality
- value

of storm water

In the United Kingdom (UK), best management practices are referred to as *Sustainable Urban Drainage Systems* (SUDS). The purpose of these systems is to:

- Manage runoff flow rates thereby reducing flooding
- Protect or enhance water quality
- Be sympathetic to the environmental setting and the needs of the local community
- Provide a habitat for wildlife in urban watercourses
- Encourage natural groundwater recharge (where appropriate)

by:

Table 1. Excerpts from U.S. EPA's structural post-construction storm water 'Menu of BMPs.' *(Source: USEPA, 2006)*

Category	Best Management Practice	Description
Infiltration	Grassed Channel	A vegetated, open-channel designed specifically to treat and attenuate a specified volume of storm water runoff. Storm water runoff is treated by vegetation slowing the water to allow sedimentation, filtering through a subsoil matrix, and/or infiltration into the underlying soils. The grassed channel, is a flow-rate-based design. Based on the peak flow, the channel are designed so that runoff takes, on average, 10 minutes to flow from the top to the bottom of the channel.
	Dry Swale	A vegetated, open-channel designed specifically to treat and attenuate a specified volume of storm water runoff. This design incorporates a fabricated soil bed. The native soil is replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain system is installed at the bottom of the soil bed. This underdrain is a gravel layer that encases a perforated pipe. Storm water treated in the soil bed flows into the underdrain, which routes the treated storm water to the storm drain system or receiving waters.
	Wet Swale	A vegetated, open-channel designed specifically to treat and attenuate a specified volume of storm water runoff. Wet swales intersect the ground water. This design variation incorporates a shallow permanent pool and wetland vegetation to provide storm water treatment.
	Infiltration Trench	A rock-filled trench with no outlet that receives storm water runoff. Storm water runoff passes through some combination of pretreatment measures, such as a swale and detention basin, and into the trench. There, runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix.
	Infiltration Basin	A shallow impoundment which is designed to infiltrate storm water into the soil.
	Porous Pavement	A permeable pavement surface, often built with an underlying stone reservoir that temporarily stores surface runoff before it infiltrates into the subsoil.
Filtration	Bioretention	Landscaping features adapted to provide on-site storm water treatment. They are commonly located in parking lot islands or within small pockets of residential land. Surface runoff is directed into shallow, landscaped depressions. These depressions are designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems.
	Catch Basin Inserts	Catch basins, also known as storm drain inlets and curb inlets, are inlets to the storm drain system. They typically include a grate or curb inlet and a sump to capture sediment, debris, and pollutants. Catch basins are used to capture floatables and settle some solids, and they act as pretreatment for other treatment practices by capturing large sediments. Inserts designed to remove oil and grease, trash, debris, and sediment can improve the efficiency of catch basins.
	Sand and Organic Filters	Usually designed with two-chambers; the first is a settling chamber, and the second is a filter bed filled with sand or another filtering media. As storm water flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as storm water flows through the filtering medium.
	Vegetated Filter Strip	Vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. They slow runoff velocities and filter out sediment and other pollutants, and provide some infiltration into underlying soils.
Retention / Detention	Dry Detention Ponds	Basins with outlets that have been designed to detain storm water runoff for some minimum time to allow particles and associated pollutants to settle. These facilities do not have a large permanent pool of water. However, they are often designed with small pools at the inlet and outlet of the basin.
	In-line Storage	Storage within the storm drain system that detain flows. Storage is achieved by placing devices in the storm drain system to restrict the rate of flow. Devices can slow the rate of flow by backing up flow, as in the case of a dam or weir, or through the use of vortex valves, devices that reduce flow rates by creating a helical flow path in the structure.
	Storm Water Wetland	As storm water runoff flows through this structural practice that incorporates wetland plants into the design, pollutant removal is achieved through settling and biological uptake within the practice. Storm water wetlands are designed specifically for the purpose of treating storm water runoff, and typically have less biodiversity than natural wetlands in terms of both plant and animal life.
	Wet Ponds	Constructed basins that have a permanent pool of water throughout the wet season. Ponds treat incoming storm water runoff by allowing particles to settle and algae to take up nutrients. The primary removal mechanism is settling as storm water runoff resides in this pool, and pollutant uptake, particularly of nutrients, also occurs through biological activity in the pond.
	On-lot Treatment	A range of practices designed to treat runoff from individual residential lots. The primary purpose of most on-lot practices is to manage runoff from rooftops and, to a lesser extent, driveways and sidewalks.
Other	Alum Injection	The process of adding aluminum sulfate salt, otherwise known as alum, to storm water. Alum causes fine particles to flocculate into larger particles. The process can also be applied to other pollutants. Alum treatment systems generally consist of three parts, a flow-weighted dosing system that fits inside a storm sewer manhole, remotely located storage tanks that provide alum to the doser, and a downstream pond that allows the alum, pollutants and sediments to settle out.
	Manufactured Products	Swirl separators are modifications of traditional oil-grit separators. They contain an internal component that creates a swirling motion as storm water flows through a cylindrical chamber. Sediments settle out as storm water moves in this swirling path, and additional compartments or chambers are sometimes present to trap oil and other floatables. There are several different types of proprietary separators, each incorporating slightly different design variations.

- Managing runoff close to where the rain falls
- Controlling potential pollution at its source
- Protecting water resources from point source pollution (such as accidental spills) and diffuse sources. (SUDS, 2004)

In Australia, a framework called *Integrated Catchment Management* (ICM) promotes innovation in storm water storage and reuse as a supplement to the water supply and as having the potential to eliminate the need for additional water supply dams in the future, which have large infrastructure and environmental costs. The guiding principals of ICM are:

- Total water cycle based planning and management.
- Total catchment based planning and management.
- Integration of subdivision and allotment design with storm water management.
- Adoption of integrated infrastructure and service provision.
- Adoption of *Ecological Sustainable Development* [7]approaches.
- Community involvement.

ICM recognises that land and water use and environmental impacts are interconnected. It acknowledges that actions in the upper catchment will have cumulative impacts on areas downstream and that a holistic approach to the coordination of land and water management is essential. ICM engages all of the stakeholders including those involved in land use planning, natural resource management, and conservation in working together to improve the overall management of their local area. Introducing new management techniques and strategically investing in wastewater and storm water reuse technology has the potential to create regional economic drivers for agriculture and industry, changing storm water quality problems into Ecological Sustainable Development opportunities (Environment Australia, 2002).

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[7] Ecological Sustainable Development has been described as development that uses, conserves and enhances the community's resources so that ecological processes, on which life depends, are maintained and the total quality of life now and in the future can be increased. (Environment Australia, 2002)

In the U.S., *Low Impact Development* is the strategy used to maintain the natural characteristics of the runoff, in quality, rate, and quantity. Low Impact Development (LID) is a land planning and engineering design approach with the goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds (Figure 2). This design approach incorporates large-scale planning with small-scale management techniques to achieve environmental protection, while allowing for development or infrastructure rehabilitation to occur (LIDC, 2006).

Figure 2. A parking lot island that allows for storm water infiltration is an example of a LIP BMP.
(Source: USEPA, 2006)

California's Phase II Municipal Storm Water General Permit (General Permit)[8] obliges municipalities to:

> "require long-term post-construction BMPs that protect water quality and control runoff flow, to be incorporated into development and significant redevelopment projects. Post-construction programs are most efficient when they stress (i) low impact design; (ii) source controls; (iii) treatment controls."[9]

The General Permit standard for compliance is *Maximum Extent Practicable* (MEP).

> "Permittees must implement BMPs that reduce pollutants in storm water to the technology-based standard of MEP."[10]

> "The MEP standard is an ever-evolving, flexible, and advancing concept, which considers technical and economic feasibility. As knowledge about controlling urban runoff continues to evolve, so does that which constitutes

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[8] (SWRCB, 2003) STATE WATER RESOURCES CONTROL BOARD (SWRCB) WATER QUALITY ORDER NO. 2003 – 0005 – DWQ NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) GENERAL PERMIT NO. CAS000004 WASTE DISCHARGE REQUIREMENTS (WDRS) FOR STORM WATER DISCHARGES FROM SMALL MUNICIPAL SEPARATE STORM SEWER SYSTEMS (GENERAL PERMIT)

[9] (SWRCB, 2003) FACT SHEET for the GENERAL PERMIT, General Permit Requirements, Preparation of SWMP, 1. (Page 6)

[10] (SWRCB, 2003) GENERAL PERMIT, C. Effluent Limitations, 1. (page 8)

> MEP. Reducing the discharge of storm water pollutants to MEP in order to protect beneficial uses requires review and improvement, which includes seeking new opportunities."[11]

Although post-construction BMPs are required to protect water quality and control runoff flow to the maximum extent practicable, there is much confusion about how to select the most appropriate BMP to meet the General Permit standard for compliance.

IV. The Solution

For every new or re-development project in California that disturbs an acre or more of land, the owner, who is often the developer, is responsible for implementing post-construction storm water best management practices that protect water quality and control runoff flow. The owner hires a design engineer to select and design the appropriate BMPs for the site and the city or county planning department approves the plans. The developer, through contractors, constructs the BMPs. The regulatory agency audits the planning department to ensure that every new or re-development that disturbs an acre or more of land has implemented post-construction storm water best management practices that protect water quality and control runoff flow.

A common language for discussing BMP selection is needed.

When it comes to BMP selection, the owner, developer, and contractor are mainly concerned with cost. They are most interested in low cost BMPs as well as low cost maintenance requirements. A design engineer's main focus in selecting a BMP is the site constraints. They are mostly concerned with design parameters such as the amount of space available, the slope of the site, the soil type, the depth to groundwater, and the drainage area. Local government and regulatory agency's are most concerned with the effectiveness of the BMP in reducing pollutants and runoff volume. Local government is concerned with the impacts to their drainage system, including clogging due to the discharge of sediment or debris and flooding as a result of large volumes of runoff or failed drainage systems. Regulatory agency's are mostly concerned with impacts to

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[11] (SWRCB, 2003) GENERAL PERMIT, finding 17. (page 4)

the waters they protect and their *beneficial uses* such as drinking water supply, agriculture water supply, recreational use, aquatic and wildlife habitat. With all of the various focuses of the different parties, communication concerning appropriate BMP selection is difficult; each party viewing BMP selection from their own perspective.

A common language for discussing BMP selection is needed so that all of the concerns of all of the parties involved are considered.

Chapter 2. The Need

I. Decision Making

Decisions have four elements: the *choice* (the design or decision options) of action, the influence of *uncertainty* (the exercise of a particular choice does not guarantee the actual decision outcome) on the eventual outcome, *preferences* (satisfaction of decision criteria) over those outcomes and *constraints* that limit the feasible choices. If there is no uncertainty, then the decision reduces simply to finding the choice that leads to the preferred outcome, while satisfying the constraints. If there is no preference, than any feasible choice will do, and if there is no choice, there is no decision (SWARD, 2002).

The 4 elements of decisions:
- Choice
- Uncertainty
- Preferences
- Constraints

Choice

There are many different post-construction storm water BMPs. The U.S. EPA has created a menu of BMPs which lists the types of practices representative of those found to successfully achieve the regulatory requirements. Although any BMP that is effective at removing pollutants and reducing the runoff volume may be used, the menu of BMPs constitutes what is widely accepted as the choice of BMPs available to meet regulatory requirements.

Uncertainty

There is some uncertainty associated with the BMP selection process. For example, since many BMPs rely on the biological processes of vegetation, the health of the plants determines the effectiveness of the BMP. If the conditions prove to be unfavourable for the plants, the BMP may not perform as designed and might require modification. Likewise, improper construction of the BMP can greatly affect its performance. If the slope of a constructed pond is not graded according to the design standards, the BMP will not function as anticipated.

Preferences

In order to determine the preferences of BMP selection, the *decision criteria* (objectives) must be defined. The decision criteria categories need to include technical performance, as that is the original purpose of a BMP. However, technical performance cannot be the only decision criteria as BMPs cost money to build and to maintain. They also have economic value such as the ability to prevent flooding downstream which saves money. Therefore, economic matters should be a decision criteria category. As the objective of BMPs is to protect the environment by protecting the water quality of surface water bodies as well as their riparian habitat, the construction or maintenance of the BMP should not adversely impact the any aspect of the environment through air pollution, water pollution, waste generation, or energy consumption. For this reason, environmental impacts should be a decision criteria category. Finally, since BMPs are often above ground structures that hold water, they are part of the landscape and the human environment and therefore impact people. In addition, people have the ability to impact their functionality. For this reason, social considerations should be a decision criteria category.

Decision criteria categories:
- Technical performance
- Economic matters
- Environmental impacts
- Social considerations

The decision criteria related to technical performance include volume reduction and pollutant removal because they are the intended functions of the BMP. Since different BMPs treat different pollutants with varying levels of effectiveness, it is important to consider the land uses in the drainage area discharging to the BMP to determine which pollutants may be present in the runoff.

Technical performance decision criteria:
- Volume reduction
- Pollutant removal
- Temperature sensitivity
- Drainage area size
- Depth to groundwater
- Soil type
- Site slope

Some BMPs are only effective in small drainage areas, some require impervious soils. Some BMPs require contact with the groundwater table, others require significant separation from groundwater. Some BMPs function better in an arid climate or a semi-arid climate, and some rely on gravity flow and require a slight slope, whereas others must be on flat ground. Some detention BMPs hold storm water in shallow ponds, thereby increasing the water's temperature before releasing it to the receiving water. The receiving water habitat should be considered in the selection process as certain detention BMPs should not be used near cold water streams where the native fish are temperature sensitive. For these reasons, temperature sensitivity, drainage area size, depth to groundwater, soil type, and site slope should be included as technical performance decision criteria.

In addition to these technical considerations, there are non-technical considerations that address the sustainability of the BMP.

Economic decision criteria:
- Construction costs
- Maintenance costs
- Economic value

The cost of the construction of a BMP, as well as the cost of maintenance of the BMP, should be considered together with the expected lifetime of the BMP in mind. Catch basin inserts that fit inside a storm drain drop inlet do not infringe on useful space and cost very little. However, they require the use of a vactor truck for maintenance. The truck itself has to be maintained and that cost should be considered as well. Additional value provided by the BMP should also be taken into consideration. Some BMPs, such as storm water wetlands, actually improve surrounding property value. Other BMPs eliminate flooding downstream. These economic benefits should be considered with the cost of the BMP. The economic decision criteria should include construction costs, maintenance costs, and economic value.

Environmental impact decision criteria:
- Construction impacts
- Waste disposal

The environmental impact decision criteria should include construction impacts and waste disposal. Construction impacts include not only those associated with land disturbance, but also the transportation of construction materials to the site. The *embodied energy*[1] of the BMP should also be considered. A product manufactured in a factory and transported to the site has much higher embodied energy than a swale made of local

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[1] The ecological impact of the extraction process of the materials (Brandon P.S.& Lombardi P., 2005).

soil and gravel. The amount of waste generated, and whether or not that waste can be recycled or composted, should be evaluated. For example, in many absorbent containing BMPs, the absorbent material must be replaced periodically and disposed of in a landfill; whereas, vegetated BMPs can be mowed and the clippings can be composted.

One advantage of some types of BMPs is that they keep rain water in the local watershed by recharging the groundwater aquifers so that the water can be used locally, later. This is important to communities that pay for imported water from other parts of the region. Social acceptance of these BMPs is crucial to their success. Some dry detention ponds double as dog parks or sports fields during the dry season. If the public is knowledgeable about the benefits of their local storm water BMPs, the environmental benefits in the wet season and recreational benefits in the dry season, they will come to view the flooding of the dog park during the rainy season as an expected outcome rather than an inconvenience. This requires public education and community acceptance. If engineers approach drainage systems designs in the traditional fashion, where the engineer selects the system to be used because the engineer it the technical expert and only functionality and economics are considered, the system will not be successful as these systems are a part of a community and hence require community support. Instead of traditional linear engineering, a more iterative approach is needed where the input of the community, in which the system will function, is considered together with technical, economic, and environmental impacts (Geldof, G.D. & Stahre, P., 2005). For these reasons, the social consideration decision criteria should include an evaluation of social acceptance and input.

Social consideration decision criteria should include an evaluation of social acceptance and input.

Constraints

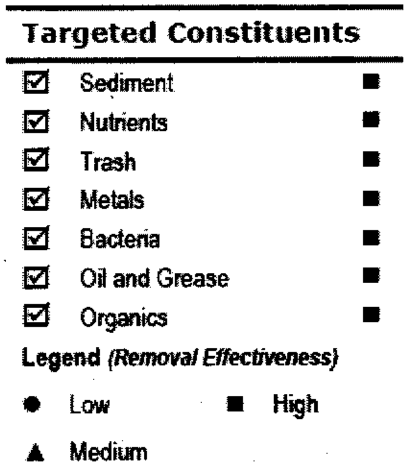
The preferences of BMP selection, or way in which decision criteria are satisfied, vary depending upon the constraints of each project's location, the stakeholders involved, and the local planning restrictions.

A tool is needed that can make all of the information necessary for the decision process available in an easily comparable format.

II. The Gap

Currently, there are many guidance manuals readily available with accurate and useful information about BMP design criteria, pollutant removal efficiencies and costs. Some of these documents, such as the *California Stormwater Best Management Practice New Development and Redevelopment Handbook* (CASQA, 2003), have handy tables (Figure 3) with symbols which allow the reader to determine at a glace which pollutants are treated by a particular BMP and how effective that BMP is at removing a pollutant of concern. While these tables are useful for summarising pollutant removal, they do not include other important factors such as costs or design parameters and they do not allow an easy comparison of one BMP with another.

Figure 3. Pollutants removed and level of effectiveness for an Infiltration trench at a glance.



Targeted Constituents		
☑	Sediment	■
☑	Nutrients	■
☑	Trash	■
☑	Metals	■
☑	Bacteria	■
☑	Oil and Grease	■
☑	Organics	■

Legend ***(Removal Effectiveness)***

● Low ■ High

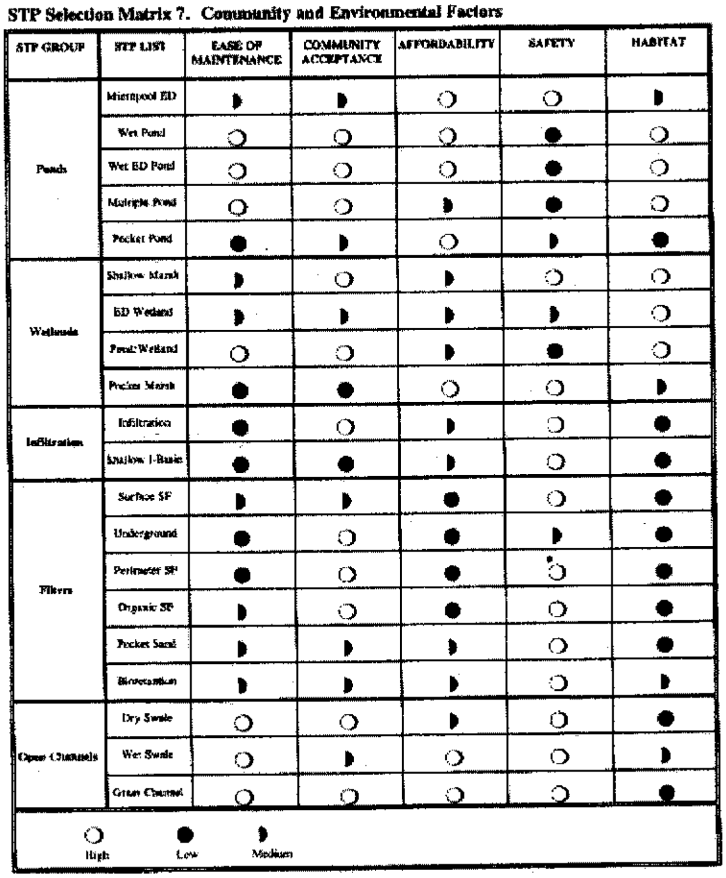
▲ Medium

(*Source: CASQA, 2003, Section 5.7 TC-10 Infiltration Trench*)

There are also numerous screening matrices readily accessible. The Storm Water Manager's Resource Center has a *Screening Matrices Manual* that can be used to screen BMPs in a seven step process (SMRC, 2006). The screening factors include:

1. Land Use
2. Physical Feasibility
3. Climate/Regional Factors
4. Watershed Factors
5. Storm Water Management Capability
6. Pollutant Removal
7. Community and Environmental Factors

There is a table (Figure 4) in every step that compares the data associated with that factor for each BMP. Some of the tables use symbols to depict the level of performance at a glance, but others use narrative which makes comparison within the table difficult. Also, because each matrix is separate and uses a different format, comparison of all of the factors at once is not possible.



STP Selection Matrix 7. Community and Environmental Factors

STP GROUP	STP LIST	EASE OF MAINTENANCE	COMMUNITY ACCEPTANCE	AFFORDABILITY	SAFETY	HABITAT
Ponds	Micropool ED	◗	◗	○	○	◗
	Wet Pond	○	○	○	●	○
	Wet ED Pond	○	○	○	●	○
	Multiple Pond	○	○	◗	●	○
	Pocket Pond	●	◗	○	◗	●
Wetlands	Shallow Marsh	◗	○	◗	○	○
	ED Wetland	◗	◗	◗	◗	○
	Pond/Wetland	○	○	◗	●	○
	Pocket Marsh	●	●	○	○	◗
Infiltration	Infiltration	●	○	◗	○	●
	Shallow I-Basin	●	●	◗	○	●
Filters	Surface SF	◗	◗	●	○	●
	Underground	●	○	●	◗	●
	Perimeter SF	●	○	●	○	●
	Organic SF	◗	○	●	○	●
	Pocket Sand	◗	◗	◗	○	●
	Bioretention	◗	◗	◗	○	◗
Open Channels	Dry Swale	○	○	◗	○	●
	Wet Swale	○	◗	○	○	◗
	Grass Channel	○	○	○	○	●

○ High
● Low
◗ Medium

Figure 4. The Screening Matrix for Step 7. Community and Environmental Factors
(*Source: SMRC, 2006, Step 7. Community and Environmental Factors*)

III. The Options

There are two types of tools that can be used for analysing the options of a decision. *Procedural tools* focus on specific procedures to guide the way to reach a decision. This type of tool is particularly useful when there are many individuals involved in the decision process. A specific procedure allows for transparency in the decision making process and provides a framework for the process. *Analytical tools* provide information about the consequences of a choice. This type of tool is useful in informing decisions made individually. It provides data for all of the options but allows the decision maker to apply his/her preferences to obtain the desired outcome (SWARD, 2002).

For a tool to be effective, it should have a strong element of learning, or understanding more about the problem, the objectives, and one's own preferences. When complex decisions are reduced to simple mechanistic processes, the decision maker may lack confidence in the outcome (SWARD, 2002). The assumptions used to create the mechanistic process are often hidden. The human element is removed making the decision less holistic. If the tool is not flexible, the decision outcome it generates will likely not be considered valid. More robust decision making processes yield higher quality outcomes.

The decision criteria for the selection of post-construction storm water BMPs can be divided into two categories; *limiting criteria* and *informative criteria*. If a project includes a large drainage area, for example, there is no sense in considering BMPs that are only effective in small drainage areas. In this way, drainage area is an example of a limiting criteria in BMP design. However, waste disposal information, including the nature of the waste and the manner in which is must be disposed, is used to inform the decision maker of the sustainability of the BMP option. In this way, waste disposal is an example of informative criteria.

The limiting criteria can be considered in a much more simple format than informative criteria which require some deliberation. In essence, the tool needed to aid in BMP selection should have both procedural and analytical aspects, since the decision process can be done within a community or as an individual depending upon the specific site location. The tool should provide a strong element of learning and because of the diverse criteria have simple and mechanistic aspects, where appropriate, and more flexible aspects that provide information and encourage innovation, where that is needed.

Chapter 3. The Proposal

I. The Process

For the decision making process to be of value, it is important that the method contributes to the decision maker's understanding of the issues, rather than creating a focus of attention and distraction in its own right (SWARD, 2002). As the decision maker's understanding of the issues increases he/she will be able to make better, more informed, decisions and may begin to take ownership of those decisions. An increased understanding of the issues surrounding a decision can also lead to innovation. Rather than relying upon the already existing options, better alternatives can be developed that combine the decision maker's preferences more efficiently, attaining the desired outcome with fewer compromises.

In the selection of structural post-construction storm water BMPs, there are many different BMPs to consider and many decision criteria used to evaluate each BMP which results in a large amount of data to process at once. Using the limiting criteria to reduce the number of BMPs that would be practicable for a specific application, quickly simplifies the selection process. Then only the BMPs that still remain as possible options need to be evaluated using the informative criteria.

II. The Tool

The limiting criteria - volume reduction, temperature sensitivity, drainage area size, depth to groundwater, soil type and site slope - are easily evaluated given the constraints of the site conditions and regulatory requirements. For this reason, a mechanistic screening tool is appropriate for narrowing the BMP choices. However, all of the information should remain available to the decision maker so that the screening process is understood.

Hard Gates

The proposed selection tool consists of '*hard gates*' (Figure 5) that eliminate the BMPs that do not fit the design parameters. Each of the limiting decision criteria are shown in different colours across the top of the table and the choices of BMPs are listed on the left. The BMPs are not listed in alphabetical order but are instead grouped by those that provide volume reduction and those that do not, as volume reduction is an important key function of a BMP. BMPs that provide treatment but no volume reduction are still included in the 'hard gates' as they may be used in location where volume reduction is not required or in conjunction with BMPs that provide volume reduction but little or no treatment.

> 'Hard gates' eliminate the BMPs that do not fit the design criteria.

Methods such as flow charts or decision trees are often used for simple decision processes. However, the data is hidden in an ambiguous process that leads the decision maker to a conclusion, often with no flexibility. The benefit of the format used for the selection tool is that the data is available for side-by-side comparison and evaluation leaving room for flexibility and professional judgement when site conditions are unique or complex. The fact that all of the limiting decision criteria are shown side-by-side allows for easy visual comparison. A tool that does not appear to be quick and easy to use will not be employed. Because the data remains visible for the purpose of explanation and no assumptions are hidden in the process, if, over time, new evidence is presented that changes the results of the decision criteria, the selection tool can be easily modified without having to completely reassess the process.

> Benefits of the selection tool format:
> - Side-by-side comparison of data
> - Can be easily modified

The 'hard gates' were created by compiling data concerning the volume reduction capability, thermal pollution potential, soil type necessary, depth to groundwater constraints, drainage area size limitations and optimal site slope for the 17 structural post-construction storm water BMPs listed in the U.S. EPA's menu of BMPs. The data sources used are the U.S. EPA's menu of BMPs (USEPA, 2006), the *California Stormwater Best Management Practice New Development and Redevelopment*

Figure 5. The ‘hard gates’ of the proposed BMP selection tool.

HARD GATES	Volume Reduction		Cold Water Stream Discharge?		Soil Type		Depth to Groundwater			Drainage Area Size (acres)				Site Slope (%)					
Best Management Practice	**yes**	**no**	**yes**	**no**	**infiltration rate less than 0.5 in/hr**	**infiltration rate more than 0.5 in/hr**	**bottom of BMP intersects groundwater table**	**4 to 9 ft. separation**	**sufficient separation to make sure the BMP never intersects the groundwater table**	**less than 5**	**5 to 10**	**10 to 25**	**25 or more**	**0**	**1 to 3**	**4 to 5**	**6**	**7 to 15**	**16+**
Infiltration Basin	■		■	■		■		■	■	■	■			■	■	■	■	■	
Grassed Channel	■		■	■		■		■	■	■				■	■				
Infiltration Trench	■		■	■		■		■	■	■				■	■	■	■	■	
Porous Pavement	■		■	■		■		■	■	■	■	■	■	■	■				
Vegetated Filter Strip	■		■	■		■		■	■	■					■	■	■		
On-Lot Treatment	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Dry Swale	■		■	■	■	■		■	■	■				■	■				
Bioretention	■		■	■	■	■			■	■				■	■	■			
Dry Detention Ponds	■			■	■	■			■			■	■	■	■	■	■	■	
Wet Swale		■	■	■		■	■			■				■	■				
Sand and Organic Filters		■	■	■	■	■		■	■	■	■			■	■	■	■		
Alum Injection		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Catch Basin Inserts		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Manufactured Products		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
In-Line Storage		■	■	■	■	■	■	■	■	■	■	■			■				
Wet Ponds		■		■	■	■	■	■	■				■	■	■	■	■	■	
Storm Water Wetlands		■		■	■	■	■	■	■				■	■	■	■	■	■	

Handbook (CASQA, 2003), and the Storm Water Manager's Resource Center's *Screening Matrices Manual* (SMRC, 2006). These data sources are common, peer reviewed resources that are respected by, and familiar to, most people who work with post-construction BMPs. The data sources represent federal level, public sources as well as state specific, non-profit sources. The specific references for each piece of data can be found in Appendix 1.

Soft Gates

Once the BMP options have been narrowed based on limiting design criteria, the '*soft gates*' (Figure 6) consider the remainder of the criteria by applying preferences. These 'soft gates' include pollutant load reduction, costs, environmental impacts, and social acceptance.

Each of the informative decision criteria are listed across the top of the table and the choices of BMPs are listed on the left. A colour code system highlights the data so that it can be easily visually compared. Once again, the BMPs are not listed in alphabetical order but in order of pollutant load reduction, an important key function of a BMP. BMPs that provide little treatment are included as options in the 'soft gates' as they may be used in locations where pollutant load reduction is not necessary, such as with uncontaminated roof runoff, or in conjunction with other BMPs. Beneath the table is a colour code key indicating the significance of each colour for each decision criteria. The rose colour represents the most favourable option, dark blue the least favourable option, with a spectrum of colours in between indicating various degrees of favourability. The decision criteria for which the explanations are too long to fit in the table have been assigned numbers with the corresponding description listed below. This allows all of the data to still be displayed side-by-side without cluttering the table.

> The 'soft gates' consider the remainder of the decision criteria by applying preferences.

The 'soft gates' were created by compiling data concerning the percent removal of six common pollutants, the construction costs, maintenance costs, additional factors affecting the cost or value of the BMP, environmental impacts, and the social acceptance of each BMP. The data sources used are the U.S. EPA's menu of BMPs

Figure 6. The ‘soft gates’ of the proposed BMP selection tool.

SOFT GATES	Pollutant Load Reduction (% Removal)						Cost				
Best Management Practices	Total Suspended Solids	Total Phosphorus	Total Nitrogen	Nitrate as Nitrogen	Metals	Bacteria	Construction	Annual Maintenance	Additional Costs/Value	Environmental Impacts	Social Acceptance
On-Lot Treatment	N/A	N/A	N/A	N/A	N/A	N/A	$100 to $200	N/A	1,3,4,7,10,11,12	5	
Bioretention	90	70-83	49	15-16	43-98	90	$3 to $4 residential, $10 to $40 commercial/sq ft	typical landscaping costs	1,2,3,4,5,7,9,11,15	6	1,5,6,7,13
Porous Pavement	82-95	65	80-85		98-99		$10,105 for a one acre watershed	$3,960 for 1 acre watershed	1,7,16,20,22	1	4
Alum Injection	95-99	37-95	52-70		41-90	99	$135,000 to $400,000	$6,500 to $25,000	18,25	13,14,15,16	
Dry Swale	77-99	8-99	67-99	45-99	37-99	-33	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,4,7,9,15	1,2	1,3,13
Infiltration Trench	75				85-90	90	$5/cubic ft treated	5 - 20 % of the const. cost	4,5,6,20	1,2,4,11	3
Infiltration Basin	75				85-90	90	$2/cubic ft of storage	5 -10% of the const. cost	5,6,20	1,2,3,4,11	3
Storm Water Wetlands	83	43	26	73	36	76	$57,100 for a one acre ft facility	3 to 5% of const. cost	2,13,14,19	2,6,12	1,2,3,8,11,12,13
Sand and Organic Filters	65-89	40-85	17-47	-76	25-90	55-65	$5/cubic ft treated	$2,000 to $4,000 every 2 -10 years	10,16	10	
Wet Swale	67-81	17-39	40	9-52	-35 - 69		$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,2,3,4,7,9	2	1,3,13
Grassed Channel	67-83	4-29		-25-31	2-73	-100 - -25	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,2,4,7,9,15,20	1,2	1,3,13
Vegetated Filter Strip	54-84	-25-40	15	-27-20	-16-88		$0.30 to $0.70/sq ft	$350/acre/year	2,4,9,15	1	1,4
Catch Basin Inserts	32-97				3-15		$2,000 - $3,000 per inlet	$125,000 to 150,000 for a vactor truck	16,17,18,23,24	7,8,9	
Wet Ponds	32-99	12-91	-12-85	-85-97	-51-90	46-91	$45,700 for a one acre-ft facility	3 to 5 % of const. costs	2,3,8,13,14,19	2,5,6	1,3,8,9,12,13
Dry Detention Ponds	61	19	31	9	26-54		$41,600 for a one acre-ft pond	3 to 5% of const. cost	5,6,14,15,19,21	1,2	3,9,14
Manufactured Products	21-51	17			17-51		$5,000 to $35,000 or $5,000 to $10,000 per impervious acre	$125,000 to 150,000 for a vactor truck	16,17,18,23,24,25	8,9	13
In-Line Storage	0	0	0	0	0	0	low	low	12,16		10

key:	84 - 100%			$0 - $50,000	$0 - $10,000	favourable	favourable	favourable
	67 - 83%			$50,000 - $100,000	$10,000 - $20,000			
	50 - 66%	▨	Data not available	$100,000 - $150,000	$20,000 - $30,000			
	33 - 49%	N/A	Not Applicable	$150,000 - $200,000	$30,000 - $40,000			
	16 - 32%			$200,000 - $250,000	$40,000 - $50,000			
	0 - 15%			$250,000 - $300,000	$50,000 - $60,000	least favourable	least favourable	least favourable

Additional Costs/Value:

1: Less expensive than, or reduces the cost of, a traditional design concrete sewer system
2: Aesthetic value
3: Captured water may be used for irrigation reducing water use and utility costs
4: Can fit into small otherwise unusable portions of a site
5: Recharges groundwater
6: Maintains flows in streams
7: May reduce the need for land intensive BMPs
8: Recreational value
9: Replaces an area that would have been landscaped
10: More flexibility in design sizing compared to other manufactured BMPs
11: Maintained by homeowner/reduces public maintenance costs
12: Requires little maintenance
13: May increase property values by 10 to 25%
14: Long life time (more than 20 years)
15: Maintenance overlaps with landscaping maintenance
16: Consumes no surface space
17: Truck maintenance and fuel
18: Staff costs to operate the BMP equipment
19: Requires a large land area
20: Particularly susceptible to failure if not maintained
21: Can detract from the value of adjacent homes by 3 to 10%
22: Requires a vacuum sweeper for maintenance
23: Requires a vactor truck for maintenance
24: Material disposal costs
25: Requires frequent maintenance

Environmental Impacts:

1: Provides groundwater recharge
2: Provides channel protection
3: Maintains flows in streams
4: 100% load reduction to surface waters
5: Conserves water, may be used for irrigation
6: Provides habitat
7: Provides spill control
8: Can become a source of pollutants through resuspension
9: Concentration of pollutants in sediments may have to be disposed of as hazardous waste
10: Sorbent pillows may have to be disposed of as hazardous waste
11: Potential for groundwater contamination
12: May release nutrients during the non-growing season
13: Settled floc contains high concentrations of dissolved chemicals, bacteria and viruses and must be disposed of properly
14: Requires electricity to operate pumps that dispose of floc to sludge drying beds or sanitary sewer (with permit).
15: Experimental practice, little is known about long term impacts.
16: Chemicals added during the process may have negative impacts on down stream waters.

Social Acceptance:

1: Provides aesthetic value
2: Educational value
3: Provides flood control
4: Unobtrusive, high level of acceptance by the public
5: Provides noise reduction
6: Provides shade
7: Provides wind breaks
8: May increase the value of nearby homes
9: Recreational value
10: May cause up stream flooding
11: Can look swampy
12: Safety concerns where there is public access
13: May allow mosquito breeding
14: May devalue nearby homes

(USEPA, 2006) and the *California Stormwater Best Management Practice New Development and Redevelopment Handbook* (CASQA, 2003). The references for the 'soft gates' data can be found in Appendix 2.

A colour was assigned to each piece of data to indicate, at a glance, how each BMP compares with the others. For the percent removal data, each colour represents a 15% increment. The percent removal range was obtained from the data sources and is provided in the table. The median number in the data range was used to assign the colour according to the key.

Economic Matters

Comparing cost data for structural post-construction storm water BMPs is difficult for the following reasons. First, construction costs, and other costs based on transportation, fluctuate with the costs of fuel. Depending upon the amount of material that needs to be transported to the construction site, and the distance the material must travel, the cost of fuel can equate to a large percentage of the construction costs. Since fuel costs are always changing and since the distance of material sources away from sites is different for each project, it is difficult to compare costs. Secondly, because the way in which BMPs are sized or designed varies, the way in which BMPs are priced varies as well. Some BMPs are manufactured products that are made in standard sizes and therefore sell at standard prices. Other BMPs are sized based upon the area of the watershed that drains to them. Some BMPs are designed based on the amount flow they can process. For these reasons, the way in which costs are reported varies and can be difficult to compare. However, BMP costs are an important part of BMP selection and so some comparison, even if crude, must be made.

Construction Costs

The construction cost data is provided in the 'soft gates' table. The method used to compare BMP construction costs involves equating the BMPs based on the treatment of one acre-foot of water (43,560 ft^3). Although costs cannot necessarily be compared on a linear scale, as there are some economies of scale, it is the best way of estimating the differences in price range. A colour was assigned to each piece of data to indicate how each BMP compares with the others. For construction cost data, each colour represents a US$50,000 increment.

Maintenance Costs

BMP maintenance cost data is difficult to compare since the maintenance frequency of BMPs depends on proper design and construction of the practice. The pollutant load in the drainage area also effects the maintenance regularity. However, it is important to consider maintenance costs in conjunction with construction costs since maintenance costs are ongoing. While BMPs that are inexpensive to construct may be tempting to select, the high maintenance costs may prove another BMP to be more cost effective. The maintenance cost data is provided in the ‘soft gates’ table. The method used to compare BMP annual maintenance costs involves equating the BMPs based on the treatment of one acre-foot of water (43,560 ft^3). A colour was assigned to each piece of data indicating how each BMP compares with the others. For maintenance cost data, each colour represents a US$10,000 increment.

Additional Costs/Value

In addition to construction and maintenance costs, there are other economic incentives and disincentives to consider in the BMP selection process. The additional costs or added value are described in Table 2. The first 16 items are economic incentives whereas items 17 through 25 are economic disincentives. The additional costs or value applicable to each BMP are listed on the ‘soft gates’ table. The colours highlighting the list of economic incentives and disincentives for each BMP indicate how many additional costs versus value there are to consider for each BMP. The number of disincentives were subtracted from the number of incentives to obtain an adjusted number of economic incentives. BMPs with eight or nine incentives (after adjustment) were highlighted pink, six or seven incentives were highlighted orange, down to zero or one incentive which were highlighted light blue. BMPs with more disincentives than incentives were highlighted dark blue.

Environmental Impacts

Since the purpose of storm water BMPs is to protect the environment by protecting water quality and riparian habitat, it would be counter productive to implement a BMP with negative environmental impacts that outweigh the environmental benefit of

Table 2. Additional economic incentives and disincentives to consider when selecting a structural post-construction storm water BMP. *(Source: USEPA, 2006; CASQA, 2003)*

Additional Costs/Value	Economic Incentive or Disincentive
1: Less expensive than, or reduces the cost of, a traditional design concrete sewer system	Above ground storm water conveyance systems, such as swales, are less expensive to construct and maintain than traditional underground pipe storm sewers because they do not require trenching and burying pipelines and the maintenance generally consists of mowing and debris removal rather than clearing blockages from difficult to reach confined spaces. BMPs that capture storm water on-site reduce the cost of traditional storm sewer systems by reducing the design flow, and subsequently, the size of the sewer system.
2: Aesthetic value	Some BMPs can increase property values and improve neighbourhood and community aesthetics which is good for business and the real estate market.
3: Captured water may be used for irrigation, reducing water use, and therefore utility costs	Storm water captured by some types of BMPs can be used for irrigation, reducing the amount of potable water used for this purpose, thereby reducing utility costs.
4: Can fit into small, otherwise unusable, portions of a site	BMPs that fit into otherwise unusable portions of a site save valuable space for larger commercial or residential buildings equating to higher property values.
5: Recharges groundwater	If groundwater aquifers are not replenished, utility costs increase due to water shortage and community growth is slowed.
6: Maintains flows in streams	Large infiltration BMPs that contribute to interflow help to maintain adequate flow in streams which results in an economic benefit on the tourism industry surrounding waterbodies' recreational use and aesthetic value. Some industries, such as fishing, rely on sufficient flows to provide access to spawning grounds.
7: May reduce the need for land intensive BMPs	BMPs that capture or infiltrate storm water on-site reduce, or in some cases eliminate, the need for large central BMPs that take up valuable real estate.
8: Recreational value	The recreational value of some BMPs can increase the surrounding property values.
9: Replaces an area that would have been landscaped	By replacing an area that would have been landscaped with a vegetated BMP, there is no loss of otherwise usable space.
10: More flexibility in design sizing compared to other manufactured BMPs	Some manufactured BMPs come in a few standard sizes which means that a BMP may be oversized for a particular site. BMPs that can be designed to the necessary size for a particular site are less expensive because they use fewer unnecessary materials.
11: Maintained by homeowner/reduces public maintenance costs	BMPs that are maintained by the homeowner as a part of regular yard maintenance reduce the cost to the tax payer by reducing publicly funded maintenance.
12: Requires little maintenance	BMPs that require little maintenance are generally less prone to failures and emergency repairs and are therefore less expensive.
13: May increase property values by 10 to 25%	The results of one study suggest that "pond front" property can increase the selling price of new properties by about 10 percent (USEPA, 1995). 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 percent when located near a wet pond (Emmerling-Dinovo, C., 1995).
14: Long life time (more than 20 years)	If a BMPs is designed to last a long time the construction and maintenance costs can be amortized over a longer period of time, usually making the money spent per year of benefit gained, lower than other BMPs.
15: Maintenance overlaps with landscaping maintenance	The benefit of BMP maintenance overlapping with landscaping maintenance is that the same crew and equipment can be used for both activities eliminating the cost of separate site visits by additional maintenance crews.
16: Consumes no surface space	BMPs that do not consume valuable real estate space allow the surface area above it to be used for another purpose, such as a parking lot or an access road.
17: Truck maintenance and fuel	The cost of vehicle/equipment maintenance and fuel should be considered in addition to the cost of the large equipment required to maintain some BMPs.
18: Staff costs to operate the BMP equipment	In addition to the cost of purchasing large equipment to maintain some BMPs, is the staff costs to operate the equipment. For example, alum injection requires ongoing operation by a qualified person, unlike most other post-construction storm water treatment practices.
19: Requires a large land area	Land consumed by large BMPs cannot be used to build additional houses or commercial property.
20: Particularly susceptible to failure if not maintained	BMPs that are particularly susceptible to failure if not maintained, can pose the threat of additional expenses if there are catastrophic failures resulting in emergency repairs or clean-ups.
21: Can detract from the value of adjacent homes by 3 to 10%	One study found that dry ponds can detract from the perceived value of homes located adjacent to them, by between 3 and 10 percent (Emmerling-Dinovo, C., 1995).
22: Requires a vacuum sweeper for maintenance	In order to prevent clogging, a vacuum sweeper is needed for the maintenance of porous pavement.
23: Requires a vactor truck for maintenance	Vactor trucks cost between US$125,000 and $150,000 (CASQA, 2003). While the cost is high, it may be possible to share a vactor truck with another community. Each truck can clean 750 to 1,000 catch basins per year, assuming semi-annual cleaning.
24: Material disposal costs	The material collected in some BMPs may have to be disposed of as hazardous waste which includes higher disposal costs than landfill disposal. Other BMPs have the option of discharge to the sanitary sewer which requires the payment of permit fees.
25: Requires frequent maintenance	BMPs that require frequent maintenance are generally more prone to failures and emergency repairs which can incur additional costs.

the BMP. Therefore, the environmental impacts of BMP implementation must be assessed. Unfortunately, environmental impacts are difficult to assess and compare because there is no single correct way to evaluate the environmentally related attributes of products and processes and because the results of each evaluation depend upon where the boundaries are drawn. The tools currently used for the evaluation of environmental impacts are in the midst of rapid development and the way in which the tools are used varies depending on the scope of the evaluation, making comparison difficult. One common tool, *Life Cycle Assessment* (LCA), can be used to compare two or more alternatives and takes into account things such as the amount of material and energy used for its construction, operating lifetime, and disposal or reuse. While this method of assessment is very thorough and informative, it is also time consuming, expensive, and requires a significant amount of data (Graedel, T.E., 1998.). Since the selection of structural post-construction storm water BMPs needs to occur in an inexpensive and timely manner, an LCA cannot be completed for the BMP options considered for each project site. However, the considerations used in an LCA should, and can, still be evaluated. While these considerations cannot be adequately captured in the ‘soft gates,’ they are addressed in the third step of the proposed selection tool.

The environmental benefits and impacts associated with structural post-construction storm water BMPs that are considered in the ‘soft gates’ are described in Table 3. The first seven items are environmental benefits whereas items eight through 16 are environmental impacts. The environmental benefits or impacts applicable to each BMP are listed on the ‘soft gates’ table. The colours highlighting the list of environmental benefits or impacts for each BMP indicate how many benefits versus impacts there are for each option. The number of impacts were subtracted from the number of benefits to obtain an adjusted number of environmental benefits. BMPs with three benefits (after adjustment) were highlighted pink, two benefits were highlighted orange, down to zero benefits which were highlighted green. BMPs with more impacts than benefits were highlighted light blue or dark blue.

Table 3. Environmental benefits and impacts associated with structural post-construction storm water BMPs. *(Source: USEPA, 2006; CASQA, 2003)*

Environmental Benefits and Impacts	Environmental Incentives and Disincentives
1: Provides groundwater recharge	Groundwater recharge is beneficial because it restocks water supply aquifers and provides a consistent flow of filtered water to surface water bodies.
2: Provides channel protection	The increased volume and velocity of storm water runoff from developed watersheds can cause erosion in creeks and streams. BMPs that retain storm water and meter flow can provide protection to stream channels.
3: Maintains flows in streams	Large infiltration BMPs that contribute to interflow help to maintain adequate flow in streams that provide habitat for wildlife as well as access to spawning grounds for aquatic life.
4: 100% load reduction to surface waters	The unnatural volume, velocity, and pollutant load of storm water runoff from developed areas is detrimental to surface water bodies. Infiltrating storm water into the ground provides natural filtration and results in a consistent subsurface discharge of filtered water to surface water bodies, rather than flash floods of untreated runoff.
5: Conserves water, may be used for irrigation	BMPs that capture water for reuse supplement the amount of potable water needed for irrigation. This reduces the demand on groundwater aquifers and water supply reservoirs.
6: Provides habitat	Development often results in the reduction of wildlife habitat. BMPs that provide habitat help to restore balance to the natural environment.
7: Provides spill control	BMPs that provide spill control aid in the capture of harmful materials or chemicals so that they can be cleaned up before the material is washed into a surface water body.
8: Can become a source of pollutants through re-suspension	Some BMPs can actually become a source of pollutant discharge if they are not maintained properly. The pollutants can become re-suspended in storm water and discharged to surface water bodies.
9: Concentration of pollutants in sediments may have to be disposed of as hazardous waste	Sediments from highly urban or industrial areas may contain high concentrations of pollutants which can trigger hazardous waste disposal requirements.
10: Sorbent pillows may have to be disposed of as hazardous waste	Depending upon the type of pollutant(s) trapped by the sorbent pillow, it may need to be disposed of as a hazardous waste.
11: Potential for groundwater contamination	BMPs that infiltrate storm water have the potential to contaminate for groundwater depending upon the types of pollutants that are found in the runoff, the depth to groundwater, and the soil type.
12: May release nutrients during the non-growing season	It is possible that storm water wetlands may release nutrients during the non-growing season (USEPA, 2006).
13: Settled floc contains high concentrations of dissolved chemicals, bacteria and viruses and must be disposed of properly	It's important to dispose of the floc that settles in downstream basins because it contains high concentrations of dissolved chemicals, as well as viable bacteria and viruses (Kurz R., 1998).
14: Requires electricity to operate pumps that dispose of floc to sludge drying beds or sanitary sewer (with permit)	A floc collection pump-out facility should be installed to reduce the chance of re-suspension and transport of floc to receiving waterbodies. The facility's pumps dispose of the floc into a sanitary sewer system, a nearby upland area, or a sludge drying bed. Pumping into a sanitary sewer system requires a permit, however. The quantity of sludge produced at a site can be as much as 0.5 percent of the volume of water treated (Gibb, A. *et al*., 1991).
15: Experimental practice, little is known about long term impacts	There are risks associated with using a practice that does not yet have a long enough history for all environmental impacts to be known.
16: Chemicals added during the process may have negative impacts on down stream waters	Failure of the alum injection system could result in down stream environmental damage. For example, chemicals, such as lime, sometimes added during the process to enhance pollutant settling, increases the pH to between 8 and 11 (USEPA, 2006). Storm water released to surface water bodies with a pH of 11 could have severe impacts on aquatic life.

Social Considerations

The social aspects of the BMP selection process are the most complex features of the process and, therefore, the most difficult to address. The main social concerns are:

- Health
- Equitability
- Acceptance

Health

Health concerns include disease vectors, cross-connections and safety. In 1998, the California Department of Health Service's Vector-Borne Disease Section (VBDS) conducted a two-year study of vector production associated with 37 operational storm water BMP structures in Southern California. The study found that because standing water creates habitat for mosquito breeding, BMPs that are improperly designed, or lack maintenance, contribute to mosquito production. BMP designs that let water stand for more than 72 hours allow mosquitoes to breed. Lack of maintenance allows the accumulation of vegetation, silt, and debris to trap standing water in the BMP long enough to produce mosquitoes (Metzger, M.E., *et al*., 2003).

The term *cross-connection* refers to the connection of a sanitary waste sewer pipe to a storm sewer system. This connection is illegal but can occur as a result of out-dated sewer maps leading to incorrectly identified sewer systems in the field. Cross-connections result in the discharge of untreated sanitary waste to surface water bodies. This creates human health problems when people come in contact with the contaminated water body, usually through recreational use.

Human safety is an important social aspect of BMP selection. For example, not only are children often attracted to wet ponds, but crews are required to operate machinery, such as lawnmowers, near the BMP in order to maintain it's effectiveness. However, safety concerns can be mitigated by proper design. For instance, ensuring that embankment slopes are not too steep, utilising 'safety benches' around the perimeter of the pond and eliminating vertical walls that require a person who falls in, to swim, help to reduce the hazards (Jones, J.E., *et al*., 2006).

Another means of mitigating the danger of access to open water within a community is the posting of signs warning the public of the nearby water hazard as depicted in Figure 7. Fences are often thought to be an effective means of limiting the public's access to storm water practices, however, there are some risks associated with this mitigation measure. While fences discourage some people from accessing ponds, children often view fences as a challenge. Fences make it difficult for rescue crews to reach a person requiring assistance, and for crews to maintain the facility. As a result, fenced storm water practices are often not as well maintained as their unfenced counterparts. Fences are, themselves, another part of the practice that requires maintenance. If they fall into disrepair, they can be ineffective and unattractive. (Jones, J.E., *et al*., 2006)

Figure 7. Signs posted around wet ponds warn the public about the nearby danger of open water.
(Source: Jones, J.E., et al., 2006)

Equitability

Equitability addresses the concept of sending water quality and quantity problems downstream, as well as equal access to public input opportunities. For example, uncontrolled urban runoff usually has the greatest impact on the least economically advantaged neighbourhoods. Low-lying areas that flood are usually inhabited by the less wealthy members of the community, whereas the wealthier members of a community can afford to live on higher ground in homes that are not in danger of flooding. If these upland residential areas do not implement BMPs that capture or infiltrate the runoff from their impervious areas, the low-lying areas will receive the additional storm water, putting them at risk for frequent flooding of their neighbourhoods as a result. In addition, lesser economically advantaged neighbourhoods usually do not have many residents that have time to be involved in the public process of planning for, and selecting, BMPs. While wealthier communities have more members that can afford to spend time being involved in the public process, less wealthy communities are often less vocal, which could result in inappropriate BMPs being selected due to a lack of resistance.

Acceptance

Acceptance of BMPs refers to the human perception of a BMP's value. There is some already existing general data concerning the overall acceptance of BMPs reflected in the 'soft gates,' however, more location specific information can be gained through engaging the public. Public participation in environmental and social impact assessments can produce higher quality decisions due to the incorporation of local knowledge and the public examination of 'expert' knowledge. The legitimacy of the final outcome is higher when the affected parties have had the opportunity to state their case in the presence of other members of the community and provide input on the final decision (Webler, T., *et al.*,1995).

Only health and acceptance can be addressed in the 'soft gates' as the data remains consistent. Equitability varies with the location of the BMP and is addressed elsewhere in the proposed selection tool.

These social concerns occur at three levels:

- Individual
- Community
- Government

Social concerns at an individual level can be, for example, an individual home owner concerned about a BMP next to his house potentially devaluing his property, or a mother concerned that a BMP in her neighbourhood could pose a safety risk for her children.

Social concerns at a community level usually take the form of special interest groups that are organised groups of people with a common focus. For instance, the Surfrider Foundation is interested in protecting the health of surfers and the environment they enjoy, and may, therefore, be concerned about BMPs that are not effective at removing pollutants from storm water that is eventually discharged into the ocean.

There are also social concerns that occur at the government level. For example, local government is tasked with protecting the interests of the people in the community. Sometimes these interests can appear to conflict. A municipality might be concerned with aiding growth, ensuring a safe and equitable community, and complying with State or Federal environmental law. Facilitating growth means reviewing plans and efficiently processing building permits. However, the law requires the BMP planning process to be open to public input. If members of the public raise concerns about safety, it slows the building process because the concerns must be addressed as they are pertinent to the role of the government, forcing local government to balance the interests of the community.

There are a few ways to address the various levels of social concerns. Stakeholder engagement provides an opportunity for all parties affected by a decision to communicate their perspectives. Through the stakeholder engagement process, citizens are able to contribute their local knowledge of a particular area which is valuable information that is often unwritten or otherwise inaccessible to other parties. Stakeholder engagement also provides an opportunity for decision makers and design engineers to be held accountable for their decisions by answering questions about their part of the process. An additional benefit of stakeholder engagement is that by involving the public, a sense of ownership or responsibility is established, which is crucial. The public plays an important role in reducing pollution that comes in contact with urban runoff. By reducing the pollutants at the source, BMPs are able to function more effectively.

The most difficult part of stakeholder engagement is finding what Geldof and Stahre (2005) call the *middle path*; the balance between the two extremes of giving the public complete control over the decision making, and giving the technical experts complete control over the process outcome. If the public input is relied upon to heavily, the outcome may not reflect the best technical solution and therefore may not function as well as other alternatives. Conversely, if the input of the technical experts is given exclusive consideration, the technical solution expected to function best in theory, may not actually perform well when integrated into the local environment and community.

Public education can also help alleviate social concerns. Although public education usually consists of information flowing in one direction with little opportunity for feedback, there is a certain level of education that is necessary for the stakeholders to participate effectively. Educational information should be made available at all levels. Individuals should be able to access information about BMPs that have an effect on them. Whole communities can be educated through advertising campaigns on the radio, the television, or in newspapers or magazines. Even billboards and bus advertisements can be used to educate the public about the BMPs around them. All levels of the government should be educated about BMPs. Elected officials, as well as staff engineers, should be informed about all of the aspects surrounding appropriate BMP selection.

The social aspects of structural post-construction storm water BMPs that are considered in the ‘soft gates’ are described in Table 4. The first nine items are social incentives whereas items 10 through 14 are social disincentives. The social incentives and disincentives applicable to each BMP are listed in the ‘soft gates’ table. The colours highlighting the list of social aspects for each BMP indicate how many incentives versus disincentives there are for each BMP. The number of disincentives were subtracted from the number of incentives to obtain an adjusted number of social incentives. BMPs with three incentives (after adjustment) were highlighted pink, two incentives were highlighted orange, down to zero incentives which were highlighted green. BMPs with more impacts than benefits were highlighted light blue.

III. Intended Use

Post-construction BMPs are required to protect water quality and control runoff flow to the maximum extent practicable. However, there are so many BMPs to choose from, it is difficult to ascertain which BMP is the most appropriate choice for protecting water resources and meeting regulatory requirements.

The ‘hard gates’ and ‘soft gates’ are intended to be used as a part of the proposed selection tool (Figure 8). The selection tool aids the user in understanding the factors

Table 4. The social aspects of structural post-construction storm water BMP selection considered in the 'soft gates.' *(Source: USEPA, 2006; CASQA, 2003)*

Social Acceptance	Social Incentives and Disincentives
1: Provides aesthetic value	BMPs that provide aesthetic value are socially beneficial because they increase property values and improve neighbourhoods and pride in the community.
2: Educational value	Some BMPs, such as storm water wetlands, can be used for educational purposes. Many communities establish educational centres adjacent to these types of BMPs to inform the public about the benefits of the local ecosystems and the community's impacts on the environment.
3: Provides flood control	BMPs that provide flood control, benefit the community by reducing or eliminating the occurrence and impacts of flood damage.
4: Unobtrusive, high level of acceptance by the public	BMPs are often integrated into the human environment and can therefore meet public opposition if they are perceived as undesirable. Unobtrusive BMPs have a higher level of public acceptance.
5: Provides noise reduction	Some BMPs have a secondary benefit of noise reduction which can increase it's social value in high density neighbourhoods.
6: Provides shade	Some BMPs have the secondary benefit of providing shade which can increase it's social value in new developments that lack mature trees.
7: Provides wind breaks	BMPs that act as wind breaks are socially beneficial because they provide a more comfortable environment for the people within the community.
8: May increase the value of nearby homes	BMPs that increase property values have a high level of social acceptance within a community.
9: Recreational value	If dry detention ponds are vegetated, they can be used as ball fields or dog parks during dry weather. This provides a social benefit to the community during the dry season and an environmental benefit during the wet season. Also, walking paths, picnic tables and native landscaping can be added to the area around wet ponds making them into parks for the community to enjoy.
10: May cause up-stream flooding	Flooding is disruptive and inconvenient, and can also be dangerous. Flooded roads and houses can leave people temporarily stranded and homeless.
11: Can look swampy	Some BMPs, depending on design and maintenance, can look 'swampy' which is a socially undesirable quality.
12: Safety concerns where there is public access	Since some BMPs hold water, there can be safety issues surrounding community access to the water body.
13: May allow mosquito breeding	Because mosquitoes can aid in the spread of human disease, some BMPs require extra precautions to ensure that they do not become mosquito breeding grounds.
14: May devalue nearby homes	BMPs that devalue nearby property have a lower level of social acceptance within a community. This can be remedied by, for example, vegetating dry ponds to be used as dog parks or ball parks during the dry season thereby contributing to the value of the community.

Figure 8. Structural Post-construction Storm Water Best Management Practice Selection Tool

Step 1: Eliminate infeasible Best Management Practices (BMPs) for a specific site by applying the site information and requirements to the 'Hard Gates.'

HARD GATES	Volume Reduction		Cold Water Stream Discharge?		Soil Type		Depth to Groundwater			Drainage Area Size (acres)				Site Slope (%)					
Best Management Practice	yes	no	yes	no	infiltration rate less than 0.5 in/hr	infiltration rate more than 0.5 in/hr	bottom of BMP intersects groundwater table	4 to 9 ft. separation	sufficient separation to make sure the BMP never intersects the groundwater table	less than 5	5 to 10	10 to 25	25 or more	0	1 to 3	4 to 5	6	7 to 15	16+
Infiltration Basin	■	□	■	■	□	■	□	■	■	■	■	□	□	■	■	■	■	■	□
Grassed Channel	■	□	■	■	□	■	□	■	■	■	□	□	□	■	■	□	□	□	□
Infiltration Trench	■	□	■	■	□	■	□	■	■	■	□	□	□	■	■	■	■	■	□
Porous Pavement	■	□	■	■	□	■	□	■	■	■	■	■	■	■	■	□	□	□	□
Vegetated Filter Strip	■	□	■	■	□	■	□	■	■	■	□	□	□	□	■	■	■	□	□
On-Lot Treatment	■	□	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Dry Swale	■	□	■	■	■	■	□	■	■	■	□	□	□	■	■	□	□	□	□
Bioretention	■	□	■	■	■	■	□	□	■	■	□	□	□	■	■	■	□	□	□
Dry Detention Ponds	■	□	□	■	■	■	□	□	■	□	□	■	■	■	■	■	■	■	□
Wet Swale	□	■	■	■	□	■	■	□	□	■	□	□	□	■	■	□	□	□	□
Sand and Organic Filters	□	■	■	■	■	■	□	■	■	■	■	□	□	■	■	■	■	□	□
Alum Injection	□	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Catch Basin Inserts	□	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Manufactured Products	□	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
In-Line Storage	□	■	■	■	■	■	■	■	■	■	■	■	□	□	■	□	□	□	□
Wet Ponds	□	■	□	■	■	■	■	■	■	□	□	□	■	■	■	■	■	■	□
Storm Water Wetlands	□	■	□	■	■	■	■	■	■	□	□	□	■	■	■	■	■	■	□

Step 2: Evaluate the remaining BMP options using the 'Soft Gate' criteria after considering the land uses of this site and the pollutants of concern that will need to be treated.

SOFT GATES	Pollutant Load Reduction (% Removal)						Cost			Environmental Impacts	Social Acceptance
Best Management Practices	Total Suspended Solids	Total Phosphorus	Total Nitrogen	Nitrate as Nitrogen	Metals	Bacteria	Construction	Annual Maintenance	Additional Costs/Value		
On-Lot Treatment	N/A	N/A	N/A	N/A	N/A	N/A	$100 to $200	N/A	1,3,4,7,10,11,12	5	▨
Bioretention	90	70-83	49	15-16	43-98	90	$3 to $4 residential, $10 to $40 commercial/sq ft	typical landscaping costs	1,2,3,4,5,7,9,11,15	6	1,5,6,7,13
Porous Pavement	82-95	65	80-85	▨	98-99	▨	$10,105 for a one acre watershed	$3,960 for 1 acre watershed	1,7,16,20,22	1	4
Alum Injection	95-99	37-95	52-70	▨	41-90	99	$135,000 to $400,000	$6,500 to $25,000	18,25	13,14,15,16	▨
Dry Swale	77-99	8-99	67-99	45-99	37-99	-33	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,4,7,9,15	1,2	1,3,13
Infiltration Trench	75	▨	▨	▨	85-90	90	$5/cubic ft treated	5 - 20 % of the const. cost	4,5,6,20	1,2,4,11	3
Infiltration Basin	75	▨	▨	▨	85-90	90	$2/cubic ft of storage	5 -10% of the const. cost	5,6,20	1,2,3,4,11	3
Storm Water Wetlands	83	43	26	73	36	76	$57,100 for a one acre ft facility	3 to 5% of const. cost	2,13,14,19	2,6,12	1,2,3,8,11,12,13
Sand and Organic Filters	65-89	40-85	17-47	-76	25-90	55-65	$5/cubic ft treated	$2,000 to $4,000 every 2 -10 years	10,16	10	▨
Wet Swale	67-81	17-39	40	9-52	-35 - 69	▨	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,2,3,4,7,9	2	1,3,13
Grassed Channel	67-83	4-29	▨	-25-31	2-73	-100 - -25	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,2,4,7,9,15,20	1,2	1,3,13
Vegetated Filter Strip	54-84	-25-40	15	-27-20	-16-88	▨	$0.30 to $0.70/sq ft	$350/acre/year	2,4,9,15	1	1,4
Catch Basin Inserts	32-97	▨	▨	▨	3-15	▨	$2,000 - $3,000 per inlet	$125,000 to 150,000 for a vactor truck	16,17,18,23,24	7,8,9	▨
Wet Ponds	32-99	12-91	-12-85	-85-97	-51-90	46-91	$45,700 for a one acre-ft facility	3 to 5 % of const. costs	2,3,8,13,14,19	2,5,6	1,3,8,9,12,13
Dry Detention Ponds	61	19	31	9	26-54	▨	$41,600 for a one acre-ft pond	3 to 5% of const. cost	5,6,14,15,19,21	1,2	3,9,14
Manufactured Products	21-51	17	▨	▨	17-51	▨	$5,000 to $35,000 or $5,000 to $10,000 per impervious acre	$125,000 to 150,000 for a vactor truck	16,17,18,23,24,25	8,9	13
In-Line Storage	0	0	0	0	0	0	low	low	12,16		10

key:

84 - 100%
67 - 83%
50 - 66%
33 - 49%
16 - 32%
0 - 15%

▨	Data not available
N/A	Not Applicable

$0 - $50,000	$0 - $10,000	favourable	favourable	favourable
$50,000 - $100,000	$10,000 - $20,000			
$100,000 - $150,000	$20,000 - $30,000			
$150,000 - $200,000	$30,000 - $40,000			
$200,000 - $250,000	$40,000 - $50,000			
$250,000 - $300,000	$50,000 - $60,000	least favourable	least favourable	least favourable

Additional Costs/Value:

1: Less expensive than, or reduces the cost of, a traditional design concrete sewer system
2: Aesthetic value
3: Captured water may be used for irrigation reducing water use and utility costs
4: Can fit into small otherwise unusable portions of a site
5: Recharges groundwater
6: Maintains flows in streams
7: May reduce the need for land intensive BMPs
8: Recreational value
9: Replaces an area that would have been landscaped
10: More flexibility in design sizing compared to other manufactured BMPs
11: Maintained by homeowner/reduces public maintenance costs
12: Requires little maintenance
13: May increase property values by 10 to 25%
14: Long life time (more than 20 years)
15: Maintenance overlaps with landscaping maintenance
16: Consumes no surface space
17: Truck maintenance and fuel
18: Staff costs to operate the BMP equipment
19: Requires a large land area
20: Particularly susceptible to failure if not maintained
21: Can detract from the value of adjacent homes by 3 to 10%
22: Requires a vacuum sweeper for maintenance
23: Requires a vactor truck for maintenance
24: Material disposal costs
25: Requires frequent maintenance

Environmental Impacts:

1: Provides groundwater recharge
2: Provides channel protection
3: Maintains flows in streams
4: 100% load reduction to surface waters
5: Conserves water, may be used for irrigation
6: Provides habitat
7: Provides spill control
8: Can become a source of pollutants through resuspension
9: Concentration of pollutants in sediments may have to be disposed of as hazardous waste
10: Sorbent pillows may have to be disposed of as hazardous waste
11: Potential for groundwater contamination
12: May release nutrients during the non-growing season
13: Settled floc contains high concentrations of dissolved chemicals, bacteria and viruses and must be disposed of properly
14: Requires electricity to operate pumps that dispose of floc to sludge drying beds or sanitary sewer (with permit).
15: Experimental practice, little is known about long term impacts.
16: Chemicals added during the process may have negative impacts on down stream waters.

Social Acceptance:

1: Provides aesthetic value
2: Educational value
3: Provides flood control
4: Unobtrusive, high level of acceptance by the public
5: Provides noise reduction
6: Provides shade
7: Provides wind breaks
8: May increase the value of nearby homes
9: Recreational value
10: May cause up stream flooding
11: Can look swampy
12: Safety concerns where there is public access
13: May allow mosquito breeding
14: May devalue nearby homes

Step 3: To narrow the remaining BMP options consider:

Design considerations:
- Climate of the project location
- Incorporates input of those affected

Construction considerations:
- Materials are locally sourced
- Transport distance is minimised (materials and labour)
- Renewable resources utilised in place of non-renewable resources

Operation considerations:
- Flooding impact on downstream communities eliminated

Disposal considerations:
- Materials used are recyclable or reusable
- Maintenance wastes are recyclable or compostable

The material and energy use during the construction, operation, and disposal of the BMP should be minimised.

If the use of one BMP will not meet the needs of a unique or diverse site, two or more BMPs can be used in parallel or in series to accomplish volume reduction or treatment goals. Large sites may be divided into multiple small drainage areas to utilise BMPs that best serve smaller areas.

(Sources: USEPA, 2006; CASQA, 2003; SMRC, 2006) Data last verified August 2006.

to consider when selecting the most appropriate BMP by making the information necessary for the decision process available in an easily comparable format.

Step 1 uses the ‘hard gates’ to eliminate infeasible BMPs for a specific site early in the decision making process. *Step 2* evaluates the remaining BMPs based on the pollutants likely to be found in the runoff that the BMP will process, but also considers costs, environmental impacts and the social aspects of each BMP option. There are some aspects of the decision making process that are site specific. These factors are addressed in *Step 3* where the decision maker compares site specific considerations for each remaining BMP option in order to select the most appropriate BMP for that specific location.

Methods such as mechanistic screening tools are not appropriate for evaluating data that is used to inform the sustainability of a decision. Ultimately decision makers must use human judgement to make the final selection of the most sustainable option. This requires the decision maker to make a choice based on experience, values, perception and intuition. The selection tool helps to overcome a number of cognitive limitations of the human decision maker by reducing the data to a manageable scale (SWARD, 2002).

The BMP selection process can be done quickly for small, isolated projects but may take more time for larger projects with more stakeholders. Either way, the proposed selection tool attempts to provide a common framework for discussing BMP selection, so that all of the concerns of all of the parties involved are considered, and the best possible solution can be found as quickly as possible.

IV. Application

In order to test the proposed selection tool’s application, two case studies were selected. Both projects have already been built and so the site data as well as the BMPs selected are known. The site information for each case was applied to the selection tool to see if the same BMPs would be selected using the tool as were selected by the decision makers for each project, and to discover whether or not the tool could be used to achieve the goal of aiding in the selection of appropriate BMPs while encouraging innovation.

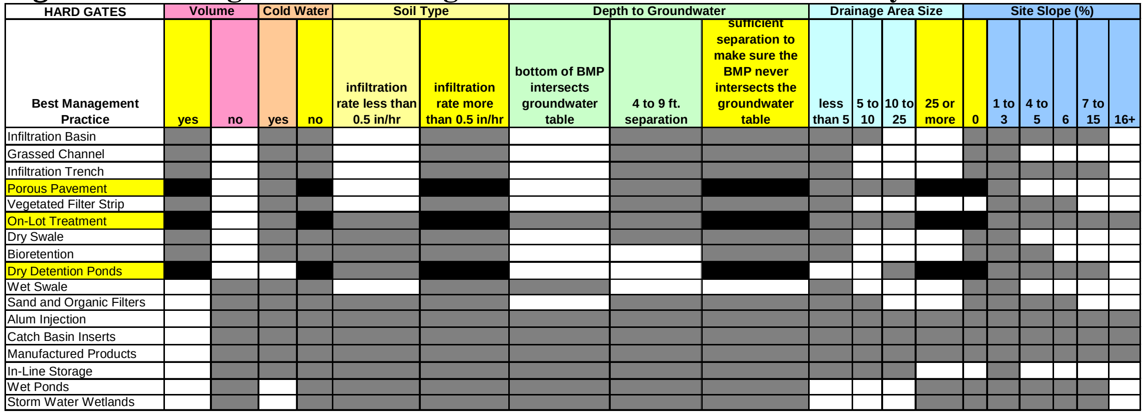
Palmdale Case Study

The first case study is a single family home development located in Palmdale, California. The site is 52.4 acres with an average slope of 0.5%. The soils percolate at a rate of 42 gallons/ft^2/day and the depth to groundwater is unknown, probably because it is deeper then equipment can detect as the site was a vacant desert before development.

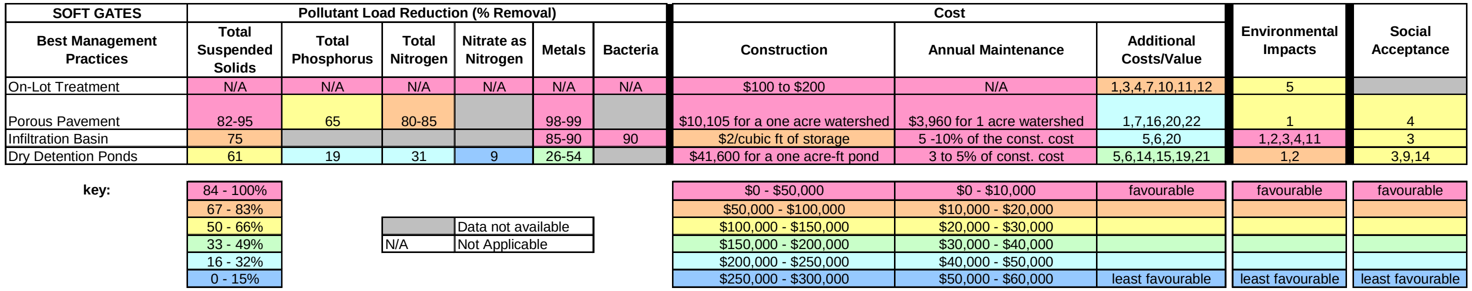
Applying this information to the ‘hard gates,’ three BMP options remain; porous pavement, on-lot treatment, and dry detention ponds (Figure 9). However, an infiltration basin is the BMP that was implemented at the site. Ordinarily, an infiltration basin would not be used for a site that is over 10 acres because the size of the basin needed to capture and retain the runoff it receives until it can percolate would be quite large and land intensive. BMPs that require a large land area can be expensive if real estate prices are high. However, an infiltration basin could have been selected because the percolation rate is so high that land area needed for an infiltration basin and a dry detention pond are equal. Additionally, if there is no nearby storm sewer system or surface water body into which the BMP could discharge, an infiltration basin could have been selected because it is a terminal BMP with no discharge point. When the four BMPs are compared in the ‘soft gates,’ an infiltration basin is a more favourable option than the dry detention pond because it has better pollutant load reduction capabilities and fewer environmental impacts, however, it is more susceptible to failure if not maintained.

In this case, the BMP options narrowed by the selection tool and the BMP implemented are quite similar. The only difference between the two in the ‘hard gates’ is the drainage area size. The details of the selection process used by the decision makers for the Palmdale case is not known, however, this case demonstrates that human input in the decision process is important. The unique soils of this site allow for a considerable level of percolation and make the use of an infiltration basin comparable to the use of a dry detention pond, in this case.

Figure 9. 'Hard gates' and 'soft gates' for the Palmdale case study.



HARD GATES	Volume		Cold Water		Soil Type		Depth to Groundwater			Drainage Area Size				Site Slope (%)					
Best Management Practice	yes	no	yes	no	infiltration rate less than 0.5 in/hr	infiltration rate more than 0.5 in/hr	bottom of BMP intersects groundwater table	4 to 9 ft. separation	sufficient separation to make sure the BMP never intersects the groundwater table	less than 5	5 to 10	10 to 25	25 or more	0	1 to 3	4 to 5	6	7 to 15	16+
Infiltration Basin	▨		▨	▨		▨		▨	▨	▨	▨			▨	▨	▨	▨	▨	
Grassed Channel	▨		▨	▨		▨		▨	▨	▨				▨	▨				
Infiltration Trench	▨		▨	▨		▨		▨	▨	▨				▨	▨	▨	▨	▨	
Porous Pavement	■		▨	■		■		▨	■	▨	▨	▨	■	■	▨				
Vegetated Filter Strip	▨		▨	▨		▨		▨	▨	▨					▨	▨	▨		
On-Lot Treatment	■		▨	■	▨	■	▨	▨	■	▨	▨	▨	■	■	▨	▨	▨	▨	▨
Dry Swale	▨		▨	▨	▨	▨		▨	▨	▨				▨	▨				
Bioretention	▨		▨	▨	▨	▨			▨	▨				▨	▨	▨			
Dry Detention Ponds	■			■	▨	■			■			▨	■	■	▨	▨	▨	▨	
Wet Swale		▨	▨	▨		▨	▨			▨				▨	▨				
Sand and Organic Filters		▨	▨	▨	▨	▨		▨	▨	▨	▨			▨	▨	▨	▨		
Alum Injection		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Catch Basin Inserts		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Manufactured Products		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
In-Line Storage		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨				
Wet Ponds		▨		▨	▨	▨	▨	▨	▨				▨	▨	▨	▨	▨	▨	
Storm Water Wetlands		▨		▨	▨	▨	▨	▨	▨				▨	▨	▨	▨	▨	▨	



SOFT GATES	Pollutant Load Reduction (% Removal)						Cost			Environmental Impacts	Social Acceptance
Best Management Practices	Total Suspended Solids	Total Phosphorus	Total Nitrogen	Nitrate as Nitrogen	Metals	Bacteria	Construction	Annual Maintenance	Additional Costs/Value		
On-Lot Treatment	N/A	N/A	N/A	N/A	N/A	N/A	$100 to $200	N/A	1,3,4,7,10,11,12	5	▨
Porous Pavement	82-95	65	80-85	▨	98-99	▨	$10,105 for a one acre watershed	$3,960 for 1 acre watershed	1,7,16,20,22	1	4
Infiltration Basin	75	▨	▨	▨	85-90	90	$2/cubic ft of storage	5 -10% of the const. cost	5,6,20	1,2,3,4,11	3
Dry Detention Ponds	61	19	31	9	26-54	▨	$41,600 for a one acre-ft pond	3 to 5% of const. cost	5,6,14,15,19,21	1,2	3,9,14

key:

	Construction	Annual Maintenance	Additional Costs/Value	Environmental Impacts	Social Acceptance
84 - 100%	$0 - $50,000	$0 - $10,000	favourable	favourable	favourable
67 - 83%	$50,000 - $100,000	$10,000 - $20,000			
50 - 66%	$100,000 - $150,000	$20,000 - $30,000			
33 - 49%	$150,000 - $200,000	$30,000 - $40,000			
16 - 32%	$200,000 - $250,000	$40,000 - $50,000			
0 - 15%	$250,000 - $300,000	$50,000 - $60,000	least favourable	least favourable	least favourable

▨	Data not available
N/A	Not Applicable

Additional Costs/Value:

1: Less expensive than, or reduces the cost of, a traditional design concrete sewer system
3: Captured water may be used for irrigation reducing water use and utility costs
4: Can fit into small otherwise unusable portions of a site
5: Recharges groundwater
6: Maintains flows in streams
7: May reduce the need for land intensive BMPs
10: More flexibility in design sizing compared to other manufactured BMPs
11: Maintained by homeowner/reduces public maintenance costs
12: Requires little maintenance
14: Long life time (more than 20 years)
15: Maintenance overlaps with landscaping maintenance
16: Consumes no surface space
19: Requires a large land area
20: Particularly susceptible to failure if not maintained
21: Can detract from the value of adjacent homes by 3 to 10%
22: Requires a vacuum sweeper for maintenance

Environmental Impacts:

1: Provides groundwater recharge
2: Provides channel protection
3: Maintains flows in streams
4: 100% load reduction to surface waters
5: Conserves water, may be used for irrigation
11: Potential for groundwater contamination

Social Acceptance:

3: Provides flood control
4: Unobtrusive, high level of acceptance by the public
9: Recreational value
14: May devalue nearby homes

Lompoc Case Study

The second case study is a single family home development in Lompoc, California. The 30.5 acre site has an average slope of 1% and an unknown depth to groundwater. The site was previously used for agriculture and has moderate infiltration rate (more than 0.5 in/hr).

Using the 'hard gates,' the BMPs that fit the site criteria are porous pavement, on-lot treatment, and dry detention ponds (Figure 10). However, the BMPs that have been implemented at the site are grassed channels that discharge to storm water wetlands. This case is an example of breaking a large site into smaller drainage areas, and combining volume reduction BMPs with treatment BMPs, both of which increase the number of possible BMP choices. Storm water wetlands fit all of the site criteria but do not provide any volume reduction, which is required by California law (Chapter 1).

Grassed channels provide volume reduction and fit all of the site criteria except for site size. The site is 30.5 acres and grassed channels can only handle drainage from less than five acres. However, if the site is broken into more than six drainage areas, each smaller then five acres, grassed channels can be used to convey the storm water to the wetland which functions best when treating 25 acres or more. Combining both the grassed channels and storm water wetlands satisfies the 'hard gates' criteria.

A comparison of the 'soft gates' criteria (Figure 10) reveals that storm water wetlands and grassed channels are better at removing suspended solids than dry detention ponds. Storm water wetlands are more expensive to construct than dry detention ponds. However, the volume reduction provided by the grassed channels reduces the quantity of water discharged to the wetland, reducing the size of the wetland that is needed, which means the cost of the wetland is minimised.

The grassed channels may have been chosen because they serve as a conveyance method as well as a BMP, reducing or eliminating the need for an underground storm sewer system. This savings reduces the cost of the project, allowing funds to be spent on storm water wetlands which increases property value. For these reasons, grassed channels and storm water wetlands are an economical choice for a housing

Figure 10. ‘Hard gates’ and ‘soft gates’ for the Lompoc case study.

HARD GATES	Volume		Cold Water		Soil Type		Depth to Groundwater			Drainage Area Size				Site Slope (%)					
Best Management Practice	yes	no	yes	no	infiltration rate less than 0.5 in/hr	infiltration rate more than 0.5 in/hr	bottom of BMP intersects groundwater table	4 to 9 ft. separation	sufficient separation to make sure the BMP never intersects the groundwater table	less than 5	5 to 10	10 to 25	25 or more	0	1 to 3	4 to 5	6	7 to 15	16+
Infiltration Basin	▨		▨	▨		▨		▨	▨	▨	▨			▨	▨	▨	▨	▨	
Grassed Channel	▨		▨	▨		▨		▨	▨	▨				▨	▨				
Infiltration Trench	▨		▨	▨		▨		▨	▨	▨				▨	▨	▨	▨	▨	
Porous Pavement	■		▨	■		■		▨	■	▨	▨	▨	■	■	▨				
Vegetated Filter Strip	▨		▨	▨		▨		▨	▨	▨					▨	▨	▨		
On-Lot Treatment	■		▨	■	▨	■	▨	▨	■	▨	▨	▨	■	■	▨	▨	▨	▨	▨
Dry Swale	▨		▨	▨	▨	▨		▨	▨	▨				▨	▨				
Bioretention	▨		▨	▨	▨	▨			▨	▨				▨	▨	▨			
Dry Detention Ponds	■			■	▨	■			■			▨	■	■	▨	▨	▨	▨	
Wet Swale		▨	▨	▨		▨	▨			▨				▨	▨				
Sand and Organic Filters		▨	▨	▨	▨	▨		▨	▨	▨	▨			▨	▨	▨	▨		
Alum Injection		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Catch Basin Inserts		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Manufactured Products		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
In-Line Storage		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨				
Wet Ponds		▨		▨	▨	▨	▨	▨	▨				▨	▨	▨	▨	▨	▨	
Storm Water Wetlands		▨		▨	▨	▨	▨	▨	▨				▨	▨	▨	▨	▨	▨	

SOFT GATES	Pollutant Load Reduction (% Removal)						Cost			Environmental Impacts	Social Acceptance
Best Management Practices	Total Suspended Solids	Total Phosphorus	Total Nitrogen	Nitrate as Nitrogen	Metals	Bacteria	Construction	Annual Maintenance	Additional Costs/Value		
On-Lot Treatment	N/A	N/A	N/A	N/A	N/A	N/A	$100 to $200	N/A	1,3,4,7,10,11,12	5	▨
Porous Pavement	82-95	65	80-85	▨	98-99	▨	$10,105 for a one acre watershed	$3,960 for 1 acre watershed	1,7,16,20,22	1	4
Storm Water Wetlands	83	43	26	73	36	76	$57,100 for a one acre ft facility	3 to 5% of const. cost	2,13,14,19	2,6,12	1,2,3,8,11,12,13
Grassed Channel	67-83	4-29	▨	-25-31	2-73	-100 - -25	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,2,4,7,9,15,20	1,2	1,3,13
Dry Detention Ponds	61	19	31	9	26-54	▨	$41,600 for a one acre-ft pond	3 to 5% of const. cost	5,6,14,15,19,21	1,2	3,9,14

key:						
	84 - 100%	$0 - $50,000	$0 - $10,000	favourable	favourable	favourable
	67 - 83%	$50,000 - $100,000	$10,000 - $20,000			
	50 - 66%	$100,000 - $150,000	$20,000 - $30,000			
	33 - 49%	$150,000 - $200,000	$30,000 - $40,000			
	16 - 32%	$200,000 - $250,000	$40,000 - $50,000			
	0 - 15%	$250,000 - $300,000	$50,000 - $60,000	least favourable	least favourable	least favourable

▨	Data not available
N/A	Not Applicable

Additional Costs/Value:
1: Less expensive than, or reduces the cost of, a traditional design concrete sewer system
3: Captured water may be used for irrigation reducing water use and utility costs
4: Can fit into small otherwise unusable portions of a site
5: Recharges groundwater
6: Maintains flows in streams
7: May reduce the need for land intensive BMPs
10: More flexibility in design sizing compared to other manufactured BMPs
11: Maintained by homeowner/reduces public maintenance costs
12: Requires little maintenance
14: Long life time (more than 20 years)
15: Maintenance overlaps with landscaping maintenance
16: Consumes no surface space
19: Requires a large land area
20: Particularly susceptible to failure if not maintained
21: Can detract from the value of adjacent homes by 3 to 10%
22: Requires a vacuum sweeper for maintenance

Environmental Impacts:
1: Provides groundwater recharge
2: Provides channel protection
3: Maintains flows in streams
4: 100% load reduction to surface waters
5: Conserves water, may be used for irrigation
11: Potential for groundwater contamination

Social Acceptance:
3: Provides flood control
4: Unobtrusive, high level of acceptance by the public
9: Recreational value
14: May devalue nearby homes

development since the developer is interested in selling the homes at the highest value.

Interestingly, if all of the volume reduction BMPs are compared (Figure 11), there are some other BMPs such as bioretention and on-lot treatment that would be beneficial for residential developers to implement. Both bioretention and on-lot treatment BMPs provide significant volume reduction as well as treatment capabilities and cost very little to construct and almost nothing to maintain. Economically, environmentally, and socially, the incentives out number the disincentives. By implementing these BMPs, the size of the other large BMPs, such as storm water wetlands or dry detention ponds, can be minimized. This reduces the construction and maintenance costs and frees up space for more homes to be built, which provides more income to the developer.

Figure 11. A comparison of the ‘soft gates’ for volume reducing BMPs.

SOFT GATES	Pollutant Load Reduction (% Removal)						Cost			Environmental Impacts	Social Acceptance
Best Management Practices	Total Suspended Solids	Total Phosphorus	Total Nitrogen	Nitrate as Nitrogen	Metals	Bacteria	Construction	Annual Maintenance	Additional Costs/Value		
On-Lot Treatment	N/A	N/A	N/A	N/A	N/A	N/A	$100 to $200	N/A	1,3,4,7,10,11,12	5	▨
Bioretention	90	70-83	49	15-16	43-98	90	$3 to $4 residential, $10 to $40 commercial/sq ft	typical landscaping costs	1,2,3,4,5,7,9,11,15	6	1,5,6,7,13
Porous Pavement	82-95	65	80-85	▨	98-99	▨	$10,105 for a one acre watershed	$3,960 for 1 acre watershed	1,7,16,20,22	1	4
Dry Swale	77-99	8-99	67-99	45-99	37-99	-33	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,4,7,9,15	1,2	1,3,13
Infiltration Trench	75	▨	▨	▨	85-90	90	$5/cubic ft treated	5 - 20 % of the const. cost	4,5,6,20	1,2,4,11	3
Infiltration Basin	75	▨	▨	▨	85-90	90	$2/cubic ft of storage	5 -10% of the const. cost	5,6,20	1,2,3,4,11	3
Grassed Channel	67-83	4-29	▨	-25-31	2-73	-100 - -25	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,2,4,7,9,15,20	1,2	1,3,13
Vegetated Filter Strip	54-84	-25-40	15	-27-20	-16-88	▨	$0.30 to $0.70/sq ft	$350/acre/year	2,4,9,15	1	1,4
Dry Detention Ponds	61	19	31	9	26-54	▨	$41,600 for a one acre-ft pond	3 to 5% of const. cost	5,6,14,15,19,21	1,2	3,9,14

key:

84 - 100%
67 - 83%
50 - 66%
33 - 49%
16 - 32%
0 - 15%

▨	Data not available
N/A	Not Applicable

$0 - $50,000	$0 - $10,000	favourable	favourable	favourable
$50,000 - $100,000	$10,000 - $20,000			
$100,000 - $150,000	$20,000 - $30,000			
$150,000 - $200,000	$30,000 - $40,000			
$200,000 - $250,000	$40,000 - $50,000			
$250,000 - $300,000	$50,000 - $60,000	least favourable	least favourable	least favourable

Additional Costs/Value:

1: Less expensive than, or reduces the cost of, a traditional design concrete sewer system
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Social Acceptance:

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4: Unobtrusive, high level of acceptance by the public
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14: May devalue nearby homes

Chapter 4. Conclusion

I. The Vision

The impact that urban development is having on the environment is unacceptable. Around the world, policies are being put into place in an attempt to reverse the urban runoff pollution problem. There are many potential solutions to this challenge. It is important that the most appropriate solution is utilized. Otherwise, the urban pollution problem will merely be traded for another problem, seen or unforeseen.

If sustainable development has three pillars: environmental protection, social development, and economic development (United Nations, 2002); then sustainable engineering has four. The fourth pillar of sustainable engineering is technical performance. Without the ability to accomplish the technical performance goals of pollutant removal and volume reduction, a storm water management practice, or suite of practices, should not be considered for implementation. Likewise, storm water management practices that have unacceptable environmental, social, or economic impacts should not be implemented. There are enough options available that an appropriate management practice, or set of practices, can be found for any situation. The difficult part of the selection process is ensuring that all of the applicable factors have been considered.

The 4 pillars of sustainable engineering:

- environmental protection
- social development
- economic development
- technical performance

There can be many parties involved in the BMP selection process. Property owners, local government, governmental agencies, consulting firms, special interest groups, and the public can, at times, be interested in the decision making process and/or its outcome.

A selection tool can aid in the decision making process by providing basic information about a wide variety of BMP options covering the main categories of consideration. Having a common tool to refer to, gives a starting point for dialogue among the parties involved. The use of the selection tool can also provide consistency and transparency to the stakeholder process.

Because the selection tool provides all of the data for the decision maker to view at once, it can make the selection process an educational experience as well. BMPs can be compared on many levels and combinations or innovations can be created to meet the needs of varying sites and regions.

The data in the selection tool will eventually become outdated. As new BMPs become widely accepted or other disappear from use or current BMPs are perfected the ‘hard gates’ and soft gates’ will need to be modified with new performance data. The selection tool can also be modified to be specific to a particular climate or region if there is sufficient data for that area. Fortunately, the format of the selection tool allows for easy modification by merely replacing the data in one or more cells of the table with more accurate information. Modification of the ‘hard or soft gates’ will not change the process or the way in which the selection tool is used.

II. Factors Affecting Implementation

It is now well accepted that the traditional approaches to urban water management contribute to the degradation of waterways, facilitate the wastage of a valuable water resource and no longer reflect the environmental values of society (Brown, R.R., *et al.*, 2005). Brown (2005) believes impediments to the widespread implementation of sustainable drainage practices include:

- Undefined organizational responsibilities
- Limited political incentives and disincentives
- Poor organisational commitment
- Technological path dependency
- Poor community capacity to meaningfully participate
- Lack of experiential knowledge with facilitating integrated management approaches

Often, it is not clear who is responsible for the successful implementation of sustainable drainage measures. The fact that political terms of office are short, limits the incentive to work on solving problems with long term solutions. A lack of commitment on the part of stakeholders can hinder the process for implementing sustainable drainage systems. Relying too heavily on a technological solution can hinder the advancement of social change. New and better BMPs can only solve the pollution problem for so long. Eventually, behaviour must be changed in order to reduce the sources of urban pollution. Some communities lack the ability to participate in the BMP selection process either because they have not been provided with enough information to understand the process or because they do not have the time to participate in the process. Frequently, sustainable drainage systems are not implemented simply because the concept of considering the technical, environmental, social, and economic aspects of a solution to a problem is new to the parties involved.

Governance systems need to support good decision making by being adaptable and flexible. Too often these are constrained so that the more sustainable option is precluded even from the outset (Starkl, M.,& Brunner, N., 2004).

The highest priority is improving the capacity of local government. Of all of the levels of government, local government has the weakest institutional capacity, yet is the most important sector for enabling on the ground change toward sustainability (Peltenburg, M., *et al.*, 2000; Wakely, P., 1997; UNDP, 1998). Institutional and governance systems need to support good decision making by being adaptable and flexible. Too often these are constrained so that the more sustainable option is precluded even from the outset (Starkl, M., & Brunner, N., 2004).

Not until a change has been made in the group of social processes, will something actually change on a large scale in the group of physical, chemical and biological processes (Geldof, G.D., 2005).

III. Further Work

The work surrounding urban storm water management is only just beginning. There is still more advancement in education and stakeholder involvement and BMP design that can be made. The removal rates by certain BMPs for particular urban pollutants have not been analysed to the extent in which they can be published with confidence.

Proposed Selection Tool

However, there are three things that can been done to further improve the proposed selection tool. First, the tool should be used for the BMP selection process of two or more sites with different stakeholders to evaluate:

- The usefulness of the tool; does it achieve the goal of aiding in the selection of the most appropriate BMP by providing information and opportunity for innovation?
- The practicality of the tool; does it make sense to all parties involved, can all parties involved use and understand the tool?
- The areas of improvement; can the tool be modified in some way to maintain it's original purpose but improve its functionality?

Secondly, stakeholders should be interviewed to discover their perspectives on the above questions as well as how and where the tool should be made available. By putting it on the Internet, everyone can have access and updates to the data can be known by all parties right away. A web based version of the tool could also have links to guidance documents such as the U.S. EPA's menu of BMPs (USEPA, 2006), the *California Stormwater Best Management Practice New Development and Redevelopment Handbook* (CASQA, 2003) for more information about each BMP.

3 things can be done to improve the tool:
1. Use it and evaluate it's practicality
2. Interview stakeholders to gather ideas for improvement
3. Inspect sites to build local knowledge

Finally, regulators do not inspect and/or monitor structural post-construction storm water BMPs during storm events as frequently as they monitor structural construction storm water BMPs during the wet season. As a result, there is much more local knowledge about which construction BMPs work well and which require special implementation techniques for a certain region with specific soil types and rain fall intensities. Regulators, as well as design engineers and other stakeholders, need to build their knowledge base concerning how well BMPs function in their region long after implementation. Understanding which BMPs work best and why, can lead to innovation or modification of other BMPs to function even better in a given location.

Additional Application

Because the selection tool can be easily modified to incorporate local or region specific data, the proposed selection tool could potentially be used in any part of the world. The BMP terminology and specific data could be tailored to the area to make it applicable and meaningful to the parties involved in that region.

The proposed tool may also be beneficial in other fields of application. Other industries that use best management practices, such as the construction industry or the agricultural industries, may benefit from a selection tool that helps decision makers consider all of the necessary factors and provides information and opportunities for innovation. It is possible that the tool could be modified for the purposed of being used in those fields.

Analytical tools do not remove the need for human judgement on issues such as risk and uncertainty and on the influence of intangible issues (those that defy monetary assessment) on the final decision (SWARD, 2002). However, in any field with large numbers of BMPs to choose from and large numbers of factors to consider, a selection tool will, ideally, ensure that all aspects of BMP selection are considered, not just the technical performance of the BMP. Hopefully this selection tool will provide a common tool for stakeholders to use in their discussion about the selection of the most appropriate BMP.

Appendix 1. References for data used to create the ‘hard gates.’

<table>
<tr><th>HARD GATES</th><th colspan="2">Volume</th><th colspan="2">Cold Water</th><th colspan="2">Soil Type</th><th colspan="3">Depth to Groundwater</th><th colspan="4">Drainage Area Size</th><th colspan="6">Site Slope (%)</th></tr>
<tr><th>Best Management Practice</th><th>yes</th><th>no</th><th>yes</th><th>no</th><th>infiltration rate less than 0.5 in/hr</th><th>infiltration rate more than 0.5 in/hr</th><th>bottom of BMP intersects groundwater table</th><th>4 to 9 ft. separation</th><th>sufficient separation to make sure the BMP never intersects the groundwater table</th><th>less than 5</th><th>5 to 10</th><th>10 to 25</th><th>25 or more</th><th>0</th><th>1 to 3</th><th>4 to 5</th><th>6</th><th>7 to 15</th><th>16+</th></tr>
<tr><td>Infiltration Basin</td><td>1,2</td><td></td><td colspan="2">1</td><td></td><td>1,2</td><td></td><td colspan="2">1</td><td colspan="2">1</td><td></td><td></td><td colspan="5">2</td><td></td></tr>
<tr><td>Grassed Channel</td><td>2</td><td></td><td colspan="2">1</td><td></td><td>1</td><td></td><td colspan="2">1</td><td>1</td><td></td><td></td><td></td><td colspan="2">1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Infiltration Trench</td><td>2</td><td></td><td colspan="2">1</td><td></td><td>1,2</td><td></td><td colspan="2">1</td><td>1,2</td><td></td><td></td><td></td><td colspan="5">1</td><td></td></tr>
<tr><td>Porous Pavement</td><td>2</td><td></td><td colspan="2">1</td><td></td><td>1</td><td></td><td colspan="2">1,2</td><td colspan="4">1</td><td colspan="2">1,2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Vegetated Filter Strip</td><td>1</td><td></td><td colspan="2">1</td><td></td><td>1</td><td></td><td colspan="2">1</td><td>1,2</td><td></td><td></td><td></td><td></td><td colspan="3">1</td><td></td><td></td></tr>
<tr><td>On-Lot Treatment</td><td>1</td><td></td><td colspan="2">1</td><td colspan="2">1</td><td colspan="3">1</td><td colspan="4">1</td><td colspan="6">1</td></tr>
<tr><td>Dry Swale</td><td>1</td><td></td><td colspan="2">1</td><td colspan="2">1</td><td></td><td colspan="2">1</td><td>1</td><td></td><td></td><td></td><td colspan="2">1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bioretention</td><td>1</td><td></td><td colspan="2">1</td><td colspan="2">1</td><td></td><td></td><td>1,2</td><td>1</td><td></td><td></td><td></td><td colspan="3">1</td><td></td><td></td><td></td></tr>
<tr><td>Dry Detention Ponds</td><td>2</td><td></td><td></td><td>1</td><td colspan="2">1</td><td></td><td></td><td>1</td><td></td><td></td><td colspan="2">1,2</td><td colspan="5">1</td><td></td></tr>
<tr><td>Wet Swale</td><td></td><td>1,3</td><td colspan="2">1</td><td></td><td>1</td><td>1</td><td></td><td></td><td>1</td><td></td><td></td><td></td><td colspan="2">1</td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Alum Injection</td><td></td><td>1</td><td colspan="2">1</td><td colspan="2">1</td><td colspan="3">1</td><td colspan="4">1</td><td colspan="6">1</td></tr>
<tr><td>Catch Basin Inserts</td><td></td><td>1</td><td colspan="2">1</td><td colspan="2">1</td><td colspan="3">1</td><td colspan="4">1</td><td colspan="6">1</td></tr>
<tr><td>Manufactured Products</td><td></td><td>2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="3">2</td><td colspan="4">2</td><td colspan="6">2</td></tr>
<tr><td>In-Line Storage</td><td></td><td>1</td><td colspan="2">1</td><td colspan="2">1</td><td colspan="3">1</td><td colspan="3">1</td><td></td><td></td><td>1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Wet Ponds</td><td></td><td>3</td><td></td><td>1</td><td colspan="2">1</td><td colspan="3">1</td><td></td><td></td><td></td><td>1,2</td><td colspan="5">1</td><td></td></tr>
<tr><td>Storm Water Wetlands</td><td></td><td>3</td><td></td><td>1</td><td colspan="2">1</td><td colspan="3">1</td><td></td><td></td><td></td><td>1</td><td colspan="5">1</td><td></td></tr>
</table>

reference key:
1 = (USEPA, 2006)
2 = (CASQA, 2003)
3 = (SMRC, 2006)

Appendix 2. References for data used to create the ‘soft gates.’

SOFT GATES	Pollutant Load Reduction (% Removal)						Cost				
Best Management Practices	**Total Suspended Solids**	**Total Phosphorus**	**Total Nitrogen**	**Nitrate as Nitrogen**	**Metals**	**Bacteria**	**Construction**	**Annual Maintenance**	**Additional Costs/Value**	**Environmental Impacts**	**Social Acceptance**
On-Lot Treatment	N/A	N/A	N/A	N/A	N/A	N/A	$100 to $200	N/A	1,3,4,7,10,11,12	5	▨
Bioretention	90	70-83	49	15-16	43-98	90	$3 to $4 residential, $10 to $40 commercial/sq ft	typical landscaping costs	1,2,3,4,5,7,9,11,15	6	1,5,6,7,13
Porous Pavement	82-95	65	80-85	▨	98-99	▨	$10,105 for a one acre watershed	$3,960 for 1 acre watershed	1,7,16,20,22	1	4
Alum Injection	95-99	37-95	52-70		41-90	99	$135,000 to $400,000	$6,500 to $25,000	18,25	13,14,15,16	▨
Dry Swale	77-99	8-99	67-99	45-99	37-99	-33	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,4,7,9,15	1,2	1,3,13
Infiltration Trench	75	▨	▨	▨	85-90	90	$5/cubic ft treated	5 - 20 % of the const. cost	4,5,6,20	1,2,4,11	3
Infiltration Basin	75	▨	▨	▨	85-90	90	$2/cubic ft of storage	5 -10% of the const. cost	5,6,20	1,2,3,4,11	3
Storm Water Wetlands	83	43	26	73	36	76	$57,100 for a one acre ft facility	3 to 5% of const. cost	2,13,14,19	2,6,12	1,2,3,8,11,12,13
Sand and Organic Filters	65-89	40-85	17-47	-76	25-90	55-65	$5/cubic ft treated	$2,000 to $4,000 every 2 -10 years	10,16	10	▨
Wet Swale	67-81	17-39	40	9-52	-35 - 69	▨	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,2,3,4,7,9	2	1,3,13
Grassed Channel	67-83	4-29	▨	-25-31	2-73	-100 - -25	$0.50 per sq ft	$0.58 to $0.75 per linear ft	1,2,4,7,9,15,20	1,2	1,3,13
Vegetated Filter Strip	54-84	-25-40	15	-27-20	-16-88	▨	$0.30 to $0.70/sq ft	$350/acre/year	2,4,9,15	1	1,4
Catch Basin Inserts	32-97	▨	▨	▨	3-15	▨	$2,000 - $3,000 per inlet	$125,000 to 150,000 for a vactor truck	16,17,18,23,24	7,8,9	▨
Wet Ponds	32-99	12-91	-12-85	-85-97	-51-90	46-91	$45,700 for a one acre-ft facility	3 to 5 % of const. costs	2,3,8,13,14,19	2,5,6	1,3,8,9,12,13
Dry Detention Ponds	61	19	31	9	26-54	▨	$41,600 for a one acre-ft pond	3 to 5% of const. cost	5,6,14,15,19,21	1,2	3,9,14
Manufactured Products	21-51	17	▨	▨	17-51	▨	$5,000 to $35,000 or $5,000 to $10,000 per impervious acre	$125,000 to 150,000 for a vactor truck	16,17,18,23,24,25	8,9	13
In-Line Storage	0	0	0	0	0	0	low	low	12,16	▨	10

reference key:
(USEPA, 2006)
(CASQA, 2003)
Both

▨ Data not available

Bibliography

Bowles, G., 2002. *Impervious Surface – an Environmental Indicator* [online]. Center for Land Use Education, University of Wisconsin, Stevens Point. Available from: http://www.uwsp.edu/cnr/landcenter/tracker/Summer2002/envirindic.html [Accessed 15 July 2006].

Brandon P.S.& Lombardi P., 2005. *Evaluating Sustainable Development in the Built Environment.* Blackwell Publishing Company.

Brown, R.R., 2005. *Facilitating local organisational development for advancing sustainable urban water futures.* 10th International Conference on Urban Drainage, Copenhagen/Denmark, 21-26 August 2005.

Brown, R.R., Sharp, L., Ashley, R.M., 2005. *Implementation impediments to institutionalising the practice of sustainable urban water management.* 10th International Conference on Urban Drainage, Copenhagen/Denmark, 21-26 August 2005.

CASQA, 2003. California Stormwater Quality Association. 2003. *California Stormwater Best Management Practice New Development and Redevelopment Handbook* [online]. Available from: http://www.cabmphandbooks.com/Development.asp [Accessed 10 May 2006]

Emmerling-Dinovo, C. 1995. Stormwater detention basins and residential locational decisions. *Water Resources Bulletin*, 31(3):515.52.

Environment Australia, 2002. *Introduction to Urban Stormwater Management in Australia.* Commonwealth of Australia, 2002.

Geldof, G.D., 2005. *Interactive implementation.* 10th International Conference on Urban Drainage, Copenhagen/Denmark, 21-26 August 2005.

Geldof, G.D. & Stahre, P., 2005. *On the road to a new stormwater planning approach: from Model A to Model B.* 10th International Conference on Urban Drainage, Copenhagen/Denmark, 21-26 August 2005.

Gibb, A., Bennet, B. & Birkbeck, A., 1991. *Urban Runoff Quality and Treatment: A Comprehensive Review*. Prepared for the Greater Vancouver Regional District, the Municipality of Surrey, British Columbia, Ministry of Transportation and Highways, and British Columbia Ministry of Advanced Education and Training. Document No. 2-51-246 (242).

Graedel, T. E., 1998. *Streamlined Life-Cycle Assessment.* New Jersey: Prentice Hall.

Jones, J.E., Guo, J., Urbonas, B., Pittinger, R., 2006. Safety at Urban Stormwater Ponds; What designers and owner should know about retention and detention ponds. *Stormwater Journal for Surface Water Quality Professionals* [online], January/February 2006. Available from: http://www.gradingandexcavation.com/sw_0601_safety.html [Accessed 5 August 2006]

Kurz, R. 1998. *Removal of Microbial Indicators from Stormwater Using Sand Filtration, Wet Detention, and Alum Treatment Best Management Practices*. Southwest Florida Water Management District, Brooksville, FL.

LIDC, 2006. Low Impact Development Center [online]. Available from: http://www.lowimpactdevelopment.org/ [Accessed 28 May 2006]

Metzger, M.E., Messer, D.F., Beitia, C.L., Hyers, C.M., Kramer, V.L., 2003. The Dark Side of Stormwater Runoff Management: Disease Vectors Associated with Structural BMPs. *Stormwater Journal for Surface Water Quality Professionals* [online], March 2003. Available from: http://www.forester.net/sw_0203_dark.html [Accessed 5 August 2006].

NRC, 2002. National Research Council, *Oil in the Sea III: Inputs, Fates, and Effects*. National Academy Press, Washington D.C.

Peltenburg, M., de-Wit, J., & Davidson, F., 2000. Capacity Building for Urban Management: Learning from Recent Experiences. *Habitat International, 24*, 363-373.

POC, 2003. Pew Oceans Commission. 2003. *America's Living Oceans: Charting a Course for Sea Change*. A Report to the Nation. May 2003. Pew Oceans Commission, Arlington, Virginia.

Rapid City, 2006. City of Rapid City, South Dakota. *Storm Water Regulatory History* [online]. Available from: http://www.rcgov.com/pubworks/stormwater/regulatory_history.htm [Accessed 15 July 2006].

SMRC, 2006. Stormwater Manager's Resource Center. *Screening Matrices Manual* [online]. Available from: http://www.stormwatercenter.net/ [Accessed 15 July 2006]

Starkl, M. and Brunner, N., 2004. Feasibility versus sustainability in urban water management. *Journal of Environmental Management,* 71 (3), 245-260.

SUDS, 2004. National SUDS Working Group, July 2004. *Interim Code of Practice for Sustainable Drainage Systems*. Available from: http://www.ciria.org/suds/ [Accessed 15 July 2006].

SWARD, 2002. Ashley, R., Butler, D., Jowitt, P., Pearson, P. J. G. et al., 2002. *The SWARD Guidebook: A Guide to Incorporating Sustainability Criteria into Decision Making for Water Service Providers and Their Stakeholders*, Imperial College, University of Bradford, Heriot-Watt-University, University of Abertay, Dundee.

SWRCB, 2003. State Water Resources Control Board (SWRCB), *Water Quality Order No. 2003-0005-DWQ National Pollutant Discharge Elimination System (NPDES) General Permit No. CAS000004 Waste Discharge Requirements (WDRs)* *for Storm Water Discharges from Small Municipal Separate Storm Sewer Systems (General Permit)* [online]. California State Water Resources Control Board. Available from: http://www.waterboards.ca.gov/stormwtr/phase_ii_municipal.html [Accessed 28 May 2006].

UNDP, 1998. *Capacity Assessment and Development: In a Systems and Strategic Management Context*, Technical Advisory paper No. 3. Management, United Nations Development Programme Development and Governance Division, Bureau for Development Policy, January 1998.

United Nations, 2002. *Report of the World Summit on Sustainable Development, Johannesburg, South Africa, 26 August- 4 September 2002.* New York: United Nations.

USEPA, 2006. United States Environmental Protection Agency, *National Pollutant Discharge Elimination System, Post-Construction Stormwater Management in New Development and Redevelopment* [online]. Available from: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm [Accessed 28 May 2006].

USEPA, 1995. U.S. Environmental Protection Agency (USEPA). 1995. *Economic Benefits of Runoff Controls*. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

Wakely, P., 1997. Capacity Building for Better Cities, *Journal of the Development Planning Unit*, University College London. Available from: http://www.gdrc.org/uem/capacity-build.html. [Accessed 20 August 2006].

Webler, T., Kastenholz, H. and Renn, O., 1995. Public Participation in Impact Assessment: A Social Learning Perspective, *Environmental Impact Assessment Review*, 15, 443-463.