WATER QUANTITY AND QUALITY ASSESSMENTS OF STORMWATER PURIFICATION IN BIOECODS

by

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LIST OF ABBREVIATIONS

Ag	Silver
APHA	American Public Health Association
ARI	Average Return Interval
Be	Berium
BIOECODS	Bio-Ecological Drainage System
BMP	Best Management Practices
BOD	Biological Oxygen Demand
Cd	Cadmium
COD	Chemical Oxygen Demand
COV	Coefficient of Variances
Cr	Chromium
CSO	Combined Sewer Overflow
Cu	Copper
DP	Detention Pond
EMC	Event Mean Concentration
ER	Efficiency Ratio
FWS	Free Water Surface
Hg	Mercury
HSPF	Hydrologic Simulation Program Fortran
INWQS	Interim National Water Quality Standards
IQR	Inter Quartile Range
MSMA	Urban Stormwater Management Manual for Malaysia
NH_3	Ammoniacal Nitrogen
Ni	Nickel

NO_2^-	Nitrite
NO_3^-	Nitrate
NPS	Non-Point Source
Pb	Lead
PO_4^{3-}	Ortho-Phosphate
PREWET	Pollutant Removal Efficiency by Wetland
REDAC	River Engineering and Urban Drainage Research Centre
RG	Rain Gauge
RP	Recreational Pond
Sb	Antimony
SOL	Summation of Load
SSHF	Subsurface Horizontal Flow
SSVF	Subsurface Vertical Flow
SUDS	Sustainable Urban Drainage System
SWR	Stormwater Runoff
SWMM	Stormwater Management Model
TKN	Total Kjeldal Nitrogen
TN	Total Nitrogen
TP	Total Phosphate
TSS	Total Suspended Solid
USM	Universiti Sains Malaysia
V	Vanadium
WL	Wetland
WP	Wet Pond
WSR	Wilcoxon Signed-Rank Test
Zn	Zinc

LIST OF SYMBOLS

C_i, C_{out}	Inlet and outlet pollutants concentration (mg/l) at i^{th} time
d	Storm duration (hours)
EMC_i, EMC_{out}	Inlet and outlet event mean concentration (mg/l) at i^{th} time
ER_{EMC}	Efficiency ratio calculated using EMC (%)
ER_{SOL}	Efficiency ratio calculated using SOL (%)
H_0	Null hypothesis
H_a	Alternative hypothesis
i	Average rainfall intensity (mm/hr)
i	Ranks of pollutant concentration
N	Manning’s constant
n	Sample size
P	Probability
PR	Percent removal (%)
Q	Flow (m^3/s)
R	Hydraulic radius (m)
SOL_i, SOL_{out}	Inlet and outlet summation of load (mg) at i^{th} time (mg)
T	Average recurrence interval (ARI)
V_i, V_{out}	Inlet and outlet flow discharges (m^3/s) at i^{th} time
λ, κ, θ and η	Fitting constant dependent on the rain gauge location

PENILAIAN KUANTITI DAN KUALITI AIR BAGI PENYUCIAN AIR RIBUT DALAM BIOECODS

ABSTRAK

Sistem Saliran Bio-ekologi atau BIOEOCDS yang dibina di USM merupakan project kebangsaan dan juga perintis kepada sistem saliran dalam bandar mampan di Malaysia yang berkonsepkan penyucian air ribut bandar melalui pengawalan di punca. Komponen-komponen BMP dalam BIOECODS adalah alur rumput, kolam basah, kolam kering, kolam tahanan, tanah bencah buatan dan kolam rekreasi. Penilaian prestasi BIOECODS dalam perawatan kuantiti dan kualit air ribut dijalankan dari tahun 2011 ke 2012. Parameter hidraulik air ribut diukur dengan meter aliran dan parameter kualiti air dicerap dengan pensampalan kaut dan pensampelan automasi. Peratus penyingkiran dan nisban kecekapan digunakan untuk penilaian prestasi BMPs dan disokong dengan kaedah statistic grafik dan andaian seperti box plot, ujian Wilcoxon signed-rank. Keputusan analisis menunjukkan bahawa kolam basah dan kolam tahanan berkesan dalam mengurangkan kadar aliran puncak. Sementara itu, hanya tanah bencah buatan didapati berupaya merawat air ribut dengan peratus pengurangan 9%, 28%, 74%, 72%, 70%, 54%, dan 35%, untuk BOD, COD, TSS, NO_3^-, NO_2^-, NH_3, dan PO_4^{3-} masing-masing. Keseluruhannya, BIOECODS menunjukkan prestasi yang baik dalam menggunakan konsep perawatan berturutan untuk merawat kuantiti dan kualiti air ribut. Diharpakan bahawa pengalaman daripada projek perintis ini dapat menyumbang kepada rekabentuk pada masa depan.

WATER QUANTITY AND QUALITY ASSESSMENTS OF STORMWATER PURIFICATION IN BIOECODS

ABSTRACT

Bio-ecological drainage system (BIOECODS) in USM is a national pioneer project on sustainable urban drainage system adopted in Malaysia with the concept to provide treatment to urban stormwater runoff through control at source approach. The BMPs components of BIOECODS are wet pond, detention pond, wetland and recreational pond. Investigation on the performances of BIOECDOS in stormwater quantity and quality treatment is conducted from year 2011 to 2012. Stormwater hydraulic parameters were measured via flow meter and stormwater quality parameters are sampled via both grab and automated sampling method. Percent Removal and Removal Efficiency methods are utilized to evaluated performances of BMPs backed up by graphical and hypothetical statistical tools such as box plot, and Wilcoxon signed-rank test. The results show that wet pond and detention pond are effective in reducing peak flows. Meanwhile, only wetland shows significant treatment of stormwater quality with percent removal of 9%, 28%, 74%, 72%, 70%, 54%, and 35%, for BOD, COD, TSS, NO_3^-, NO_2^-, NH_3, and PO_4^3 respectively. Overall, BIOECODS shows good performance in utilizing the treatment train concept to treat stormwater quantity and quality performances. It is hoped that the experiences from this pioneer project could contribute to the design practices in future.

CHAPTER 1

INTRODUCTION

1.1 Background

The world has been undergoing a rapid pace of urbanization since 1950s and 1960s and this trend are not likely to slow down but to keep on increasing (UN-Habitat 2012). It is expected that by 2050, 67.2% of world population, which equivalent to 6,252,175,000 peoples will be occupying urban area. Out of this, 81.97 % of the population, which is equivalence to 5,124,953,000 peoples, will come from less developed region (UN-Habitat 2012). Being densely populated with high intensity of socio-economic activities, urban areas are major consumer and polluter of water resource (Bao and Fang 2012). Water resource are claimed to be the most valuable resource over land and food (Farrelly and Brown 2011), and it should be taken serious consideration (Zhang and Wen 2008).

Urban water resource management has become an important occupation in this rapid urbanizing world to safeguard human's life, health, and property. Improper planning and design of urban water resource would lead to catastrophic consequences such as flooding, channel erosion, land sliding and destruction of aquatic habitat (Booth 1991). Fresh water is the most crucial natural resource and it should be well funded and managed carefully as at the broadest level, it underpins basic ecosystem function (Giupponi et al. 2006). Water resource could constraint urbanization by slowing socio-economic growth rate, prevent poverty eradication and sustainable development (Bao and Fang 2007).

Developing countries in Asia are particularly vulnerable to urban flood. 90% of those killed or affected by floods lived in Asia causing about half of worldwide economic loss. This situation is worsening with 80% of population in Bangladesh and 70% in Vietnam are at risk of flooding (Normile 2012). In November 2009, Jeddah in Saudi Arabia are effected by flash flooding after precipitation of 90mm rainfall within four hours, causing hundreds of lives and estimated business losses of US$270 million (Jha et al. 2012). In 2010, floods in China has affected 17,866, 690 ha of crops and 211 million people of which 3,222 people were killed. Direct economic losses were 374,543 million RMB Yuan (Huang et al. 2012). Meanwhile, in 2011, 65 of Thailand's province are hard hit by flood causing 815 death and 13.6 million people affected and estimated economic loss of 1,425 billion baht (US$45.7 billion) (Figure 1.1).

Malaysia is also a country where floods had cost billions of economics lost and has affected many of her citizens for decades. Figure 1.2 shows flood event in Pahang on 24th December 2012. States in east of Peninsular Malaysia such as Kelantan, Terengganu, and Pahang are frequently affected by flood during the monsoon seasons. In 2000, frequent occurrences of flash flood occur that affected 9 % of Malaysia land mass which occupied by 12% of the population. This has resulted in an average loss of RM100 million, and the estimated cost to mitigate all existing flood problems by that time is reaching RM10 billion! (Mohd Sidek et al. 2002). Zakaria, et al. (2003) conclude that the increasing annual budget spend by Department of Irrigation and Drainage (DID) Malaysia for flood mitigation indicated that there is a need for a change in stormwater management approach. According to EM-DAT (2013), from 1980 to 2011, the disaster that effected most of Malaysia population and caused most economical damage are floods. Figure 1.3 shows that flood is the disaster that affected most people compared to others disaster. Figure 1.4

shows that flood has caused an estimated economic loss of US$ 1,012,500, which is equivalent to RM3.27 million (EM-DAT 2013).

Figure 1.1 Flood in Bangkok 2011 (Goldman 2011)

Figure 1.2 Flood in Pahang 2012 (Yunus and Lingan 2012)

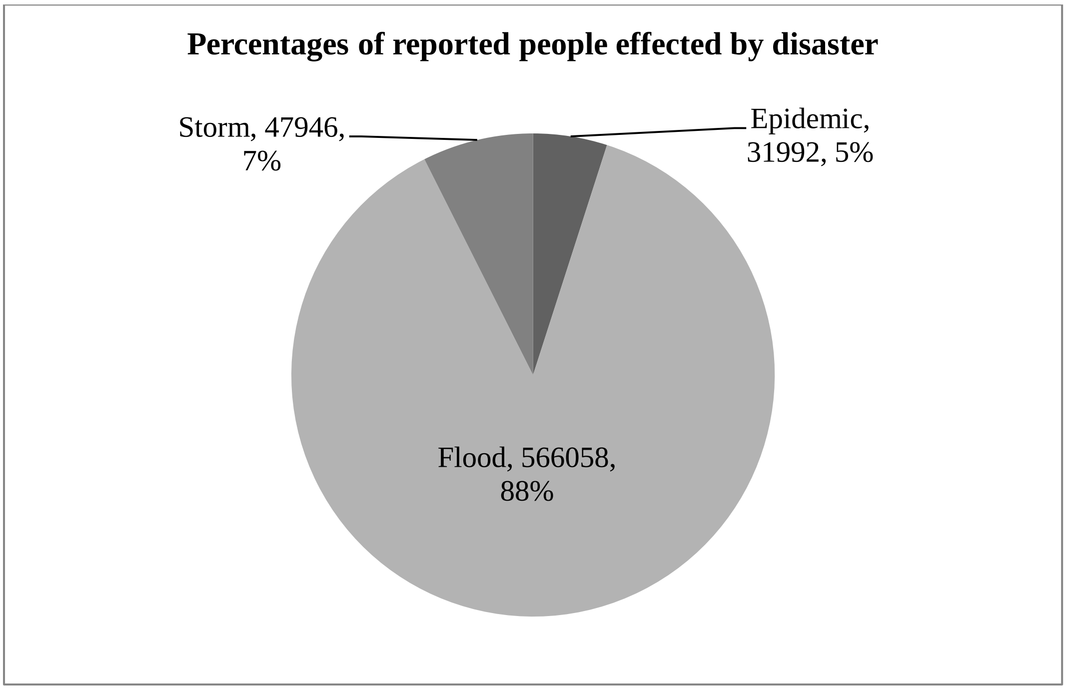

Figure 1.3 Percentages of reported people effected by disaster in Malaysia from 1980-2011 (EM-DAT 2013)

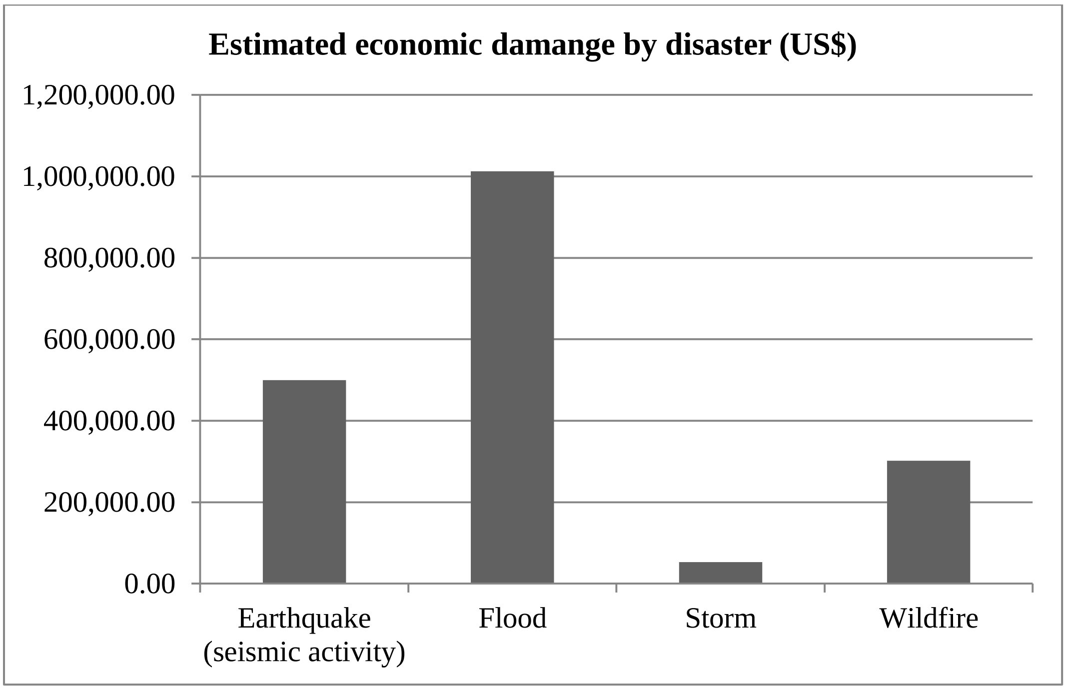

Figure 1.4 Estimated economic loss by disaster in Malaysia from 1980-2011 (USD) (EM-DAT 2013)

While urban floods are the major focus in past and current urban water resource management due to acute effects of enormous economic losses and width of affected people, changes of water urban water quality are slowly emerged out and its severity are being recognized throughout the long history urban water resource management. Urban land uses such road, roof, commercial and residential areas are among the main contributor of pollutant loads. Barbosa et al (2012) has compared several source of pollutant and found that urban stormwater are the most important source of heavy metals resulting from vehicles wear and tear, fuels and industries while wastewater constitutes the main source of organic and nitrogenous pollutions. Water quality deterioration affect aquatic life; caused erosion and deposition of sediments in river bodies, groundwater recharges deficits due to diverted runoffs, soil and ground pollution by infiltrating urban runoffs, and public health risk due to pollutions of fresh water supply by bacteria and viruses (Hvitved-Jacobsen et al. 2010).

Aware to above mentioned problems, stormwater management have shifted from conveyance approach to control at source approach. From there, not only the runoff quantity is retained to ensure that peak flow and volume remained as pre-development conditions, the water quality issues are also incorporated into design and planning. Stormwater Best Management Practices (BMPs) are one solution arise from this paradigm shift. They are also known as Low Impact development (LID), Water Sensitive Urban Design (WSUD) which are mostly used in UK, and Innovative Stormwater Management which are mostly used in Canada (Barbosa et al. 2012). Many successful cases of adopting BMPs have been recorded all around the world. Three Drainage systems in France which consists of vegetated roof, underground pipeline or tank, swale, grassed detention pond are observed to induced flow attenuation, reduced water discharges at rate of about 50% and reduced runoff pollutants by 20%-80% (Bressy et al. 2014). Stagge et al. (2012) have shown that grass swale could reduce the probability of instantaneous TSS concentration that exceeding 30mg/l from 41%-56% to 1-19%. Meanwhile, in Malaysia, a pioneer sustainable urban drainage system, named Bio-ecological Drainage System (BIOECODS), has been established in USM Engineering Campus, Nibong Tebal, Pulau Pinang. It is a drainage system that consists of grass swale, dry pond, wet detention pond, and wetland designed to cater runoff quantity and quality in USM Engineering Campus. The objectives of this research is to re-evaluate the performance of BIOECODS to provide an insight how the adopted BMPs could functions under the climate of Malaysia.

1.2 Problem Statements

Across the globe, the applications of BMPs in urban stormwater management have been and are still facing many challenges. One of the challenges is difficulty in the design of BMPs due to uncertainties in performances. The evaluation of stormwater BMPs efficiency has been hampered by high variable performances that are affected by many factors such as geographical climate, incoming inflow concentrations, evaluation methods and aging. Acquiring a liable BMPs performance is important to ensure cost effective and sound engineering practices in stormwater management.

It is found that, in previous researches on BIOECODS, comparisons of outflow concentration to inflow concentration and water quality standards such as Water Quality Standard for Malaysia (MWQS) are commonly used as evaluation methods for water quality performance of BMPs. It gives a good indications on whether the BMPs have treated stormwater and also whether the outflow concentration met the water quality regulations. However, lacking in statistical analysis, many other trend of water quality performance could not be evaluated. As example, for BMPs with high ranges of inflow concentration and outflow concentration, the spreads and distributions should be identified before concluding the efficiency to avoid biased results due to possible outliers. Also, removal efficiency backed by statistical analyses give more confident than just visual inspections (Strecker et al. 2001). Therefore, the evaluations of BMPs efficiency in BIOECODS still required larger sampling size, with improved sampling techniques to allow to developments of the statistical analysis.

Meanwhile, the periods of samplings in BIOECODS are also another factor affecting the performances evaluations. Through non-recorded conversations and literature review, it is observed that BMPs in BIOECODS were sampled during pre-matured and matured stage. There also a research conducted when there is an on-going construction on the upper stream which resulted in high pollutant load. Plant uptake varies during pre-mature and mature stages of BMPs would effects the BMP performance. Craft (1997) reported that high phosphate uptake by wetland vegetation during early stage of succession will decrease when the sedimentation are decrease and sorption are saturated. Meanwhile, as sedimentation occurs continuously throughout the service period of BMPs, the re-suspension of pollutant near shallow bed also might affect the BMPs performance (Struck et al. 2005). BIOECODS has been implemented over 10 years and are believed to achieve its mature state currently. There is a need to re-evaluate the performances on BMPs in stormwater quantity and quality purifications to provide information needed for future constructions and designs of stormwater BMPs.

Other than sampling period, different in sampling technique will affects analysis methods and results obtained. Grab sampling method are used by previous researchers of BIOECODS. This method is reliable only when the pollutant concentrations in the system are constant throughout the storm events. Automated sampling, on the other hand, are capable of capturing pollutant concentrations in short interval more effectively. If the efficiency of BMPs changes dynamically within on storm event, or when the knowledge on the BMPs efficiency are lacking, automated sampling method is preferred over grab sampling methods.

Differ from water quality efficiency, water quantity efficient of BIOECODS are not likely to vary much from previous researchers. This is because the parameter affecting water quantity efficiency such as inlet/outlet configuration, bed slope, detention/retention size are not like to change so much overtime. However, water quantity efficiency of BMPs still remained an important analysis in this research for evaluations of water quantity. Moreover, in stormwater management practice, a properly controlled flow mean that most part of the water quality issues is resolved because eventually, BMPs that adopted will be designed to remove pollutants from runoffs (Roesner et al. 2001).

1.3 Research Objective

The main objectives of this study are as followed:

a) To re-evaluate the water quantity and quality performance of wet pond, detention pond, wetland and recreational pond in BIOECODS collected in 2011-2012 against the previous collected data.

b) To enhanced the analysis of water quality efficiency of wet pond, detention pond, wetland and recreational pond in BIOECODS using statistical tools.

1.4 Scope of Studies

The study site is located at USM Engineering Campus, Nibong Tebal, Pulau Pinang, Malaysia. It is located at latitude 5°8’40.9023”, longitude 100° 29’32.9273”. This study focused on the water quantity and quality performances of BIOECODS. Four targeted stormwater BMPs namely wet pond, detention pond, wetland, and recreational pond are selected for studies. BIOECODS receive stormwater runoff from research centre sub-catchment and residential hostel sub-catchment.

Hydrologic and hydraulic data in this research are collected from the rain gauge and flow meter installed in BIOECODS. Meanwhile, water quality data are collected through grab sampling and automated sampling method, and in-situ measurement using water quality probe during storm event. Water quality parameters such as BOD, COD, TSS, NH_3, NO_3^-, NO_2^-, and PO_4^{3-} are tested at environmental laboratory in USM. All the testing and laboratory work are comply with APHA standard methods.

Meanwhile, stormwater performances of BIOEOCDS will be evaluated using basic data plot, box plot, Wilcoxon-signed rank test, percent removal and efficiency ratio. For design procedures of rehabilitated wetland will comply with MSMA regulation for wetland size, removal percentages, and flow routing.

1.5 Thesis Outline

This thesis is organized into five chapters. Chapter 1 gives brief introduction that focuses on the background of current condition of stormwater management, and emphasis on the objectives, scope and problem statements of this study. Chapter 2 further elaborate the current state of stormwater management by focusing on problems, solutions, and measurements and analysis methods. Chapter 3 includes the details research methodology such as measurement of hydrology, hydraulic and water quality data, selected analysis method and site descriptions. In Chapter 4, results of hydrologic, hydraulic and water quality parameters are presented and recommendations are made for the design of rehabilitated wetland. Finally, Chapter 5 consists of recommendation and conclusion for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the impacts of urban runoff are presented in Section 2.2 while the challenges faced in urban stormwater management are described in Section 2.3. The origins of pollutant sources in stormwater are identified in Section 2.4. It is important that the sources and constituents of pollutant are understood and effectively quantified for better and more confident decisions making in management approaches. In Section 2.5, water quality pollutants are classified and discussed in four different groups namely sediments, nutrient, oxygen demand material and heavy metals. Stormwater treatment processes currently available and adopted are presented in Section 2.6. Most treatment processes are adopted from wastewater treatment practices. However, due to the variability in stormwater inflow volume, discharges, and incoming pollutant concentrations, the treatment practices have to be adjusted and altered to what we termed here as stormwater Best Management Practices (BMPs). Section 2.7 describes the methods used to evaluate BMP performances. In Section 2.8, two stormwater BMPs namely detention pond and wetland are being discussed and the previous studies and gap analysis are conducted on the water quantity and quality treatment performances of BMPs in BIOECODS.

2.2 Impacts of Urban Stormwater Runoff to Environment

Stormwater runoffs are generally characterized by two factors: impervious surface and land use. Removal of vegetation and replacement of pervious areas with impervious surface changes the runoff hydrographs by increasing surface runoffs and reducing runoff infiltration (Goonetilleke et al. 2005). Different types of land uses increase the pollutants variety and loads for urban storm runoffs.

Impervious surfaces in urban area have been identified as one of the main reason for changes in urban hydrology effecting the quantity and quality of runoffs (Booth 1991, Hellman 2011, Fletcher et al. 2013). Precipitations are normally trapped as depression storage by vegetation in pre-development area where runoffs are attenuated and reduced by infiltration and evaporations. However, these precipitations are directly converted into runoffs in impervious surface. Due to high percentages of impervious surfaces in urban area, urban stormwater runoffs have the largest effects on flow regimes in urban streams and rivers compared to water supply and wastewater treatment (Walsh et al. 2012). Simulation by Booth (1991) using Hydrologic Simulation Program Fortran (HSPF) shows that urbanization not only amplify urban stormwater runoff peak flow, but it also creates new flow peaks thus increasing the occurrences of flood. Figure 2.1 shows the increments in peak flow and Figure 2.2 shows the increments of peak frequency due urbanization. This statement is further supported by Roesner et al. (2001) stating that runoff peak increases by a factor of 2 to more than 10 in urban area while the frequency also increases to 6-18 times of pre-developed peak flows. Figure 2.3 shows the effects of urbanization on flow frequency curve. It is found that not only urbanization increased the peak flow of the runoff (point A) but also increase the frequency of the peak runoff for the same peak (point B). This increase in the magnitudes and frequency of runoff are the reasons for flash flood in urban area as existing stormwater mitigation practices fail to accommodate additional runoff due to upstream development.

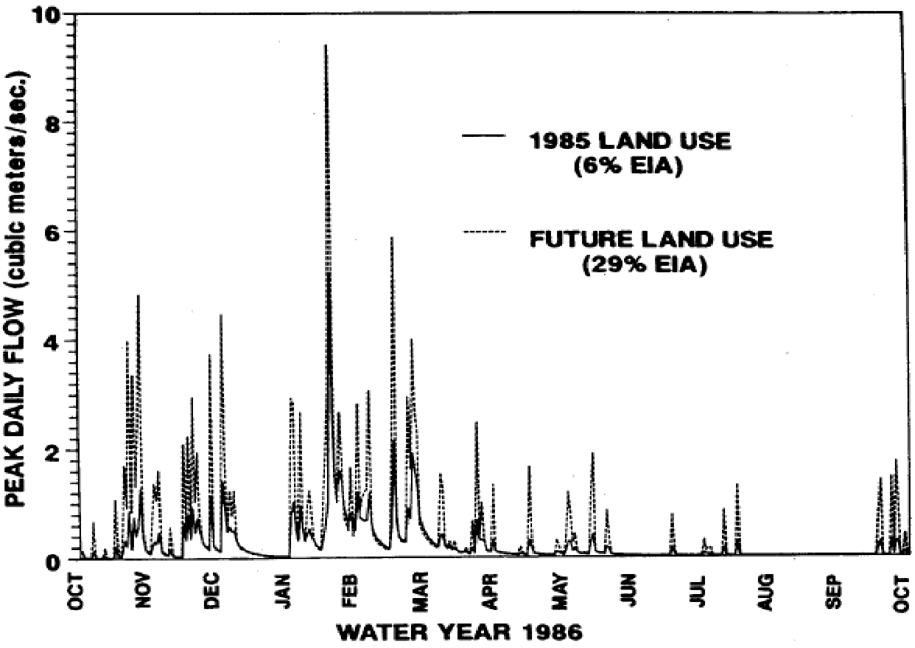

Figure 2.1 Simulation of stream flow using HSPF for 13 km^2 drainage basin under different effective impervious area (EIA) (Booth 1991)

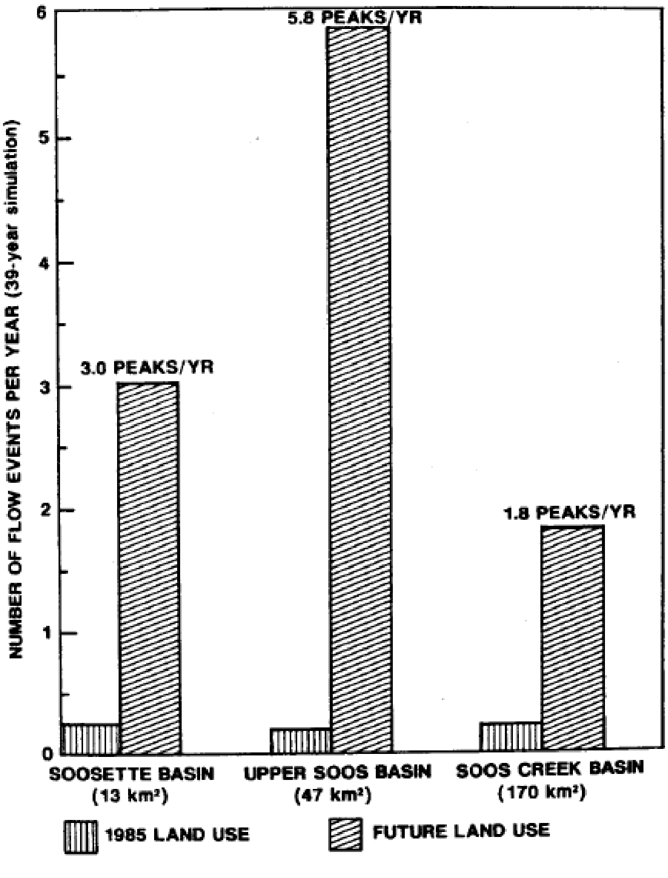

Figure 2.2 Simulation of changes in frequency of flood peak in Soos Creek basin under different land use (Booth 1991)

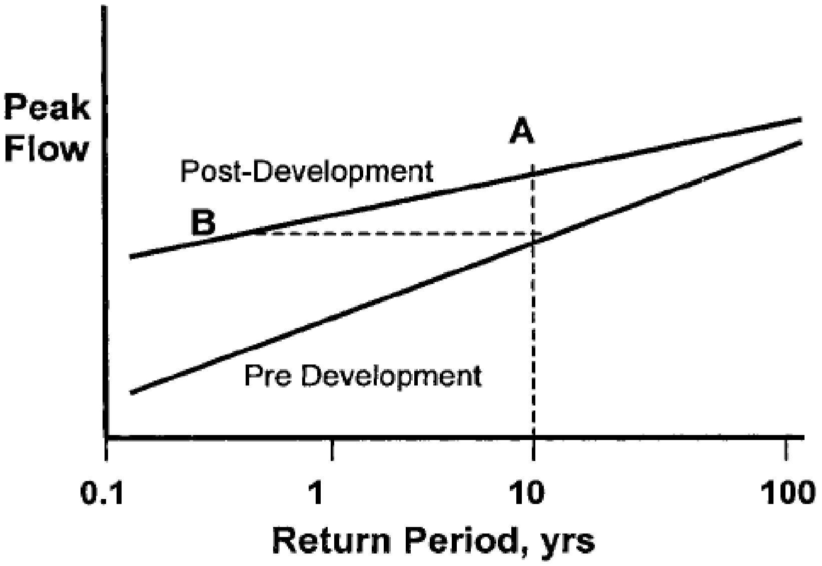

Figure 2.3 Effects of urbanization on flow frequency curve (Roesner et al. 2001)

Figure 2.4 Channel incision as a results of channel widening (Sear et al. 2010)

Besides inducing urban flood, urban runoff also caused stream channel erosion and further increasing the risk of flooding downstream. Erosion could expend stream channel catastrophically consuming land never before affected, transporting sediment to low-lying areas, overwhelm stormwater facilities with more frequent, lager flow beyond designed capacities, and decimate populations of aquatic organism (Booth 1991). Urban areas produce higher discharge peaks and runoff volumes; these processes increase the flow velocities and, therefore, force the streams to adjust their geomorphic properties (Tillinghast et al. 2011). Stream incisions shown in Figure 2.4 are one of the phenomena observed from profound channel expansion. Stream incision could void habitat diversity and eroded sediment will further clog downstream system. Incised stream are found to yield higher pollutant concentration such as turbidity, suspended solid, total phosphorous, total Kjeldahl nitrogen, and chlorophyll while supporting lesser species diversity and yield less biomass (Shields Jr et al. 2010). Stream erosion are further worsen by the clearing of vegetation for development around river banks which deprived stream from stabilizing elements that helps dissipate flow energy (Booth 1991).

Meanwhile, water quality deterioration due to urban stormwater runoff is one of the major concerns in international society since 1960s (Huang et al. 2007). Lin et al. (2009) found that main pollutant contributors to receiving water bodies comes from urban land uses. Urban land uses such as residential, commercial, industrial and agricultural area produced non-point source pollutant such as debris and pesticides. The concentrations of pollutants amplified with high population density in urban area and become significant sources of pollutants. Stormwater pollutants pose threat to aquatic plants and animals, and also human. Sediment depositions reduce light penetration could effects photosynthesis and suffocate fish by clogging their grills. Depletion in dissolved oxygen due to decays of biomass has voided biological communities of oxygen, the essentials substance for life. Toxic pollutant such as heavy metals and organic micro pollutants also post both acute and chronic health threat depending on its concentrations. Pathogenic microorganisms, virus and bacteria could threaten human through direct impacts such as drinking or through contaminated food such as fish and crops (Hvitved-Jacobsen et al. 2010).

2.3 Challenges in Urban Stormwater Management

Over the long history, the approaches in urban stormwater management have undergone several phases as experiences accumulated and technologies advanced. Debates have been mingled over many approaches such as centralized over decentralized, conveyance over source control, and the used to ecological treatment. However, the approaches denominated stormwater best management practices (BMPs) are the current trend and are widely applied in the world.

BMPs is an approach where stormwater are dealt in a way where current and future needs are satisfied while nature resources and ecosystem are protected (Hvitved-Jacobsen et al. 2010). BMPs are usually installed or constructed near the source (source control) to allow stormwater retentions and treatment. Source control measures have been proven to be more efficient and cost effective for reduction of the environmental impacts from stormwater runoff compared to conventional combined or separated sewer systems (Barbosa et al. 2012). However, the performances of BMPs are not universal and preliminary studies should be conducted before the adoption of certain BMPs.

BMPs can be structural and non-structural. Structural BMPs include engineered and built systems designed to provide treatment for water quantity and/or quality control based on either rainwater retention or infiltration into the soil. Non-structural BMPs can be a series of pollution prevention, education, management and development practices designed to reduce runoff and pollutants generation by rainfall (Martin et al. 2007). Structural BMPs are likely to provide acute solutions of the stormwater problems mainly involving engineering practices while non-structural BMPs such as education provide a long term sustainable targets.

Seven major impediments to stormwater BMPs are uncertainties in the performances and the associated costs, inadequate engineering knowledge, standards and guidelines, blurry responsibilities from governmental department, lack of institutional capacities, lack of legislative mandates, lack of funding and effective market incentives, resistance to changes (Roy et al. 2008). Moreover, sustainable development required achievements of multiple criteria such as hydraulic and technical performance, environmental and sociological perspectives, as well as economic and operation and maintenance considerations (Ellis et al. 2004) that would demand participation of professional from multiple fields

In structural BMPs, design process are complicated by great varieties in the performances of BMPs owning to the complex influencing factors such as geographical location, contributing watershed, rainfall characteristic, design configuration (Barrett 2008, Young et al. 2010, McNett et al. 2011). Dietz (2007) compared the performance of three BMPs namely bio-retention, green roof and permeable pavement and found high variability in their performance despite using same treatment mechanism of storage and infiltration. The performance of single BMPs over time is also observed to be highly fluctuated.

Numerous studies on many solutions for stormwater management have led to development of database such as International Stormwater BMP Database (www.bmpdatabase.org), which aids the BMPs assessment and selection by providing ranges of criteria. However, evaluation of BMPs remained a difficult task (Martin et al. 2007). Engineers often select BMPs that remove a percentage of pollutant loads until the above loading rates are met, often necessitating multiple BMPs in series. Due to lack of requirements in BMP performance monitoring, BMPs design are often hampered by lack of data especially in developing country and frequently resulted in prescriptive design that tend to be over simplified (Fassman 2012).

Many of the characteristic of urban runoff are site specified. One of the phenomena in urban stormwater runoff is first flush effects. First flush effects is the phenomena where large portions of pollutant mass or concentration appear in the initial stages of storm event (Sansalone and Cristina 2004). Practicing engineers need to identify this pattern to determine whether to treat stormwater runoff during early part of storm event. However, first flush pattern are not consistently noted in urban watersheds and are dependent on factors such as storm size, rainfall intensity, watershed characteristic, and various hydrologic and transport factors (Deletic 1998, Sansalone and Cristina 2004). Deletic (1998) concluded that strong first effects, if exists, is not likely caused by the inflow concentration concentration but rather transformation and transports of pollutants in the system. Watershed managers and researchers have questioned the existence of a first flush and the volume of required treatment under first flush analysis (Bach et al. 2010). Lee et al. (2004) has reported that strong first flush phenomena effects are observed in organics, minerals and heavy metals except lead with pollutant concentration in the initial stage 1.2 to 20 times higher than the concentration near the end of season. Many uncertainties in first flush effects hamper its incorporation into design manual and guidelines.

Another phenomenon that should be attended in BMPs design is the irreducible limits. It is a concentration indicates where treatment systems cannot provide further pollutant concentration reduction below this background or baseline level (Hathaway and Hunt 2010). Irreducible concentration limits are likely to depend on the types of BMPs and its treatment mechanism. For example, settling treatment mechanism that are commonly used in pond are commented to be “never” being able to remove colloids which can be done by chemical addition (Strecker et al. 2002). Irreducible concentration limits are especially important when treatment train are to be incorporated. Hathaway and Hunt (2010) monitored three storm-water wetland in series and found that only the first wetland have significant pollutant removal while the other two do not have significant removal. In current practices where BMPs with associated performance are selected from manual or guidelines list, it is suggested that irreducible limits is taken into consideration so that engineers do not overestimated the final outflow concentration.

Monitoring of BMPs performances are also another important criteria to ensure significant and high level of confident in results. There are currently two commonly practices methods in stormwater monitoring, grab sampling and automated sampling. Grab sampling are easy to set up but could resulted in high variability of results and required high labour work forces (Lee et al. 2007). Automated sampling are more representative, and also can be used to estimate pollutant loading and event mean concentration (EMC) (Lee et al. 2002). However, automated sampling such as flow-weighted composite samples is more difficult and expensive due to the set up cost, high frequency sampling, and training and operating cost (Lee et al. 2004). Site evaluation and pre-measurement are therefore suggested before any sampling strategy or analysis method is adopted.

2.4 Source of Urban Stormwater Runoff Pollutant

In urban area, pollutants are contributed by both natural process and human activities. Management of pollutants from storm events is often more complex than managing pollutant from a specific point such as treatment plant or industrial waste. Pollutants from urban area are defined as non-point sources (NPS) making quantifications of its exact origin basically not possible (Aryal et al. 2010, Hvitved-Jacobsen et al. 2010). Based on the sources of pollutant, management of urban water can be divided into stormwater runoff (SWR) and combined sewer overflows (CSO) (Figure 2.5). In this research, only SWR is concerned. Understanding and better categorizing of urban pollutant sources are important for prediction and control of pollutant loads (Adams and Papa 2000, Gulliver et al. 2010).

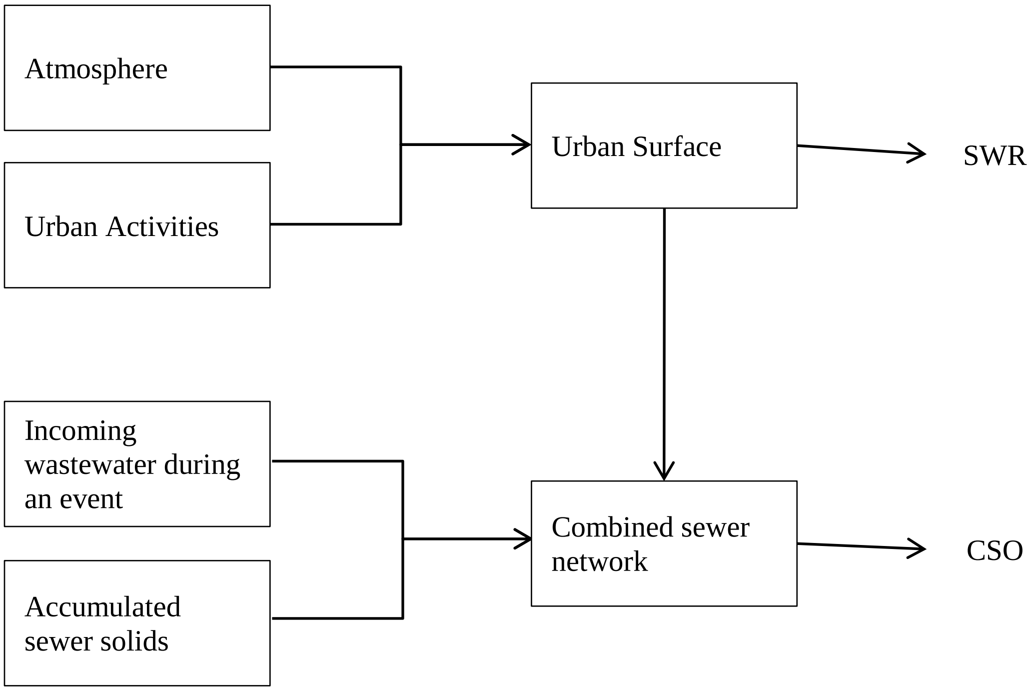

Figure 2.5 Pollutant sources and pathways for stormwater runoff (SWR) and combined sewer overflows (CSO) (Hvitved-Jacobsen et al. 2010)

Atmospheric deposition is one of the major contributor to urban pollutants such as gases (volatile sub-stances), aerosols (liquid particles, i.e., associated with raindrops and fog), and suspended solid particles (dust), heavy metals (Hvitved-Jacobsen et al. 2010, Björklund 2011, Barbosa et al. 2012). The input to atmospheric deposition could either be from local or distant sources. Particles with size less than 1 μm has been observed to travel much longer distances from the source (Gunawardena et al. 2011). Often, congested urban and industrial area have higher deposition of atmospheric particulate matter than rural or residential area (Adams and Papa 2000, Hvitved-Jacobsen et al. 2010). Increments in heavy metals deposition has been observed to related with increase in population density (Hvitved-Jacobsen et al. 2010) and traffics volume and congestion (Gunawardena et al. 2013). Other sources of atmospheric pollutant are emissions from local and regional sources such as industries, power plan and corrosion products from buildings and industries.

Dry and wet depositions are the two mechanisms of atmospheric depositions. Dry deposition is the accumulations of pollutants to the underlying surface such as roofs and roads through the effects of air turbulences and gravitational settlement, in the absence of precipitations (Wesely and Hicks 2000, Adams and Papa 2000). Coarser particles (normally of size larger than 1µm) and increase in antecedent dry days has been observed to increase the amount of dry depositions (Gunawardena et al. 2011). Meanwhile, wet deposition is the result of adsorption of pollutant in atmosphere by raindrops or snows. It is said that wet deposition are capable of cleansing atmospheric pollutions but may contribute to first flush effects where the pollutant level is higher during the initial period of rainfall event. Wet deposition is often related to acidic rain (pH value less than 5) that may damages Portland cement buildings. Also, wet deposition of nitrogen compound, heavy metals, and organic compounds has been reported to cause substantial effects to the water quality of open water (Adams and Papa 2000).

Another major contribution of pollutant load in urban area is the anthropogenic activities. Basically, automotive traffic is a significant source of urban pollutions. Pavement maintenance and abrasion, tire wear and tear, brake pad wear and tear, exhaust emission and chemical leaks are contributors to pollutants like suspended solids, organic matter, heavy metals, nitrogen, phosphorous and polycyclic aromatic hydrocarbon (Adams and Papa 2000, Hvitved-Jacobsen et al. 2010, Min and Zhibin 2012). Wear and tear of tire, brakes and automotive body generates particulates that are the main sources of suspended solids. Tire wear contributes to zinc generations while other heavy metals such as lead, cadmium, nickel, copper are generated from exhaust combustions (Min and Zhibin 2012, Gunawardena et al. 2013). Pavement type also affected pollutant load. Runoff from asphalt road is 3 to 5 times higher in lead, zinc, COD and TOC concentration that concrete road due to higher abrasion and wear and tear rate (Adams and Papa 2000, Min and Zhibin 2012). Road surface is also a media for atmospheric depositions.

2.5 Constituent of Pollutant Runoff

Pollutant constituents associated with land used should be identified to ease the decisions making before implementations any management approaches. It is however important to note that characterizing of pollutant with land uses could just be served as references and are not the absolute conditions. Site investigations and surveys should be carried out for better justifications in design approach.

2.5.1 Sediments and Suspended Solid

Sediments or suspended solid are particulates generated by exhaust gas, traffic, asphalt/building erosion, or transported by wind. Meanwhile, urban development’s convert forest areas to agricultural or residential areas also release huge amounts of sediments. Trimble (1997) measurements in San Diego Creek in southern California showed that stream channel erosion accounted for two third of sediment yield downstream. Evaluation by Nelson and Booth (2002) in Issaquah

Creek, western Washington found that urban activities such as channel-bank and road surface erosion caused almost half of total annual sediment yield. Yin and Li (2008) found that 60±12% of suspended solid at sewer outlet are originated from sediments in drainage system while the rest was from wash-off of urban impervious ground surface.

Common parameters used to measured sediments are total suspended solid (TSS) or turbidity. Generally, their sizes ranged from 1µm to greater than 10,000µm (Sansalone and Kim 2008). High turbidity could reduce ample light penetration to water, thus prohibiting growths and activities of photosynthetic plants. Meanwhile, suspended solid could also result in clogging of fish gills. Most stormwater pollutants are found to be attached to fractions of sediment particulates and organics matters especially in fine sediment. Over 50% of heavy metals are found to affiliate with sediment particles less than 43µm. Despite being only small fractions (5.9%) of the total solids, find sediment contributed to one third to half of algal nutrient, three quarters of total pesticides and half of heavy metals total loads. These criteria make TSS and important parameter of for concerns. Its settlement in downstream could pose threat of toxic accumulations and increments in oxygen demand. Meanwhile, scouring and mixing of sediments during storm event also may remobilize and release the toxic component (Aryal et al. 2010). Uncontrolled, sediments could lead to clog stormwater drainage systems, increasing maintenance costs and flooding problems.

2.5.2 Nutrient

Nutrients are essential element for the growth and limiting agent in aquatic ecosystem. However, excessive nutrient input can lead to algae overgrowth and resulted in eutrophications, unpleasant odours, unsightly surface scums, and lower dissolved oxygen. Common sources of nutrients are fertilizers, animal wastes, failing septic systems, detergents, road de-icing salts, automobile emissions, and organic matters (Aryal et al. 2010). Agricultural and residential areas are the major non-points sources of nutrient contributors (Wernick et al. 1998). Decomposition of grass and plant leaves should also be considered as possible nutrient sources. Alison et al. (1998) reported that leaf litters could contribute about 5-20% of TP and TN to nutrient load in stormwater runoff. In nutrient enriched water, high rate of leaf/grass decomposition induced by high microbial activity could lead to high nutrient sources (Gulis and Suberkropp 2003).

Two common parameters used to measure nutrients are nitrogen and phosphorus. Phosphorus appears in both inorganic phosphate (phosphate, polyphosphates, ortho-phosphates) and organic bound phosphate. Specific test of phosphorous are total orthophosphate, total phosphorous, the dissolved phosphorous, insoluble phosphorus. Phosphates exist in soluble reactive phosphorus or orthophosphates, polyphosphate and organic bound phosphates. Organic phosphates are found in animal or plant tissues and are introduced to drainage systems via body waste and food residues. It also can be obtain through the breakdown of organic pesticides. Orthophosphate (also known as “reactive phosphate”) are the most stable phosphate in water, and is the form used by plant. It is commonly found in sewerage and natural sources. Polyphosphate (also known as Meta phosphate or condensed phosphate) are used for treating boiler water and in synthetic substances such as