Review of Federal Urban Stormwater Regulatory Structure and Best Management Practices Mitigation Measures

Kim, Tae Jin*

Abstract

Stormwater discharge derives from urbanization, which itself is due to population increase, and is one of the main causes of water-related issues, such as soil erosion and flooding. In addition, although stormwater is considered to have point sources, it actually has non-point sources of pollutants. Accordingly, the U.S. Environmental Protection Agency (EPA) has regulated all point-source discharge from municipal separate storm sewer systems (MS4) corresponding to Phases I and II. In this study, information about U.S. federal stormwater phase rules covered by the National Pollutant Discharge Elimination System as well as an overview of specific structural best management practices (BMPs) are summarized and reviewed. Additionally, this study provides a summary of U.S. federal stormwater phase rules and a review of various BMP-related literature to provide a better understanding of urban stormwater management.

Key words : U.S. Environmental Protection Agency, Low Impact Development, Runoff, Water Pollutant

요 지

인구 증가에 따른 도시화로 발생하는 도시 우수 유출은 토사 유출, 홍수 등과 같은 물 관련 문제의 중요 원인의 하나이다. 또한 이런 도시 우수는 점 오염원으로 구분되지만 우수지 비점오염원 물질을 운반한다. 따라서 미 환경청은 Phase I 및 II에 따라 도심 분류식 우수 하수 시스템(MS4)에서 배출되는 모든 점 오염원에 대해 법률적으로 규정하였다. 본 연구에서는 미 연방 우수 법률에 따른 국가오염물질 제거시스템(NPDES)과 구조적 우수 저감 최적 관리 방안에 대한 내용을 중점으로 정리되었다. 또한, 방대한 미 연방 우수 관련 법률 요약과 다양한 최적관리방안 관련 문헌 조사를 통해 도심 우수 관리방안에 관한 이해를 위한 정보를 제공하였다.

핵심용어 : 미 환경청, 저영향성 개발, 유출, 물오염

1. Introduction

Stormwater is precipitation that does not soak into the ground, but instead runs off its surface and carries and deposit water pollutants (e.g. sediment, nutrients, and pesticides) into surface-water bodies (Jaber, 2008). Pollution from nonpoint sources, including sediment deposition, erosion, contaminated runoff, hydrologic modifications that degrade water quality, and other diffuse sources of water pollution, has been the largest cause of water quality impairment in the United States because of the past and current successes in controlling

point sources (EPA, 1995). As population increases, land development for human living spaces has been accelerated and is leading to increased discharge of pollutants from Municipal Separate Storm Sewer Systems (MS4s), because development almost always increases the amount of impervious surfaces (which is a good measure of land use intensity). In particular, urbanization causes fundamental modifications to the hydrological cycle, typically resulting in an increase in the volume of stormwater discharges and associated pollutant loadings. Also, chemical, physical, and thermal changes associated with new development in urban

*Corresponding Author, Member, Assistant Professor, Department of Civil Engineering, Daegu University
(Tel: +82-53-850-6526, Fax: +82-53-850-6529, E-mail: kimtj@daegu.ac.kr)

areas can adversely affect receiving waters (EPA, 2002b).

Accordingly, urban activities that reduce these side effects have been required, which include the following approaches: 1) erosion and sediment control; 2) onsite sewage disposal systems (septic tanks); 3) runoff control from development sites; and 4) site-specific activities (e.g. oil and grit separators at gas stations) (EPA, 2001). Among these side-effect water pollutants, sedimentation is one of the most widespread pollutants, affecting assessed rivers and streams, second only to pathogens (bacteria) in construction sites. Sediment runoff rates from construction sites are typically 20 times greater than that of normal land use (Jaber, 2008), 10 to 20 times greater than those from agricultural land, and 1,000 to 2,000 times greater than those from forest land. In a short period of time, construction activity can contribute more sediment to streams than can be deposited over several decades. Accordingly, most erosion and sediment controls require regular maintenance to operate correctly. Accumulated sediments should be removed frequently, and materials should be checked periodically for wear. Also, regular inspections by qualified personnel should be performed after major rain events (EPA, 2005).

Although stormwater discharges are regarded as point sources of pollution, stormwater carries pollutants that are considered as non-point sources of pollution. All point-source discharges, unlike nonpoint sources such as agricultural runoff, are required to be controlled under the Clean Water Act (CWA) to be covered by federally enforceable National Pollutant Discharge Elimination System (NPDES) permits (EPA, 2005; 2012a). Established in 1972, the CWA regulates three types of stormwater activity from MS4s, industrial activities, and construction activities as follows: 1) Medium (population between 100,000 and 249,999) and large

(population of 250,000 or more) MS4s; 2) Eleven categories of industrial activity; 3) Construction activity disturbing 5 or more acres of land regulated by Phase I issued in 1990 under the CWA. Phase II was expanded from Phase I and includes additional operators of MS4s in urbanized areas that are not defined as any MS4 not medium or large MS4s and operators of small construction sites that cover between 1 and 5 acres.

In Texas, small MS4s are defined as (1) all small MS4s located in urbanized areas as defined by the Bureau of the Census and (2) small MS4s located outside of the US but designated by Texas Commission on Environmental Quality (TCEQ) (Jaber, 2008). Efforts to improve water quality under the NPDES program traditionally have focused on reducing pollutants in industrial process wastewater and municipal sewage treatment plant discharges. Over time, it has become evident that more diffuse sources of water pollution, such as stormwater runoff from construction sites, are also significant contributors to water quality problems (EPA, 2005).

The small MS4s regulated by Phase II under the NPDES stormwater permits require six minimum control measures and an optional seventh control measure as follows (Jaber, 2008): (1) public education and outreach; (2) public participation/involvement; (3) illicit discharge detection and elimination; (4) construction site runoff control; (5) post-construction runoff control; (6) pollution prevention/good housekeeping; and (7) authorization for municipal construction activities (EPA, 2005). In particular, construction activities require stormwater pollution prevention plans, for which best management practices (BMPs) are erosion and sediment controls and stormwater management controls used during construction (Table 1).

Table 1. Best Management Practices Used During Construction

Controls	Measures	BMPs	Variables
Erosion and Sediment Controls	Construction Stabilization	Temporary seeding	Soil erosion
		Permanent seeding	Soil erosion
		Mulching	Soil erosion
	Structural Control Measure	Earth dikes	Contaminated flow
		Silt fences	Sediment
		Sediment traps	Sediment
Stormwater Management Controls	Structural Control Measure	Sediment basins	Sediment
		Retention Pond	Runoff
		Detention Pond	Sediment
		Infiltration Measures	Percolation of water
		Vegetated Swells & Natural Depression	Sediment & Infiltration of Water

Source: Jaber (2008)

According to the EPA (2002a), most traditional approaches to stormwater management increase downstream property damage and necessitate expensive public works, while more recent approaches to stormwater management seek natural drainage by providing stormwater quantity reduction and quality improvement. Additionally, stormwater is regarded as a resource that can be used for recharging groundwater, supplying freshwater, increasing recreational opportunities, and augmenting drinking water supplies in some cases. Also, stormwater management can lead to the reduction of erosion, flooding, and damage to natural drainage features that provide wildlife habitats.

In this study, the federal urban stormwater regulatory structures and various stormwater control measures are reviewed. The Phase II final rule published by the U.S. EPA is summarized for construction sites, although the publication is outdated because it provides the sight of urban stormwater management. Also, recent BMP application measures for stormwater mitigation are summarized and reviewed.

2. Urban Stormwater Management Measures and BMP Applications

Generally, urban stormwater management is called BMP. BMPs can be divided into two categories: structural BMPs and non-structural or source-control BMPs. They can be tracked more easily in urban areas than in forest or agricultural areas because there is little change once an area is developed and structural BMPs are installed (EPA, 2001). The structural BMPs are erosion and sediment controls along with runoff, while the non-structural BMPs are the minimization of disturbances, preservation of natural vegetation, and good housekeeping practices. Structural BMPs involve building structures that include ponds, vegetated biofilters, and so on to store stormwater. Ponds generally consist of wet ponds (retention ponds), dry ponds (extended detention ponds), constructed wetland ponds, and infiltration basins. Vegetated biofilters are usually vegetated filter strips, bio-retention cells, or grass swales.

General nonstructural or source-control BMPs limit pesticide use in agricultural areas or retaining rainwater on residential lots (EPA, 2002a). In the past, BMP models considered only hydrology.

However, at present, three components of hydrology, sediment transport, and water quality are integrated and considered together. In particular, many receiving water quality issues are due to the high level of contaminants

generated by three types of urban wet-weather flow (WWF) discharge: stormwater, combined sewer overflow (CSO), and sanitary-sewer overflow (SSO) (EPA, 2012c). Also, low flow or dry-weather flow originating from sanitary wastewater, industrial and commercial pollutant entries, and septic tank systems can cause significant pollutant loading to receiving water in urban drainage systems.

To implement BMPs in the planning of stormwater management, various stormwater models have been developed. The EPA has developed an Integrated Stormwater Management Decision Support Framework (ISMDSF), Urban Stormwater Treatment and Analysis Integration (SUSTAIN), and a Storm Water Management Model (SWMM). The ISMDSF is a decision support system for developing, evaluating, selecting, and placing BMP options based on cost and effectiveness (Lai et al., 2005). The SUSTAIN was designed for use by watershed and stormwater practitioners to develop, evaluate, and select optimal BMP combinations at various urban watershed scales based on user-defined cost and effectiveness criteria (EPA, 2012b). The SWMM is a dynamic rainfall-runoff simulation model used for single-event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas (Huber and Dickson, 1988; Rossman, 2009).

Recently, several traditional and newly developed BMPs have been used in urban stormwater management: conventional retention ponds with a floating treatment wetland for water pollutants such as TSS, copper, and zinc (Borne et al., 2013; Winston et al., 2013), field-scale rain gardens for nitrate, phosphate and others (Yang et al., 2013), rain barrels/cisterns, and porous pavement (Ahiablame et al., 2013), bioretention (Brown et al., 2013), bioretention/porous pavement (Lee et al., 2012), detention basins (Park and Roesner, 2012), bioinfiltration rain gardens (Komlos and Traver, 2012; Flynn and Traver, 2013), pervious concrete infiltration basins (Horst et al., 2011), irrigated green roof systems (Hardin et al., 2012), rainwater harvesting and permeable pavements (Damodaram and Zechman, 2013), and wetlands (O'Connor et al., 2012). Also, environmental indicators of urban BMP implementation for runoff control and pollution prevention are provided (Table 2) for understanding the role of BMPs in urban stormwater management, along with management measures (MMs), which are economically achievable measures to control the addition of pollutants (EPA, 1993, 2001; Clayton and Brown, 1996).

While certain structural control measures are effective in certain circumstances, their measures may not be available for previous developed land for implementation. In these circumstances, the EPA (2012a) explains examples of improper

Table 2. Good Indicators of Urban Stormwater Management Measures

Management Measures	Good Indicators	Locations
<u>Urban Runoff</u>		
New Development	Trained staff	Subwatershed Development Site
Watershed Protection	Percent of erodible soil Percent of natural drainage ways	Subwatershed
Site Development	Ratio of area of land with structures Area of sensitive land to total area	Subwatershed
<u>Construction Site Activities</u>		
Erosion and Sediment Control	Distributed runoff travel on distributed soils Adequacy of erosion and sediment control practices	Development Site
Chemical Control	Proper installation and use Proper timing and application rate of nutrients	Development Site
<u>Existing Development</u>		
Existing Development	Proper operation and maintenance of runoff Installation of appropriate BMPs	Subwatershed
<u>Onsite Disposal Systems</u>		
New onsite disposal Systems (OSDS)	Proper siting and installation of new OSDS Density of development with OSDS	Subwatershed City or Town
Operating Onsite Disposal Systems	Increase in proper OSDS operation and maintenance Average time between OSDS visits	Subwatershed City Town
<u>Pollution Prevention</u>		
Pollution Prevention	Increase in volume of wastes collected	City or Town
<u>Roads, Highways, and Bridges</u>		
Planning, Siting, and Developing Roads and Highways	Right-of-ways set aside for roads and highway	Subwatershed
Bridges	Total distance of bridges	Subwatershed
Construction Projects	Installation of erosion and sediment control practices early environmental sensitive development (ESC) practices installed early	Subwatershed
Construction Sites Chemical Control	Proper installation and use Proper timing and application rate of nutrients	Subwatershed
Operating and Maintenance	Operating efficiency of non-point source (NPS) pollution control Ratio of exposed slopes and damaged vegetated area Street sweeping	Subwatershed
Road, Highway, and Bridge Runoff Systems	Schedule for implementation of runoff control Percent of roadway refurbishment projects	Subwatershed

Source: EPA (1993, 2001)

structural measures, which are first flush diversion systems, detention/infiltration basins, retention basins, extended detention basins, infiltration trenches, porous pavement, grass swales, and swirl concentrators. Accordingly, the following non-structural or source-control BMPs can be considered as alternative practices when land is limited or unavailable: erosion control, stream bank management techniques, street cleaning

operations, vegetation/lawn maintenance controls, debris removal, road salt application management, public outreach, education, and awareness. As shown in Table 3, water quantity (e.g. storm flow, peak flow, and runoff) and water quality (e.g. TP, TN, CU, and so on) BMP measures are applied in various locations of urban or laboratory.

Table 3. BMP Applications for Water Quantity, Quality, and Pollutants

Papers	BMPs	Variables	Locations
Bedan and Clausen (2009)	Low Impact Development (LID) including grass swales, cluster housing, shared driveways, rain gardens, and a narrower pervious concrete paver road	Storm flow, peak discharge, nitrate+nitrite-nitrogen ($\text{NO}_3+\text{NO}_2\text{-N}$), ammonia-nitrogen($\text{NH}_3\text{-N}$), total Kjeldahl nitrogen (TKN), TP, TSS, total copper (Cu), lead(Pb), and zinc(Zn)	Town of Waterford, CT
Jin and Engle (2009)	Erosion control (wood chips, straw bedding, temporary seeding, geojute netting, and curlex fiber blanket)	Soil	Residential area, LA
Berndtsson (2010)	Green roof	Phosphorus, Nitrogen, Heavy metals, pH, first flush, and fertilizers	-
Blecken et al. (2010)	Biofiltration	N, P, TN, dissolved nitrogen (DN), and nitrate-nitrogen ($\text{NO}_3\text{-N}$)	Laboratory
Collins et al. (2010)	Dry ponds, wet ponds, green roofs, permeable pavement, bioretention, vegetated open channels, sand filters, and wetlands	Nitrogen	-
Damodaram et al. (2010)	Pond and LID including permeable pavements, rainwater harvesting, and green roof	Runoff and peak flow	College station, TX
DeBusk et al. (2010)	Bioretention, wet ponds, stormwater wetlands, sand filters, green roofs, cisterns, level spreader/filter strip combinations and permeable pavement	Total suspended solid (TSS), total phosphorus (TP), total nitrogen (TN)	City of Durham, NC
Emerson et al. (2010)	Infiltration trench	TSS	Villanova University, PA
Hancock et al. (2010)	Wet retention pond	Peak flow and flow duration	James City County, VA
Ko et al. (2010)	Wetland	BOD, $\text{NH}_4\text{-N}$, and TP	Dahan Creek, Taipei
Wadzuk et al. (2010)	Constructed stormwater wetland	TSS, total dissolved solids (TDS), TN, TP, chloride, heavy metal (zinc, lead, and copper), and Escherichia coli	Philadelphia, PA
Horst et al. (2011)	Infiltration basin	Water quantity, pH, Copper, TN, TP, chloride, Suspended solids, and dissolved solids	Villanova University, PA
Hurley and Forman (2011)	Ponds and biofilters	TP	Boston, MA
Trowsdale and Simcock (2011)	Bioretention	Peak flow, volume, TSS, Pb, Cu, Zn	Auckland, New Zealand
Bakr et al. (2012)	Erosion control (compost/mulch)	TSS, turbidity, and BOD	Parish, LA
Fassman (2012)	Dry detention basins, retention basins, wetland basins, media filters, grassed swales, bioretention, and permeable pavement	TSS, total zinc, dissolved zinc, total copper, dissolved copper	Auckland, NZ
Jia et al. (2012)	Green roof, bioretention, infiltration, trench	Runoff and peak flow	Beijing Olympic village, China
Kaplowitz and Lupi (2012)	Dry and wet ponds, wetlands, filtering and infiltration practices, and swales	Non-point source pollution	Sycamore Creek, MI
Kim et al. (2012)	Bioretention with the following vegetation: shrubs, grass species, Texas native grasses, and Bermuda grass	Escherichia coli	Semi-arid regions
Yuen et al. (2012)	Street sweeping	Road deposited sediment and toxic element	Singapore, Malaysian
Ahiablame et al. (2013)	LID including with rain barrel/cistern, porous pavement, and combined materials	Runoff, stream flow, base flow, TP, and TN	Little Eagle Creek and Little Buck Creek, IN

Table 3. (Continued)

Papers	BMPs	Variables	Locations
Borne et al. (2013)	Ponds with a floating treatment wetland	TSS, particulate zinc, particulate copper, and dissolved copper	Auckland, New Zealand
Kroger et al. (2013)	Conservation practices including controlled drainage, chemical treatment of waters and soils, receiving ditch management, and wetland	Phosphorus	-
Lee et al. (2013)	Extensive green roof	Runoff and storm water	Laboratory
Marimon et al. (2013)	Floating treatment wetlands in a wet detention pond	Nitrogen	Orlando, FL
O'Driscoll et al. (2014)	Buffer zone	Runoff, total reactive phosphorus and SS	Co. Mayo, Ireland
Park et al. (2014)	Detention pond	Runoff and peak discharge	Ulsan, South Korea
Winston et al. (2013)	Ponds with a floating treatment wetland	TSS, TP, and TN	Durham, NC
Yang et al. (2013)	Biphasic rain garden	Runoff, peak flow, nitrate, phosphate, atrazine, dicamba, glyphosate, and 2,4-d	Wooster campus at OSU, OH
Kang and Lee (2016)	artificial wetland and vegetative swale	non-point pollution	Songsan
Lee et al. (2014)	Porous media	Suspended Solid	-
Yoon et al. (2017)	Storage efficiency	runoff	Busan

3. Prevention or Treatment of Stormwater Related Issues

Preventing the generation of polluted runoff costs less than treatment. Accordingly, many municipalities have been implementing non-structural or source-control BMPs to prevent runoff, as well as utilizing structural BMPs in construction sites or redevelopment sites (EPA, 2002a). Construction sites commonly discharge sediment, solid and sanitary waste, phosphorous, nitrogen, pesticides, oil and grease, concrete truck washout, construction chemicals and debris pollutants. These pollutants cause physical, chemical, and biological harm to water resources. In particular, within a short period of time, construction sites can contribute more sediment to streams than can be deposited naturally over several decades.

Several site-specific BMPs are required to prevent stormwater pollutants in traditional stormwater management controls in construction. These BMPs are used to reduce the amount of pollutants contaminating surface water bodies, prevent erosion, and redirect stormwater flow. These controls can be used after actual BMP construction to prevent pollution due to stormwater runoff (EPA, 2005). Also, the BMPs can be divided into pre- and post-construction BMPs, depending on the point in construction. The pre-construction BMP control

measures are erosion and sediment controls by temporary seeding, permanent seeding, and mulching, as well as pollutant prevention by limiting the amount of water flow, or changing the water direction with earth dikes, silt fences, sediment traps, and sediment basins (Jaber, 2008). The post-construction BMP control measures include retention ponds, detention ponds, infiltration measures, vegetated swells, and natural depressions. Retention ponds store stormwater runoff, with runoff removed only through evaporation, infiltration, or emergency bypass. In detention ponds, all sediments are allowed to settle, and then the retained water is slowly released.

Infiltration measures include trenches, basins, and dry wells used to allow water to percolate from the surface into the soil below. Vegetated swells and natural depressions are lined with vegetation (usually grass), which removes sediments from runoff and allows water to infiltrate into subsurface soil (Jaber, 2008). Brush barriers, filter strips, silt fencing, vegetated channels, and inlet protections (EPA, 2001) can be used for implementing the construction site erosion and sediment control management measures. Often, the effectiveness of structural stormwater controls, especially detention and retention basins and infiltrations devices, is limited by a lack of maintenance. Accordingly, catch basins and drainage channels require regular maintenance (EPA, 2002b). Additionally, redevelopment projects – one kind of

post-construction measure – are done to alter the footprint of an existing site or building in such a way that there is a disturbance greater than or equal to 1 acre of land. Because redevelopment projects may have site constraints that are not found on new development sites, the U.S. EPA Phase II Final Rule provides flexibility for implementing post-construction controls on redevelopment sites that consider these constraints.

Utilization of BMPs can increase the availability of the water supply and convert stormwater and water pollutant problems into sustainable water sources. Also, prior planning and design for the minimization of pollutants in post-construction stormwater discharges can be the most cost-effective approach to stormwater quality management. However,

the EPA (2005) indicates two forms of substantial impacts of post-construction runoff: an increase in the type and quantity of pollutants in stormwater runoff and runoff increase by the quantity of water delivered to the water body during storms. Table 4 lists the measurable parameters for pre- and post-construction site stormwater runoff controls.

Operators can develop and implement strategies that include a combination of structural or non-structural BMPs, and implement post-construction runoff controls corresponding to ordinances. The EPA (2005) recommends that small MS4 operators develop and implement structural and non-structural or source-control measures. The structural BMPs are as follows: 1) stormwater retention/detention ponds for both controlling stormwater volume and settling out particulates

Table 4. Lists of Measurable Parameters Pre- and Post-Construction Site Stormwater Runoff Control

Pre-Construction Site	Post-Construction Site
<ul style="list-style-type: none"> • BMP inspection and maintenance • brush barrier • check dams • chemical stabilization • construction entrances • construction reviewer • construction sequencing • contractor certification and inspector training • dust control • filter berm • general construction site waste management • geotextiles • gradient terraces • grass-lined channels • land grading • model ordinances • mulching • permanent diversions • permanent seeding • preserving natural vegetation • riprap • sediment filters and sediment chambers • sediment traps • sediment basins and rock dams • silt fence • sodding • soil roughening • soil retention • spill prevention and control plan • storm drain inlet protection • temporary slope drain • temporary slope drain • temporary stream crossings • vegetated buffer • vehicle maintenance and washing areas • wind fences and sand fences. 	<ul style="list-style-type: none"> • alternative turnarounds • alternative pavers • alum injection • bioretention • BMP inspection and maintenance • buffer zones • catch basin • conservation easements • dry extended detention ponds • eliminating curbs and gutters • grassed swales • grassed filter strip • green parking • in-line storage • infiltration basin • infiltration trench • infrastructure planning • manufactured products for storm water inlets' narrower residential streets • on-lot treatment • open space design • ordinances for post-construction runoff • porous pavement • san and organic filters • storm water wetland • urban forestry • wet ponds • zoning

Source: EPA (2002a)

for pollutant removal; 2) infiltration BMPs (infiltration basins/trenches, dry wells, and porous pavement) that facilitate the percolation of runoff through the soil to ground water, resulting in reduced stormwater runoff quantity and reduced mobilization of pollutants; and 3) vegetative BMPs (grassy swales, filter strips, artificial wetlands, and rain gardens) that remove pollutants and facilitate percolation of runoff, thereby maintaining natural site hydrology, promoting healthier habitats, and increasing aesthetic appeal. The non-structural BMPs are planning procedures and site-based BMPs (buffer strip and riparian zone preservation, minimization of disturbance and imperviousness, and maximization of open space). The non-structural or source-control BMPs (EPA, 2002a) are a type of low impact development (LID) that can help to meet NPDES requirements and offer construction-cost savings along with other benefits compared with the traditional practices, such as detention ponds and retention basins. The focus of LID is on emulating the functions of natural systems to reintegrate rainfall into the water cycle rather than disposing of it as a waste product. LID can be integrated into municipal stormwater programs that help communities meet NPDES permit requirements. LID BMPs can reduce runoff and associated pollutants across a watershed through 1) disconnected impervious surfaces; 2) preservation of open space/natural features; 3) bioretention cells (rain gardens); 4) flow-through planters and tree boxes; 5) porous pavement; 6) water harvesting (rain barrels, cisterns); 7) ecoroofs; 8) low-input landscaping; and 9) grassed swales.

Sometimes, LID is considered as a type of environmental sensitive development (ESD) with features such as better site design, green infrastructure, conservation design, integrated site design, sustainable development, and smart growth. ESD has a number of advantages over traditional and engineered stormwater drainage approaches: 1) stormwater at its sources; 2) more protective of streams and watersheds; 3) promotion of groundwater recharge; 4) more flexible site layouts; 5) enhanced aesthetics and public access/use; 6) cost savings; 7) groundwater saving; 8) reduction of impervious surfaces and runoff (peak flow volume and rate); and 9) improvement of water quantity (e.g. reduced risk of flooding) and quality (EPA, 2009).

4. Summary and Conclusion

Stormwater derived from precipitation carries water pollutants that are regarded as a Non-Point Source (NPS), although stormwater discharges are considered as point

sources of pollution, because the U.S. EPA has regulated all point source discharge (e.g. stormwater) from MS4s to be covered by NPDES since 1972. Also, Phases I and II under the CWA have regulated the MS4s as small, medium, and large sizes based on population, construction activity, industrial activity categories, and designation. In this study, the pre- and post-construction BMPs were focused on and separated into two categories: 1) structural BMPs and non-structural or source-control BMPs. The structural BMPs are generally constructed to reduce the runoff and water pollutants from runoff, while the non-structural BMPs are institutional and educational measures to limit the stormwater amount and water pollutants derived from landscapes. The recent literature on BMP applications to various locations have been reviewed and summarized based on two categories: water quantity applications and water quantity, quality and pollutant applications. The summary and review of urban stormwater management provide understanding of BMPs and beneficial knowledge to model operators and users.

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