The Study of Stage and Discharge Relationship of Detention Pond

By:

Nur Fatin binti Hilmi

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

SEPTEMBER 2011

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak DarulRidzuan

CERTIFICATION OF APPROVAL

The Study of Stage and Discharge Relationship of Detention Pond

by

Nur Fatin binti Hilmi

A project dissertation submitted to the

Civil Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfilment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(CIVIL ENGINEERING)

Approved by,

(Ms. Husna Takaijudin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NUR FATIN BINTI HILMI

ABSTRACT

Due to rapid development nowadays, the natural storage of rainfall water is affected as water cannot infiltrate into the soil and thus, the water will remain as surface water which can lead to flooding. Detention basin had been applied by most of the countries in the world to encounter this problem and many researches had been done in this field. The objective of this research is to study the stage and discharge relationship of the detention pond. The study had been done using physical model of detention pond in the laboratory which has been scaled down 100 times from the real size. The experiment was repeated by manipulating the number of valve rotation to get different discharge of inflow. For every rotation, the stage and discharge was calculated and relationship was developed. From the experiment that had been done, it is proved that the stage will increase with increased discharge. Besides, the storage also increased as the stage increased. This experiment however can be further studied and corrected using the physical model that having the same characteristic and condition as the real detention pond so that the result obtained more accurate and precise.

ACKNOWLEDGEMENTS

The author wishes to take the opportunity to express her utmost gratitude to the individual that have taken the time and effort to assist the author in completing the project. Without the cooperation of these individuals, no doubt the author would have faced some minor complications throughout the course.

First and foremost the author's utmost gratitude goes to the author's supervisor, Ms Husna Takaijudin. Without her guidance and patience in assisting the author, the author would not succeed to complete the project. To the Final Year Research Project Coordinator, Dr Teo Wee for providing her with all the general information required to complete the project.

Not to forget to Hydrology lab technicians, Mr. Mohd Idris Mokhtar and Mr. Meor Asniwan Meo Ghazali for helping her with her laboratory and experimental work. To all technicians in Civil Engineering Department, thank you for assisting the author in completing her project.

To all individuals who helped the author in any way, but whose name is not mentioned here, the author thank you all.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background Study

Detention pond is used to store water where there is excess water in a short period of time. Normally it is located at the downstream of development areas and near to the existing river or stream. From the study focus that has been done toward dry detention pond situated in Section 6, Kota Damansara, Selangor built in 1996, it shows that the current drainage system is functioning well and no recommendation on improvement is needed. Besides, it is recommended that the construction of detention pond needs to be further encouraged for any new housing development to control water quantity (Liew, Z. Selamat, & A. Abd. Ghani, 2009).Detention pond will store the water for a short period of time, normally between a few hours or days and most of the time the detention pond will just remain dry.

The detention pond needs to be design so that its capacity can accommodate the excess water in order to meet the objective. Otherwise, the flood problem still unsolved although the detention pond is already built.

Taking the example of the detention basins for the Fort Collins and detention basin for Atlanta, the detention basins for the Fort Collins watershed were sized according to the Urban Storm Drainage Criteria Manual for Denver, Colorado (UDFCD 2001) using the simulated hydrograph from a 2-h design hyetograph. Meanwhile, the detention basins for the Atlanta investigation were sized using the 24-h rainfall with an SCS Type II distribution. For both areas, the simulated BMP is an extended detention basin designed according to the procedure recommended in the ASCE (1998) manual of practice for urban runoff quality managementFigure. This procedure defines a ‘‘maximum detention volume’’ (or water quality capture volume).(Nehrke, 2004)

1.2 Problem statement

Historically, human preferred to live near to the river and sea due its location that is strategic for social and economic factor. However, flooding which is the main issue at these particular areas that affected the social and economic growth. In Malaysia, there are two types of monsoon, the northeast monsoon which is last from November to March and affect the north and east coasts of Malaysia and also southwest monsoon which is last from May to September and affect west coast of Malaysia. Heavy rainfalls always occur during that period of time. This heavy rainfall will lead to flood especially at the downstream areas (Gleick, Cooley, & Katz, 2006). For example, recently, flash flood has occurred in Kuala Lumpur. From The Star online on 14th December 2011 by Nur Hidayah Ramli, it was reported that heavy rain had caused Sg Bunus to overflow and thigh-high floodwaters. It had cut off traffic along Jalan Tun Razak in front of the National Library, causing a massive traffic jam. Thus, flood control need to be done in order to cater this problem and one of the actions that can be done is by applying detention pond at the affected area. The detention pond will temporarily hold an amount of water especially when there is water excess before release it to another location.

Detention pond is designed as part of the solution for flooding problem. However, the detention pond has its limitation. By comparing to other structural storm water practices, the detention ponds have only moderate pollutant removal. Besides, they are ineffective at removing soluble pollutants. The detention ponds need to be properly maintained otherwise it will encourage the breeding of mosquito. Stagnant water for more than 7 days will also lead to this problem. The third limitation is although wet ponds can increase property values, dry ponds can actually detract from the value of a home. Next, it also may lead to habitat destruction during construction, if the practice is designed in-stream or within the stream buffer.

1.3 Objective

The objectives of this study are:

1. to produce inflow and outflow hydrograph from the experimental work
2. to develop the stage-discharge-storage relationship of detention pond
3. to compare the lab result with the establish equation

1.4 Scope of study

- Physical model

  An experimental work was done at the hydraulics lab by using physical model of detention pond. Based on this, an experimental work to study the relationship between the discharge of water at the inlet with the depth of water in the detention pond and the discharge at the outlet was done. Besides, the relationship between the stage and the storage of the detention pond were also studied.

- Experimental setup

  Before the experimental began, some experimental setup needed to be done such as to place the ruler or the measuring tape at the required location for instance at the inlet and outlet structure. Besides, the equipment that needed to be used in order to get the data were prepared. Further explanation for the experimental setup can be referred in Chapter 3 under experimental setup section.

- Analysis

  Results obtained through the experimental setup were analyzed using theoretical equation such as Modified Puls Method and Muskingum Method. Comparison between the outflow obtained from the experimental work and outflow calculated using Muskingum method was done. Besides, the Modified Puls method was used to verify the inflow and the outflow of the experimental work were balanced with one another.

Based on the data of detention pond depth and length, the capacity of the detention pond can be calculated. Meanwhile, the reading that has been recorded will be analyzed to get the stage-discharge relationship at the inlet and also the outlet of the detention pond.

CHAPTER 2

LITERATURE REVIEW

2.1 The concept of storm water management

Land development especially in urban areas gives significant changes to runoff characteristics. Removal of trees and vegetation and grading of the site are examples of activities of land development that lead to reduction in rainfall storage in soil matrix. Besides, increased impervious cover in urban areas also reduces the potential of infiltration and soil storage of rainwater. Reduction in natural storage causes changes in runoff characteristics.

Realizing the impacts of these changes in runoff characteristics on the inhabitants of local community, many measures have been proposed so that reduction in natural storage can be minimized.

According to (McCuen, 2004), the intent of storm water management (SWM) is to mitigate the hydrologic impacts of this lost natural storage, usually using manmade storage. Although a variety of SWM alternatives have been proposed, the storm water management basin remains the popular. The SWM basin is frequently referred to as a detention or retention basin, depending on its effects of the inflow hydrograph.

2.2 Detention pond

Detention pond is an excavated open area meant for flood control management. It functions when there is excess discharge of water. It is called detention pond because it stores excess water for a short period of time, which is between a few hours to a few days only. (Martin P. Wanielista, 1993)

Detention pond helps to slow the rate of runoff from the neighborhood and improve the quality of the storm water leaving the detention pond. The detention ponds are important to protect the public and private property, public health and safety, and water quality. The detention pond collects and traps sediment from storm water that would otherwise end up clogging our rivers and streams and degrading the environment for fish, birds, and other wildlife.

Wet detention ponds are also one of the most robust stormwater control practices available. Although a good maintenance program is necessary to ensure the best performance and minimize associated problems, many stormwater ponds have functioned well with minimal maintenance. In addition, as long as certain design guidelines are followed, many design details that are worthwhile to consider do not create critical problems if incorrectly implemented. (Pitt, 2004)

Key considerations for the detention pond are as stated in the Knox County Tennessee Stormwater Management Manual such as:

- This pond will only cover for overbank and extreme flood protection but it is not intended to check for water quality and provide the treatment.
- The drainage areas are up to 75 acres.
- Less excavation is required and thus less cost needed.
- When the pond is dry, it can be used for other purpose such as for recreational or open space facilities.

Based on the Knox County Tennessee Stormwater Management Manual, it also stated the physical specifications and geometry for dry detention pond were:

- The vegetated embankments are not more than 20 feet or 6.1 meter in height and the side slopes shall not exceed the ratio of 3:1. The purpose of having this ratio is to ease the maintenance process. Meanwhile, the rest of the pond's side slopes cannot be steeper than 2:1 although 3:1 is preferred. Benching of the slope is required for embankments greater than 10 feet in height and having greater than a 3:1side slope. Riprap-protected embankments shall be no steeper than 2:1. Geotechnical slope stability analysis is recommended for embankments greater than 10 feet in height and is mandatory for embankment slopes steeper than those given above. All embankments must be designed to State of Tennessee guidelines for dam safety.

- The maximum depth of the basin shall not exceed 10 feet or 3.05 meter.
- Areas above the normal high water elevations of the detention pond shall be sloped toward the basin to allow drainage and to prevent standing water. Careful finish grading is required to avoid creation of upland surface depressions that may retain runoff. The pond bottom shall be graded toward the outlet to prevent standing water. A low flow or pilot channel across the facility bottom from the inlet to the outlet (often constructed with riprap) is recommended to convey low flows and prevent standing water conditions.

Several studies on detention pond had been made before. For instance, there was a study to investigate a small open detention pond predominantly receiving storm water drainage from a highway. The results showed a difference in pollutant removal characteristics. Particle-associated pollutants were effectively removed during storm events as indicated by EMC (Event Mean Concentrations) while dissolved pollutants were not effectively removed. Outflow pollutant loads followed linear profiles when seven consecutive storm events were represented as cumulative graphs. PEMC's (Partial EMC's) during a storm event showed an association between the specific surface area of small particles and lead content. A detention pond should be designed according to capacity to detain the complete storm volume, thus avoiding short-circuiting of the pond by pollutants (Pettersson, 1998).

A numerical detention pond volume model was established based on the hydrological continuity equation and the Runge-Kutta numerical method. Experiments for the conditions of both steady and unsteady flow have been used to verify the model. In unsteady flow cases, the outflow hydrograph by numerical simulation are fairly consistent with experimental value. Both experimental and numerical results indicate that wider rectangular sharp-crested weirs or larger rectangular slot tend to induce greater outflow discharges, which undesirably cut down the detention volume (Hong, 2008).

A study on was done on several purposes of small, earth dammed detention ponds, established at field borders, were discussed according to a 9-year watershed experiment. Prevention of linear erosion in downslope fields, trapping of sediments and sediment bound nutrients, effects on runoff and water-soluble agrochemicals as well as costs were analyzed. The results indicate that: (i) small ponds can prevent linear erosion in downslope fields if outflow is routed to the toe slope via a grassed waterway or a pipe; (ii) they trap 50-80% of the incoming sediments; (iii) if the ponds are combined with effective soil conservation in the fields, total sediment trapping is small, and hence, costs due to crop damages or necessary dredging operations incurred only in case of severe erosion events; (iv) the ponds can remarkably reduce peak runoff rates. At the test site even for one of the largest runoff events occurring during the study period of 32 watershed years and in case of the pond with the most unfavorable runoff to pond volume ratio, peak runoff rate was reduced to one third; (v) according to the sealing of the pond bottom, the short ponding time and the small ponded area no significant reduction of runoff volume can be expected; and (vi) the ponds can also significantly reduce peak concentrations of agrochemicals, exemplarily shown for the Terbutylazin concentration, which approximately dropped to the half (Fiener, 2005).

2.3 Flow measurement

In order to measure the discharge, data that will be required are:

- Area of flow
- Average velocity of flow

To measure the area, there are two methods that can be used:

1) Simple Segment Method

In this Method, the whole Width of River is divided into a number of Segment at Length, say L_1,L_2,L_3 (Length of Segments) and at Depth say d_1,d_2,d_3 (mean Depth of Segment).Now, the Area of Flow is Sum of all Area of Segments.($L_1d_1+L_2d_2+L_3d_3+L_nd_n$)

2) Simpson's Rule

In this Method, the whole Width of River is divided into an even number of equal Segments, so that there is odd number of depths taken at the end of each Segment.

Meanwhile, to measure the velocity of the flow, methods that can be applied are floats, pitot tube and current meter

2.3.1 Floats

To measure stream velocities beneath the river surface, specialized equipment is typically needed. The surface velocity can be measured easily with a stopwatch and small floats (small enough that their movement is unaffected by wind, e.g., ping pong balls). A surveying tape is needed to measure the river/stream width and the distance traveled. It is more convenient to have 2 tapes placed transverse to the river flow just above the surface at two sections separated a distance at least 2 or 3 times the nominal river width so that it is easy to note when the float passes the start and finish positions.

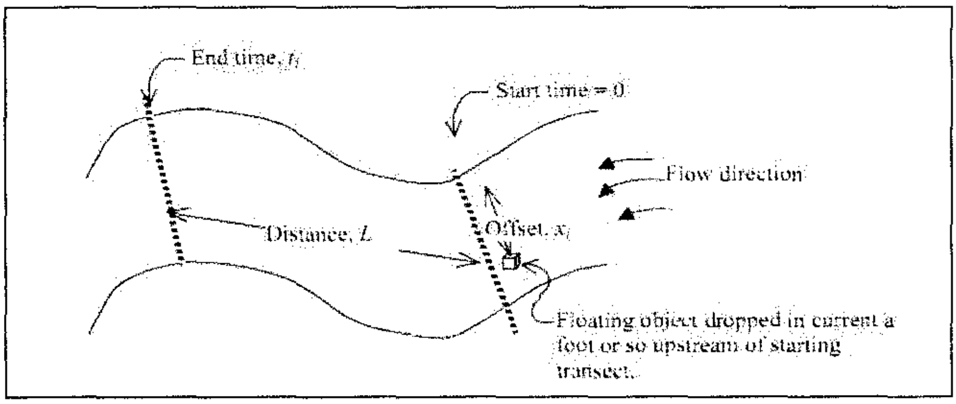

Figure 2.1: Float-method setup for measuring the stream/river surface velocity distribution. The velocity of section, i, is equal to L/t_i.

Figure 2.2 shows the format for recording data in table form.

Distance from Stream Bank	Width[a], w	Average Depth[b], h	Distance Traveled[c] L	Elapsed Time[d] t	VELOCITY, V[g] Surface, v_s[e]	Mean, v[f]	Area[h], a	Discharge[i], q
(feet)	(feet)	(feet)	(feet)	(s)	(ft/s)	(ft/s)	(ft²)	(cfs)
Total[j]/***Average***[k]:					$V =$		$A =$	$Q =$

[a]Width based on distance between midpoints of adjacent measurements (see Figure 2 and Eq. 4).
[b]Estimate of average depth of section.
[c]Approximate travel distance taken by float downstream (see Figure 5).
[d]Elapsed time of travel.
[e]Float velocity at the surface, L/t.
[f]Mean velocity in section based on surface velocity (Eq. 6).
[g]Average stream velocity, Q/A.
[h]Initial Section area, $a = wh$.
[i]Discharge in section, $q = va$.
[j]Total is summation of the individual section values.
[k]Average depth is the total area divided by the total width.
Average velocity is the total discharge divided by the total area.

Figure 2.2: Data sheet for stream discharge measurements using the float method

2.4 Stage Discharge Relationship

For water resources planning and management, the most important aspect in flood control that needs to be count in is the water discharge especially during flood periods. However, usually the flood discharge cannot be measured by using conventional method due to its high flood velocities. For instance, direct measurement of the discharge of river might be very laborious and time consuming. It also cannot be used directly as daily information. Normally, the discharge is determined from the observation at the gauging station. The gauging station will provide the data such as the discharge and the water level of the river or reservoir.

During a flood event, large streams and rivers generally do not exhibit rapid changes in stage. Hence it is assumed that the unsteadiness of the flow is not considered and it can be applied to establish a reliable stage–discharge relationship. When the discharge is increasing, the water table also will rise up and thus the measured velocity getting larger. (Maghrebi, 2006)

2.5 Puls Method

Along this research, Puls Method will be implemented to calculate the stage-discharge relationship. This method is often used for reservoir routing and may also be applied to river routing. A curve will be plotted as relationship between the storage and the outflow. Equation that is being used in this method is:

$$(\frac{S_2}{\Delta t}+\frac{O_2}{2})=(\frac{S_1}{\Delta t}+\frac{O_1}{2})-O_1+(\frac{I_1+I_2}{2}) \qquad \text{(equation 2.1)}$$

Assumption that is applied in this model is a unique and single-valued stage-storage outflow relationship exists for each reach, and by changing downstream conditions will not alter this relationship. However, the method is not recommended for (1) channels with gradients less than 3 feet/mile, (2) reaches with time varying downstream boundaries such as tidal influences; or (3) rapidly rising flood hydrographs such as dam breaks (HEC, 1990).

Basic equation that being used in this method is:

$$\frac{I_1+I_2}{2}-\frac{O_1+O_2}{2}=\frac{S_2-S_1}{\Delta t} \qquad \text{(equation 2.2)}$$

Then, after algebraic transformation is applied, the equation turned out to be in the form as below:

$$I_1+I_2+(\frac{2S_1}{\Delta t}-O_1)=\frac{2S_2}{\Delta t}+O_2 \qquad \text{(equation 2.3)}$$

The left side of the equation is known with respect to time, while the right side of the equation needs to be calculated. The result will turn out in form of a graph of relationship between outflow and storage.

2.6 Muskingum Method

Muskingam Method is one of the simplest models used for flood routing. The most common form of Muskingum Method is:

$S_t = K[xI_t + (1-x)O_t]$ (equation 2.4)

S_t = the absolute channel storage at time t

I_t = rates of inflow at time t

O_t = rates of outflow at time t

K = storage time constant

x = weighting factor varying between 0 and 0.5

Equation 2.5 needed to be solved in conjunction with continuity equation in order to perform channel flood routing. The equation is:

$$\dot{S}_t = \frac{dS_t}{dt} = I_t - O_t \quad \text{(Equation 2.5)}$$

S_t = the time rate of change of channel storage at time t

Based on both equations, it results in the well-known Muskingum routing equation:

$$O_t = C_0 I_t + C_1 I_{t-1} + C_2 O_{t-1} \quad \text{(Equation 2.6)}$$

where C_0, C_1, and C_2 is the coefficients that are function of K, x, and discretized time interval.

The application of the Muskingum model basically involves two steps: calibration and prediction. The calibration procedure, in essence, is centered on model parameter identification using historical inflow-outflow data (Tung, 1985).

CHAPTER 3

METHODOLOGY

3.1 Project Flow

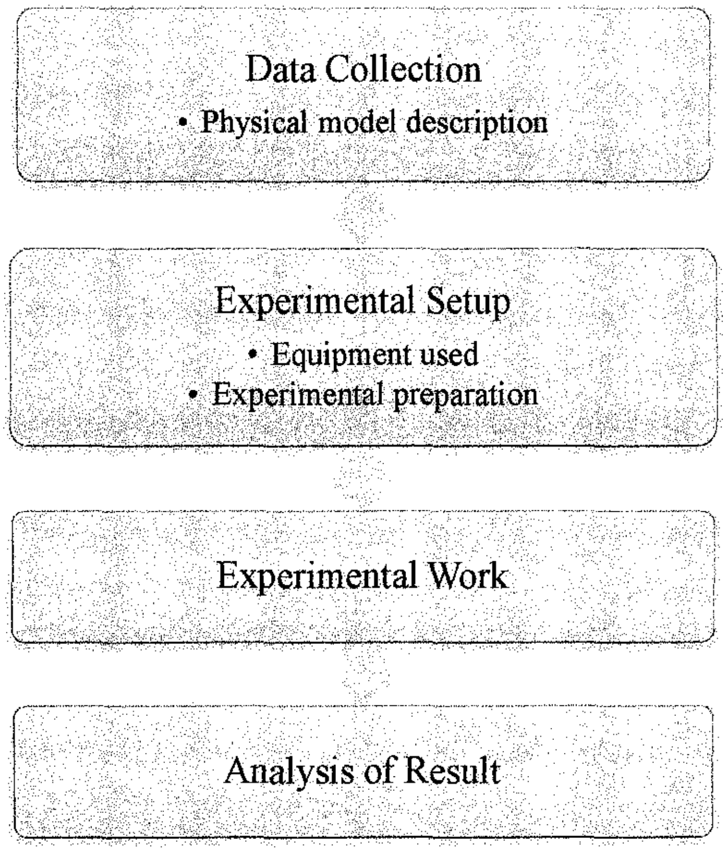

Figure3.1: Process flow of the project

Figure 3.1 illustrates the process flow of this project. Initially, the title was selected and further literature from previous research was investigated in detail.

3.1.1 Physical model description

This project was done with series of experimental works by using physical model of pond built in the lab. Before starting the experimental work, some data collection regarding the pond has been done. The actual capacity of the pond is 1.5×10^6 m^3 with size of 820m x 300m. For the physical pond, it has been scale down by ratio 1:100 compared to the actual pond.

Figure 3.2 describe the water circulation system for the physical model of the pond in the lab. Water from the elevated water tank will go to the ground sump. From there, the water will be sucked using suction pipe and pumped into the pond through a 100 mm diameter PVC pipe. The water will go through a tunnel and enter the pond through a rectangular opening. Then, the water will pass the outlet which is a rectangular weir with opening that can be controlled.

From the rectangular weir, water was collected in sink or water collector and was channeled to the v-notch weir tank through 200mm diameter PVC pipe. The water then flow into ground reservoir. From the ground reservoir, the water flow into ground sump and then either being pumped back into the pond or pumped into the elevated water tank for storage.

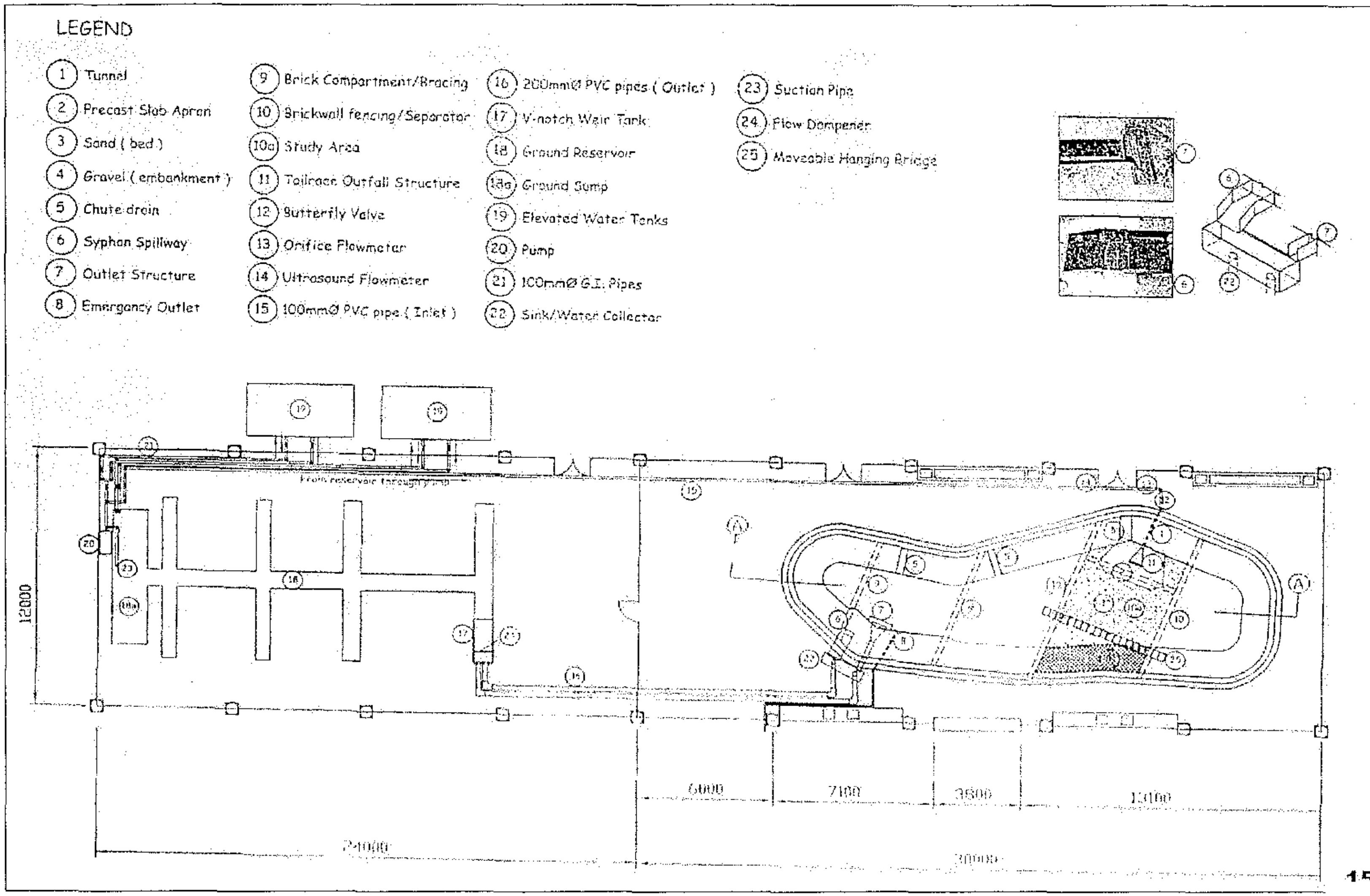

Figure 3.2: Physical model of pond

Meanwhile, Figure 3.3 illustrates the water circulation system in details for example the valve system of the physical model of the physical pond.

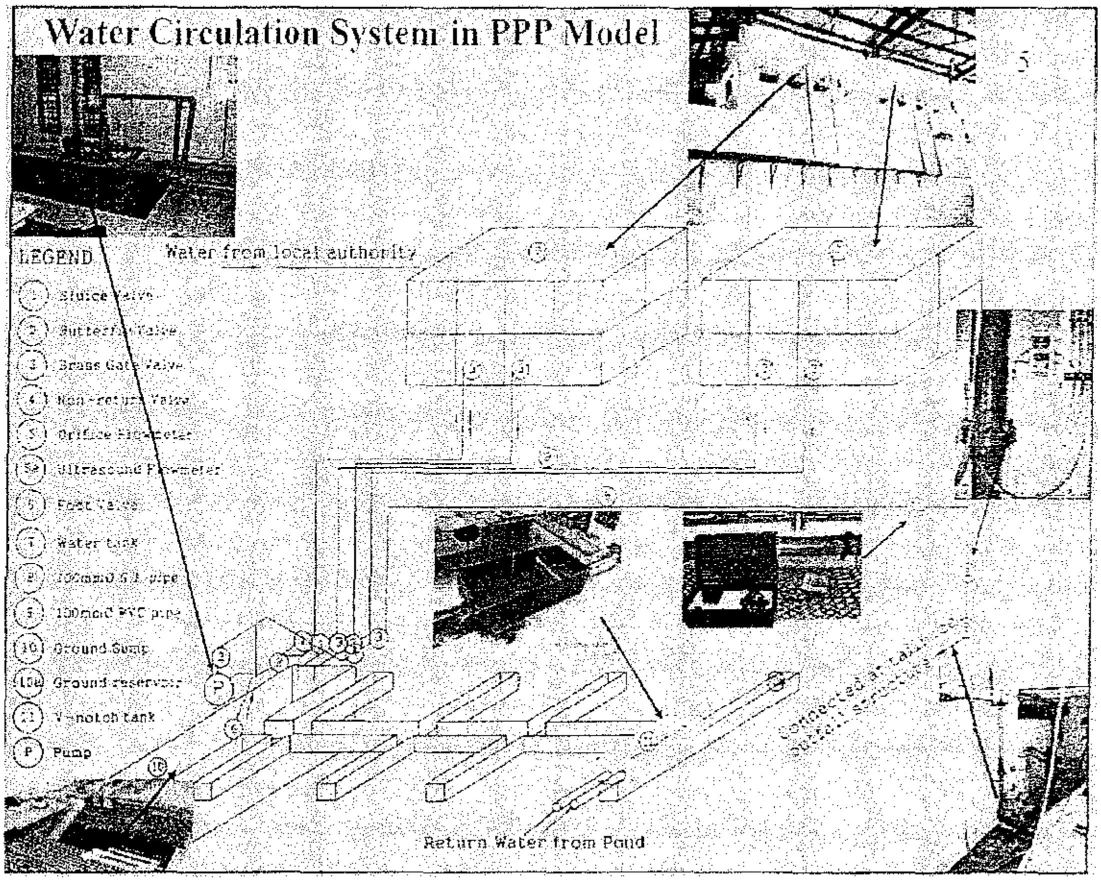

Figure 3.3: Water circulation system

There are 4 types of valve used in the system.

i. Sluice valve: Sluice valve also known as gate valve. The valve is opens by lifting a round or rectangular gate/wedge out of the path of the fluid. The distinct feature of the valve is the sealing surfaces between the gate and seats are planar, so gate valves are often used when a straight-line flow of fluid and minimum restriction is desired.

ii. Butterfly valve: Butterfly valve can be used to isolate and regulate the flow. The closing mechanism of it takes the form of a disk. The mechanism is similar to that of a ball valve, which allows for quick shut off, meaning after being closed, no more fluid can pass through it. These valves are generally favored because they are cheaper compared to other valve designs as well as being lighter in weight, which means that less support is required. The disc is positioned in the center of the pipe, and passing through the disc is a rod connected to an actuator on the outside of the valve. By rotating the actuator, it will turn the disc either parallel or perpendicular to the flow. Unlike a ball valve, the disc is always present within the flow, therefore a pressure drop is always induced in the flow, regardless of the valve position

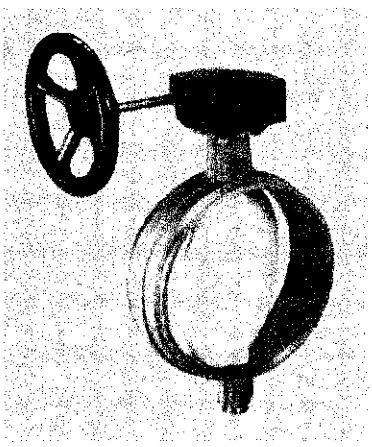

Figure 3.4: Example of butterfly valve

iii. Brass Gate valve: Valve that allows for two-way flow direction. It is also used to close or open the medium flow. This valve can be installed either in horizontal or vertical position in the pipelines system.

iv. Non-return valve: The valve allows fluid (liquid or gas) to flow through it in only one direction. Non-return valves consist of two-port valves, meaning they have two openings in the body, one for fluid to enter and the other for fluid to leave.

The inlet structure is illustrated by Figure 3.5. It is rectangular in shape with dimension 18 cm height x 22cm width. Water will pass the tunnel and the rectangular inlet before entering the pond. Thus, the maximum height of water that can pass through the inlet is 18 cm.

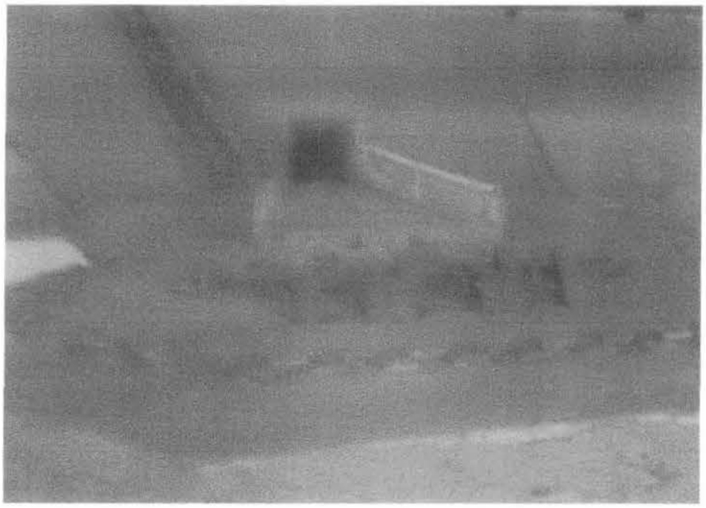

Figure 3.5: Inlet structure

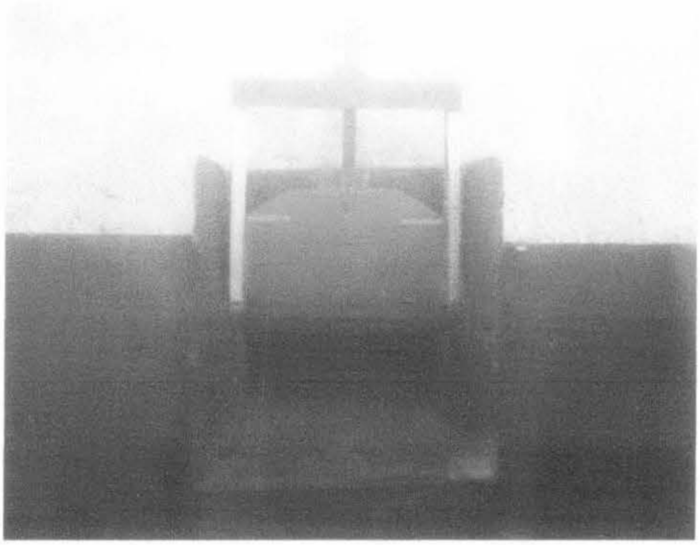

Figure 3.6: Rectangular weir (outlet) with controlled opening.

Figure 3.6 shows the outlet structure of the pond which is a rectangular weir. It has opening with height that can be controlled up to 8cm. the width of the rectangular weir is 18cm.

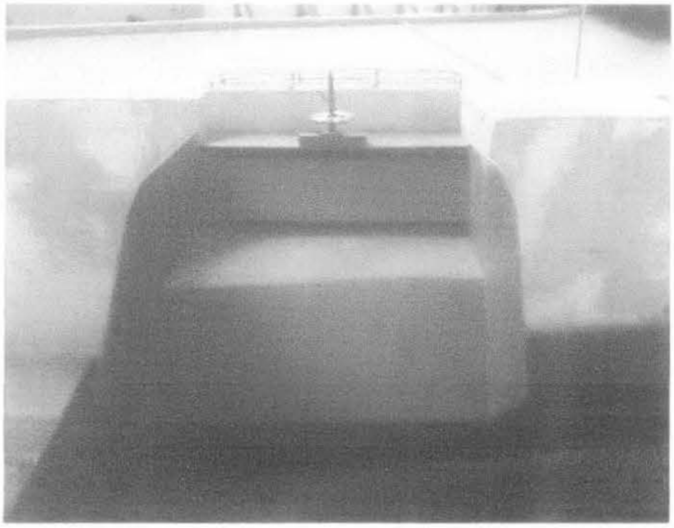

Figure 3.7: Syphon spillway

Figure 3.7 illustrate the secondary outlet of the pond that is syphon spillway. It act as emergency access as the excess water will flow through this spillway if the water has reach certain depth.

3.1.2 Experimental Setup

3.1.2.1 Equipment used

The equipment used for this experiment are stopwatches, Streamflo Probe and ruler.

- Stopwatch

  There are 3 stopwatches used during the experiment. First one was used to record time at the inlet, second one was used to record time for measuring water level in the pond and the third one was used to record time for measuring water level at outlet structure.

- Streamflo Probe

  The STREAMFLO miniature current flowmeter system is designed for measuring low velocities of conducting fluids, usually water, in open channels. It is primarily intended for laboratories and specialized industrial use. The measuring head with a cage approximately 15mm diameter enables readings to be taken in confined spaces thus the accurate measurement of velocity in hydraulic models of river estuaries and irrigation schemes are two of its many uses. The system is highly sensitive, responding to velocities as low as 5.0 cm/s. Two probes are available covering velocities up to 300 cm/s.

Principle of Operation

The measuring head consists of a five bladed rotor mounted on a hard stainless steel spindle. The spindle terminates in fine burnished conical pivots which run in jewel bearings mounted in an open frame. Frictional torque is thus extremely low and results in a linear output over a wide range of velocities. The pivots and jewels are shrouded to reduce the possibility of fouling should the flow channel become unduly contaminated. The head is attached to the end of a stainless steel tube containing an insulated gold wire terminated 1.0mm away from the rotor, and is connected to an electronic measuring unit via aco-axial cable. When the rotor is immersed in a fluid, the passage of the rotor blades past the gold wire tip slightly varies the measurable impedance between the tip and the tube. This variation is used to modulate a 15 KHz carrier signal generated within the indicating instrument which in turn is applied to the electronic detector circuits. Automatic compensation is made for change in liquid conductivity and following amplification and filtering of the carrier frequency a square wave signals obtained. In the digital indicator the pulses are counted over a known time period to obtain a digital reading. Figure 3.7 illustrate the streamflow probe.

Figure 3.8: Streamflo probe

- Rulers and measuring tape

  Rulers and measuring tape were used at three different locations to measure the water level corresponding to time. The rulers were attached at the inlet structure and at the outlet structure while the measuring tape was attached to a stand and put at the middle of pond so that water level in the pond can be measured.

3.1.2.2 Experimental preparation

Before starting the experimental work, some initial data were measured first. These include the diameter of pipe that connects the ground sump and the pond, the dimension of the inlet structure, dimension of outlet structure or rectangular weir and the angle of v-notch. Secondly, the rulers were attached to the inlet structure and outlet structure so that the water level can be measured easier. Besides, one measuring tape also being attached to a stand and being put at the middle of pond so that the water level inside the pond can be measured. Next, locations for data acquisition were also being determined.

3.1.3 Experimental work

The experimental work was done by manipulating the rotation of valve which is controlling the volume of water entering the pond. Firstly, the experiment was started by rotating the valve one time. Then, data such as velocity of water at the inlet, depth of water at the inlet, depth of water in the pond and depth of water at the outlet were collected every minute for about 30 minutes. After 30 minutes, the valve was closed to stop the water from entering the pond. However, the depth of water at the outlet structure still needed to be collected for every minute until the pond became empty. From these data, the discharge at the inlet and outlet were calculated. The opening of the rectangular weir at the outlet was kept at its maximum that is 8cm. Then, the experiment was continued by varying the number of rotation of the valve.

There were some difficulties in running the experiment such as during the first few trials of experiment, it was noticed that there was air trap in the pipe and this air trap did affected the experiment as the velocity of the water entered the pond would be fluctuating. Thus, the experiment had to be repeated again. Secondly, the experiment area was large where it led to difficulties in standardizing the time recorded. This was because the three locations where data needed to be collected were quite far from each other and it had make it difficult for the three data collectors to communicate with each other.

Next, one round of the experiment taking quite long duration that is more than one hour. If there was any mistake or disruption during the experiment was run, it was quite time consuming to repeat the cycle again. One more difficulty faced was the laboratory did not have the equipment to measure the discharge directly. So, the discharge needed to be calculated from the measured velocity.

pond because real condition of detention pond would receive runoff water that give a bell like curve of hydrograph.

4.1.2 Theoretical Inflow and Outflow hydrograph using Modified Puls method

The velocity of water entered the pond was calculated by using equation

$v = L/t$ (Equation 4.3)

The length of the pipe was approximately 60m.

The discharge of the water entered the pond was calculated by multiplying the velocity with the water depth at the inlet and the length of the inlet.

Then, the outflow was calculated by using Modified Puls method. The detail of the calculation was attached in the Appendix II.

Figures 4.4 to 4.6 show the relationship between the discharge and time using Modified Puls method.

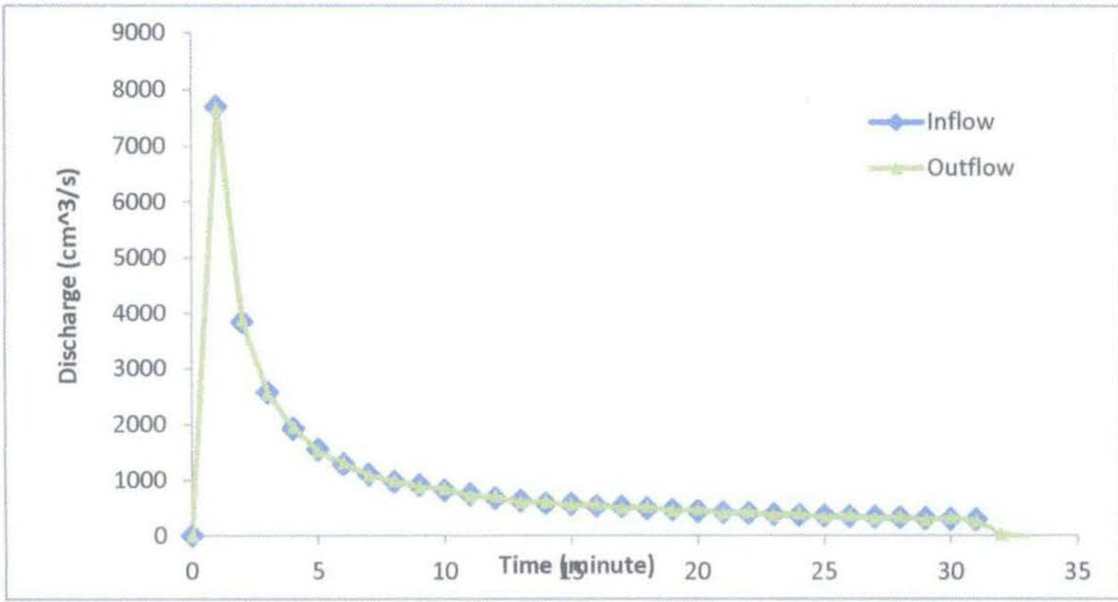

Figure 4.4: Discharge versus time for rotation one using Modified Puls Method

Figure 4.4 illustrate the inflow and the outflow calculated using Modified Puls method. The result shows that there was slightly difference between the inflow value and the outflow value. For rotation one, the highest inflow and outflow discharge was 7680cm^3/s. The discharge was quite small compared to discharge from rotation two and three because the water depth at the inlet for rotation one was smaller.

There was outflow since the minute first because the calculation did not consider the size of the pond. In real detention pond, the water took some time to reach the outlet structure, thus the outflow would only there after a few minutes.

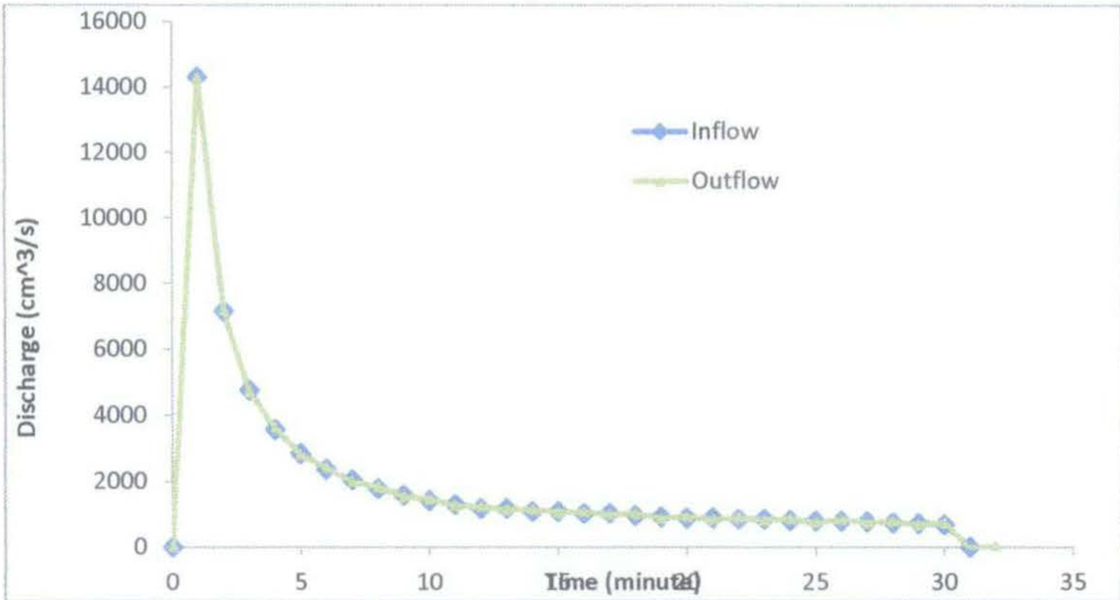

Figure 4.5: Discharge versus time for rotation two using Modified Puls Method

Figure 4.5 shows the inflow and outflow calculated for rotation two. The calculated inflow was almost the same as the calculated outflow. Besides, both of the inflow and outflow had maximum value of 14 266cm^3/s on the first minute. This was because it assumed to have largest inflow at the beginning since the pond was still empty. After there was storage of water, the velocity of the water going into the pond decreased. The outflow had same pattern as the inflow because it was very much depending on the inflow rate.

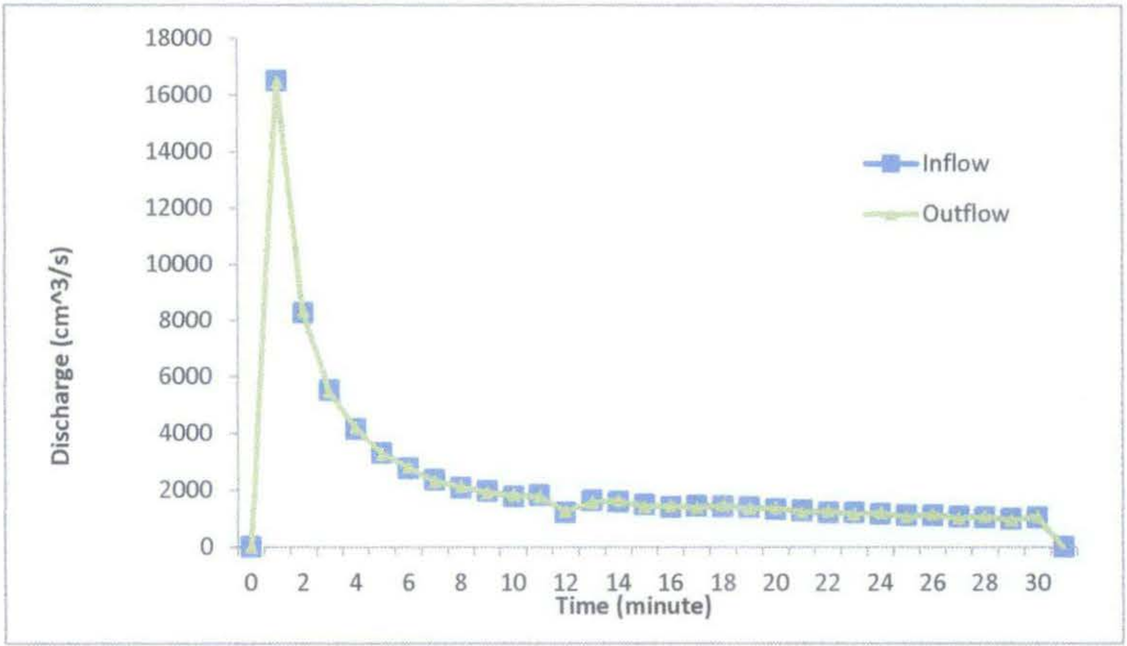

Figure 4.6: Discharge versus time for rotation three using Modified Puls Method

Based on Figure 4.6, it shows that the calculated inflow had slightly difference compared to the outflow. Both inflow and outflow stopped at minute thirtieth. For rotation three, the inflow and the outflow were the largest among three rotations because it had the highest reading of water depth at the inlet.

For the calculated inflow, it shows that the inflow increase drastically at minute first at then decrease by time. This was because at the first minute the velocity was the highest and the velocity of water decreased with time after that because of there was water inside the pond. The calculated inflow represented the inflow for the physical model of pond but not the real condition of detention pond because actual detention pond received inflow from the runoff. So, the inflow would be like a bell curve graph.

The calculated outflow actually did not represent the true condition of the detention pond. In real case situation the water need to fill the pond first before it could reach to the outlet structure. However this theoretical calculation shows that the amount of water entering the pond is equal to the water coming out from the pond.

4.1.3 Theoretical Outflow hydrograph using Muskingum method

Muskingum method used to compare the outflow reading obtained from the experimental work with the theoretical one. Inflow and outflow obtained from the experimental work were used to calculate the value of the coefficient C_0, C_1 and C_2.

Firstly, the storage for each point was calculated by using equation 4.4 as below.

$$S_{t+1} = S_t + \Delta t \left(\frac{I_t + I_{t+1}}{2} - \frac{O_t + O_{t+1}}{2}\right) \qquad \text{(equation 4.4)}$$

Secondly, the value of [xI + (1-x)O] for each point in time was calculated using trial value of x. Then, graph of storage versus [xI + (1-x)O] was plotted. The value of x was revised until the plot showed a minimum amount of deviation from a straight line. The slope of the line was used as the best estimate of K value and the value of x that produced the smallest deviation was used as the estimate of x. with the value of K and x obtained, the value of coefficient C_0, C_1 and C_2 were calculated using equation 4.5, equation 4.6 and equation 4.7.

$$C_0 = \frac{-(Kx - 0.5\Delta t)}{K - Kx + 0.5\,\Delta t} \qquad \text{(equation 4.5)}$$

$$C_1 = \frac{Kx + 0.5\Delta t}{K - Kx + 0.5\,\Delta t} \qquad \text{(equation 4.6)}$$

$$C_2 = \frac{K - Kx - 0.5\Delta t}{K - Kx + 0.5\,\Delta t} \qquad \text{(equation 4.7)}$$

By using the equation below, the new outflow was calculated.

$$O = C_0 I_1 + C_1 I_1 + C_2 O_1 \qquad \text{(equation 4.8)}$$

The detail calculation for rotation one, two and three as per attached in the Appendix III.

From the outflow obtained from the Muskingum method, comparison had been made between the calculated outflow and the outflow obtained from the experimental work. Figure 4.7 until Figure 4.9 illustrated the comparison between the calculated outflow using Muskingum method and outflow obtained from experiment.

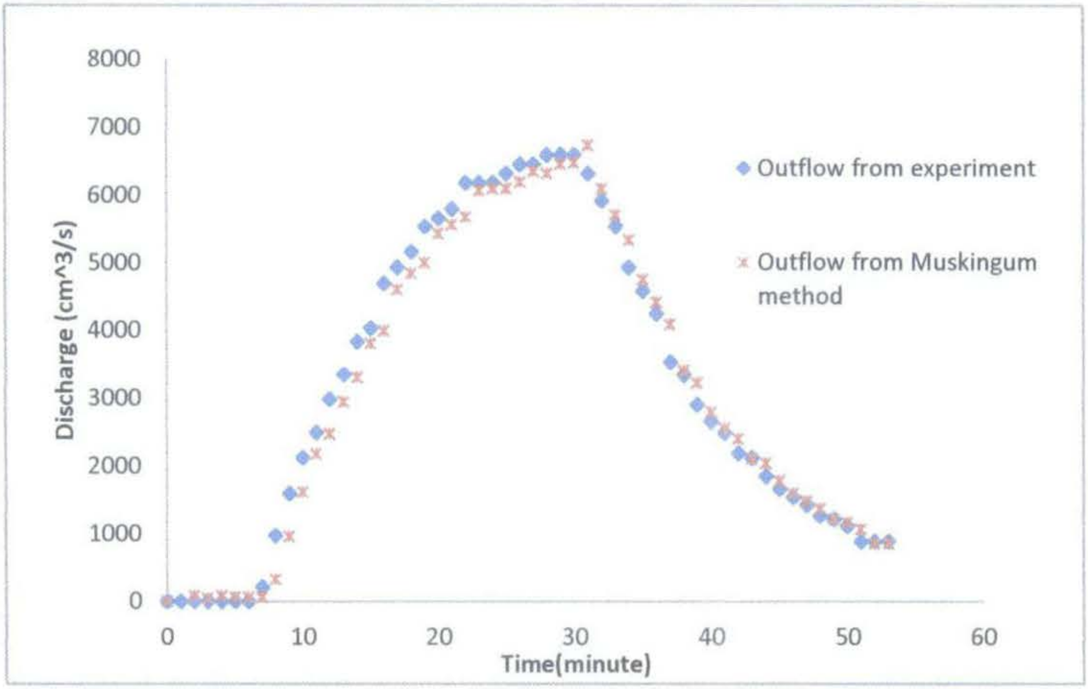

Figure 4.7: Comparison of theoretical and experimental outflow for rotation one

Based on Figure 4.7, the percentage difference between the theoretical outflow and the experimental outflow for the first eight minutes were high as it reached value of 100%. The percentage difference however decreased with time. When it reached the fifteenth minute, the percentage difference was below 10%. This was because in the theoretical calculation, the dimension of the pond was not included. So, there was outflow since the first minute.

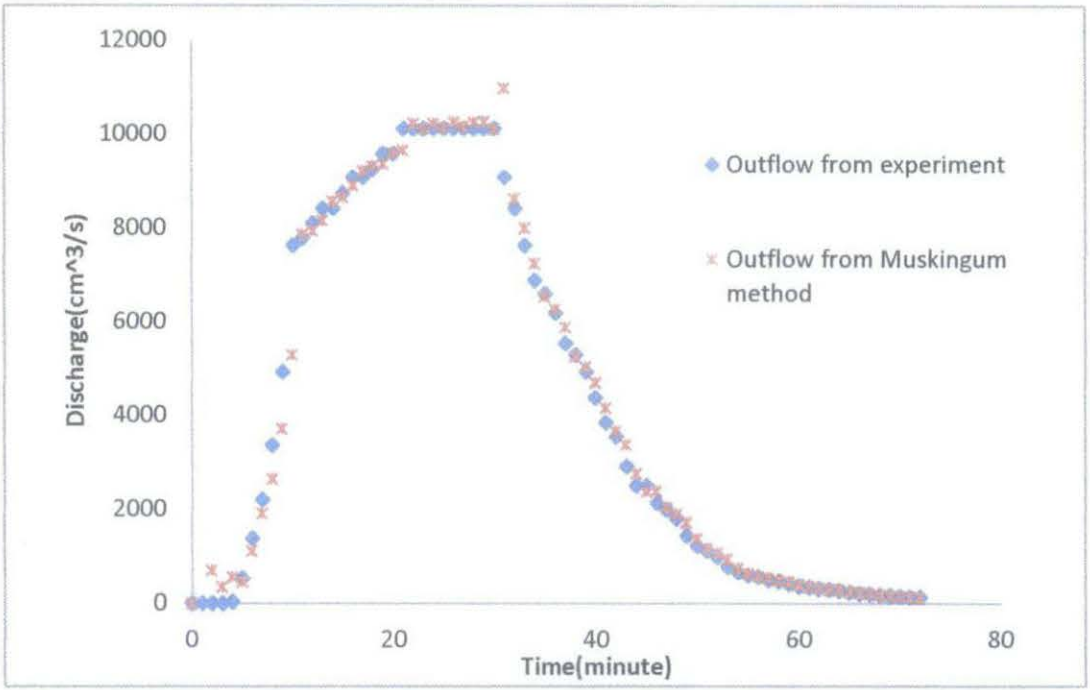

Figure 4.8: Comparison of theoretical and experimental outflow for rotation two

For rotation two, the percentage difference between the calculated outflow and experimental outflow reached up to 100% for the first four minutes. In the experiment, it took time for the water to reach the outlet structure because of the size of the pond. However, in the calculation this condition was not considered. That was why there was outflow since the first minute. The percentage difference became smaller when it reached the eleventh minute. Most of the percentage differences were below 5%. It showed that the experimental outflow was reliable.

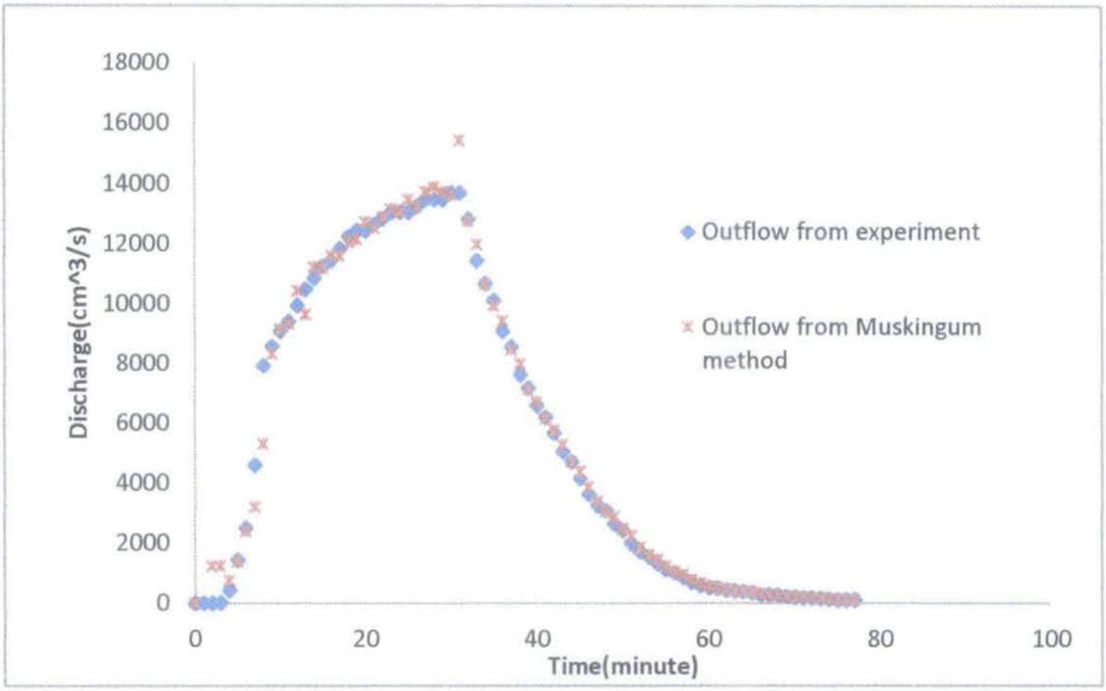

Figure 4.9: Comparison of theoretical and experimental outflow for rotation three

Based on Figure 4.9 above, the percentage difference between the two values of outflow was very high at the first three minutes where the percentage differences were nearly 100%. This was due to in the calculation, there was outflow since the minute first, however in the experiment, there were outflow only after three minutes. the outflow seemed to be quite similar after approaching the ninth minute as the percentage differences were below 5%.

The detail of the percentage differences for rotation one, two and three were attached in Appendix IV.

4.1 Stage and Discharge relationship

4.1.1 From experimental work

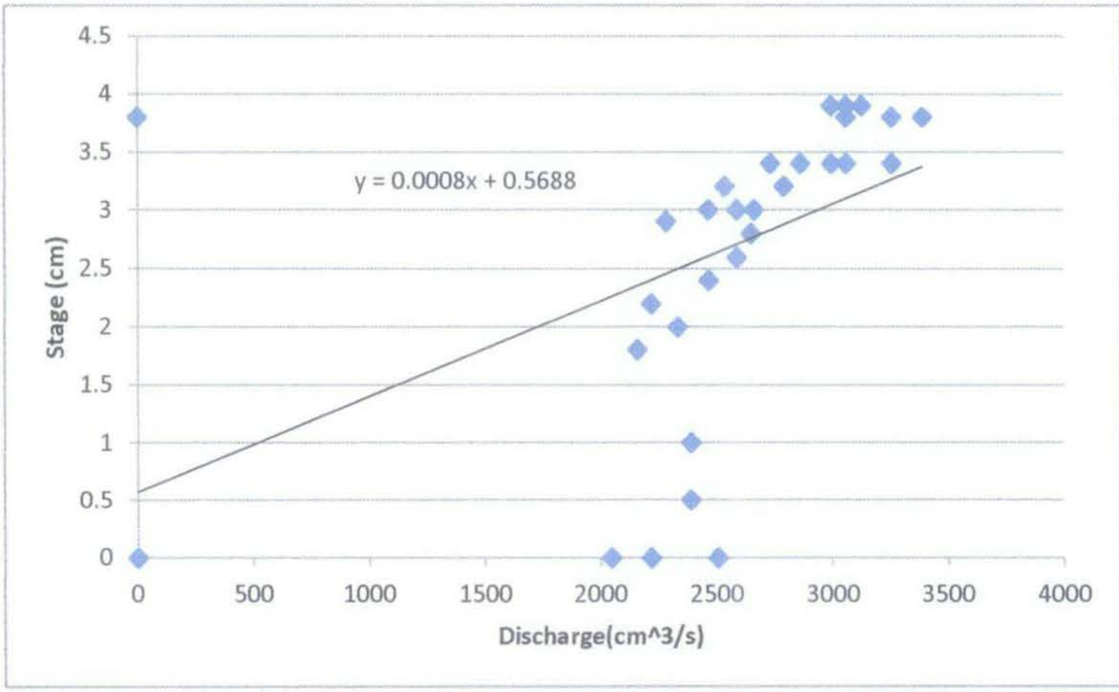

Figure 4.10: Stage versus discharge for rotation one

For Figure 4.10, it shows that when the discharge is increased, the water depth inside the pond will also increase. For rotation one, the starting water depth approximately 0.57cm according to the equation develop from the trend line. The starting water depth was low because for rotation one, the amount of water allowed to flow into the pond was small. From the experimental work, the data got were quite scattered. This was due to the fluctuating reading from the streamflo probe.

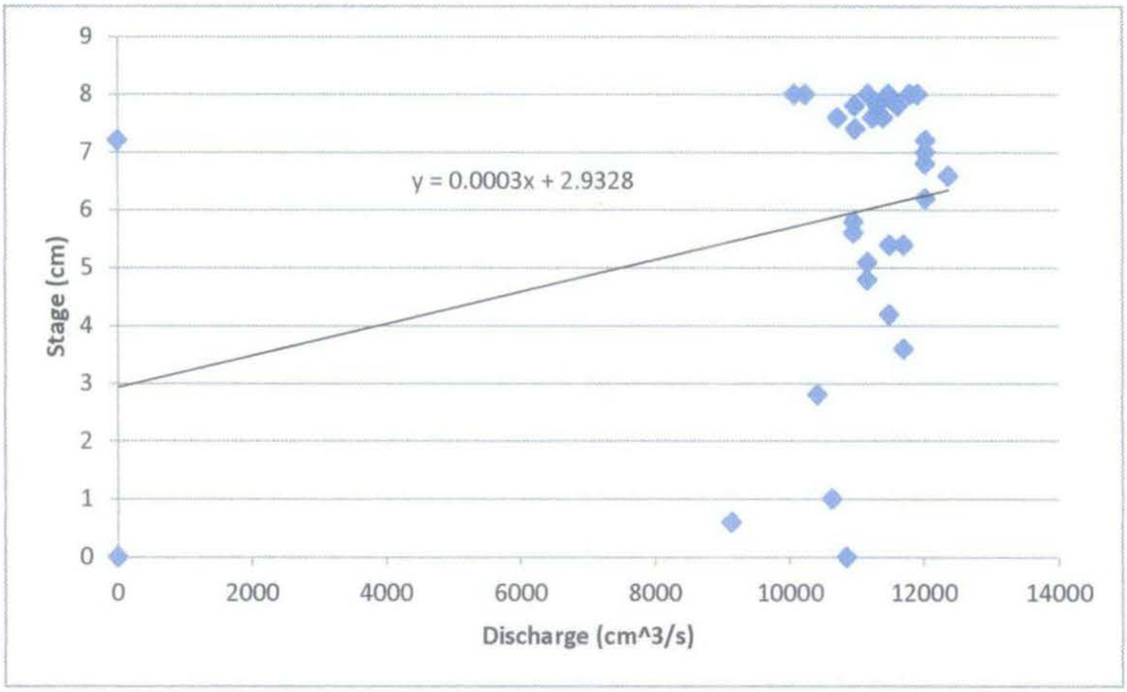

Figure 4.11: Stage versus discharge for rotation two

Figure 4.11 shows that the stage inside the pond increased as the inflow discharge increased. For rotation two, the starting stage was approximately 2.93cm. The data obtained from the experimental work were quite scattered but still showed that the highest stage was at the bigger discharge. This was because higher discharge would increase the storage of the pond. Thus, the water depth inside the pond will increase.

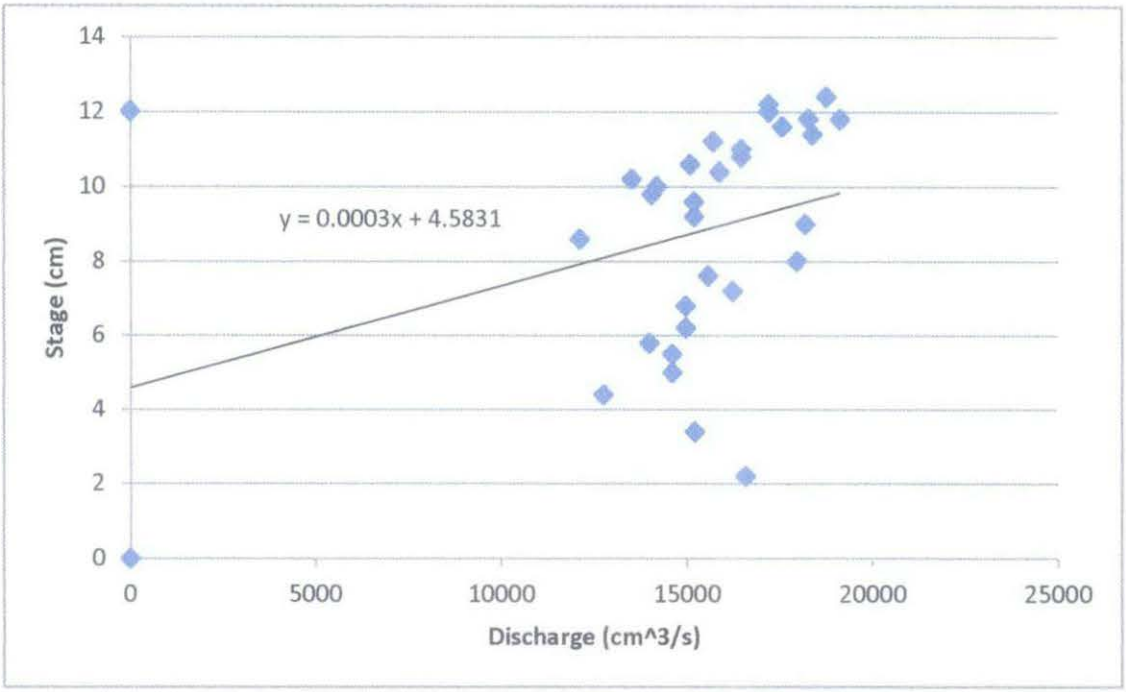

Figure 4.12: Stage versus discharge for rotation three

Figure 4.12 illustrate that the stage of water in the pond will increase with increasing inflow discharge. The starting water depth for rotation three approximately around 4.58cm from the equation develop.

From the graph obtained, it shows that stage will increase with the increasing inflow. Rotation two and three gave similar rate of stage increment with respond to the discharge that is 0.0003. However, rotation three show higher starting water depth compared to rotation two because the discharge of rotation three is higher.

4.1.2 From theoretical calculation

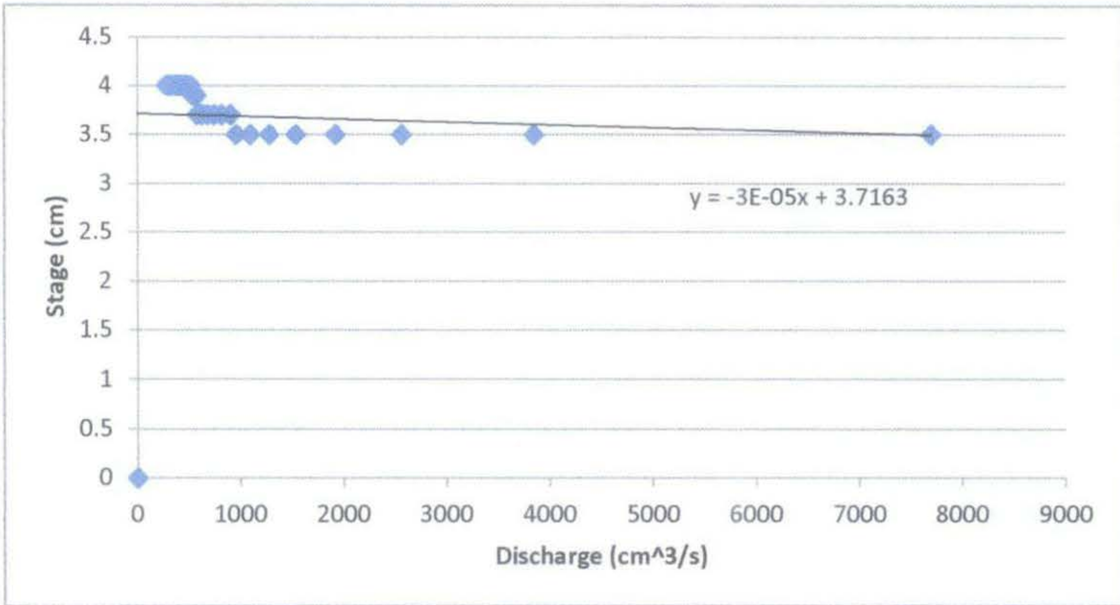

Figure 4.13: Stage versus discharge for rotation one from theoretical calculation

From Figure 4.13, the relationship between the stage and discharge for rotation one can be presented as the discharge increased, the stage would be decreased. The initial stage of water was approximately 3.72cm.

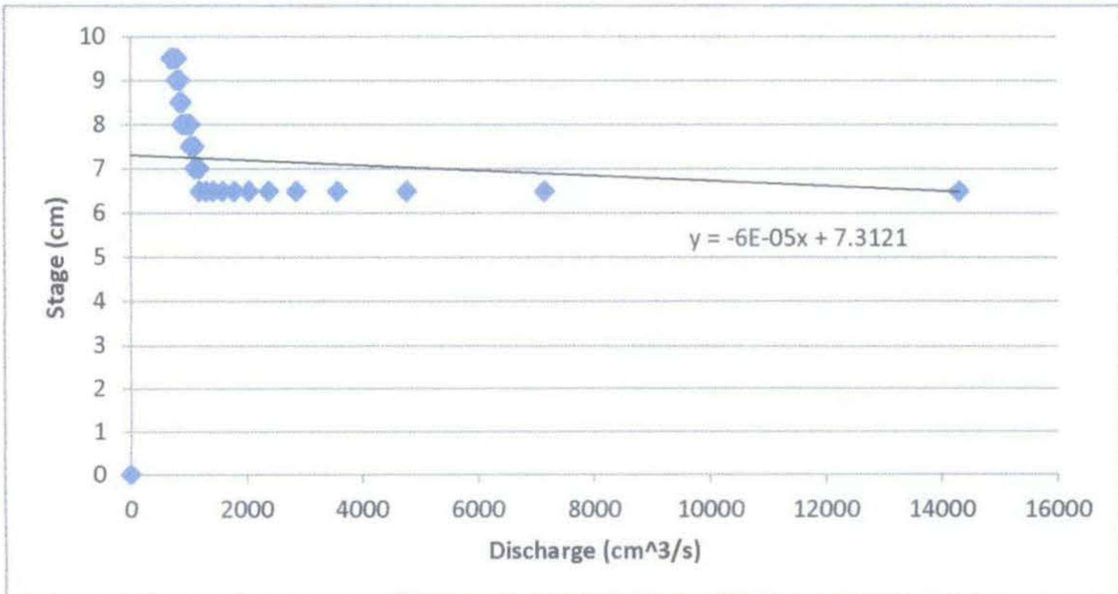

Figure 4.14: Stage versus discharge for rotation two from theoretical calculation

Based on Figure 4.14, the water depth inside the pond was inversely proportional to the inflow. The stage decreased as the discharge increased. Meanwhile, the initial stage was approximately 7.31cm.

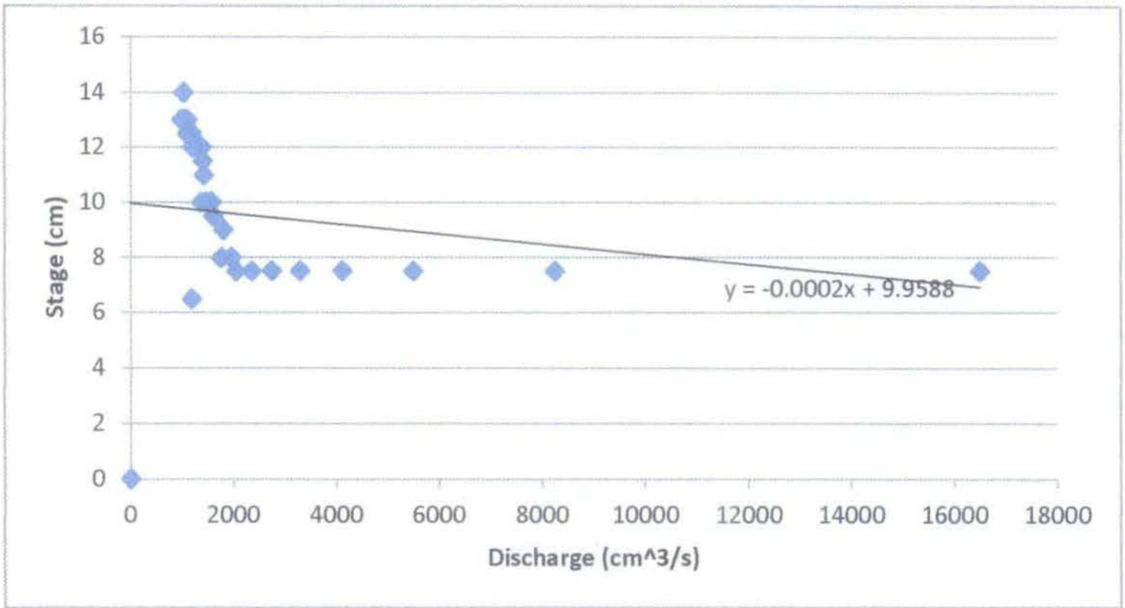

Figure 4.15: Stage versus discharge for rotation three from theoretical calculation

From Figure 4.15, it can be concluded that when the discharge of water at the inlet increased the water depth inside the pond decreased. The initial stage of rotation three was approximately 9.96cm which was derived from the trend line

Figure 4.10- Figure 4.12 however did not represent the real stage and discharge relationship. This was due to in the theoretical calculation; it was assumed that the velocity of water going into the pond decreased with time. Thus, the calculated discharge would be decreased although the water depth inside the pond was increasing.

4.1.3 Comparison between calculated and experimental Stage-Discharge relationship

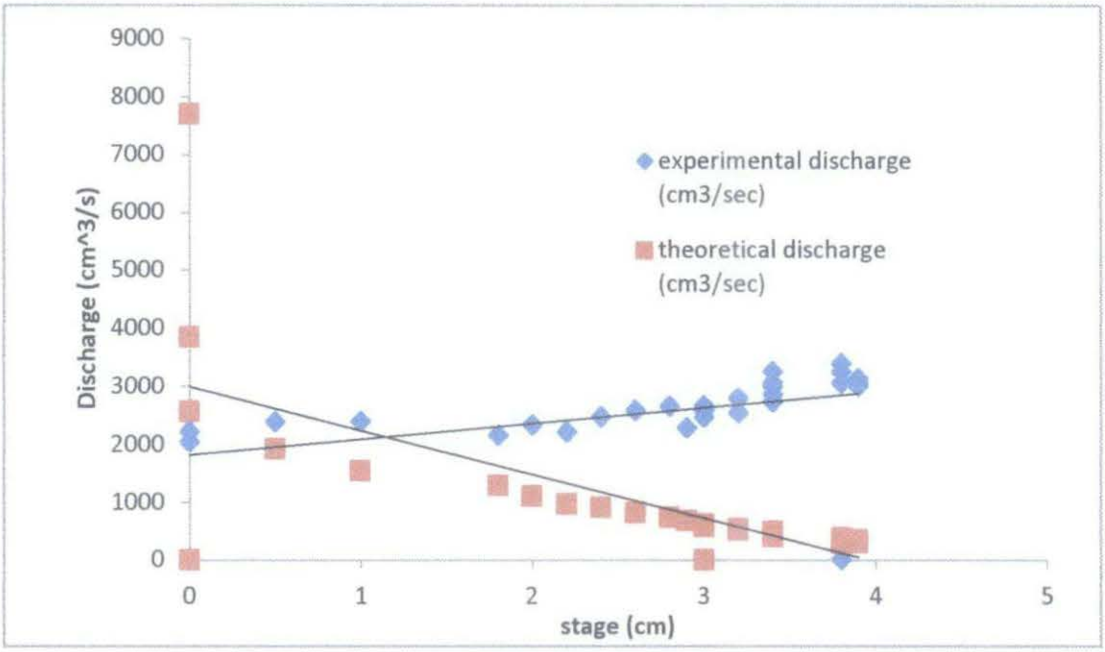

Figure 4.16: Comparison between calculated and experimental stage-discharge relationship

Figure 4.16 illustrate the comparison between the stage-discharge relationship developed from experimental work and also from the theoretical calculation using Modified Puls method. Both of the results were contradict to each other because of the assumption made by each of them. For the experimental work, the velocity of the water into the pond was assumed to be increased with time. However, in the Modified Puls method, the velocity of water coming in was assumed to decrease with time.

4.2 Stage and Storage relationship

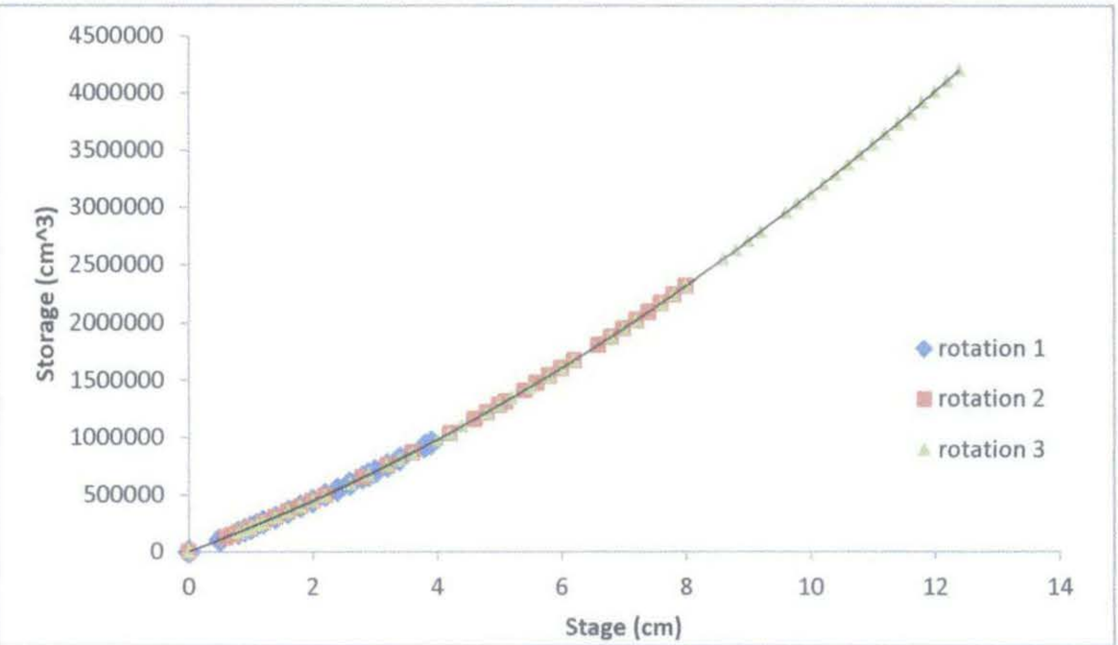

Figure 4.17: Stage-Storage relationship for rotation one to three

Based on Figure 4.17 above, the storage increased when the discharge increased. The stage storage relationships for all the three rotation were the same in rate. The stage and the storage for rotation one was the lowest since the discharge was the smallest among the three rotations.

The stage storage relationships developed a parabolic equation and this result was in line with usual stage storage relationship develop for watershed and river routing.

Throughout the laboratory work, there were some weaknesses of this experimental work which had led to inconsistency in the result as the inflow reading fluctuated according to time, and the inflow hydrograph did not represent real condition of detention pond inflow. This is due to some errors which are:

1. Time for recording the velocity at inlet, depth of water in the pond, and depth of water at outlet may not be the same as it were recorded by three different people. This is because the data need to be collected at three different locations which are quite far from one another.

2. There is air trap in the pipe at the beginning of the experiment which caused the flow entering the pond become unsteady.
3. The streamflo probe instrument easily get stuck with small particles that floating in the water which caused the reading of velocity either lower than it should be.
4. The Streamflo probe also very sensitive in term of producing the velocity value. If the location of Streamflo moved a bit from its original point, it will give different value of reading.
5. The velocity reading was made exactly in front of the inlet structure where the turbulent flow most likely to occur. Thus, it affected the accuracy of the velocity reading.
6. The water entering the pond was controlled by valve rotation. As the valve closed, the water immediately stop entering the pond and caused the inflow graph could not be a perfect hydrograph which supposed to be bell-like curve.

Some precautions have been done in order to minimize the error. Some of them are:

1. By repeating the experiment at least twice so that the value recorded more consistent. The experiment took at least 30 minutes for each rotation and almost one hour to empty the pond before starting the next rotation. Thus, to repeat it three times is quite a problem because time is very limited.
2. To avoid the air trap from affecting the result, the water is allowed to flow for a few minutes before starting the experiment.
3. The scale on the ruler need to be read three times and the average data is calculated so that parallax error can be reduced.
4. Initial point of streamflo probe location need to be marked so that the instrument location did not varies with time.
5. The streamflo probe needs to be put far from the inlet structure to avoid the turbulent flow that could contribute to fluctuated reading of velocity.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

From the results obtained from the experimental work, it can be concluded that the inflow and outflow discharge increased as the number of rotation increased. Besides, the water depth inside the pond also increased when the inflow of the detention pond increase. As the stage increased, the storage of the detention pond also increased. These results were in line with the theory, however, in order to produce a fix relationship between the stage-discharge and stage storage for this experiment was quite inaccurate. This is because the physical model of detention pond that had been used in this experiment did not satisfy the condition of real detention pond as it has its limitations such as:

1. The detention pond was designed to cater overflow from dam which would receive high inflow. That was why the inflow obtained from the experimental work increase drastically and constant throughout the time. A detention pond should receive runoff that can be presented in hydrograph.
2. The water stored in the tank was not sufficient compared to the capacity of the pond. Thus, the experiment could not be done for a long period of time for a cycle.
3. There is no instrument in the lab that can measure the discharge directly and that had led to inconsistency to the discharge value.

Some recommendations for further research on this experiment are to prepare standby water so that after the valve is closed, there is still water entering the pond in smaller quantity. Thus, with decreasing inflow after 30 minutes, the bell-like curve can be obtained. Otherwise, the experiment needs to be adjusted so that the required inflow can be obtained. It is important to make sure the experimental work satisfied with the real detention pond condition so that the results produced are reliable. Besides, proper equipment is also very important. It is better to have equipment that can measure discharge directly from the flow of water to avoid fluctuated reading.

References

Bauer, R. D. (2008, May). Optimization of detention ponds for urbanizing watersheds. Carbondale, Illinois, United States.

Fiener, P. (2005, November). Managing Erosion and Water Quality in Agricultural Watersheds by Small Detention Ponds. *Agriculture, Ecosystems & Environment, 110*(3-4), 132-142.

Gould, J. W. (1969). *The United States and Malaysia.* Harvard University Press.

Hong, Y.-M. (2008, September). Numerical Simulation of Laboratory Experiments in Detention Pond Routing With Long Rainfall Duration. *International Journal of Sediment Research, 23*(3), 233-248.

Liew, Y. S., Z. Selamat, & A. Abd. Ghani. (2009). *Perfomance of Stormwater Drainage System through Dry Detention Pond for Medium Size Housing Development using InfoWorks CS*, 19.

Maghrebi, M. R. (2006, October). Flow Measurement and Instrumentation. *Prediction of stage–dischargenext term curves in open-channels using a fixed-point velocity measurement, 17*(5), 276-281 .

Martin P. Wanielista, Y. A. (1993). *Stormwater management.* Wiley-Interscience.

McCuen, R. H. (2004). *Hydrologic Analysis And Design* (3rd ed.). New Jersey: PEARSON Prentice Hall.

Nehrke, S. M. (2004). JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT. *Effects of Design Practice for Flood Control and Best Management Practices on the Flow-Frequency Curve*, 133.

Peter H. Gleick, H. C. (2006). *The world's water, 2006-2007:the biennial report on freshwater resources.* Island Press.

Pettersson, T. J. (1998). Water Quality Improvement In A Small Stormwater Detention Pond. *Water Sience and Technology, 38*(10), 115-122.

Pitt, R. (2004, April 12). Detention Pond Design and Analysis.

Tung. (1985). Journal of hydrology. *RIVER FLOOD ROUTING BY NONLINEAR, 111*, 1447-1448.

Appendix I – Detail calculation of inflow and outflow calculation from experimental work

i) Rotation 1

time (minute)	velocity (cm/sec)	water depth at inlet (cm)	discharge (cm^3/sec)	water depth in the pond (cm)	water depth at outlet (cm)	water depth at outlet (m)	discharge at outlet (m^3/sec)	discharge at outlet (cm^3/sec)
0	0.00	0	0.000	0	0	0	0	0.000
1	26.57	3.5	2045.672	0	0	0	0	0.000
2	28.81	3.5	2218.060	0	0	0	0	0.000
3	32.54	3.5	2505.373	0	0	0	0	0.000
4	31.04	3.5	2390.448	0.5	0	0	0	0.000
5	31.04	3.5	2390.448	1	0	0	0	0.000
6	28.06	3.5	2160.597	1.8	0	0	0	0.000
7	30.30	3.5	2332.985	2	3	0.03	0.000221	220.954
8	28.81	3.5	2218.060	2.2	5.5	0.055	0.001006	1005.556
9	30.30	3.7	2466.299	2.4	6.7	0.067	0.001647	1646.973
10	31.79	3.7	2587.791	2.6	7.5	0.075	0.002183	2183.497
11	32.54	3.7	2648.537	2.8	8	0.08	0.002566	2565.810
12	28.06	3.7	2284.060	2.9	8.6	0.086	0.003074	3074.295
13	30.30	3.7	2466.299	3	9	0.09	0.003444	3444.338
14	31.79	3.7	2587.791	3	9.5	0.095	0.003943	3942.834
15	31.04	3.9	2663.642	3	9.7	0.097	0.004154	4153.640
16	32.54	3.9	2791.701	3.2	10.3	0.103	0.004826	4826.058
17	28.81	4	2534.925	3.2	10.5	0.105	0.005064	5063.755
18	31.04	4	2731.940	3.4	10.7	0.107	0.005308	5308.342
19	32.54	4	2863.284	3.4	11	0.11	0.005688	5688.283
20	34.03	4	2994.627	3.4	11.1	0.111	0.005818	5818.445
21	34.78	4	3060.299	3.4	11.2	0.112	0.00595	5950.378
22	37.01	4	3257.313	3.4	11.5	0.115	0.006357	6356.881
23	38.51	4	3388.657	3.8	11.5	0.115	0.006357	6356.881
24	37.01	4	3257.313	3.8	11.5	0.115	0.006357	6356.881
25	34.78	4	3060.299	3.8	11.6	0.116	0.006496	6495.977
26	35.52	4	3125.970	3.9	11.7	0.117	0.006637	6636.883
27	34.03	4	2994.627	3.9	11.7	0.117	0.006637	6636.883
28	34.78	4	3060.299	3.9	11.8	0.118	0.00678	6779.607
29	35.52	4	3125.970	3.9	11.8	0.118	0.00678	6779.607
30	34.03	4	2994.627	3.9	11.8	0.118	0.00678	6779.607
31	0.00	4	0.000	3.8	11.6	0.116	0.006496	6495.977
32				3	11.3	0.113	0.00608	6084.089

							4	
33				2.6	11	0.11	0.005688	5688.283
34				2.4	10.5	0.105	0.005064	5063.755
35				2	10.2	0.102	0.00471	4709.772
36				1.8	9.9	0.099	0.004371	4371.067
37				1.8	9.2	0.092	0.003639	3638.891
38				1.6	9	0.09	0.003444	3444.338
39				1.6	8.5	0.085	0.002986	2985.704
40				1.4	8.2	0.082	0.002729	2729.192
41				1.2	8	0.08	0.002566	2565.810
42				1.2	7.6	0.076	0.002257	2257.010
43				1.1	7.5	0.075	0.002183	2183.497
44				1	7.1	0.071	0.001904	1903.905
45				0.9	6.8	0.068	0.001709	1709.117
46				0.8	6.6	0.066	0.001586	1586.205
47				0.8	6.4	0.064	0.001469	1468.755
48				0.8	6.1	0.061	0.001303	1302.639
49				0.8	6	0.06	0.00125	1249.907
50				0.8	5.8	0.058	0.001148	1148.337
51				0.8	5.3	0.053	0.000917	916.620
52				0.8	5.3	0.053	0.000917	916.620
53				0.8	5.3	0.053	0.000917	916.620

ii) Rotation 2

time (minute)	velocity (cm/sec)	water depth at inlet (cm)	discharge (cm^3/sec)	water depth in the pond (cm)	water depth at outlet (cm)	water depth at outlet (m)	discharge at outlet (m^3/sec)	discharge at outlet (cm^3/sec)
0	0.00	0	0.00	0	0	0.000	0.000	0.000
1	75.82	6.5	10842.39	0	0	0.000	0.000	0.000
2	63.88	6.5	9134.93	0.6	0	0.000	0.000	0.000
3	74.33	6.5	10628.96	1	0	0.000	0.000	0.000
4	72.84	6.5	10415.52	2.8	1.5	0.015	0.000	39.060
5	81.79	6.5	11696.12	3.6	4.3	0.043	0.001	543.464
6	80.30	6.5	11482.69	4.2	6.3	0.063	0.001	1412.053
7	78.06	6.5	11162.54	4.8	7.6	0.076	0.002	2257.010
8	78.06	6.5	11162.54	5.1	9	0.090	0.003	3444.338
9	81.79	6.5	11696.12	5.4	10.5	0.105	0.005	5063.755
10	80.30	6.5	11482.69	5.4	12.5	0.125	0.008	7830.230
11	76.57	6.5	10949.10	5.6	12.6	0.126	0.008	7987.775

12	76.57	6.5	10949.10	5.8	12.8	0.128	0.008	8308.534
13	78.06	7	12021.19	6.2	13	0.130	0.009	8636.899
14	80.30	7	12365.97	6.6	13	0.130	0.009	8636.899
15	72.84	7.5	12017.91	6.8	13.2	0.132	0.009	8972.931
16	72.84	7.5	12017.91	7	13.4	0.134	0.009	9316.686
17	68.36	8	12031.04	7.2	13.4	0.134	0.009	9316.686
18	62.39	8	10980.30	7.4	13.5	0.135	0.009	9491.479
19	60.90	8	10717.61	7.6	13.7	0.137	0.010	9846.931
20	63.88	8	11242.99	7.6	13.7	0.137	0.010	9846.931
21	60.90	8.5	11387.46	7.6	14	0.140	0.010	10394.882
22	58.66	8.5	10968.81	7.8	14	0.140	0.010	10394.882
23	58.66	9	11614.03	7.8	14	0.140	0.010	10394.882
24	57.16	9	11318.51	7.8	14	0.140	0.010	10394.882
25	60.15	9	11909.55	8	14	0.140	0.010	10394.882
26	54.93	9.5	11479.40	8	14	0.140	0.010	10394.882
27	56.42	9.5	11791.34	8	14	0.140	0.010	10394.882
28	53.43	9.5	11167.46	8	14	0.140	0.010	10394.882
29	48.21	9.5	10075.67	8	14	0.140	0.010	10394.882
30	48.96	9.5	10231.64	8	14	0.140	0.010	10394.882
31	0.00	0	0.00	7.2	13.4	0.134	0.009	9316.686
32				6.8	13	0.130	0.009	8636.899
33				6	12.5	0.125	0.008	7830.230
34				5	12	0.120	0.007	7070.540
35				4.6	11.8	0.118	0.007	6779.607
36				4.2	11.5	0.115	0.006	6356.881
37				4.2	11	0.110	0.006	5688.283
38				3.2	10.8	0.108	0.005	5433.240
39				2.8	10.5	0.105	0.005	5063.755
40				2.8	10	0.100	0.004	4482.285
41				2.2	9.5	0.095	0.004	3942.834
42				2	9.2	0.092	0.004	3638.891
43				2	8.5	0.085	0.003	2985.704
44				1.8	8	0.080	0.003	2565.810
45				1.8	8	0.080	0.003	2565.810
46				1.8	7.5	0.075	0.002	2183.497
47				1.6	7.3	0.073	0.002	2040.829
48				1.6	7	0.070	0.002	1837.573
49				1.4	6.4	0.064	0.001	1468.755
50				1.2	6	0.060	0.001	1249.907
51				0.8	5.8	0.058	0.001	1148.337
52				0.8	5.5	0.055	0.001	1005.556
53				0.8	5	0.050	0.001	792.364

54				0.8	4.7	0.047	0.001	678.804
55				0.8	4.5	0.045	0.001	608.879
56				0.8	4.4	0.044	0.001	575.614
57				0.8	4.2	0.042	0.001	512.416
58				0.8	4.1	0.041	0.000	482.458
59				0.8	3.9	0.039	0.000	425.756
60				0.8	3.7	0.037	0.000	373.253
61				0.8	3.6	0.036	0.000	348.542
62				0.8	3.5	0.035	0.000	324.840
63				0.8	3.4	0.034	0.000	302.132
64				0.8	3.3	0.033	0.000	280.404
65				0.8	3.1	0.031	0.000	239.830
66				0.8	3	0.030	0.000	220.954
67				0.8	2.9	0.029	0.000	202.999
68				0.7	2.8	0.028	0.000	185.949
69				0.7	2.7	0.027	0.000	169.789
70				0.7	2.6	0.026	0.000	154.502
71				0.7	2.5	0.025	0.000	140.071
72				0.7	2.5	0.025	0.000	140.071

iii) Rotation 3

time (minute)	velocity (cm/sec)	water depth at inlet (cm)	discharge (cm^3/sec)	water depth in the pond (cm)	water depth at outlet (cm)	water depth at outlet (m)	discharge at outlet (m^3/sec)	discharge at outlet (cm^3/sec)
0	0.00	0	0.00	0	0	0.000	0.000	0.000
1	100.45	7.5	16573.88	2.2	0	0.000	0.000	0.000
2	92.24	7.5	15219.40	3.4	0	0.000	0.000	0.000
3	77.31	7.5	12756.72	4.4	0.7	0.007	0.000	5.666
4	88.51	7.5	14603.73	5	3.9	0.039	0.000	415.112
5	88.51	7.5	14603.73	5.5	6.4	0.064	0.001	1432.036
6	84.78	7.5	13988.06	5.8	8	0.080	0.003	2501.664
7	90.75	7.5	14973.13	6.2	10.2	0.102	0.005	4592.028
8	90.75	7.5	14973.13	6.8	12.7	0.127	0.008	7943.527
9	92.24	8	16234.03	7.2	13.1	0.131	0.009	8583.854
10	88.51	8	15577.31	7.6	13.4	0.134	0.009	9083.769
11	90.75	9	17967.76	8	13.6	0.136	0.009	9426.519
12	84.78	6.5	12122.99	8.6	13.9	0.139	0.010	9954.996
13	87.01	9.5	18186.12	9	14.2	0.142	0.011	10500.862

14	69.10	10	15202.99	9.2	14.4	0.144	0.011	10874.526
15	69.10	10	15202.99	9.6	14.6	0.146	0.011	11256.056
16	63.88	10	14053.73	9.8	14.7	0.147	0.011	11449.788
17	58.66	11	14194.93	10	14.9	0.149	0.012	11843.219
18	53.43	11.5	13518.51	10.2	15.1	0.151	0.012	12244.652
19	60.15	12	15879.40	10.4	15.2	0.152	0.012	12448.387
20	57.16	12	15091.34	10.6	15.2	0.152	0.012	12448.387
21	62.39	12	16470.45	10.8	15.3	0.153	0.013	12654.141
22	62.39	12	16470.45	11	15.4	0.154	0.013	12861.923
23	57.16	12.5	15720.15	11.2	15.5	0.155	0.013	13071.738
24	66.87	12.5	18388.06	11.4	15.5	0.155	0.013	13071.738
25	63.88	12.5	17567.16	11.6	15.5	0.155	0.013	13071.738
26	66.87	13	19123.58	11.8	15.6	0.156	0.013	13283.594
27	63.88	13	18269.85	11.8	15.7	0.157	0.013	13497.497
28	60.15	13	17202.69	12	15.7	0.157	0.013	13497.497
29	60.15	13	17202.69	12.2	15.7	0.157	0.013	13497.497
30	60.90	14	18755.82	12.4	15.8	0.158	0.014	13713.453
31	0.00	0	0.00	12	15.8	0.158	0.014	13713.453
32				10.8	15.4	0.154	0.013	12861.923
33				9.6	14.7	0.147	0.011	11449.788
34				8.8	14.3	0.143	0.011	10686.714
35				7.8	14	0.140	0.010	10135.010
36				7	13.4	0.134	0.009	9083.769
37				6	13.1	0.131	0.009	8583.854
38				5.2	12.5	0.125	0.008	7634.474
39				4.8	12.2	0.122	0.007	7184.618
40				4.2	11.8	0.118	0.007	6610.117
41				4	11.5	0.115	0.006	6197.959
42				3.6	11.1	0.111	0.006	5672.984
43				3.2	10.6	0.106	0.005	5055.554
44				2.9	10.3	0.103	0.005	4705.407
45				2.9	9.8	0.098	0.004	4154.983
46				2.6	9.3	0.093	0.004	3645.117
47				2.2	8.9	0.089	0.003	3265.721
48				2	8.7	0.087	0.003	3085.334
49				1.8	8.2	0.082	0.003	2660.962
50				1.8	7.9	0.079	0.002	2424.219
51				1.8	7.3	0.073	0.002	1989.808
52				1.6	6.9	0.069	0.002	1728.331
53				1.6	6.6	0.066	0.002	1546.550
54				1.4	6.2	0.062	0.001	1322.767
55				1.2	5.8	0.058	0.001	1119.629

56				1.2	5.6	0.056	0.001	1025.591
57				1.1	5.2	0.052	0.001	852.143
58				1	4.8	0.048	0.001	697.601
59				1	4.5	0.045	0.001	593.657
60				1	4.3	0.043	0.001	529.877
61				1	4.2	0.042	0.000	499.606
62				0.9	4	0.040	0.000	442.236
63				0.8	3.9	0.039	0.000	415.112
64				0.8	3.8	0.038	0.000	389.012
65				0.8	3.6	0.036	0.000	339.829
66				0.8	3.4	0.034	0.000	294.579
67				0.8	3.3	0.033	0.000	273.394
68				0.8	3.2	0.032	0.000	253.151
69				0.8	3	0.030	0.000	215.431
70				0.8	2.9	0.029	0.000	197.924
71				0.8	2.8	0.028	0.000	181.301
72				0.8	2.7	0.027	0.000	165.544
73				0.8	2.6	0.026	0.000	150.639
74				0.8	2.4	0.024	0.000	123.320
75				0.8	2.3	0.023	0.000	110.872
76				0.8	2.3	0.023	0.000	110.872
77				0.8	2.3	0.023	0.000	110.872

Appendix II – Detail calculation of modified Puls method calculation

i) Rotation 1

time (minute)	water depth at inlet (cm)	Velocity (cm/s)	I (cm^3/s)	I1 +I2	$(2S_1/\Delta t)$ - O	$(2S_2/\Delta t)$ + O	Outflow (cm^3/s)	Storage (cm^3)
0	0	0.00	0.00		0.00		0.00	
1	3.5	100.00	7700.00	7700.00	-7659.55	7700.00	7679.77	606.78
2	3.5	50.00	3850.00	11550.00	-3865.24	3890.45	3877.85	378.21
3	3.5	33.33	2566.67	6416.67	-2531.57	2551.43	2541.50	297.87
4	3.5	25.00	1925.00	4491.67	-1942.60	1960.10	1951.35	262.39
5	3.5	20.00	1540.00	3465.00	-1506.65	1522.40	1514.53	236.12
6	3.5	16.67	1283.33	2823.33	-1301.76	1316.68	1309.22	223.78
7	3.5	14.29	1100.00	2383.33	-1067.60	1081.57	1074.58	209.67
8	3.5	12.50	962.50	2062.50	-981.27	994.90	988.09	204.47
9	3.7	11.11	904.44	1866.94	-872.48	885.67	879.07	197.92
10	3.7	10.00	814.00	1718.44	-832.93	845.97	839.45	195.54
11	3.7	9.09	740.00	1554.00	-708.53	721.07	714.80	188.04
12	3.7	8.33	678.33	1418.33	-697.31	709.80	703.56	187.37
13	3.7	7.69	626.15	1304.49	-595.10	607.18	601.14	181.21
14	3.7	7.14	581.43	1207.58	-600.38	612.49	606.44	181.53
15	3.9	6.67	572.00	1153.43	-541.18	553.04	547.11	177.96
16	3.9	6.25	536.25	1108.25	-555.15	567.07	561.11	178.80
17	4	5.88	517.65	1053.90	-487.10	498.75	492.92	174.70
18	4	5.56	488.89	1006.54	-507.71	519.44	513.57	175.95
19	4	5.26	463.16	952.05	-432.91	444.34	438.63	171.44
20	4	5.00	440.00	903.16	-458.71	470.25	464.48	172.99
21	4	4.76	419.05	859.05	-389.08	400.33	394.71	168.80
22	4	4.55	400.00	819.05	-418.59	429.97	424.28	170.58
23	4	4.35	382.61	782.61	-352.91	364.01	358.46	166.62
24	4	4.17	366.67	749.28	-385.13	396.37	390.75	168.56
25	4	4.00	352.00	718.67	-322.55	333.53	328.04	164.79
26	4	3.85	338.46	690.46	-356.79	367.91	362.35	166.85
27	4	3.70	325.93	664.39	-296.72	307.60	302.16	163.24
28	4	3.57	314.29	640.21	-332.47	343.50	337.98	165.39
29	4	3.45	303.45	617.73	-274.47	285.26	279.87	161.90
30	4	3.33	293.33	596.78	-311.37	322.31	316.84	164.12
31	4	3.23	283.87	577.20	-255.12	265.83	260.48	160.73
32		3.13	0.00	283.87	-18.98	28.75	23.87	146.51
33				0.00	28.56	-18.98	-23.77	143.64

ii) Rotation 2

time (minute)	water depth at inlet (cm)	velocity (cm/s)	I (cm^3/s)	I1 +I2	$(2S_1/\Delta t)$ - O	$(2S_2/\Delta t)$ + O	Outflow (cm^3/s)	Storage (cm^3)
0	0	0.00	0.00		0.00		0.00	
1	6.5	100.00	14300.00	14300.00	-14233.15	14300.00	14266.57	1002.78
2	6.5	50.00	7150.00	21450.00	-7178.33	7216.85	7197.59	577.79
3	6.5	33.33	4766.67	11916.67	-4709.73	4738.33	4724.03	429.08
4	6.5	25.00	3575.00	8341.67	-3607.76	3631.94	3619.85	362.70
5	6.5	20.00	2860.00	6435.00	-2806.28	2827.24	2816.76	314.41
6	6.5	16.67	2383.33	5243.33	-2417.65	2437.05	2427.35	291.00
7	6.5	14.29	2042.86	4426.19	-1990.85	2008.54	1999.70	265.29
8	6.5	12.50	1787.50	3830.36	-1822.50	1839.51	1831.00	255.15
9	6.5	11.11	1588.89	3376.39	-1538.03	1553.89	1545.96	238.01
10	6.5	10.00	1430.00	3018.89	-1465.29	1480.86	1473.07	233.63
11	6.5	9.09	1300.00	2730.00	-1250.00	1264.71	1257.36	220.66
12	6.5	8.33	1191.67	2491.67	-1227.05	1241.66	1234.36	219.28
13	7	7.69	1184.62	2376.28	-1134.99	1149.24	1142.11	213.73
14	7	7.14	1100.00	2284.62	-1135.38	1149.63	1142.50	213.76
15	7.5	6.67	1100.00	2200.00	-1050.71	1064.62	1057.67	208.66
16	7.5	6.25	1031.25	2131.25	-1066.56	1080.54	1073.55	209.61
17	8	5.88	1035.29	2066.54	-986.33	999.98	993.15	204.78
18	8	5.56	977.78	2013.07	-1012.98	1026.74	1019.86	206.38
19	8	5.26	926.32	1904.09	-877.89	891.11	884.50	198.25
20	8	5.00	880.00	1806.32	-915.06	928.42	921.74	200.49
21	8.5	4.76	890.48	1770.48	-842.34	855.42	848.88	196.11
22	8.5	4.55	850.00	1740.48	-884.89	898.13	891.51	198.67
23	9	4.35	860.87	1710.87	-813.03	825.98	819.50	194.34
24	9	4.17	825.00	1685.87	-859.70	872.84	866.27	197.15
25	9	4.00	792.00	1617.00	-744.62	757.30	750.96	190.22
26	9.5	3.85	803.85	1595.85	-838.17	851.23	844.70	195.85
27	9.5	3.70	774.07	1577.92	-727.14	739.75	733.44	189.17
28	9.5	3.57	746.43	1520.50	-780.54	793.36	786.95	192.38
29	9.5	3.45	720.69	1467.12	-674.18	686.58	680.38	185.97
30	9.5	3.33	696.67	1417.36	-730.55	743.17	736.86	189.37
31	0	3.23	0.00	696.67	43.40	-33.88	-38.64	142.75
32				0.00	-33.57	43.40	38.49	147.38

iii) Rotation 3

time (min)	water depth at inlet (cm)	velocity (cm/s)	I	I1 +I2	$(2S_1/\Delta t)$ - O	$(2S_2/\Delta t)$ + O	Outflow (cm3/s)	Storage (cm3)
0	0	0.00	0.00		0.0		0.0	
1	7.5	100.00	16500.00	16500.0	-16424.3	16500.0	16462.2	1134.8
2	7.5	50.00	8250.00	24750.0	-8282.7	8325.7	8304.2	644.3
3	7.5	33.33	5500.00	13750.0	-5435.8	5467.3	5451.5	472.8
4	7.5	25.00	4125.00	9625.0	-4162.8	4189.2	4176.0	396.1
5	7.5	20.00	3300.00	7425.0	-3239.5	3262.2	3250.8	340.5
6	7.5	16.67	2750.00	6050.0	-2789.6	2810.5	2800.1	313.4
7	7.5	14.29	2357.14	5107.1	-2298.6	2317.5	2308.1	283.8
8	7.5	12.50	2062.50	4419.6	-2102.9	2121.0	2112.0	272.0
9	8	11.11	1955.56	4018.1	-1897.8	1915.2	1906.5	259.7
10	8	10.00	1760.00	3715.6	-1800.8	1817.7	1809.3	253.8
11	9	9.09	1800.00	3560.0	-1742.5	1759.2	1750.9	250.3
12	6.5	8.33	1191.67	2991.7	-1234.5	1249.1	1241.8	219.7
13	9.5	7.69	1607.69	2799.4	-1548.9	1564.9	1556.9	238.7
14	10	7.14	1571.43	3179.1	-1614.0	1630.2	1622.1	242.6
15	10	6.67	1466.67	3038.1	-1408.7	1424.1	1416.4	230.2
16	10	6.25	1375.00	2841.7	-1417.5	1432.9	1425.2	230.8
17	11	5.88	1423.53	2798.5	-1365.8	1381.0	1373.4	227.6
18	11.5	5.56	1405.56	2829.1	-1447.8	1463.3	1455.5	232.6
19	12	5.26	1389.47	2795.0	-1332.2	1347.3	1339.7	225.6
20	12	5.00	1320.00	2709.5	-1362.1	1377.2	1369.7	227.4
21	12	4.76	1257.14	2577.1	-1200.5	1215.1	1207.8	217.7
22	12	4.55	1200.00	2457.1	-1241.9	1256.6	1249.3	220.2
23	12.5	4.35	1195.65	2395.7	-1139.5	1153.7	1146.6	214.0
24	12.5	4.17	1145.83	2341.5	-1187.6	1202.0	1194.8	216.9
25	12.5	4.00	1100.00	2245.8	-1044.4	1058.3	1051.3	208.3
26	13	3.85	1100.00	2200.0	-1141.3	1155.6	1148.5	214.1
27	13	3.70	1059.26	2159.3	-1004.2	1017.9	1011.1	205.9
28	13	3.57	1021.43	2080.7	-1062.5	1076.5	1069.5	209.4
29	13	3.45	986.21	2007.6	-931.7	945.1	938.4	201.5
30	14	3.33	1026.67	2012.9	-1067.2	1081.2	1074.2	209.7
31	0	0.00	0.00	1026.7	50.0	-40.6	-45.3	142.3

Appendix III- calculation of outflow using Muskingum method

i) Rotation 1

Time (min)	I (ft3/s)	C_0I_2	C_1I_1	C_2O_1	O
0	0	-	-	-	0
1	1930.75	-176.06	0	0	-176
2	1815.82	-165.58	245	0	80
3	2045.67	-186.54	231	0	44
4	1930.75	-176.06	260	0	84
5	2045.67	-186.54	245	0	59
6	2160.6	-197.02	260	0	63
7	2332.99	-212.73	275	0	62
8	1930.75	-176.06	296	207	328
9	2466.3	-224.89	245	944	964
10	2587.79	-235.97	313	1546	1623
11	2162.57	-197.19	329	2050	2181
12	2284.06	-208.27	275	2408	2475
13	2466.3	-224.89	290	2886	2951
14	2587.79	-235.97	313	3233	3311
15	2407.52	-220	329	3701	3810
16	2279.46	-208	306	3899	3997
17	2337.91	-213	290	4530	4607
18	2206.57	-201	297	4753	4849
19	2863.28	-261	280	4983	5002
20	2994.63	-273	364	5339	5430
21	3060.3	-279	380	5462	5563
22	3257.31	-297	389	5585	5677
23	3388.66	-309	414	5967	6072
24	3257.31	-297	431	5967	6101
25	3060.3	-279	414	5967	6102
26	3125.97	-285	389	6098	6201
27	2994.63	-273	397	6230	6354
28	3060.3	-279	380	6230	6331
29	3125.97	-285	389	6364	6468
30	2994.63	-273	397	6364	6488
31	0	0	380	6364	6744
32	0	0	0	6098	6098
33	0	0	0	5711	5711
34	0	0	0	5339	5339
35	0	0	0	4753	4753
36	0	0	0	4421	4421

37	0	0	0	4103	4103
38	0	0	0	3416	3416
39	0	0	0	3233	3233
40	0	0	0	2803	2803
41	0	0	0	2562	2562
42	0	0	0	2408	2408
43	0	0	0	2119	2119
44	0	0	0	2050	2050
45	0	0	0	1787	1787
46	0	0	0	1604	1604
47	0	0	0	1489	1489
48	0	0	0	1379	1379
49	0	0	0	1223	1223
50	0	0	0	1173	1173
51	0	0	0	1078	1078
52	0	0	0	860	860
53	0	0	0	860	860

ii) Rotation 2

Time (min)	I (ft3/s)	C_0I_2	C_1I_1	C_2O_1	O
0	0	-	-	-	0
1	10842.4	-902	0	0	-902
2	9134.93	-760	1447	0	687
3	10629	-884	1219	0	334
4	10415.5	-867	1418	0	551
5	11696.1	-973	1390	36	453
6	11482.7	-956	1561	503	1108
7	11162.5	-929	1532	1306	1909
8	11162.5	-929	1489	2087	2648
9	11696.1	-973	1489	3185	3701
10	11482.7	-956	1561	4682	5288
11	10949.1	-911	1532	7241	7862
12	10949.1	-911	1461	7386	7936
13	12021.2	-1000	1461	7683	8144
14	12366	-1029	1604	7987	8562
15	12017.9	-1000	1650	7987	8637
16	12017.9	-1000	1604	8297	8901
17	12031	-1001	1604	8615	9218
18	10980.3	-914	1605	8615	9307
19	10717.6	-892	1465	8777	9350
20	11243	-936	1430	9106	9600
21	11387.5	-948	1500	9106	9658
22	10968.8	-913	1519	9612	10219
23	11614	-966	1464	9612	10109

24	11318.5	-942	1550	9612	10220
25	11909.6	-991	1510	9612	10131
26	11479.4	-955	1589	9612	10246
27	11791.3	-981	1532	9612	10163
28	11167.5	-929	1573	9612	10256
29	10075.7	-838	1490	9612	10264
30	10231.6	-851	1344	9612	10105
31	0	0	1365	9612	10977
32	0	0	0	8615	8615
33	0	0	0	7987	7987
34	0	0	0	7241	7241
35	0	0	0	6538	6538
36	0	0	0	6269	6269
37	0	0	0	5878	5878
38	0	0	0	5260	5260
39	0	0	0	5024	5024
40	0	0	0	4682	4682
41	0	0	0	4145	4145
42	0	0	0	3646	3646
43	0	0	0	3365	3365
44	0	0	0	2761	2761
45	0	0	0	2373	2373
46	0	0	0	2373	2373
47	0	0	0	2019	2019
48	0	0	0	1887	1887
49	0	0	0	1699	1699
50	0	0	0	1358	1358
51	0	0	0	1156	1156
52	0	0	0	1062	1062
53	0	0	0	930	930
54	0	0	0	733	733
55	0	0	0	628	628
56	0	0	0	563	563
57	0	0	0	532	532
58	0	0	0	474	474
59	0	0	0	446	446
60	0	0	0	394	394
61	0	0	0	345	345
62	0	0	0	322	322
63	0	0	0	300	300
64	0	0	0	279	279
65	0	0	0	259	259
66	0	0	0	222	222
67	0	0	0	204	204
68	0	0	0	188	188
69	0	0	0	172	172
70	0	0	0	157	157
71	0	0	0	143	143
72	0	0	0	130	130

iii) Rotation 3

Time (min)	I (cm3/s)	C_0I_2	C_1I_1	C_2O_1	O (cm3/s)
0	0	-	-	-	0
1	16573.9	-1214	0	0	-1214
2	15219.4	-1115	2343	0	1228
3	12756.7	-935	2152	0	1217
4	14603.7	-1070	1804	5	739
5	14603.7	-1070	2065	386	1381
6	13988.1	-1025	2065	1333	2373
7	14973.1	-1097	1978	2328	3209
8	14973.1	-1097	2117	4273	5293
9	16234	-1189	2117	7392	8319
10	15577.3	-1141	2295	7987	9142
11	17967.8	-1316	2203	8453	9339
12	12123	-888	2541	8772	10424
13	18186.1	-1332	1714	9263	9645
14	15203	-1114	2571	9771	11229
15	15203	-1114	2150	10119	11155
16	14053.7	-1030	2150	10474	11594
17	14194.9	-1040	1987	10654	11602
18	13518.5	-990	2007	11020	12037
19	15879.4	-1163	1911	11394	12142
20	15091.3	-1106	2245	11584	12723
21	16470.4	-1207	2134	11584	12511
22	16470.4	-1207	2329	11775	12897
23	15720.1	-1152	2329	11968	13146
24	18388.1	-1347	2223	12164	13039
25	17567.2	-1287	2600	12164	13477
26	19123.6	-1401	2484	12164	13246
27	18269.9	-1338	2704	12361	13726
28	17202.7	-1260	2583	12560	13883
29	17202.7	-1260	2432	12560	13732
30	18755.8	-1374	2432	12560	13618
31	0	0	2652	12761	15413
32	0	0	0	12761	12761
33	0	0	0	11968	11968
34	0	0	0	10654	10654
35	0	0	0	9944	9944
36	0	0	0	9431	9431
37	0	0	0	8453	8453
38	0	0	0	7987	7987
39	0	0	0	7104	7104
40	0	0	0	6685	6685
41	0	0	0	6151	6151
42	0	0	0	5767	5767
43	0	0	0	5279	5279
44	0	0	0	4704	4704
45	0	0	0	4378	4378

46	0	0	0	3866	3866
47	0	0	0	3392	3392
48	0	0	0	3039	3039
49	0	0	0	2871	2871
50	0	0	0	2476	2476
51	0	0	0	2256	2256
52	0	0	0	1852	1852
53	0	0	0	1608	1608
54	0	0	0	1439	1439
55	0	0	0	1231	1231
56	0	0	0	1042	1042
57	0	0	0	954	954
58	0	0	0	793	793
59	0	0	0	649	649
60	0	0	0	552	552
61	0	0	0	493	493
62	0	0	0	465	465
63	0	0	0	412	412
64	0	0	0	386	386
65	0	0	0	362	362
66	0	0	0	316	316
67	0	0	0	274	274
68	0	0	0	254	254
69	0	0	0	236	236
70	0	0	0	200	200
71	0	0	0	184	184
72	0	0	0	169	169
73	0	0	0	154	154
74	0	0	0	140	140
75	0	0	0	115	115
76	0	0	0	103	103
77	0	0	0	103	103

Appendix IV- percentage difference between experimental outflow and outflow calculated using Muskingum method

i) Rotation 1

time (minute)	Outflow from experiment	Outflow from Muskingum method	Percentage difference (%)
0	0	0	0.00
1	0	-176	-100.00
2	0	80	-100.00
3	0	44	-100.00
4	0	84	-100.00
5	0	59	-100.00
6	0	63	-100.00
7	215.1207103	62	248.25
8	979.0070295	328	198.70
9	1603.489399	964	66.28
10	2125.848176	1623	30.95
11	2498.066837	2181	14.53
12	2993.127482	2475	20.94
13	3353.4	2951	13.63
14	3838.73471	3311	15.96
15	4043.974627	3810	6.13
16	4698.639747	3997	17.56
17	4930.061468	4607	7.02
18	5168.190705	4849	6.58
19	5538.100075	5002	10.72
20	5664.825461	5430	4.32
21	5793.274982	5563	4.14
22	6189.045668	5677	9.01
23	6189.045668	6072	1.93
24	6189.045668	6101	1.45
25	6324.468873	6102	3.65
26	6461.654617	6201	4.20
27	6461.654617	6354	1.69
28	6600.610481	6331	4.25
29	6600.610481	6468	2.06
30	6600.610481	6488	1.74
31	6324.468873	6744	-6.23
32	5923.456386	6098	-2.86
33	5538.100075	5711	-3.03

34	4930.061468	5339	-7.67
35	4585.42417	4753	-3.53
36	4255.661466	4421	-3.74
37	3542.816468	4103	-13.65
38	3353.4	3416	-1.83
39	2906.875293	3233	-10.09
40	2657.135596	2803	-5.19
41	2498.066837	2562	-2.49
42	2197.41997	2408	-8.76
43	2125.848176	2119	0.34
44	1853.638146	2050	-9.56
45	1663.992514	1787	-6.89
46	1544.325794	1604	-3.74
47	1429.976898	1489	-3.96
48	1268.246504	1379	-8.01
49	1216.906504	1223	-0.48
50	1118.018707	1173	-4.71
51	892.4189021	1078	-17.21
52	892.4189021	860	3.72
53	892.4189021	860	3.72

ii) Rotation 2

time (minute)	Outflow from experiment	Outflow from Muskingum method	Percentage difference (%)
0	0	0	0.00
1	0	-902	-100.00
2	0	687	-100.00
3	0	334	-100.00
4	38.02832826	551	-93.10
5	529.1151849	453	16.91
6	1374.771309	1108	24.12
7	2197.41997	1909	15.11
8	3353.4	2648	26.66
9	4930.061468	3701	33.20
10	7623.494985	5288	44.18
11	7776.880922	7862	-1.08
12	8089.170894	7936	1.93
13	8408.866685	8144	3.26
14	8408.866685	8562	-1.78

15	8736.02593	8637	1.15
16	9070.705823	8901	1.91
17	9070.705823	9218	-1.59
18	9240.883766	9307	-0.71
19	9586.950926	9350	2.53
20	9586.950926	9600	-0.14
21	10120.4349	9658	4.79
22	10120.4349	10219	-0.96
23	10120.4349	10109	0.11
24	10120.4349	10220	-0.97
25	10120.4349	10131	-0.11
26	10120.4349	10246	-1.23
27	10120.4349	10163	-0.42
28	10120.4349	10256	-1.32
29	10120.4349	10264	-1.40
30	10120.4349	10105	0.15
31	9070.705823	10977	-17.37
32	8408.866685	8615	-2.40
33	7623.494985	7987	-4.55
34	6883.86273	7241	-4.93
35	6600.610481	6538	0.95
36	6189.045668	6269	-1.28
37	5538.100075	5878	-5.79
38	5289.790534	5260	0.57
39	4930.061468	5024	-1.87
40	4363.943171	4682	-6.80
41	3838.73471	4145	-7.38
42	3542.816468	3646	-2.83
43	2906.875293	3365	-13.61
44	2498.066837	2761	-9.52
45	2498.066837	2373	5.29
46	2125.848176	2373	-10.40
47	1986.946789	2019	-1.59
48	1789.057037	1887	-5.20
49	1429.976898	1699	-15.85
50	1216.906504	1358	-10.40
51	1118.018707	1156	-3.27
52	979.0070295	1062	-7.80
53	771.4434522	930	-17.04
54	660.8817075	733	-9.80
55	592.80297	628	-5.56
56	560.4163247	563	-0.47
57	498.8871438	532	-6.27

58	469.7196496	474	-0.87
59	414.515337	446	-7.09
60	363.3987228	394	-7.70
61	339.340221	345	-1.68
62	316.2635906	322	-1.87
63	294.1550976	300	-2.07
64	273.0008103	279	-2.28
65	233.4980839	259	-9.95
66	215.1207103	222	-3.00
67	197.6396523	204	-3.27
68	181.0398432	188	-3.56
69	165.3059542	172	-3.86
70	150.4223802	157	-4.19
71	136.3732241	143	-4.55
72	136.3732241	130	5.29

iii) Rotation 3

time (minute)	Outflow from experiment	Outflow from Muskingum method	Percentage difference (%)
0	0	0	0.00
1	0	-1214	-100.00
2	0	1228	-100.00
3	5.657495099	1217	-99.54
4	414.515337	739	-43.92
5	1429.976898	1381	3.52
6	2498.066837	2373	5.28
7	4585.42417	3209	42.90
8	7932.1038	5293	49.85
9	8571.509791	8319	3.03
10	9070.705823	9142	-0.78
11	9412.963124	9339	0.79
12	9940.679848	10424	-4.64
13	10485.76082	9645	8.71
14	10858.88707	11229	-3.30
15	11239.86839	11155	0.76
16	11433.3217	11594	-1.39
17	11826.18742	11602	1.94
18	12227.04343	12037	1.58
19	12430.4845	12142	2.38

20	12430.4845	12723	-2.30
21	12635.94315	12511	1.00
22	12843.42602	12897	-0.42
23	13052.9397	13146	-0.70
24	13052.9397	13039	0.11
25	13052.9397	13477	-3.14
26	13264.49078	13246	0.14
27	13478.08582	13726	-1.81
28	13478.08582	13883	-2.91
29	13478.08582	13732	-1.85
30	13693.73136	13618	0.56
31	13693.73136	15413	-11.15
32	12843.42602	12761	0.65
33	11433.3217	11968	-4.47
34	10671.34548	10654	0.16
35	10120.4349	9944	1.77
36	9070.705823	9431	-3.82
37	8571.509791	8453	1.41
38	7623.494985	7987	-4.56
39	7174.285627	7104	0.99
40	6600.610481	6685	-1.27
41	6189.045668	6151	0.62
42	5664.825461	5767	-1.78
43	5048.283659	5279	-4.37
44	4698.639747	4704	-0.12
45	4149.008033	4378	-5.24
46	3639.874902	3866	-5.86
47	3261.02481	3392	-3.86
48	3080.897274	3039	1.38
49	2657.135596	2871	-7.45
50	2420.732576	2476	-2.24
51	1986.946789	2256	-11.92
52	1725.845098	1852	-6.79
53	1544.325794	1608	-3.97
54	1320.864628	1439	-8.22
55	1118.018707	1231	-9.17
56	1024.116006	1042	-1.70
57	850.9174805	954	-10.84
58	696.5979304	793	-12.15
59	592.80297	649	-8.68
60	529.1151849	552	-4.22
61	498.8871438	493	1.18
62	441.6	465	-5.01

63	414.515337	412	0.73
64	388.4526405	386	0.56
65	339.340221	362	-6.26
66	294.1550976	316	-6.98
67	273.0008103	274	-0.41
68	252.7865904	254	-0.63
69	215.1207103	236	-8.68
70	197.6396523	200	-1.41
71	181.0398432	184	-1.70
72	165.3059542	169	-2.01
73	150.4223802	154	-2.35
74	123.1422801	140	-12.15
75	110.7130146	115	-3.52
76	110.7130146	103	7.31
77	110.7130146	103	7.31