



UNIVERSITI PUTRA MALAYSIA

***SEDIMENTATION IN STORMWATER MANAGEMENT AND ROAD
TUNNEL HOLDING POND***

JEREMY ANDY ANAK DOMINIC DAUNG

FPAS 2016 8



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TUNNEL HOLDING POND**

By

JEREMY ANDY ANAK DOMINIC DAUNG

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Master of Science**

August 2016

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirement for the degree of Master of Science

SEDIMENTATION IN STORMWATER MANAGEMENT AND ROAD TUNNEL HOLDING POND

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August 2016

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The Berembang holding pond of the Stormwater Management and Road Tunnel (SMART), located in the state Selangor, Malaysia, is designed to store floodwater diverted from the confluence of the Klang and Ampang rivers during major storm events. The sub-catchments of the Klang and Ampang Rivers are among two sub-catchments that drain into the main Klang River. The excess floodwater diverted from the confluence of the Klang and Ampang Rivers were detained in the holding pond before it is released through a bypass tunnel at the Desa Park detention pond. The diverted floodwater from the river confluence carries a high amount of suspended sediment and organic debris that will continuously settle, and, consequently, reduce the capacity of the holding pond storage. The information on sediment concentration discharge relationship and the factors affecting the supply of sediment is imperative in providing qualitative insights and quantitative data for the development and evaluation of annual suspended sediment load estimation models. Deposited bed materials comprising a high composition of cohesive or finer-grained sediment generally constitutes a relatively higher contaminant level than a coarser-grain-sized bed sediment. Therefore, the spatial distribution data of the deposited sediment properties can be used implicitly to distinguish contaminated bed surface areas. The aim of this research is to determine the relationships between the rainfall, discharge and suspended sediment transport and the variations thereof during the dry and wet periods in a tropical urban catchment, to statistically examine the spatial variation of *in situ* wet sediment bulk density profiles of deposited sediment, to determine the sand mass and organic matter distribution based on *in situ* measured wet sediment bulk density profile data, simulated water velocity data of diverted flood water and deposition thickness results of a single grain-sized particle in the Berembang stormwater holding pond. Factors that have a major influence on the suspended sediment yields during both the dry and wet periods were examined. The clockwise and counter-clockwise hysteresis loops occurred during the dry period can be described as events with moderate total rainfall, rainfall intensity, average discharge and suspended sediment load. The extra

sediment load during the dry period is a consequence of the removal of the sediment produced during the interstorm period by the first flush of water and the different time period between events. The complex loop events in the wet period occur with moderate moisture condition generated the highest suspended sediment load, which can be associated with the erosion caused by the high discharge flow at random sediment contributing areas. Two-way analysis of variance (ANOVA) was applied to investigate the significant effects of spatial sampling locations and depth variation on *in situ* wet sediment bulk density profiles of deposited sediment in the holding pond. Fifty-three sampling locations were hierarchically clustered into two groups, based on wet sediment bulk density profile data measured at six depth levels with 5 cm increments. The wet sediment bulk densities are significantly affected by depth variations at both sampling location groups. The sampling location groups have a significant main effect on the wet sediment bulk densities. There is a significant interaction effect between the sampling location groups and the depth levels on the mean wet sediment bulk densities. The effect of depth variations on the wet sediment bulk density measured at sampling location group one and two are significantly different. The measured wet sediment bulk densities indicate a stronger relationship with depth variation compared to both sampling location groups. The consolidation process rate from 5 to 10 cm depth level in group one sampling location is relatively higher than that of the group two sampling areas. Discriminant analysis (DA) was applied to spatially distinguish areas of relatively low and high composition of sand mass and organic matter content based on *in situ* measured wet sediment bulk density profile data, the simulated depth average water velocity variations and deposition thickness results of a single grain-sized particle ($d_{50} = 0.375$ mm). The spatial distribution sand and organic matter composition of surface sediment were predicted using Fisher's linear discriminant functions. Based on *in situ* measured wet sediment bulk density profile data, the model correctly predicts 88.9 and 71.4% of the sampling locations consisting of relatively low and high sand weight percentages, respectively. For organic matter distribution, the model correctly predicts 70.0 and 86.7% of sampling locations consisting of relatively low and high organic matter percentage, respectively. Wet sediment bulk density profile measured at more than 15 cm depth levels indicates better predictor for the distribution of sand mass and organic matter composition area. Based on the simulated depth average water velocity variations, the model correctly predicts 88.9% and 100.0% of sampling locations consisting of relatively high and low sand mass percentage, respectively, with the cross-validated classification showing that, overall, 82.8% are correctly classified. Based on simulated deposition thickness results of a single grain-sized particle, the discriminant function significantly differentiated the two sampling location group areas composed of a relatively high and low sand mass content with the classification results showing that the model correctly predicts 66.7% and 100.0% of the surface sediment sampling locations consisting of relatively high and low sand weight percentage, respectively. As a conclusion, the suspended sediment loads generated during the dry period are highly influenced by the rainfall intensity. During the wet period, the suspended sediment loads are related to the total rainfall and storm event duration. Generally, the spatial variation in the wet sediment bulk density in the sampling location groups is predominantly influenced by the sediment grain size, consolidation rate and flow velocity variations in the deposited sediment. Fisher's linear discriminant functions can

be used to spatial classified sand mass and organic matter composition based on in situ measured wet sediment bulk density profile data, the simulated depth average water velocity variations and deposition thickness results of a single grain-sized particle.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Sarjana Sains

SEDIMENTASI DI KOLAM TAHANAN *STORMWATER MANAGEMENT AND ROAD TUNNEL*

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Kolam tahanan Berembang, *Stormwater Management and Road Tunnel* (SMART), terletak di negeri Selangor, Malaysia, direka bentuk untuk menampung air banjir yang dilencongkan dari pertemuan sungai Klang dan Ampang semasa *event* utama. Sub-tadahan sungai Klang dan Ampang adalah di antara dua sub-tadahan yang mengalir ke sungai Klang utama. Lebihan air banjir yang dilencongkan dari pertemuan sungai Klang dan Ampang akan ditakung di kolam tahanan tersebut sebelum ia dikeluarkan melalui terowong pintasan ke kolam takungan simpanan Taman Desa. Air banjir yang dilencongkan dari pertemuan sungai tersebut mengandungi sedimen terampai dan serpihan organik yang tinggi yang akan mendap secara berterusan dan, akhirnya, mengurangkan kapasiti simpanan kolam tahanan tersebut. Maklumat berkaitan hubungan konsentration sedimen luahan dan faktor yang mempengaruhi sumber sedimen adalah penting dalam persediaan data kuantitatif dan kualitatif bagi tujuan pembangunan dan penilaian model muatan anggaran sedimen terampai tahunan. Bahan dasar mendapan yang terdiri daripada sedimen bersaiz butiran halus berkomposisi tinggi biasanya mengandungi aras bahan cemar yang secara relatifnya lebih tinggi berbanding dengan sedimen dasar yang bersaiz butiran lebih kasar. Oleh yang demikian, data taburan spatial ciri-ciri sedimen termendap boleh diguna secara tidak langsung untuk membezakan kawasan dasar permukaan yang tercemar. Kajian ini bertujuan untuk menentukan hubungan di antara hujan, luahan dan pengangkutan sedimen terampai dan variasi semasa musim kering dan hujan di kawasan tadahan tropika, menilai secara statistik variasi spatial profil ketumpatan pukal sedimen basah *in situ* bagi sedimen termendap, menentukan taburan jisim pasir dan bahan organik berdasarkan profil data ketumpatan pukal sedimen basah yang diukur secara *in situ*, simulasi data halaju air banjir yang dilencongkan dan ketebalan mendapan satu saiz butiran di dalam kolam tahanan Berembang. Faktor yang mempunyai pengaruh utama ke atas muatan sedimen terampai di sepanjang kedua-dua tempoh musim kering dan hujan juga akan dinilai. Gelung hysteresis arah jam dan lawan arah jam yang berlaku semasa musim kering boleh diterangkan sebagai *event* yang berlaku dengan jumlah hujan, kekerapan

hujan, luahan purata dan muatan sedimen terampai yang sederhana. Muatan sedimen lebih semasa musim kering adalah kesan daripada sedimen yang dihasilkan semasa pengaliran air pertama dan perbezaan tempoh masa di antara event. Event berlingkung kompleks yang terjadi semasa musim hujan dengan keadaan kelembapan yang sederhana, menghasilkan muatan sedimen terampai yang tertinggi, boleh dikaitkan dengan hakisan yang disebabkan oleh aliran luahan yang tinggi di kawasan yang menyumbang sedimen secara rawak. Analisis varian dua-hala (ANOVA) telah diaplikasi untuk menyiasat kesan signifikan lokasi persampelan spatial dan variasi kedalaman terhadap profil *in situ* ketumpatan pukal sedimen basah. Lima puluh tiga lokasi persampelan telah di kluster secara hierarki kepada dua kumpulan, berdasarkan data profil ketumpatan pukal sedimen basah yang diukur pada enam aras kedalaman dengan peningkatan setiap 5 cm. Ketumpatan pukal sedimen basah dipengaruhi secara signifikan oleh variasi kedalaman pada kedua-dua kumpulan lokasi persampelan. Kedua-dua kumpulan lokasi persampelan mempunyai kesan utama yang signifikan ke atas ketumpatan pukal sedimen basah. Terdapat kesan interaksi yang signifikan di antara kumpulan lokasi persampelan dan aras kedalaman ke atas ketumpatan pukal purata sedimen basah. Ketumpatan pukal sedimen basah yang diukur menunjukkan hubungan dengan variasi kedalaman adalah lebih kuat berbanding dengan kedua-dua kumpulan lokasi persampelan. Kadar proses konsolidasi dari aras kedalaman 5 hingga 10 cm bagi kumpulan lokasi persampelan satu adalah tinggi secara relatif berbanding dengan kawasan persampelan kumpulan dua. Analisis diskriminan telah digunakan untuk membezakan secara spatial kawasan yang secara relatifnya mempunyai komposisi jisim pasir dan bahan organik yang rendah dan tinggi, berdasarkan pengukuran *in situ* data profil ketumpatan pukal sediment basah, variasi bagi simulasi halaju air pada kedalaman purata dan ketebalan mendapan satu saiz butiran ($d_{50} = 0.375\text{mm}$). Taburan spatial komposisi pasir dan bahan organik pada sedimen permukaan diramal menggunakan fungsi diskriminan linear Fisher. Berdasarkan pengukuran *in situ* data profil ketumpatan pukal sedimen basah, model yang dihasilkan dapat meramalkan 88.9% dan 71.4% daripada lokasi-lokasi persampelan masing-masing secara relatifnya mengandungi peratusan berat pasir yang rendah dan tinggi. Untuk taburan bahan organik, model yang dihasilkan dapat meramal dengan betul 70.0% dan 86.7% daripada lokasi-lokasi persampelan masing-masing secara relatifnya mengandungi peratusan berat bahan organik yang rendah dan tinggi. Profil ketumpatan pukal sedimen basah yang diukur pada aras kedalaman lebih daripada 15 cm menunjukkan jangkaan kawasan bagi taburan jisim pasir dan komposisi bahan organik yang lebih baik. Berdasarkan simulasi variasi halaju air pada kedalaman purata, model yang terhasil meramalkan dengan betul 88.9% dan 100% daripada lokasi-lokasi persampelan, masing-masing secara relatifnya mengandungi peratusan jisim pasir yang tinggi dan rendah, dengan pengelasan validasi silang menunjukkan secara keseluruhannya 82.8% dikelaskan dengan betul. Berdasarkan hasil simulasi ketebalan mendapan satu saiz butiran, fungsi discriminant dapat membezakan dengan signifikan dua kawasan lokasi persampelan yang masing-masing secara relatifnya mengandungi jisim pasir yang tinggi dan rendah, dengan hasil pengelasan menunjukkan model meramal dengan betul 66.7% dan 100.0% lokasi persampelan sedimen permukaan yang masing-masing mengandungi secara relatifnya peratusan berat pasir yang tinggi dan rendah. Sebagai kesimpulan,

muatan sedimen terampai yang terhasil di sepanjang tempoh musim kering adalah dipengaruhi oleh kekerapan hujan. Di sepanjang tempoh musim hujan, muatan sedimen terampai mempunyai kaitan dengan jumlah hujan dan tempoh *event*. Secara umumnya, variasi spatial ketumpatan sedimen basah pukal bagi kedua-dua kumpulan lokasi persampelan adalah dipengaruhi oleh saiz butiran sedimen, kadar konsolidasi dan variasi halaju aliran pada sedimen termendap. Fungsi diskriminan linear Fisher boleh diguna untuk mengelaskan secara spatial komposisi jisim pasir dan bahan organik berdasarkan data profil ketumpatan pukal sedimen basah yang diukur secara *in situ*, variasi bagi simulasi halaju air pada kedalaman purata dan ketebalan mendapan satu saiz butiran.



ACKNOWLEDGEMENTS

I would like to thank all the people who help and supported me during my study period.

Firstly, I wish to express my sincere thanks to my supervisor, Associate Professor Dr. Ahmad Zaharin Aris for his guidance, support and encouragement throughout my studentship. To my co-supervisor, Prof. Wan Nor Azmin Sulaiman for his guidance and comments, to Associate Professor Dr. Mohd Kamil Yusoff and Associate Professor Hafizan Juahir for their knowledge sharing, to my group manager/co-supervisor Dr. Wan Zakaria Wan Muhd Tahir for his support and initiation of this project.

Secondly, I wish to thank the Drainage and Irrigation Department of Malaysia and SMART Control Centre for their cooperation and support in this project.

Thirdly, I would like to express my gratitude to colleagues, Kamaruzaman Mamat, Rohaimah Demanah, Lakam Mejus, Juhari Mohd. Yusof, Mod. Omar and Saiful Anuar Tajol Aripin for their cooperation and assistance in the field.

Last but not least, I would like to express my appreciation to my wife Emme for her patient and support.

I certify that a Thesis Examination Committee has met on 26 August 2016 to conduct the final examination of Jeremy Andy anak Dominic Daung on his thesis entitled "Sedimentation in Stormwater Management and Road Tunnel Holding Pond" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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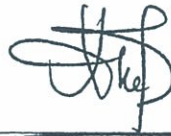
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LIST OF ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
ANFIS	Adaptive Neuro-Fuzzy Inference System
ANOVA	Analysis of variance
AP1d	Antecedent rainfall depths for periods of 1 day prior to the event
AP1hr	Antecedent rainfall depths for periods of 1 hour prior to the event
AP21d	Antecedent rainfall depths for periods 21 days prior to the event
AP7d	Antecedent rainfall depths for periods of 7 days prior to the event
DA	Discriminant Analysis
DID	Department of Irrigation and Drainage Malaysia
GM	Gieger Mouller
HACA	Hierarchical Agglomerative Cluster Analysis
HSD	Honest Significant Difference
IP	Mean rainfall intensity
IPmax	Maximum rainfall intensity
LOI	Loss of Sample Mass on Ignition
NTU	Nephelometric Turbidity Units
OBS	Optical Backscatter Sensor
PAH	Aromatic Hydrocarbons
PCA	Principal Component Analysis
PSU	Practical Salinity Unit
Pt	Total rainfall
Qav	Mean discharge
Qb	Baseflow
Qmax	Peak discharge
SMART	Stormwater Management and Road Tunnel
SSC	Suspended Sediment Concentration
SSCav	Mean Suspended Sediment Concentration
SSCmax	Maximum Suspended Sediment Concentration
SSt,	Suspended sediment load of the event
WQI	Water Quality Index

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Holding ponds are part of good urban stormwater management to prevent downstream areas from flooding by temporarily storing the stormwater runoff and increasing the river water quality through the deposition of suspended solids and associated pollutants. The construction of ponds is a common control measure to reduce or avoid damage caused by floods (Verstraeten and Poesen, 1999). River water diverted into stormwater holding ponds carries a large amount of sediment, caused by riverbank erosion and upstream anthropogenic events, for instance, corrosion of building materials, erosion of road materials and other activities. The high amount of sediment and organic debris in the diverted flood water will continuously settle, and, consequently, reduce the capacity of the holding pond storage.

The variability of suspended sediment discharge is a consequence of the many factors that interact in controlling the production and transport of sediment during a specific event, such as sediment availability (Regüés et al., 2000), rainfall and discharge characteristics (Nadal-Romero et al., 2008b), soil moisture and antecedent rainfall (Seeger et al., 2004), land use (Casalí et al., 2010) and soil surface conditions, and the distance between the sediment source and the watershed outlet (Steege et al., 2000). The sediment discharge relationship in a watershed is predominantly affected by climate conditions (Vega et al., 1998; Singh et al., 2004). In particular, many studies have demonstrated that sediment discharge relationship varies significantly between seasons (e.g. Gregory and Walling, 1973; Van Dijk and Kwaad, 1996; Steege et al., 2000; Gallart et al., 2002; Casalí et al., 2008; Nadal-Romero 2008a; Lana-Renault and Regüés, 2009).

The bottom sediments are a mixture of solid particles, water, and gas (Lick, 2009). The soil bulk density is represented by the ratio between the soil mass and the soil volume (Blake and Hartge, 1986). The high variability in the dry sediment bulk densities is influenced by the texture and organic content of the sediment as well as the hydrologic conditions (Verstraeten and Poesen, 2001). The variations in the wet bulk density with depth levels are influenced by the different grain size composition of the sediment between depth levels. Sediment composed of finer grained material shows a relatively lower bulk density than coarser grained sediment (Verstraeten and Poesen, 2001; Lick, 2009). Studies have shown that particulate-bound pollutants are predominantly attached to smaller sized particles (Pettersson 2002; Greb and Bannerman 1997; Sansalone and Buchberger 1997). Thus, bed materials comprising a high composition of cohesive or finer-grained sediment generally constitute a relatively higher contaminant level than coarser-grained size sediment. This indicates that the physical structure of the sediments and the leaching of

particles containing contaminants are considerably affected by the presence of organic matter. Therefore, in a stormwater holding pond, a preliminary study is essential to spatially identify the most likely contaminated deposited sediment areas prior to conducting any dredging activities.

1.2 Statement of Research Problem

The sub-catchments of the Klang and Ampang Rivers cover a total area of approximately 121 km², located in the upper part of the Klang River basin, in the State of Selangor, north-east of the city of Kuala Lumpur and south-west of Peninsular Malaysia. The main river is the Klang River, while the Ampang River is a tributary. The northern part of the sub-catchments is mostly covered by forest while the southern part consists mainly of forest and urban areas, with very little agricultural land. The weather conditions are characterised by different seasons: north-east monsoon from December to March, transitional period from April to May, south-west monsoon from June to September and transitional period from October to November. The mean annual rainfall is about 2,400 mm. The annual mean temperature is 27°C with the monthly mean temperature varying from maximum 32°C to minimum 23°C.

Due to the development and siltation processes, the current capacity of the Klang River in the city centre of Kuala Lumpur is incapable of accommodating the excess flood flow, and, therefore overflows the riverbanks causing flash floods in the city centre. For that reason, a tunnel was built to allow floodwater to bypass the river confluence. The Berembang holding pond is one of the main components of the Stormwater Management and Road Tunnel (SMART) project, located at the Department of Drainage and Irrigation (DID) of Malaysia, SMART control centre, Selangor, which is part of the overall Kuala Lumpur Flood Mitigation System. It is designed to detain excess floodwater diverted from the confluence of the Klang and Ampang Rivers during major storm events before it is released through a bypass tunnel at the Desa Park detention pond downstream of the Kuala Lumpur city centre.

The studies on the relationship between discharge and suspended sediment concentration in tropical urban catchment, particularly in this sub-catchment region are still lack of information. It is essential to understanding the sediment concentration discharge relationship and the factors affecting the supply of sediment in different tropical weather conditions. The information provides qualitative insights and quantitative data for the development and evaluation of annual suspended sediment load estimation models. This will support the development of strategies for sustainable catchment management as part of an effective prevention program to reduce the sediment input in the Klang River system.

Floodwater diverted from river channels carries a high amount of sediment and organic debris that will continuously settle, and, consequently, reduce the capacity of the holding pond storage. The sediment deposition process depends on the particle fall velocity and the hydraulic characteristics of the suspending medium.

Measurement of the loose accumulation of sediment deposition thickness using core sediment samples tends to underestimate the thickness of the sediment due to compaction of the sediment core during sampling, the loss during the pulling process and removal of the sample tube from the sampler.

Polluted urban stormwater contains a number of hazardous constituents, such as heavy metals and aromatic hydrocarbons (PAH). The extent of contamination of the deposited sediment in an urban stormwater holding pond can be initially related based on the particle grain size distribution of the bed material.

Particulate-bound pollutants are predominantly attached to smaller-sized particles. Thus, bed materials comprising a high composition of cohesive or finer-grained sediment generally constitutes a relatively higher contaminant level than a coarser-grain-sized bed sediment. Sediment deposits have a negative impact on the hydrology and ecology of rivers and store sediment-bound contaminants, such as heavy metals, pesticides, nutrients, and pathogenic bacteria.

The spatial distribution data of the deposited sand mass composition on the bed surface can be used implicitly to distinguish areas of relatively different contamination levels. Dredged bed material from areas consisting of a relatively higher sand mass composition that are less contaminated can be treated differently than highly contaminated bed sediment of a relatively lower sand mass composition.

1.3 Research Questions

- a. What is the relationships between the rainfall, discharge and suspended sediment transport and the variations thereof during the dry and wet periods in tropical urban catchment?
- b. What is the hysteresis types in the suspended sediment concentration/discharge relationships of individual flood events?
- c. What is the relationship between the types of hysteretic loop, and the hydrological and sediment responses?
- d. How does the deposited wet sediment bulk density spatially varies in the holding pond?
- e. How does the deposited bed material spatially distributed in the holding pond?

1.4 General Objectives

The general objective of this research is to determine the relationship between water-sediment discharge and spatial distribution of surface sediment properties in a tropical urban stormwater holding pond.

1.4.1 Specific Objectives

1. to analyse the relationships between the rainfall, discharge and suspended sediment transport and the variations thereof during the dry and wet periods in tropical urban catchment (chapter 4)
2. to assess the spatial variation of *in situ* wet sediment bulk density profiles in an urban stormwater holding pond using a statistical approach (chapter 5)
3. to determine the sand mass and organic matter distribution in an urban stormwater holding pond using *in situ* measured wet sediment bulk density profile data (chapter 6)
4. to predict the sand mass distribution in an urban stormwater holding pond using simulated water velocity data of diverted flood water (chapter 7)
5. to predict the sand mass distribution in an urban stormwater holding pond using simulated deposition thickness results of a single grain-sized particle (chapter 8)

1.5 Significance of Studies

The study contributes to a better understanding of the sediment concentration discharge relationship and the factors affecting the supply of sediment in different tropical weather conditions.

The output of this study can be applied as a procedure to forecast the sedimentation pattern, grain size distribution and deposited sediment mass based on the *in situ* wet sediment bulk sediment density profile data for future maintenance of an urban stormwater holding pond. The contaminated areas of deposited sediment can be spatially distinguished prior to conducting any dredging activities.

A relatively low wet sediment bulk density can be associated with the presence of voids as a result of organic matter decomposition in finer-grained sediment. Based on these relationships, the *in situ* wet sediment bulk density measurement of deposited bed sediment can be applied initially to spatially identify and categorise areas of relatively high and low composition of sand mass and organic matter content. Consequently, dredged bed material consisting of relatively high sand mass composition with low organic matter content can be treated differently than those comprising relatively low sand mass with high organic matter content.

The discriminant function for the prediction of sand mass distribution in an urban stormwater holding pond can be determined using simulated depth average velocity data of diverted flood water and deposition thickness variation of single grain-sized particle.

The spatial distribution data of the deposited sand mass composition on the bed surface can be used implicitly to distinguish areas of relatively different contamination levels. Thus, sampling locations of highly contaminated sediment for environmental monitoring can be determined explicitly. Deposited sediment consisting of a relatively higher sand mass composition can be treated differently than a lower sand mass composition region. Therefore, by doing the segregation process, the treatment cost of the dredge material can be substantially reduced.

1.6 Thesis Outline

This thesis consists of nine chapters. Chapter one introduces the background of the study, the statement of the research problems, the general and specific objectives, research hypothesis and significance of the study. Chapter two presents the literature review. Chapter three presents the methodology of the study. Chapter four presents the study on the relationship between the rainfall, discharge and suspended sediment transport and its variations during the dry and wet periods in tropical sub-catchments using principal component analysis. Chapter five discuss the applications of two-way ANOVA. Chapter six presents the application of discriminant analysis to assess whether the measured wet sediment bulk density profile data could distinguish areas of relatively low and high composition of sand mass and organic matter content. Chapter seven and eight introduces the application of discriminant analysis to derive the classification function to spatially determine the sand mass distribution in an urban stormwater holding pond using simulated water velocity variations and deposition thickness results of a single grain-sized particle. Chapter nine summaries the entire thesis.

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LIST OF PUBLICATIONS

Dominic JA, Aris AZ and Sulaiman WNA. Factors Controlling the Suspended Sediment Yield During Rainfall Events of Dry and Wet Weather Conditions in A Tropical Urban Catchment. Published in Water Resources Management 29:4519-4538 (Accepted in 20 July 2015) I.F:2.600

Dominic JA, Aris AZ and Sulaiman WNA and Tahir WZWM. Prediction of sand mass and organic matter distribution via *in situ* measured wet sediment bulk density profile. Submitted to Urban Water Journal (under review). NURW-2016-0119

Dominic JA, Aris AZ, Sulaiman WNA and Tahir WZWM. Discriminant analysis for the prediction of sand mass distribution in an urban stormwater holding pond using simulated depth average flow velocity data. Published in Environmental Monitoring and Assessment 188:191 DOI: 10.1007/s10661-016-5192-8 (Accepted in 16 February 2016) I.F:1.679

Dominic JA, Aris AZ, Sulaiman WNA and Tahir WZWM. Discriminant analysis for the prediction of sand mass distribution in an urban stormwater holding pond using simulated deposition thickness variation of single grain-sized particle. Published in Environmental Earth Sciences 75:812 DOI 10.1007/s12665-016-5641-2 (Accepted in 16 April 2016) I.F:1.765



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