JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 19 2011

DETERMINATION OF DETENTION POND SEDIMENT LOADS USING MONTE CARLO SIMULATION, MALAYSIA

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Suspended sediment is a pollutant of primary concern and can cause adverse environmental effects. Detention pond structures become a practical approach to handle this problem. But if too much suspended sediment settles in a stormwater detention pond, it can adversely affect the stormwater detention function. This study was carried out to obtain the maximum probability of occurrence of sediment loads and depth in a detention pond using Monte Carlo simulation. An existing detention pond situated in Universiti Teknologi Malaysia, UTM Skudai, Johor Bahru, was selected. It is shown that sedimentation may not seriously affect the operation of the detention pond for the next 100 years.

INTRODUCTION

Detention ponds are one of the most popular methods used to solve water pollution by suspended and bed load sediment problems. Basically, detention ponds provide the three basic functions that are flood control, water quality enhancement and ecological and aesthetic value (Robert, 2002).

But if too much suspended sediment settles in detention ponds, it can adversely affect detention pond functions. Therefore to ensure that detention ponds work effectively, the sediment, suspended solids, and any materials that collect in the ponds should be removed. In this way it is possible to maximize the efficiency of the pond operation and reduce the risk of water pollution. This study will assess the risks that are associated with the operational activities of a detention pond located at Universiti Teknologi Malaysia, Skudai Johor, related to sediment accumulation loads and depth. Simulation analysis will be used as the simplest model used to forecast the collected data.

There are three main objective of this study. They are:

a. To examine the relationship between flow discharge and suspended sediment rate using on-site data collection.

b. To forecast accumulated sediment loads and depth from the modified universal soil loss equation (MUSLE).

c. To analyse the uncertainties and risk of sediment loads and depths over 10 to 100 years using Monte Carlo simulation combined with a normal distribution.

LITERATURE REVIEW

The land surface of the earth is in a continuous state of denudation through the chain of processes of erosion-transportation-deposition. The terminal point of land surface denudation is final deposition of sediment in oceans and seas (Fleming, 1977). For erosion, it defined as the mechanism of detachment of sediment particles and other material from the land surface. Erosion takes place by the action of wind, precipitation (water), gravity, glaciers, rivers, frost, ice and man (Fleming, 1977). Two main types of erosion have been recognized, that is geologic erosion and accelerated erosion. After that, sediment transport is defined as the mechanism of transfer of sediment particles and other materials from a point of detachment to a new location on the land surface (Fleming, 1977). The several modes of transport of sediment load are wash load, contact load, saltation load, suspended load, bed load and solution load. Finally, deposition is defined as the reattachment of sediment particles and other materials to the land surface. Deposition takes place on hill slopes, valley floors, river channels, flood plains, lakes, lochs, reservoirs, estuaries, seas and oceans (Fleming, 1977; Steven et al., 1986). Sediment may cause severe damage depending on the amount, character, and place of deposition.

METHODOLOGY

Background of Study Area

The study area is located at Universiti Teknologi Malaysia campus, UTM Skudai, Johor Bahru. The catchment of the UTM area is about 11 km^2 (2718 acres) and it is separated into 10 sub basins. This study only focuses on the detention pond at sub basin 1 (31 acres or 125,800 m^2) known as Kolam Tahanan 1. The surface area for this pond is 3.36 acres or 13600 m^2.

Data Collection

There are three stations selected at the inlet and one station at the outlet of the pond for data collection. The field study was carried out three times. To get the flow discharge, the velocity of the flow must be measured first. The velocity was measured using a Swoffer 2100 at each station (JPS, 1976). There were two samples collected at each station near the inlet and four samples at station near the outlet of the detention pond.

Laboratory Test

The samples obtained from site are brought to the Environmental Laboratory for analysis. In the laboratory, the Total Suspended Solid (TSS) experiment was carried out to measure the sediment suspended concentrations. Calculation of TSS was made as follows:

Total suspended solid. TSS (mg/L) = ((A-B)x1000)/C (1)

where A is weight of filter and residue (mg), B is weight of filter (mg) and C is volume of sample filtered (mL).

Then, the conversion unit of mg/L to tons/day was calculated using Equation (2) (JPS, 1977):

Suspended Sediment Rate, Q_S (tons/day) = $P_m \, xS \, x \, q \, x \, 86400x10^{-6}$ (2)

where:

$$P_m = \frac{P_s}{(d_s - (Sx10^{-6})(d_s - d_w)} \text{ (tons/m}^3\text{)} \quad (3)$$

S = TSS concentration (mg/L)

q = flow discharge (m^3/s)

P_s @ d_s = bulk density of sediment = 2.65 tons/m^3

d_w = bulk density of water = 1 tons/m^3

86400= is conversion factor from seconds to day units

Then the accumulated sediment in the detention pond can be obtained from suspended sediment rate by applying the conversion factor as shown in Equation (4) (JPS, 1977):

Sediment depth, d(mm) = Q_sx 1/P_sx 1/A (4)

where:

Q_s = suspended sediment rate (tons/day)

P_s = bulk density of sediment (2.65 tons/m^3)

A = surface area of detention pond (13,607 m^2)

Estimating Sediment Yield Using The MUSLE Equation

As reported by Kenneth et al. (2003), Williams (1975) modified the Universal Soil Loss Equation (USLE) and developed the Modified Universal Soil Loss Equation (MUSLE) by replacing the rainfall energy factor in the USLE with a runoff energy factor in the MUSLE. The modification is based on the assumption that the total discharge rate resulting from a storm on the watershed depends on the duration, amount, and intensity of the storm.

The MUSLE equation is:

$$y = 11.8\ (Qxq_p)^{0.56}xKxCxPxLS \tag{5}$$

where:

y = sediment yield (tons)

Q = runoff volume (m^3)

q_p = peak runoff rate (m^3/s)

K = soil erodibility factor

C = dimensionless crop management factor

P = erosion control practice factor

LS = topographic factor, a combined dimensionless factor for slope length and slope gradient

11.8 = is conversion factor for metrics system

Regression Analysis

The prediction function based on regression analysis can be used to predict new values on a least-squares linear regression of the range of known data. Least-squares fit of the straight line to the graph of the response variable versus one predictor variable can be written as:

$$Y = mx + c \tag{6}$$

where Y is dependent variable, x is independent variable, m is slope of the graph and c is the y-intercept. In this study, the regression analysis used MUSLE equation analysis where the dependent variables are sediment load and sediment depth being forecast using rainfall data from 2000 until 2009. The linear equation obtained was used to forecast the next 100 years data from 2010 until 2109.

The Monte Carlo Simulation

The Monte Carlo method can be used to solve a wide range of physical and mathematical problems. For this study, the Monte Carlo simulation was applied by using the RiskAMP Monte Carlo Add-in installed in Microsoft Excel to run the simulation process. In this study, the normal distribution was applied because it is an easy method and needs simple parameters for the mean, μ and standard deviation, $ó$ for the distribution process (Irma, 2008). Besides that, the histogram and probability distribution functions can be quickly and automatically generated.

The function of this normal distribution used for this simulation is as follows:

$$\text{Normal Distribution in MCS, } f_x = \text{NormalValue}(\mu,\ ó) \tag{7}$$

From this simulation the histogram of the sample and the probability density function are obtained.

DATA ANALYSIS AND DISCUSSION

Flow Discharge Measurement

The velocity obtained was computed for flow discharge estimation. The velocity was measured using a Swoffer 2100 at each station located at the inlet and outlet of the pond. The average flow discharge at every station estimated for three days is shown in Table 1.

Sediment Suspended Concentrations Measurement and Suspended Sediment Rate

Table 1. Average value of flow discharge, Q.

Date	Flow Discharge, Q (m^3/s)	
	Inlet	Outlet
08/02/2010	0.00472	0.00252
22/02/2010	0.00460	0.00053
08/03/2010	0.01304	0.00281

The Total Suspended Solid (TSS) experiment was carried out at the Environmental Laboratory for sediment suspended concentration estimation. There were 18 samples taken from the inlet and 12 samples taken from the outlet of the detention pond for the TSS experiment. Equation (1) was used to calculate the TSS for all samples. The results obtained from TSS experiment which were measured in mg/L were then computed into tons/day using Equations (2) and (3).

The relationship between 18 values of flow discharge, Q and suspended sediment rate, Q_s at the inlet of the detention pond was shown using the suspended sediment rating curve in Figure 1.

Prediction Analysis

Sediment yield in this study was calculated by using the MUSLE method, Equation (5). The daily rainfall data for ten years duration (2000-2009) obtained from the JPS, Johor Bahru, were used to calculate the monthly and yearly rainfall depth, P. Based on the type of soil in the UTM, the K value used for this study is 0.27 (sandy clay loam). The value of CP and LS were 0.0096 and 4.30 respectively. Then sediment depth, d will be obtained using Equation (4), and for sediment loads, Y_i can be obtained from value of Y from MUSLE divide by 1 year. Figures 2(a) and 2(b) were plotted using sediment loads, Y_i and sediment depth, d computed from MUSLE and Equation (6).

The linear equations from both graphs were used to predict the sediment loads and sediment depths for the next 100 years from 2010 until 2109. The predicted sediment loads and sediment depths data for the next 100 years duration is shown in Figures 3 and 4.

Figures 3 and 4 show that the sediment loads and sediment depths changed linearly every year. As an example at 10 years, the sediment load was 41.9 tons then it increased after 100 years to 436 tons. This situation was similar for the prediction of sediment depths; 1.16 mm on 10 years to 12.1 mm after 100 years. The depth of detention pond in this study was 3 m, so 12.1 mm was a relatively small value of sediment depths if it was compared with the depth of detention pond. Therefore it

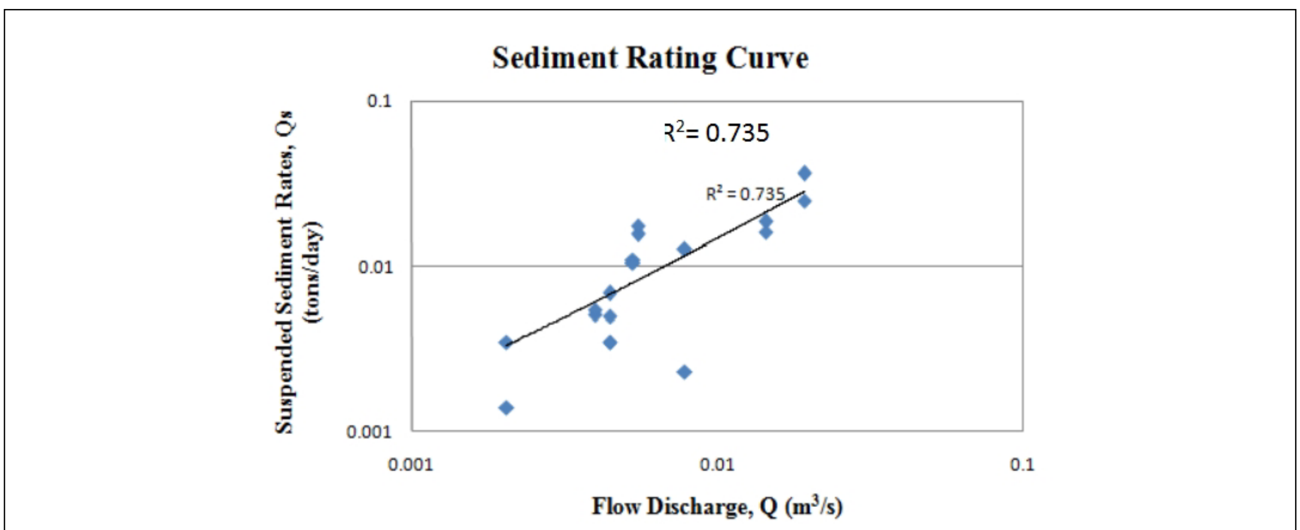

Figure 1. Sediment rating curve for the observed data.

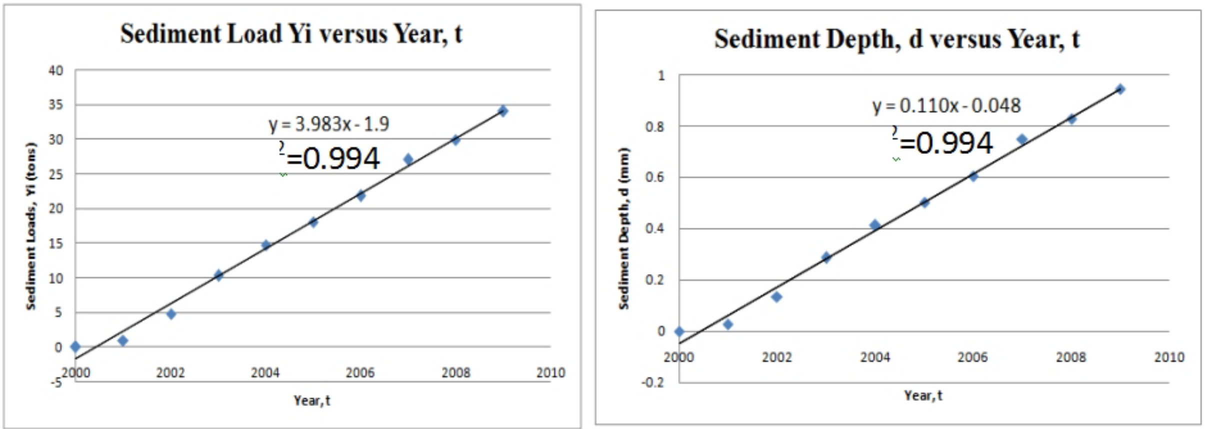

Figure 2 (a) **Figure 2 (b)**

Figure 2. Linear regression equation for sediment loads and sediment depth.

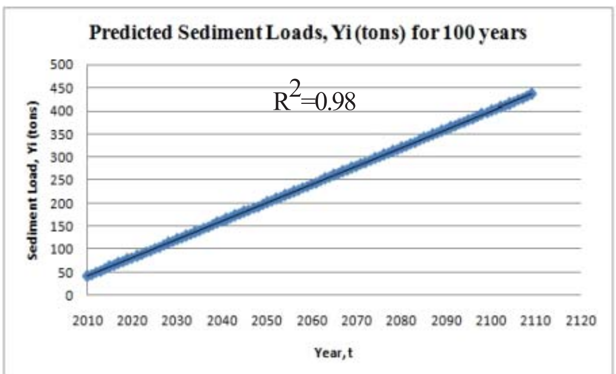

Figure 3. Sediment loads, Y_i (tons) projection for 100 years.

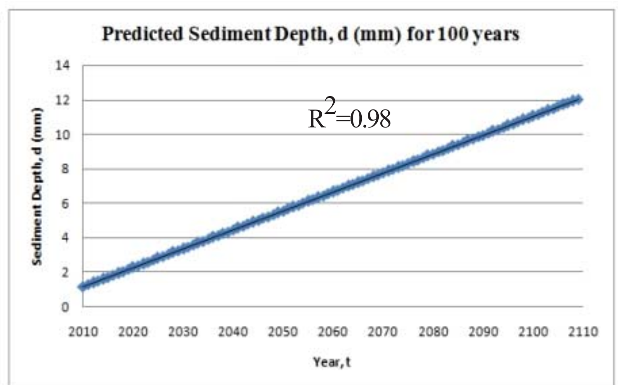

Figure 4. Sediment depths, d (mm) projection for 100 years.

may not affect the operation of detention pond for the next 100 years duration.

Monte Carlo Simulation Analysis

In this study, the simple Monte Carlo simulation was used to obtain the uncertainty and range of value of sediment loads and sediment depth based on collected data from the detention pond. To run the simulation process, the simple Monte Carlo simulation was applied by using RiskAMP Monte Carlo Add-in and it installed into Microsoft Excel and the hypothesis data collected was assumed to be normally distributed. The simulation was run by using the average or mean value, μ and standard deviation value, $ó$ of sediment loads, Y_i and sediment depth, d for each case.

Analysis for Observed Sediment Loads and Sediment Depth

From the result from the various numbers of trials for observed sediment loads, Y_i, and sediment depth d, using Monte Carlo Simulation, several conclusions can be made. Firstly, when the number of trials increased, the mean and standard deviation from the simulation become closer to the actual mean or average and actual standard deviation. If the number of trials increased, the standard error from the simulation become smaller. Lastly, the value of skewness and kurtosis from the simulation was close to the best value which is 0 and 3 respectively when the number of trials became larger.

Figures 5(a) and 5(b) show the probability density function of observed sediment loads and sediment depth for 20,000 trials to determine the maximum value of sediment loads and sediment depth from that simulation. Figures 5(a) and 5(b) show the maximum value of sediment loads and sediment depth of 0.015 tons (16.83%) and 0.00037 mm (15.47%) respectively. The most likely range for sediment loads ranged from 0.007 tons to 0.019 tons (14.36% to 13.64%) and for sediment depth ranged from 0.00017 mm to 0.00047 mm (12.14% to 13.49%). In addition, both curves give the best bell shape of the normal curve.

Analysis for Predicted Sediment Loads and Sediment Depth

From the various numbers of trials for predicted sediment loads, Y_i and sediment depth, d, by using Monte Carlo simulation, several conclusions can be made similar to the results of the simulation for the observed data

Figures 6(a) and 6(b) show the probability density function of predicted sediment loads and sediment depth for 20,000 trials.

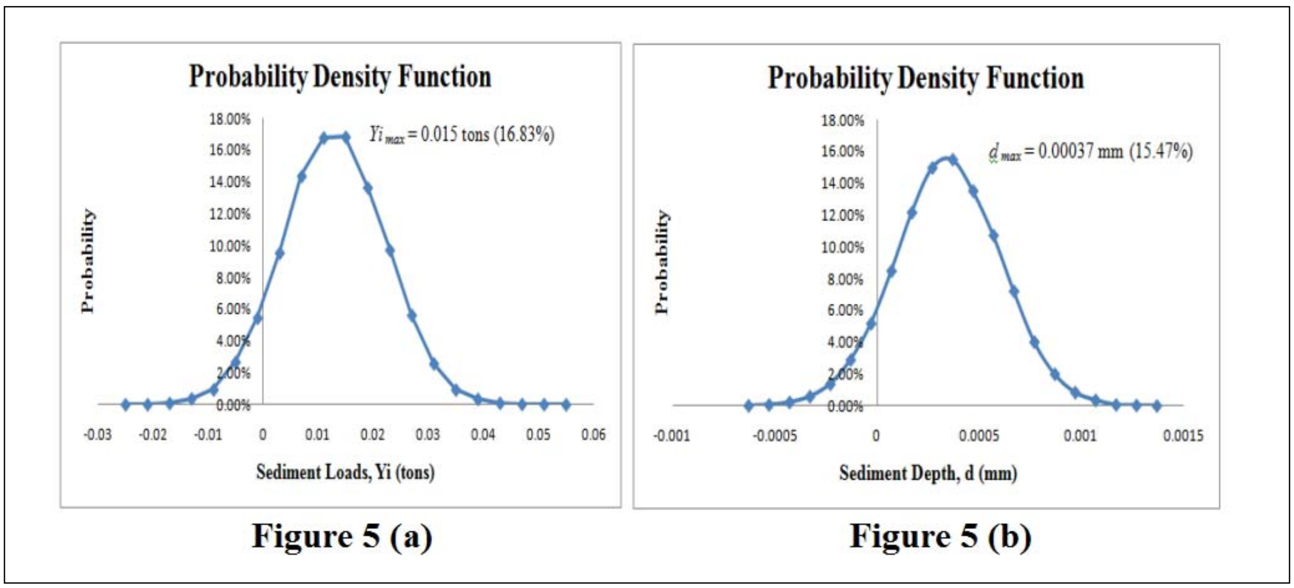

Figure 5. Probability density function of observed sediment loads and sediment depth for 20,000 trials.

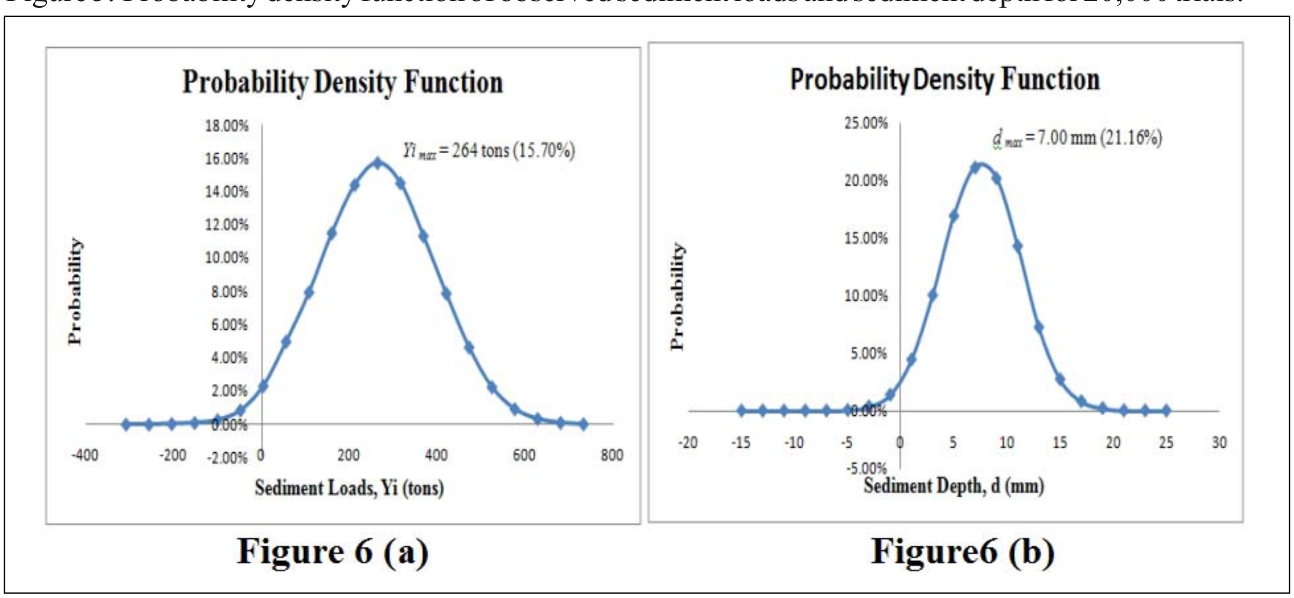

Figure 6. Probability Density Function of predicted sediment loads and sediment depth for 20,000 trials.

The summary of Monte Carlo simulation for prediction data showed the maximum probability of occurrence value for predicted sediment loads and sediment depth by MUSLE method were 264 tons (15.70%) and 7.00 mm (21.16%) respectively. The most likely range for predicted sediment loads and sediment depth obtained varied from 160 to 316 tons (11.50% to 14.49%) and 5 to 11 mm (16.96% to 14.33%) respectively.

Comparison with other study

This study was compared to another study conducted by Irma (2008) and his study area is at Ledang Height, Nusajaya, Johor. The catchment of Ledang Height, Nusajaya area is about 361 acres (1.46 km^2). For his study, the maximum probability of occurrence value for observed sediment loads and sediment depth was 0.0062 tons (16.51%) and 0.0005 mm (17.53%) respectively. Then for predicted sediment loads and sediment depth, the maximum occurrence value was 77.7 tons (16.80%) and 7.52 mm (26.79%) respectively. This study was compared to Irma (2008) and the summary of comparison from both study are shown in Tables 2 and 3.

Table 2. Summary of comparison for sediment load, Y_i.

Note	Observed data		Predicted data	
	Maximum Value (tons)	Maximum percent (%)	Maximum Value (tons)	Maximum percent (%)
Irma, 2008	0.0062	16.51	77.753	16.80
Rashid, 2010	0.0150	16.83	264.00	15.70

Table 3. Summary of comparison for sediment depth, d.

Note	Observed data		Predicted data	
	Maximum Value (mm)	Maximum percent (%)	Maximum Value (mm)	Maximum percent (%)
Irma, 2008	0.00050	17.53	7.524	26.79
Rashid, 2010	0.00037	15.47	7.000	21.10

The results show that the value for sediment loads, Yi , obtained from Irma (2008) study was lower than the value obtained from this study. But value for sediment depth, d , from Irma (2008) was greater than this study. Besides that, there were some reasons why results for both study were different. Both studies were carried out at different catchment areas, different detention ponds and the time frames for both studies were also different.

CONCLUSION AND SUGGESTIONS

The conclusions that can be drawn from this study are as follows:

1. By using on-site data collection, the relationship between suspended sediment rate, Q_s and flow discharge was obtained. The deposition of sediment into the detention pond was possible.

2. Based on the MUSLE method, the accumulation of sediment loads and sediment depth from 2000 until 2009 was estimated. It was shown that there was a linear increment of sediment loads and sediment depth with time.

3. A linear equation was used to predict for next 100 years beginning 2010 until 2109. From this, it was shown that the longer the life time of the detention pond, the heavier the sediment loads and the deeper the sediment depth accumulated.

4. The maximum probability of occurrence value for predicted sediment loads and sediment depth in the detention pond was obtained using Monte Carlo simulation. Therefore, determining and forecasting the sediment accumulation in the detention pond are very important to know the effectiveness of the detention pond.

5. This study can help to know how to determine and predict the sediment accumulation in detention pond for next 100 years using MUSLE method.

6. Determining and forecasting the sediment accumulation in detention pond are very important to know the effectiveness of the detention pond. Last but not least, for the maintenance of the detention pond it is also important to make sure that the detention pond can function properly along its service life.

7. To get better results for observed sediment loads and sediment depth, use more samples at the site over a longer time period. It can give more accurate values in calculation of prediction for sediment loads and sediment depth in detention pond.

8. Use of Geographic Information System (GIS) are encouraged because it is used widely and slope length and slope gradient factor, *LS* and crop management factor, *CP* can be obtained more accurately. This system also can be used to determine the soil loss, then comparison could be made between results from the GIS and results using the MUSLE method.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support VOT 79394 granted by Ministry of Science, Technology and Innovation Malaysia and Research Management Center, Universiti Teknologi Malaysia. We were thankful for the review and valuable comments from Associate Professor Dr. Sobri Harun and Dr. Noor Baharim Hashim from Universiti Teknologi Malaysia. The authors appreciate all the help obtained from everyone involved, either directly or indirectly, especially to UTM – Harta Bina Unit for much information related to the detention pond in UTM. Our special thanks also to the technicians of UTM - Hydraulics and Hydrology laboratory.

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