First Flush Phenomena Establishments in Detention Pond New Design Concepts

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Abstract- This research was done because of increasing the number of stormwater detention ponds due to urbanization, and problems related to using contaminated water. The research contains a new idea in pond designation for outflow quality improvement environment friendly. It is first flush separation using a separator channel-partition. The channel filled with stratified sand filter to suspended solids removal maximization. The research is associated with the amount of stormwater TSS in a scale model detention pond during the detaining time. Stormwater quality improvement for real samples have been investigated via above parameter measurement. The stormwater was detained in a scale model detention pond. The pond was retrofitted with a first flush separator (channel-partition) filled with stratified sand, and zeolite. The partition split the pond to two parts. First flush had to pass through this channel-partition before entering the second part of the pond. Outflow quality improvement was expected during detaining time. The channel partition also will prevent entering re-suspended pollutions to downstream. Results revealed that applying this channel partition can improve suspended solids removal efficiency up to 92 % compare to traditional pond with maximum 43 % TSS removal. Each set of tests were done during 24 hours. Also the partition could manage the detaining time in which providing longer detaining time for more contaminated part of stormwater (first flush), and shorter detaining time for the rest of the rain water which is more clean to improve pond outflow quality.

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1- Introduction

Quality of water and life are tied together. According to WHO in the year of 2000 more than 1 billion person in the world did not have access to enough freshwater. Every year more than 2 million dead occur due to water related disease are reported (WHO 2006). In other hand limited usable freshwater resources like rivers, lakes and groundwater are less than one percent of total earth planet water (Postel, Daily et al. 1996). A rather significant portion of the earth's overall precipitation is by annual rain in tropical areas. Meanwhile, urbanization and increase in various sources of pollution directly affect the quantity and quality of storm water.

Beside the water crises; sizeable amount of this freshwater after being contaminated directly discharges to the environment without treatment. Most part of these pollutions is carried by first flush, (Arnold 1993), (A.A. Mamun 2008). Hydrologic cycle is reinterring these contaminations from the environment (rivers or lakes) to the using water chain again. In a part of this chain, accumulated pollutions enter the ponds through the runoff and release to the rivers. This problem has dangerous consequences for public health (Papa, Adams et al. 1999). Especially in countries like Malaysia which 97% of its water supplies are from rivers yet (Yassin, Eves et al. 2009). Moreover, impacts of pollution on rivers and lakes wild life are important as some people depended to fishing.

Control and degradation of contamination before entering to the river or groundwater is a necessary step that can help to solve this problem. It will increase the amount available clean water and also decreases the water treatment costs. Research on removing the runoff pollution is an important approach to save our freshwater resources. Studies on stormwater contamination degradation in detention ponds can lead to water supply safety.

In order to control the quality of stormwater runoff in addition to its quantity various strategies have been applied. These different methods are including various hydrologic designing (Guo 2009), (Davis and Birch 2009), (Plan 2006), (Gregory 2004), hydraulic-hydrodynamic separator devices such as flow and first flush separator base on mechanically separation, gravity base mechanisms splitting stormwater as per its quality (Echols 2002) (Larry 2001), physical treatment such as filters using sand (Kellems, Randall Johnson et al. 2004), or other filter media such as zeolite (Farm 2003), perlite, compost and peat, Organo-clay to remove toxic heavy metals (Wium-Andersen, Nielsen et al. 2010), or iron-infused (Prodanoff and Mascarenhas 2010), (Rodgers, Walsh et al. 2011) (Gironas, Adriasola et al. 2008), (Liu, Berretta et al. 2009), (Brown 2003) and also swales or grass filter strips, applying chemical materials for flocculation and coagulation such as aluminum sulfate (Cical, Burtica et al. 2005) or Moringa Olifera seeds (Fahey 2005) for remove bacteria, colloids, and suspended solids (Othman, Bhatia et al. 2008), PH-adjustment (Bourlakis and Weightman 2004), clarification and ion exchange resins to reduce hardness, ions and metal concentrations in water, (Kellems, Randall Johnson et al. 2004) chlorination for degrease microorganism and organic maters removal, wetlands (El-Khateeb and El-Bahrawy), Low Impact Development (LID) (Brown, Line et al. 2010) and Best Management Practice (BMP) and recently applying nano technology (Chong, Jin et al. 2010) (Ochiai, Nakata et al. 2010), (Zhang 2009), for improve storm water quality. Each one of these methods has its advantages and disadvantages. Nowadays researches tend to new manners which are more cost effective and environment friendly with lesser maintenance requirements.

Ponds are a category of structural stormwater management facilities. They can improve captured runoff quality in addition to peak flow control. Water quality enhancement in ponds occurs due to detaining designed storm during a time and releasing slowly. Settling, biological uptake, chemical and biological reactions and photo-degradation phenomena are main reasons for water quality improvement. Also microorganisms and chemical pollutions will absorb thorough the soil or will consume via algae and other aquatic plants. Stormwater enter to the groundwater aquifers after natural filtration (Kellems, Randall Johnson et al. 2004) (Schaal 2006).

Traditionally detention ponds detain storm water and release that during special designed time (24-48 hours). Increase the detaining time in ponds can provide higher outflow quality but it will increase structure costs and downstream overflow risk follow the next precipitation. Therefore inter-event time play an important role in obtaining detaining time. Debility to provide desirable detaining time and appropriate quality is first drawback in traditional pond's designation.

A hydrological designing for detention ponds by Guo on optimization of detention time and its sensitivity to the settling time; with regard to the particle size; done in 1999. It conclude that ponds require more storage volume to achieve high levels of control (Guo and Adams 1999).

Table.1- Sedimentation velocity for suspended discrete particles (Tebbutt 1997)

Particles size µm	Settlement velocity $^{m}/_{h}$
6×10^{2}	1000
2×10^{1}	100
3×10^{-1}	10
3×10^{-3}	1
1×10^{-5}	0.1
2×10^{-7}	0.01

As can be seen in table 1 smaller size particles settle during longer detaining time. The smallest sediment size (2×10^{-7} µm) needs more than 4 days in order to settle only 1 meter which is less than most of the ponds dept.

In the other hand in quality standpoint, stormwater can be divided in two main parts. First and most contaminated part (First Flush) which contains a significant percentage of pollutions compared to its small quantity. Normally it is first half-one inch of precipitation (Guo 2001). And second and cleaner part which contain higher storm water quality and quantity. Generally the first part of stormwater runoff is more polluted compare to second part of that. A study on 197 rainfall events in Paris has claimed that the first 30% of stromwater carries 80% of all the pollutions in a single storm event (Bertrand-Krajewski, Chebbo et al. 1998). In fact the definition of first flush is leaned to this concept that the first part of rain can carry debris, oil and greases, dust, and other contaminations in watershed which have remained during inter-event and second part of rain flow on cleaner surface (Arnold 1993).

Obviously traditional pond due to mixing and holding these two parts in the pond can decrease easier treatment chance for first flush. In other word; to enhance contaminates removal efficiency; first flush need to be detain spread and release during longer time compared to second part of runoff. It is the second drawback of current ponds which are not able to do so. This work will explain that how are the impacts of applying a first flush separator with stratified filter media as a channel-partition on first flush treatment compared to normal detention ponds. Also how the first flush separators manage the detaining time in order to achieve higher outflow quality and euthrophication postponement consequently.

The aim of this research is to propose a sustainable solution to remove a wide range of contaminants, and improve outflow water quality in detention ponds before discharge to environment. It will generate a new detention pond design called "split pond", which has three remarkable characteristics and cover traditional pond drawbacks. In this research first flush via applying a channel partition separator has been separated from the rest of runoff. More effective treatment; environment friendly; has been applied on first flush during longer detaining time compared to the rest of runoff which is cleaner. Also it will prevent re-suspension of settled sediment bond contamination. The function of split pond will be same as an extended pond with a forebay plus an online sand filter.

2- Material and Methods

The complete project in this work was including below 4 stages: First designing a pond for a presumed catchment; second setting up a scale model (1:20 size) of this pond; third to split this pond to two parts using a partition to separate the first flush and forth to measure the total suspended solids in this split-pond during detaining time and compare with the normal condition. According to EPA detention pond surface area should be at least 1% of its catchment area. The pond must be able to collect rains with 95% frequency occurrence (around 1 inch). Optimum depth for a pond 6 feet (3 to 9 feet) and the length to width ratio of 2:1 are suggested. Minimum required watershed area to establish a detention pond is 10 Acer. The pond should be able to hold 2, 5 and 10 years design storm and pass 100 years return period design storm (Pitt 2004). Assumed watershed characteristics and designed pond are as below:

A = 10 Acer (40,470 m^2)
Return Period = 10 years
S = 3%
6 hours Rainfall depth (P) = 40 mm
Runoff coefficient= 0.63

Runoff coefficient for residential areas is between 0.3 and 0.75 according to SCS, and equal to 0.63 according to EPA (for 80% impervious area) (Heitz, Khosrowpanah et al. 1997). Assumed watershed is including 40% residential, 7% pavement, 8% roof, 40% forest, and 5% grazing land. Having regarded to all above parameters and calculations, pond surface area obtained to be 30×15 meter with 2 meter depth. Pond designation calculations have been summerized in the below table (Table 2).

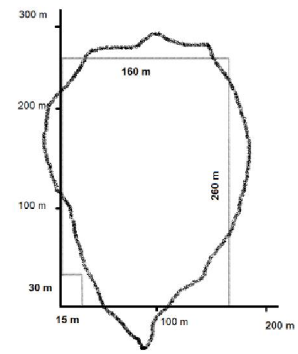

Fig. 1- Assumed watershed areas and pond surface area size comparison

Table.2- Assumed detention pond size calculations

Parameter/Formula	Amount	Method
$Tc=3.03\left(\frac{rl^{1.5}}{h^{0.5}}\right)^{0.467}$ (Gupta 2011)	25 min	Kerby
$I=\frac{98.4}{t_c^{0.687}}$ (Alizadeh 2001)	10.78 mm/hr	For rainfalls with maximum intensity
$Q=0.278CIA$ (Alizadeh 2001)	0.077 m^3/s	Rational method for maximum discharge
Inlet size	15×20 mm	To pass 100 years return period design storm
Outlet diameter	1 mm	To release within 24 hrs
Length × Width × Depth	30×15×2 m	Pond size

The scale model detention pond (Price and Yonge 1995) was designed having regard to the size of the assumed pond, laboratory space and applicability. To setup a 1:20 scale model a fiberglass rectangular shape container with 1.5 meter length, 0.75 meter width and 0.12 meter depth was used. The maximum capacity which scale model detention pond could totally collect and hold was 0.135 cubic meter (1/8000 of the real model capacity). Two third of this amount could be release during 24 hours and the one third detained stormwater could stay during inter-event time as water quality volume.

To split the pond; a channel as a partition split the detention pond to two parts. The first part of pond is applied for detaining the first flush. After filling this part the rest of runoff which is cleaner will switch the second part of pond. First flush partition is an open channel that can be built along a pond.

Detained contaminated first flush; must pass through this channel for entering to the second part (figure 2). Detaining time in traditional ponds is based on outlet size. This time is equal for every runoff with any quality. However first flush need longer settlement time obviously compare to the rest of the rain water. In the current work an inlet as flow splitter device or a flow switcher applied in order to separate the first flush. This inlet equipped with a floater same as flush tank systems. It will switch the rest of runoff flow to the second pool. This inlet can completely separate first flush designed volume from the second part of the stormwater to be held for longer time. With this devise pond will be able to manage the detaining time. It is a new strategy which will help to improve outflow quality even in current ponds.

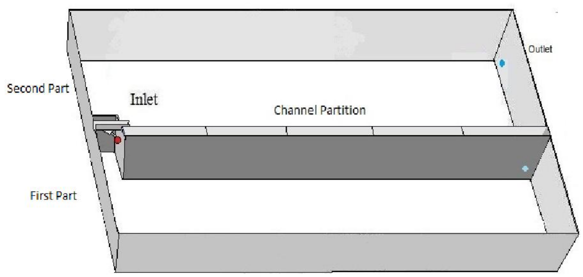

Fig. 2- Split pond concept top view eqiped with channel partition along the pond

In a split pond; stormwater from first part will release in lower rate compared to second part outflow rate. In fact it will release to the second part of pond during a longer time due to the partition smaller outlet size. As the second part releases cleaner stormwater during its shorter designed detaining time (compare to normal ponds), more detaining time for first flush would improve its quality in the outlet. This longer time is an effective parameter to increase photocatalytic reaction efficiency in addition to settlement and other water enhancement processes. In fact the partition must be placed as per designed first flush volume to the designed storm proportion. To optimization of the exact partition place needs a separate full assessment on first flush volume in tropical areas to be able to place the partition correctly. In this paper we just have divided the pond to two equivalent parts.

Overflow risk in both normal and split pond designs is the same. In short inter-event time (when the first part is still full) the second pool can provide enough capacity to decrease flood risk. In long inter-event time both sections of the pond will be empty. In fact total empty capacity for both of designs (traditional design and split pond design) are equal because nevertheless of longer discharge time for the first flush part, the second part has shorter discharge time and bigger outlet size (compared to a regular pond). It is base on this fact that detaining the stormwater for a long time in a pond is just to provide enough settlement time and enhance its quality; so cleaner water need shorter detaining time.

Filling this open channel with media filters; retrofit the detention pond to a more effective facility for storm water treatment. This online filter can remove a significant part of suspended solids, heavy metals, sediment bond pollutions, bacteria's, and microorganism. In order to guaranty that first flush will pass through the sand filter some slides installed cross the channel. These slides firstly divide different sizes particle of stratified sand filter. Secondly slides are conducting the stormwater to move in arbitrary direction. And thirdly they provide a more stable structure against pond water weight force on the channel partition (Figure 3).

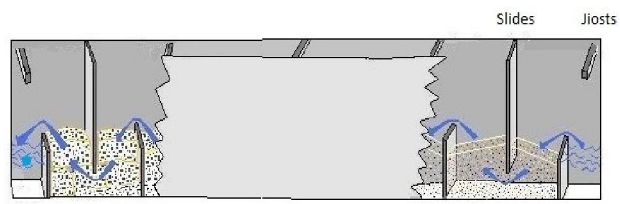

Fig.3- Channel partition

Open spaces between both sides of channel-partition connected with some horizontal Joists. It will provide more steady body in addition to easier inspection maintenance. For channel partition fabrication; a "U" shape galvanized structure was covered by two layer of galvanized mesh and then was filled by concrete.

The backwash for this system is very easy and shall be said is almost self backwash. Normally stormwater flows through the channel from first part of pond to the second part. It is due to head difference or potential difference between inlet and outlet. In the case of first part inlet has been closed and flow has been switched to second part of pond, while the fist part of pond is still empty, the potential difference will be reverse and water flow will pass through the filter in reverse direction and will backwash the filter.

3- Results

A 1:20 scale model detention pond (Price and Yonge 1995) for the above assumed pond was designed and placed at the university technology Malaysia (UTM City Campus) laboratory in Kuala Lumpur (figure 4). Real samples were collected and transferred by 20 liter water containers from nearest detention pond (Danau Kuta detention pond) in the morning before sunrise. Water containers and pond had been washed with distilled water to avoid any organic or inorganic effect on samples and tests.

Fig.4-Scale model detention pond in UTM

A flow splitter or a flow switcher device was installed to direct the first flush to the first part of the pond and then switch the rest of stormwater to the second part. It is same as a normal channel with a gate in the bed. The gate is equipped with a floater which can close the gate when water level in the first part reaches to the desirable level (Figure 5).

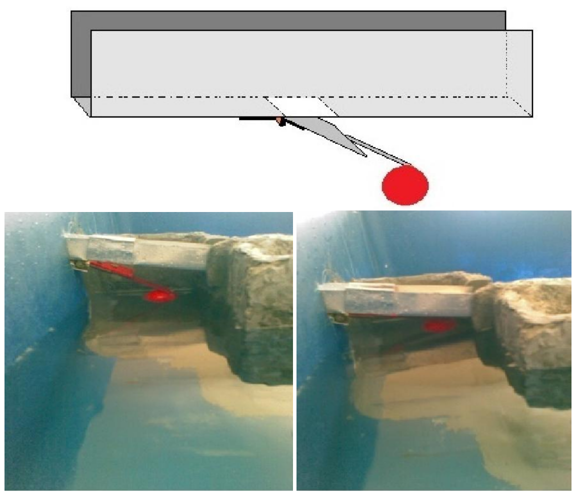

Fig.5- Flow switcher inlet with floater gate in the bed

Flow splitter device is uses to proportional dividing runoff to first flush and second part of runoff. First flush will flow to the first part through the gate when the gate is open. Since the floater move up with water level will rise and closes the gate. The excess storm water will flow to the second part of pond. Several imperfective slides have been used for dividing channel to arbitrary parts to be filled with filter media. Water flow could pass through these half slides in a sinuous and zigzag path among half slides. Below figure shows these concepts. In below pictures passing the water through the filter in channel can be seen (Figure 6).

Fig 6- Stratified sand filter in channel partition

In order to control the suspended solid removal efficiency of the applied channel partition which was filled with stratified sand filter, several tests were done to measure the amount of TSS before and after the partition; each set during 24 hours. For TSS test each 100 milliliter sample in graduated cylinder was shaken vigorously and then filtered in earl meyer flask with filter paper using vacuum pump. The cylinder was washed with distilled water to remove all remained suspended solids in and filtered. Filter papers was dried in oven and kept in desiccator to cool to room temperature and weighted; then results were recorded (Figure 7).

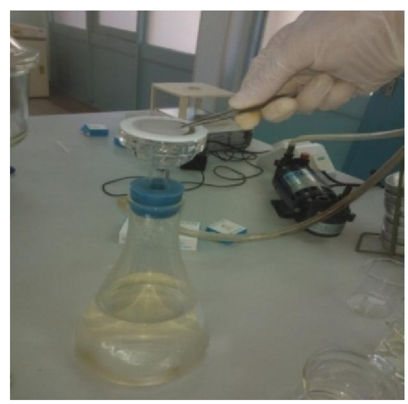

Fig-7- TSS measurement in UTM laboratory

Amount of TSS in milligrams per liter was the difference between filter paper weight before and after filtering. For each set of test, samples were collected at the beginning of 24 hours detention time. Measurement continued after 4, 8 and 24 hours to compare the results with sedimentation and TSS settling as well.

As can be seen in the below graph the amount of TSS has decreased up to 92 % due to filtering the first flush via first flush channel partition and stratified sand filter (Figure 8). While the normal pond achieved maximum of 49 % total suspended solid removal efficiency after 24 hrs due to settlement. For both regular and split ponds; same samples with same quality has been used. It shows that using the channel partition can increase the outflow quality up to 43 % higher than a normal pond during a same detaining time of 24 hours.

Table.3- Amount of TSS in mg/l for the normal pond (1st to 4th) and split pond (5th to 8th) in 100 ml sample

Test No	**1st**	**2nd**	**3rd**	**4th**
After 0 hours	0.10	0.13	0.12	0.11
After 4 hours	0.07	0.07	0.07	0.09
After 8 hours	0.07	0.04	0.07	0.07
After 24 hours	0.05	0.03	0.04	0.03
Test No	**5th**	**6th**	**7th**	**8th**
After 0 hours	0.10	0.13	0.12	0.11
After 4 hours	0.02	0.01	0.01	0
After 8 hours	0.01	0.01	0	0.02
After 24 hours	0.01	0	0.01	0.01

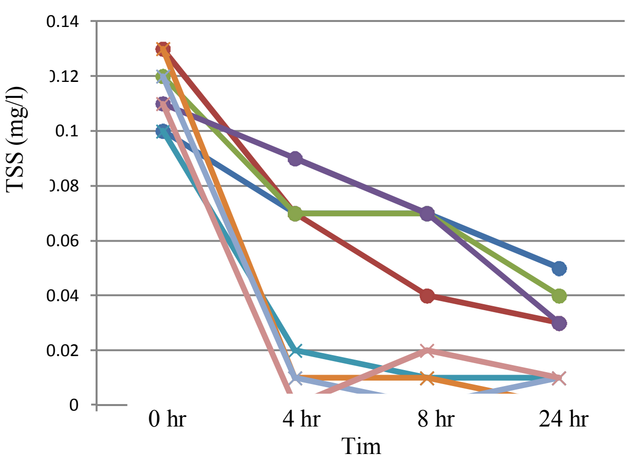

Fig.8- Amount of TSS in mg/l in outlet for split (×) and normal (•) pond comparison during 1 day

In same situation normal detention ponds need 48 hours detaining time to achieve such contamination removal efficiency. Or the pond surface area must increase to reach this level of quality. However these two are not cost effective options compared to a simple channel partition.

Moreover split pond can manage detaining time based on quality level which normal pond is not able to do so. As explained first flush; that is more polluted; will be held for longer time in the first part of the pond due to its smaller outlet size. The rest of the rain which has higher quality will be hold in the second part of the split pond for shorter time and will be released directly from the main outlet. Another important advantage of split pond is sediment re-suspension preventing. In normal ponds settled sediment bond contaminations re-suspend follow by next precipitation and discharge to the environment.

Fig.9- The effect of channel partition in TSS removal efficiency before and after the channel

But in split pond since most part of sediments is carried by first flush to the first part of pond, and this volume has to pass through the filter in channel partition so the suspension of pollution cannot affect downstream quality. Normal pond annual maintenance and dredging would be applicable as per watershed specifications and pond requirements. Easy filter back wash mechanism in this new strategy will help more cost effective maintenance.

4- Discussions

The experiment demonstrates the capability of applying first flush partition. It is a novel stormwater treatment technique for amplification of TSS removal efficiency in wet detention ponds. Result showed that separating first flush from the rest of runoff in the pond can reduce an extensive amount of stormwater sediment bond pollution. As it could be seen, outcomes show that split pond is highly capable to retrofit wet detention ponds to create a new design and provide effective degradation of TSS in stormwater compared to traditional ponds. As showed 92 % TSS removal in split pond in this study is remarkably high contrasted to 49% removal efficiency of reference samples. It is also high compared to 42% removal efficiency of normal ponds in other studies (Van Buren, Watt et al. 1996). It can generate a new wet detention pond design which can manage to increase stormwater quality before discharging to the environment or water resources. Especially in Malaysia which 97% of its water supplies are from rivers; that can be easily polluted with stormwater contamination. The overall TSS reduction efficiency rates were 43% higher than the normal pond in this work after each 24 hours of test in average. Managing and optimization of the detaining time as per stormwater quality level is another remarkable advantage for this new strategy. Preventing to discharge the re-suspended pollution due to filer existence is one of the other split pond privileges. This experiment can help to achieve a great improvement in TSS degradation, stormwater quality enhancement and finally detention ponds eutrophication postponement. More specifically in tropical areas due to their latitude have high level of rainfall, humidity and appropriate ambient temperature range, which are essential requirements to accelerate euthrophication in the ponds. This research will help to improve water supply quality and sustainable development.

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