MODELING OF NON POINT SOURCE POLLUTION FROM RESIDENTAL AND COMMERCIAL CATCHMENTS IN SKUDAI, JOHOR

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Specially dedicated to my beloved parents, brothers and sisters for their love, encouragement and endless support towards the success of this study

Last but not least, to special one, Ahmad Zurisman, thanks for everything...

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ABSTRACT

Sampling of urban runoff was carried out in two small catchments, which represent residential and commercial areas in Skudai, Johor. Ten storm events for residential and seven events for commercial catchments were analysed. Runoff quality showed large variations in concentrations during storms, especially for SS, BOD_5 and COD. Concentrations of NO_3-N, NO_2-N, NH_3-N, and P were also high. Lead (Pb) was also detected in both catchments but the levels were low (<0.001 mg/l). In general, the water quality was badly polluted and fell in class V of the Interim National Water Quality Standards. The hydrographs and pollutographs for both catchments showed rapid increases and decreases equally rapidly. Most pollutants were diluted as storm events progress. In most cases, the peak concentrations preceded the peak runoff. This suggests that the pollutants were of short distant sources/origins and the bulk of the pollutant mass arrived at the catchment's outlet much faster than the runoff itself. For the hysteresis loop, both catchments showed most of the parameters were characterized by clockwise hysteresis. Only a few plots were exhibited counterclockwise and figure eight hysteresis loop. The relative strength of the first flush for the commercial catchment was P> COD>SS> NO_3-N> NO_2-N> BOD_5> NH_3-N whereas for the residential catchment was SS> COD> BOD_5> NH_3-N> P> NO_3-N> NO_2-N. The loadings were higher in the commercial than in the residential catchment and this was attributed to a greater runoff volume per unit area and higher Event Mean Concentration (EMC) in the former. Detail calibration and validation of Storm Water Management Model (SWMM) for modeling water quantity and quality were discussed. The simulation results, evaluated in terms of runoff depth, peak flow and the hydrograph shapes, were satisfactorily. For the water quality modeling, the simulation results were evaluated in terms of total load and peak load. SWMM can model SS load reasonably well for the residential catchment, but was not satisfactory for the commercial catchment.

ABSTRAK

Air larian bandar telah disampel di tadahan perumahan dan tadahan komersil di Skudai, Johor. Sampel dari 10 kejadian ribut bagi tadahan perumahan dan tujuh kejadian ribut bagi tadahan komersil telah dianalisis. Kualiti air larian ribut menunjukkan pelbagai variasi terutamanya untuk kepekatan SS, BOD_5 dan COD. Kepekatan NO_3-N, NO_2-N, NH_3-N dan P juga mencatatkan nilai yang tinggi. Sementara kepekatan Pb dalam kedua – dua tadahan adalah rendah (< 0.001 mg/l). Secara amnya, kualiti air dikategorikan di dalam kelas V berdasarkan Piawai Interim Kualiti Air Kebangsaan. Hidrograf dan pollutograf bagi kedua – dua tadahan menunjukkan kenaikan dan juga penurunan secara mendadak. Bahan cemar mengalami pencairan sepanjang kejadian ribut. Kebanyakan ribut, menunjukkan kepekatan maksimum berlaku lebih awal berbanding air larian puncak. Ini mencadangkan bahawa sumber bahan cemar adalah berdekatan dan sejumlah besar bahan cemar tiba di salur keluar tadahan lebih awal dari air larian itu sendiri. Bagi analisis‘hysteresis loop’, kebanyakan parameter di kedua- dua kawasan tadahan menunjukkan ‘clockwise loop’. Kekuatan relatif fenomena ‘first flush’ bagi tadahan komersil adalah P> COD> SS> NO_3-N> NO_2-N> BOD_5> NH_3-N sementara bagi tadahan perumahan: SS> COD> BOD_5> NH_3-N> P> NO_3-N> NO_2-N. Beban bahan cemar di tadahan komersil adalah lebih tinggi berbanding di tadahan perumahan. Ini disebabkan isipadu air larian per unit luas dan ‘Event Mean Concentration’ yang lebih besar di tadahan komersial. Kalibrasi dan validasi menggunakan SWMM bagi pemodelan kuantiti dan kualiti air dibincangkan secara terperinci. Keputusan simulasi dinilai dari segi kedalaman air larian, aliran puncak dan bentuk hidrograf. SWMM memberi keputusan yang memuaskan untuk proses kalibrasi dan validasi. Sementara itu, bagi pemodelan kualiti air, keputusan simulasi dinilai dari segi jumlah beban dan beban puncak. Beban SS dapat dimodel dengan baik menggunakan SWMM bagi tadahan perumahan tetapi tidak begitu memuaskan bagi tadahan komersil.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS/ ABBREVIATIONS

ALD	-	Absolute Load Difference
ARE	-	Absolute Relative Error
EMC	-	Event Mean Concentratotion
F	-	Dimensionless cumulative runoff volume
FF	-	First Flush
Fp	-	Infiltration capacity
K_w	-	washoff coefficient
L	-	Dimensionless cumulative pollutant mass
M	-	Mass
R	-	Runoff rate
RE	-	Relative Error
RLD	-	Relative Load Difference
Q_o	-	Observed discharges
Q_s	-	Simulated discharges
V	-	Volume

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the research

Pollution has been defined as changes in the physical, chemical or biological quality of the resources (air, land and or water) that is injurious to the existing, intended or potential uses of the resource (Novotny and Chesters, 1981). The sources or causes of pollution can be classified as either point sources (PS) or non-point sources (NPS) of pollution. Point sources of pollution are defined as pollutants that enter the transport routes at discrete, identifiable locations and that can usually be measured. Non point sources are defined as diffuse, water flows on the surface dissolving and washing away pollutants and soil sediments along its path and finally discharging into receiving waters (Stevenson and Wyman, 1991; Taebi and Droste, 2004). There are several general characteristics that describe non point source pollution;

i) NPS discharges enter surface waters in a diffuse manner and at intermittent intervals that are related mostly to that occurrence of meteorological events

ii) Pollution arises over an extensive area of land and is in transit overland before it reaches surface waters

iii) Generally, NPS cannot be monitored at their point of origin and their exact source is difficult to trace

iv) Elimination or control of pollutants must be directed at specific sites

v) NPS pollutants cannot be measured in terms of effluent limitations

Several major factors have severely disrupted the environmental (ecological) balance, resulting in accelerated increases of nonpoint sources pollution (Novotny and Olem, 1994). They are

- population increase (sometimes termed explosion) especially in developing countries
- land-use transformation and conversion of land to intensive agriculture and increased use of chemicals to sustain high agricultural yield
- urbanization and industrialization
- increased living standard, resulting in an increased per capita use of natural resources and increasing waste generation

There are various types of diffuse sources of pollution, but the ones that are most common and regarded as having the most significant impact are agriculture (mainly nutrients and pesticides), transport (road, air, shipping), atmospheric deposition (especially on lakes and the sea), leaching and corrosion of building materials and consumer products, urban and industrial site run-off, storm water and forestry activities (Moxon, 1998). Also, some non-agricultural land use (e.g. golf courses) can be a significant contribution for nonpoint pollution source (Evans and Nizeyimana, 1998). Due to complex modes of transport and site-specific characteristics, NPS pollutants are generally more difficult to control compared to point sources. Because of the difficulty to quantify and understand the processes that contribute to pollutant generation, transport and deposition, the effective management of non-point source control is complex and always involved non-standard local boundaries. In addition the cost involved is high whereas the benefits are often not obvious.

Among non point sources, urban stormwater runoff was reported as a major contributor to the pollution of many receiving waters (Saget *et al.*, 1996; Appel and Hudak, 2001; Brezonik and Stadelmann, 2002; Buffleben et al., 2002; Lee *et al.*, 2004). The quantity and quality of stormwater runoff from urban areas are influenced by many factors including human activities, meteorological variables and catchment characteristics. The meteorological variables include rainfall, temperature, wind and inter event periods, whereas the catchment characteristic include catchment area, topography, landuse, soil types and conditions, population density, drainage systems and waste disposal practices (Driver and Tasker, 1990).

1.2 Statement of the problem

Typically, there are two main impacts of urbanization. First the hydrology is modified causing more rapid flow path and the second, increase of human activities that adds pollutants. Construction of roads and buildings reduce the vegetated area and increase the catchment's imperviousness, while the groundwater recharge is reduced (Whipple, 1983; Lazaro, 1990). These often lead to enhancement of overland flow, greater peakflow with a shorter time to peak and decrease base flow. In addition, rapid population growth and land disturbance generate significant sources of contaminants especially from residential and industrial areas. Ineffective handling of urban wastewater is quite common and results in adverse environmental problems (Bedient *et al.*, 1978; Lee *et al.*, 1996).

The more rapid hydrological pathway and readily available sources of pollutants are responsible for the quality degradation of many receiving water systems (Petry *et al.*, 2002; Pieterse *et al.*, 2003; Taebi and Droste, 2004). Numerous studies on urban runoff quality conducted in different parts of the world over recent decades have shown that runoff can carry relatively high concentrations of a variety of pollutants. In the early stages of runoff, the land surfaces, especially the impervious surfaces like streets and parking areas, as well as solids accumulated in the collection system during the antecedent dry weather period, are flushed by stormwater. Normally, the velocity of the flow is high in urban drainage systems so that the runoff is able to transport higher volume of sediments. In small catchments, this can transport large loading of pollutants in the form of a first flush.

The loadings and concentrations of suspended solids, nutrients and other contaminants are much higher in urban stormwater runoff than in runoff from unimpaired and rural areas (Sartor and Boyd, 1972; Vaze, 2002). These pollutants are transported into water bodies, such as lakes and rivers, especially during rainy season and may lead to eutrophication. Nitrogen in the form of ammoniacal-N and nitrate, and phosphorus as orthophosphates are readily available for plant growth. This could lead to algal blooms and excessive macrophytic growth and causing depletion of dissolved oxygen upon death and decay. The long term effects would include eutrophication, sedimentation of lakes and rivers, threatening habitats, losses of biodiversity, channel constriction and more frequent flooding.

The existence of the first flush of pollutants provides an opportunity for stormwater managers and engineers to control water pollution in an economic and efficient way. If most of the urban-surface pollutant load were transported during the initial phase of a storm, then a rather small volume of runoff storage would be needed to treat and remove the bulk of urban-surface pollutants. As a result, controlling the first flush has become the most practiced criterion for the design of stormwater treatment facilities; and first flush collection systems are employed to capture and isolate this most polluted runoff, with subsequent runoff being diverted directly to the stormwater system and finally into the receiving environment (Deng, 2005).

Concern over continuous degradation of urban runoff quality, emerged only recently as opposed to quantity aspects of flood mitigation. Unlike in the developed countries especially the US, Japan and the EC where funding are more readily available, monitoring of urban runoff in the developing countries generally receive less priority. This despite the fact that the latter are experiencing much more severe water quality problems. A comprehensive understanding on the processes of contaminants transport and loadings are crucial for formulating effective urban water and waste-water management strategies (Brezonik and Stadelmann, 2002). To date coordinated and comprehensive study on these aspects, particularly in tropical region, is still scarce.

Systematic evaluation of non point source impacts often requires water quality models. Models provide a predictive ability, which enables potentially expensive water quality management options to be evaluated and tested prior to their implementation. This is far more cost-effective by considerably reduce financial resources required for data collection and provides a systematic and rigorous framework for examining water quality impacts. In this study the Storm Water Management Model (SWMM) has been selected. This model performs both continuous and single event simulation. The model can also simulate backwater, surcharging, pressure flow, looped connections and has a variety of options for quality simulations, including traditional buildup and wash off formulations (Novotny and Olem, 1994).

A major advantage of using simulations model is the insight gained by gathering and organizing data required as inputs to the mathematical algorithms that made up the overall model system. Besides, many alternative schemes for development and flood control can be quickly tested and compared with simulation models (Huber and Bedient, 1992).

1.3 Objectives

The overall aim of this study is to gain a better understanding on the extent of non-point source pollution in developed urban catchments. Specifically the study will:-

i) Quantify loadings of major pollution from selected urban catchments
ii) Investigate the influence of hydrological regime (rainfall and runoff) on the pattern of pollutant loading
iii) Simulate the NPS pollution loadings using Storm Water Management Model (SWMM)

1.4 Scope of work

In order to archive the above objectives the following tasks were carried out:-

1) Selecting two small catchments representing residential and commercial catchment;
2) Measuring discharge and water level during low flow and storm flow;
3) Baseflow and stormflow sampling of water;
4) Labarotary analysis of Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Suspended Solids (SS), Nutrients (NO_3-N, NO_2-N, NH_3-N and P) and heavy metal (Pb);
5) Data analysis including Event Mean Concentration (EMC), pollutant loading, statistical analysis, box plot analysis, hysteresis loops and first flush analysis;
6) Simulation of NPS using XP-SWMM model in terms of water quantity and quality

6.2 Recommendations

In view of the large temporal and spatial variations of EMC value, a more intensive stormwater monitoring program is recommended. Preferably, the sampling design must include various storm size and to be replicated for different land-use types. Consideration on the antecedent conditions of the catchment is also crucial for a better understanding of the pollutant transport mechanism.

An important issue to be addressed is the influence of length of dry period and rainfall intensity on the water quality and pollution loading. Continuous water quality monitoring programme with reliable rainfall data, though expensive, is crucial in getting reliable data for estimating pollutant loading.

Data on pollutant buildup on catchment surfaces is extremely lacking in the tropics. More work is necessary in this line to improve water quality modeling using SWMM. In addition, data of washoff processes are also essential during calibration of the pollutographs.

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