EFFICIENCY OF SWALE AND DRY POND FOR STORMWATER MANAGEMENT

by

ASNOL ADZHAN BIN ABD. MANAP

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KEBERKESANAN SALURAN BERUMPUT DAN KOLAM TAKUNGAN KERING BAGI PENGURUSAN AIR RIBUT

ABSTRAK

Perlaksanaan tata pengurusan terbaik sistem saliran baru melalui aplikasi "Stormwater Management Manual For Malaysia" atau lebih dikenali sebagai Manual Saliran Mesra Alam (MSMA), yang memfokuskan saluran berumput dan kolam takungan kering di Malaysia telah dikaji.

Kajian ini dijalankan ke atas Sistem Saliran Bio-Ekologi (BIOECODS) di Kampus Kejuruteraan, Universiti Sains Malaysia (USM), Nibong Tebal, Pulau Pinang, yang terletak dalam Lembangan Sungai Kerian. Di samping mengkaji keberkesanan saluran berumput dan kolam takungan kering ke atas hidrograf masukan bagi satu siri kolam takungan ("wetpond", "detention pond", "wetland" dan kolam rekreasi atau ECOPOND) dalam mengurus kuantiti air ribut bagi kawasan pembangunan, faktor-faktor yang mempengaruhi keberkesanan saluran berumput dan kolam takungan kering menggunakan permodelan hidrologi dan hidraulik turut dikenalpasti dan dianalisa.

Data-data lapangan yang diambil di USM seperti data hujan, luahan, aras air, masa pengosongan dan kadar penyusupan mulai Oktober 2003 hingga Desember 2008 dianalisa menggunakan model SWMM 5. Simulasi hidrograf bagi saluran berumput, kolam takungan kering dan kolam takungan dibandingkan dengan luahan yang direkodkan di lapangan. Model SWMM 5 didapati menghasilkan kejituan sehingga 30% dalam menyelakukan hidrograf yang dicerap.

Saluran berumput dan kolam takungan kering yang direkabentuk bagi BIOECODS mampu mengecilkan luahan puncak berbanding sistem saliran konkrit.

Model SWMM 5 menunjukkan pengecilan luahan puncak sebanyak 121.4%. Peningkatan luahan puncak dijangkakan sekiranya kolam takungan kering sediada digantikan dengan pembangunan. Hasil kajian ini akan memacu ke arah pemahaman yang lebih mendalam bagi peranan saluran berumput sejajar dengan iklim dan suasana di Malaysia.

EFFICIENCY OF SWALE AND DRY POND FOR STORMWATER MANAGEMENT

ABSTRACT

The implementation of the Best Management Practices (BMPs) in a drainage system through the Stormwater Management Manual For Malaysia or better known as Manual Saliran Mesra Alam (MSMA), focusing on constructed swale and dry pond, was studied.

The study was carried out on the Bio-Ecological Drainage System (BIOECODS) at Engineering Campus, Universiti Sains Malaysia (USM), Nibong Tebal, Pulau Pinang, located in Kerian River Basin. Besides the implication of the swale and dry pond toward the inflow hydrograph of a series of ponds (detention pond, wetland and recreational pond known as ECOPOND) in managing stormwater quantity in development area, factors that affect the effectiveness of the swale and dry pond using hydrologic and hydraulic model were also identified.

The collected data such as rainfall, flow, water level, emptying time and infiltration rate from October 2003 until December 2008 at USM were analysed using SWMM 5 model. The simulated hydrographs for swale, dry pond, wetpond, detention pond, wetland and recreational pond were compared with recorded flow at the sites. The modeling shows that the SWMM 5 model has the accuracy up to 30% in simulating the observed hydrographs.

The integrated swale and dry pond as designed for BIOECODS has attenuated the peak flow compared to that of a concrete drain system. The SWMM 5 model shows that there is a reduction of 121.4% in peak flow. Also, the increase in peak flow is expected if several of the existing dry ponds are to be replaced for new development

purposes. These results can lead to better understanding of the role of swale and dry pond that suit the Malaysia climate and environment.

CHAPTER 1

INTRODUCTION

1.0 Introduction

Water play as an important entity on the earth and for human need. The important of water is proved by Quran verses meaning “Have not those who disbelieve known that the heavens and the earth were of one piece, then We parted them, and we made every living thing of water? Will they not then believe?” (Anbiya’, 30). But, if we failure to manage the water wisely, the impact of our failure will worsen our life as stated in Quran “And weigh with the true balance. Wrong not mankind in their goods, and do not evil, making mischief, in the earth” (Asy-Syu’ara’, 182 - 183).

The world is changing, the higher and more intense precipitation has already been observed in many warmer globe areas. This change includes in the terrestrial environment (hydrological systems and ecosystems) (Kundzewics and Menzel, 2005) or changes in climate: including an increasing atmospheric holding capacity for water vapour.

For the flood, the occurrence generally due to change of catchment hydrology via an increase in the impervious area and reduction in catchment storage (Schueler, 1987). Roesner et al. (2001) also mentioned that the effect of a reduction in the catchments response time due to development was to the increase in the maximum rate of flow discharge by a factor of 2 to more than 10 into the conventional drainage system thus increases the frequency of significant floods. Depressional storage in urban areas can be reduced by a factor of 5 to 10 depending on the original state of the watershed and the degree of imperviousness generated from the urbanization (Viessman and Lewis, 1996).

The importance on determining the timing and the depth of flooding is also mentioned by Collier and Fox (2003) with the amount and distribution of rainfall in space and time are the prime factors. Ward and Robinson (2000) stated that besides heavy rainfall, flood flows maybe intensified by factors associated either with the catchment itself, or with the configuration of the drainage network and stream channels.

By referring on the pre and post development hydrographs, Schueler (1987) described that the increased in peak flows are two to five times higher than pre-urbanisation conditions. A moderately developed watershed can produce over twice the runoff volume as compared to pre-urbanisation conditions. If extensive ‘drainage’ improvements are made in an urbanizing watershed, time of concentration can be decreased by a factor of 2. Land use modification can either reduce lag time or flow travel time (as in urbanization) or increase lag time or flow travel time (as for retention/ detention or infiltration).

For an engineered system, the successful operation usually depends more on a non-engineering analysis (e.g., economic and social analyses) as a sound engineering design (Chin, 2000). Therefore, a design of the hydraulic structures in urban area and river basin need knowledge and understanding of hydraulic and hydrology with experiment and engineering judgement besides creative thinking and manipulation of the input (including subjectives parameters) and output used in the design (for selected methods and tools) to satisfy site condition (Plate, 1996; Nakato and Ettema, 1996).

Looking at the frequency and intensity of rainfall in Malaysia, which are much higher than in most countries, especially those with temperate climates, design methods, which have been developed in other countries, may not always be suitable for application in Malaysia (DID, 2001). Besides that, every rainfall event is unique, varies in space and time according to general pattern of atmospheric circulation and according to local factors (Chow et al., 1988).

Study by Nehrke and Roesner (2004) on the outflow hydrograph where in their study that although the predevelopment curve can be reproduced in the developed state, but the flow verses time curve for the developed state must shift to the right. This will lead to water flowing from site impact the downstream due to increase of volume cause by the outflow hydrograph that not the exact shape and volume of the hydrograph for pre-development conditions (Glazner, 2006).

Thus, understanding on how to minimize the effect of development when practicing MSMA by maintained at pre-development flow or basin flow limit although the upper catchment is developed is a must. With establishing an environmental flow (Shirakawa and Tamai, 2003), waterway can be managed and rehabilitated by "giving room to river" (Sponge, 2001). This will lead to a better water-resources engineering which is concerned with the analysis and design of system to control the quantity, quality, timing, and distribution of water to meet the needs of human habitation and the environment (Chin, 2000).

1.1 Background of Research

There are many masterplans had been carried out by government agencies such as DID related to drainage system and river basin. In the masterplans, many stormwater facilities had been proposed are based on priority and phase. When the budget is not enough, selection on implementation of the masterplans towards the effectiveness rate and the implication of not implementing the masterplans are needed to analysis further.

In designing a stormwater facilities using MSMA, there are many parameters that can be used and analyzed by a designer using reliable data and based on certain principle and accepted formulation. Due to the effect of the parameters such as time of concentration, t_c and runoff coefficient, C that relates to losses and percent of pervious and impervious area in the design, a study need to be carried out on implication and the sensitivity of these parameters.

1.2 Objective of Research

The objectives of research are:

- To verify the flow attenuation due to an integrated swale and dry pond system in comparison with a concrete drain system, and

- To predict the effects of storage due to dry ponds in attenuating peak flow.

1.3 Scope of Research

The scope and limitations of research are as follows:

(a) The recorded data i.e. rainfall, flow discharge and water level are used from October 2003 until December 2008. These data were measured automatically at several locations along BIOECODS.

(b) The SWMM 5 model was applied in the study to evaluate the dynamic behavior of BIOECODS.

1.4 Significance of Research

Generally, research need to be carried out as Quran had mentioned that "Read: In the name of thy Lord Who createth" (Alaq, 1) and "Lo! In the creation of the heavens and the earth and (in) the difference of night and day are tokens (of His Sovereignty) for men of understanding" (Al-E-Imran, 190). Hence, by investigating and studying the creation in this world, leads to a better understanding on why the creation is formed.

This study was carried out because there have been a very few studies on combined performance of BMPs for humid tropic country. Although Ainan (2003) and Sidek (2005) had carried out a study on Bio-Ecological Drainage System (BIOECODS) to prove that BMPs can control stormwater, but detailed study on hydrologic analysis on hydrologic parameters has not been carried out due to lack of collected data for minor and major storm events.

MSMA had highlighted on importance of the storage and conveyance oriented approach in managing the stormwater. Besides, most of the design criteria and method adopted in MSMA refers from other countries manuals. Therefore, there is a need in studying the adopted design criteria to seek their suitability under tropical conditions. This study will lead in giving a clear and precise method to engineers and agencies especially in managing, designing and implementing actions (Dorge and Windolf, 2003) in developed area in a river basin.

Series of testing need to be done as proposed by Gibson (1908) and given by Knight (1985) that the best that can be done is to discuss each phenomenon on assumption that the fluid in motion is perfect. In order to achieve it, one of the easy way to gain is by doing many design and modeling. Besides that, the engineer or modeler would know and understand the use and important of subjective talents of an experienced modeler with the models, mathematical nuances and the watershed (League and Freeze, 1985).

Collier and Fox (2003) said that there are a need of research into how such precipitation forecasts can be effectively presented to hydrologists and how they can be used in combination with hydrological models to provide indications of future flows. Johnson (2000) has pointed out that generalized procedures are needed for dealing with the influence of uncertainty on hydrologic forecast. However the effectiveness and usability of these procedures needed to be established.

1.5 Thesis Summary

This thesis discusses on effectiveness and factors that affect the BMPs as a system such as grass swale and dry pond in hydrologic field to control a stormwater quantity in MSMA application.

The thesis is divided into six chapters. Chapter 1 discusses the background of the study, significance of the research and the objectives of the study. Chapter 2 elaborates the detail on literature review of stormwater management in other countries and scenario of current stormwater management practices in Malaysia. Besides that, the urbanization effect on stormwater, stormwater management facilities and relevant software that had been used to model the drainage network also is discussed.

Chapter 3 discusses on the study area and the concept and design of swale and dry pond. In addition, a discussion on research methodology in carried out the studies such on equipment for experimental set up, monitoring and collection of data in the field together with analysis on data collection is also highlighted in this chapter.

Meanwhile, Chapter 4 is designed to elaborate on hydrologic fundamental and design methods that will be used to derive the designed parameter that is used in a hydrologic and hydraulic model for studying the BMPs.

Chapter 5 describes on stormwater model and the input data in SWMM 5 model used in developing the hydrologic and hydraulic model. Elaboration on how the sensitivity analysis, calibration and validation are also further described. The hydrologic model which represents the BIOECODS system will be analyzed, calibrated and validated based on the collected results. Result and discussion from the modeling together with the simulation using design rainfall is being presented in this chapter.

Finally, Chapter 6 concludes the findings from the study which discusses on the outcome of the study and recommendations for future research related to stormwater management practices in Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.1 Stormwater Management in Malaysia

Since 1975, Malaysia has been using the DID Manual “Planning and Design procedures No.1: Urban Drainage Design Standards and Procedures for Peninsular Malaysia” in designing drainage system. The approach used is based on conveyance-oriented or known as rapid disposal.

Due to new technological developments in urban drainage and more conscious on environment, on 1 January 2001, the Department of Irrigation and Drainage (DID) Malaysia had introduced Stormwater Management Manual for Malaysia or better known as *Manual Saliran Mesra Alam* (MSMA). The new approach, combination of conveyance and storage-oriented approach, provide temporary storage of stormwater runoff at or near its point of origin with subsequent slow release to the downstream stormwater system or receiving water (detention), or infiltration into the surrounding soil (retention) through Best Management Practices (BMPs) so as to reduce the nuisance problems of flash flood and river pollution (DID, 2001).

Definition of urban stormwater management as produced by DID (2001), simply stated as everything done within a catchment to remedy existing stormwater problems and to prevent the occurrence of new problems. It involves the development and implementation of a combination of structural and non-structural measures to reconcile the conveyance and storage function of stormwater systems within the space, development and implementation of a range of measures or Best Management Practices (BMPs) to improve the quality of urban stormwater runoff prior to its discharge to receiving waters (DID, 2001) and related needs of an expanding urban population.

MSMA introduces a combination of storage and conveyance oriented including quantity control as a system by dealing and constructing natural measures, (Kundzewics and Menzel, 2005). This concept states that post development peak discharge, Q_a must be less or equivalent to pre-development peak discharge (DID, 2001). In Poland, MSMA concept can be regarded similiar to Dynamic Slow Down concept where the flows are slowed (continuity of flow is always maintained) wherever possible and at relevant point in the catchment, and providing the temporary storage (Christine et al., 2005).

In Malaysia, one of the projects that implement MSMA concept was a construction of a new building for the forensic ward of Tanjung Rambutan Hospital on the area of approximately 1.5 hectares in Ipoh, Perak Darul Ridzuan. The original condition of this area was cultivated field. For the proposed project, more than 60 % of the total area has been developed into impervious area such as paved road and car park, sheltered walkway and utilities other than the building.

The project used drainage system which is known as Bio-ecological Drainage System (BIOECODS) comprises of grassed swale, detention storage and dry pond components to focus on the control of both the quantity and quality of urban runoff for both minor and major system. The BIOECODS components were shown in Figures 2.1 to 2.3.

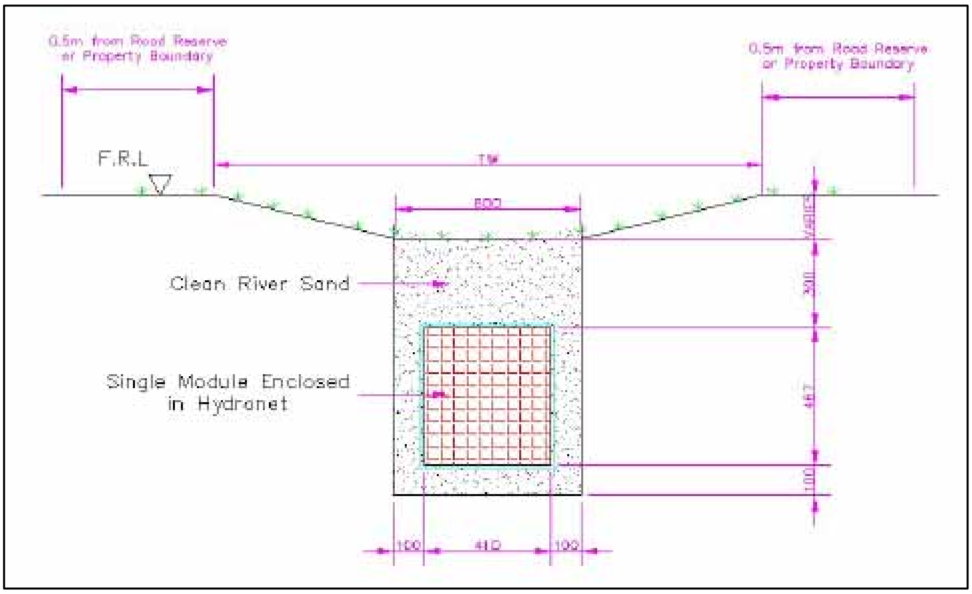

Figure 2.1: Typical Cross Section for Grassed Swale (Lau et al., 2004)

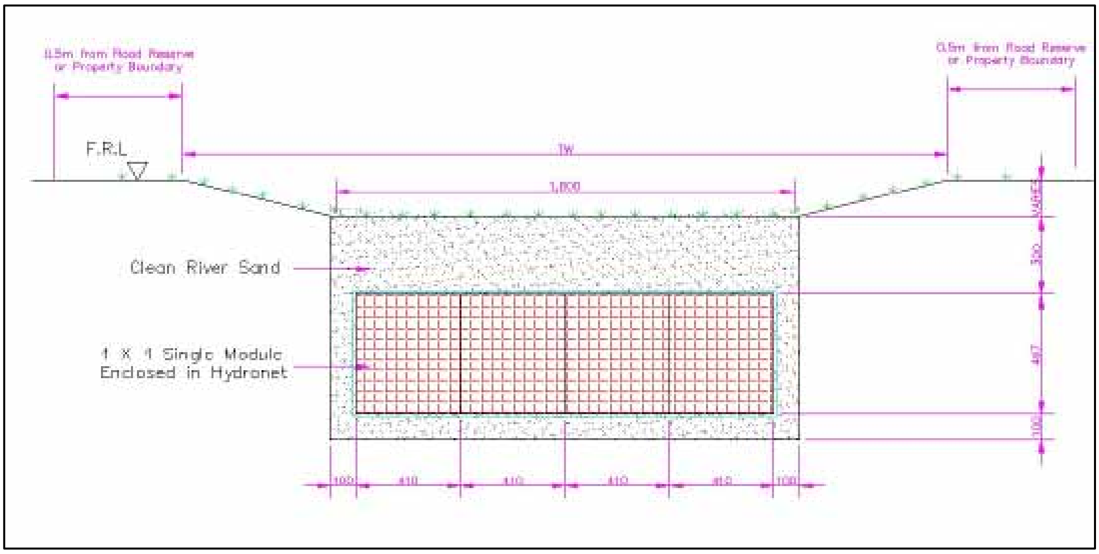

Figure 2.2: Typical Cross Section for Detention Storage (Lau et al., 2004)

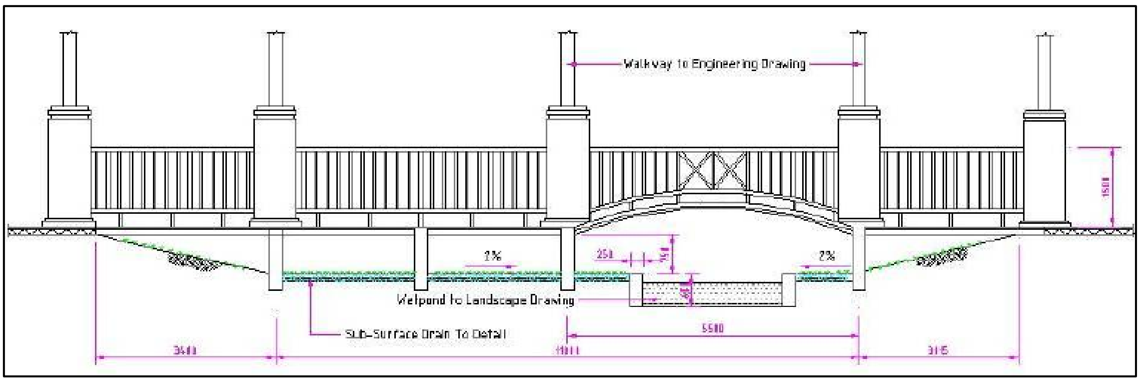

Figure 2.3: Side View of Dry Pond (Lau et al., 2004)

2.2 Overseas Studies on Stormwater Management

Stormwater Management is defined as the integrated management of stormwater to control the quantity and quality of stormwater runoff using a multi-disciplinary approach in applying appropriate technology to preserve the natural environment, enhance living standards and improve the quality of life. Stormwater management practices are used to delay, capture, store, treat, or infiltrate stormwater runoff (Urbonas, 1994; Strecker et al., 2001).

The integrated approach of comprehensive Best Management Practices (BMPs) for stormwater management is becoming a very popular topic for urban drainage in developed countries. Stormwater BMP's are widely used in drainage planning in United Kingdom (Bettes, 1996), United States (Stahre & Urbanos, 1995; Nehrke and Roesner, 2004), Germany (Fiener and Auerswald, 2006), Australia (Argue and Pezzanti, 1998), Japan (Akagawa et al., 1997) and Guo (2001). It is also mentioned (Mohd Sidek, 2005) that in order to control the increase in peak discharge for urban development, most of the urban communities require the use of stormwater detention ponds.

A number of studies with regards to the performance of detention basins have been conducted. Involving an area of 9.7 ha, a study was undertaken in Fort Collins, Colorado and Atlanta, Georgia by Nehrke and Roesner (2004) using 50 years of hourly rainfall data. Fort Collins represents an arid climate receiving relatively low amounts of annual rainfall (335 mm/year), while Atlanta represents a wetter climate (1,262 mm/year)

The study is carried out to examine the effects of the state of practice of quantity and quality controls for urban flow control by combining flood control (for large storms) and pollutant removal devices (for small storms) affecting the post development flow frequency curve. In code of practice, for the quantity control, the flow target low-frequency events (storm equal to or larger than 2-year ARI event) rather than higher-frequency events. For quality control, the removal of pollutants in urban runoff has targeted control of high-frequency event (smaller than 2-year ARI storm).

This study is carried out on a detention ponds using variety of orifices sized for peak-flow control using traditional and innovative methods. Storm Water Management Model (SWMM) was used to develop the model. The model was not calibrated, but the values used are typical for urban systems.

The simulation is carried out by modelling the detention basin as stacked orifice system shown in Figure 2.4 with the smallest orifice on the bottom and additional orifices progressively larger with increasing elevation.

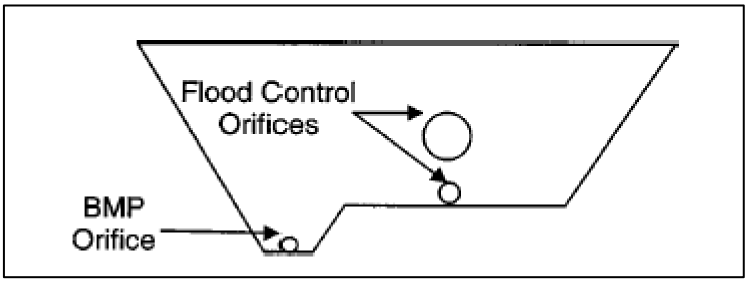

Figure 2.4: Detention basin outlet configurations (Nehrke and Roesner, 2004)

During the simulation, surcharged is assumed not occuring. The volume and discharge rate of detention basin is sized to ensure that the peak flow discharged from the basin for the specified return interval storm does not exceed the predevelopment peak flow for the same storm. Results as shown in Figures 2.5 to 2.9 at different scenarios are evaluated on how well the post-development flow frequency curve matches the pre-delopment curve.

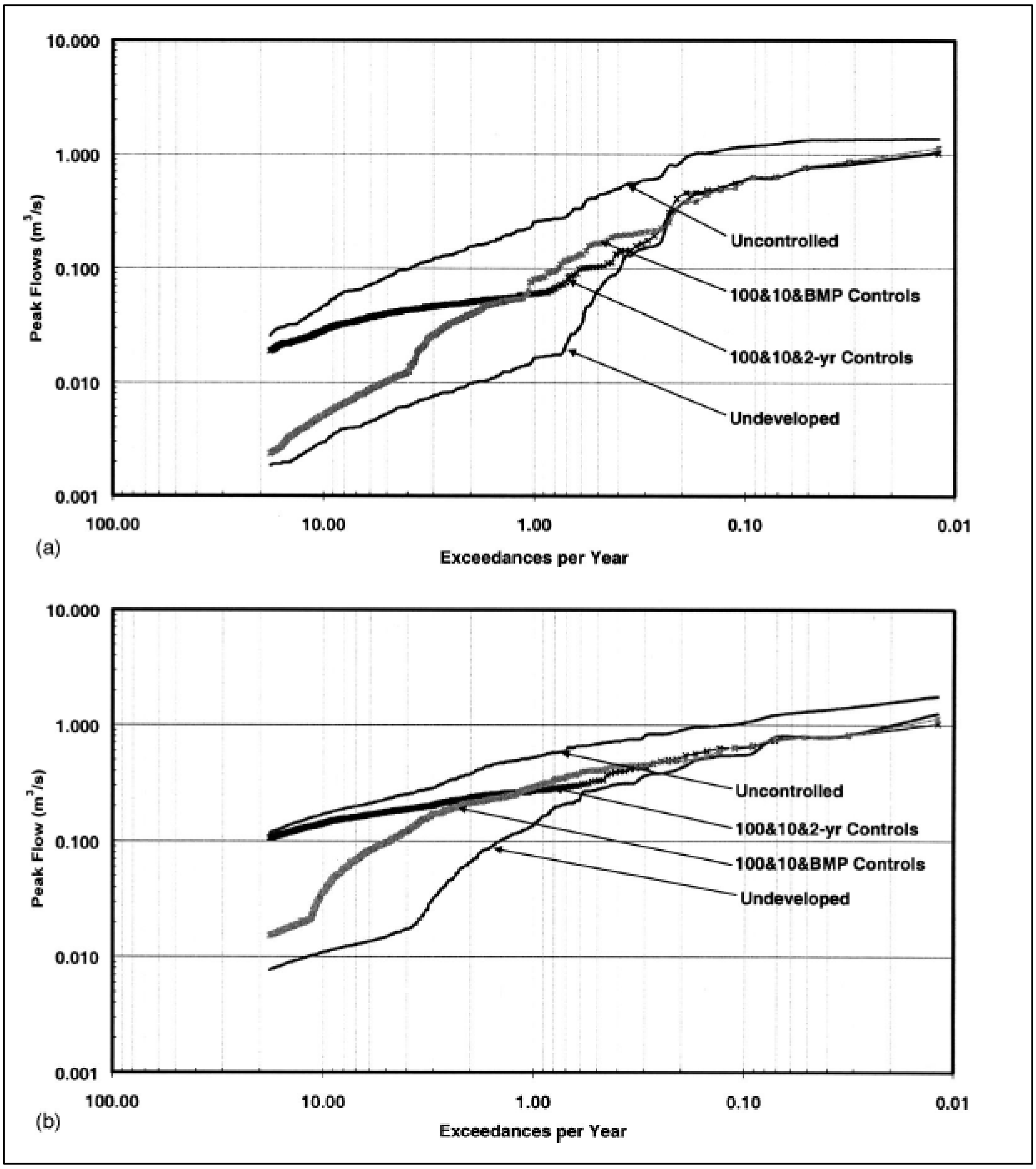

Figure 2.5: Effects of flood detention and extended detention basins in (a) Fort Collins and (b) Atlanta (Nehrke and Roesner, 2004)

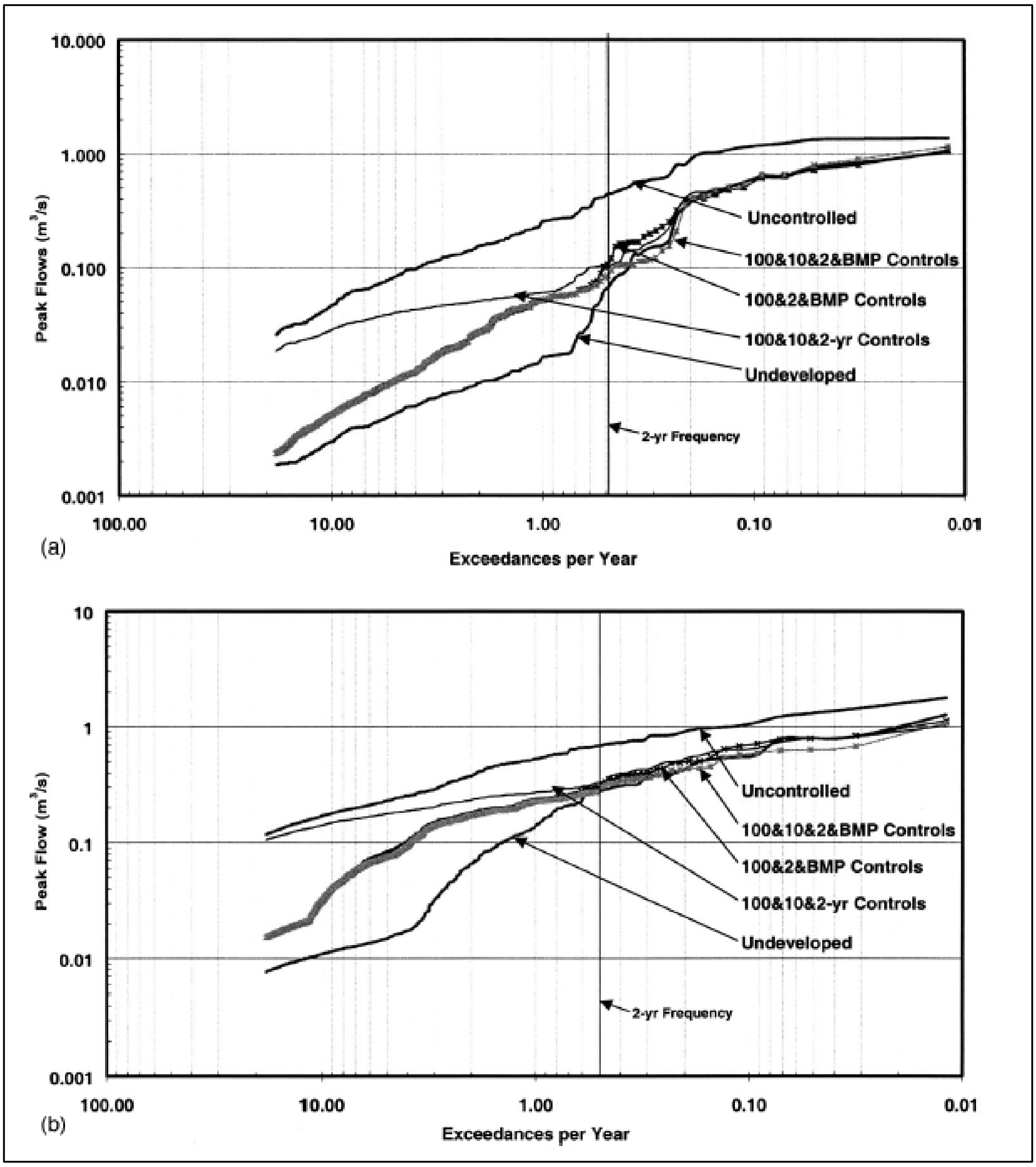

Figure 2.6: Effects of detention and four-orifice extended detention basins in (a) Fort Collins and (b) Atlanta (Nehrke and Roesner, 2004)

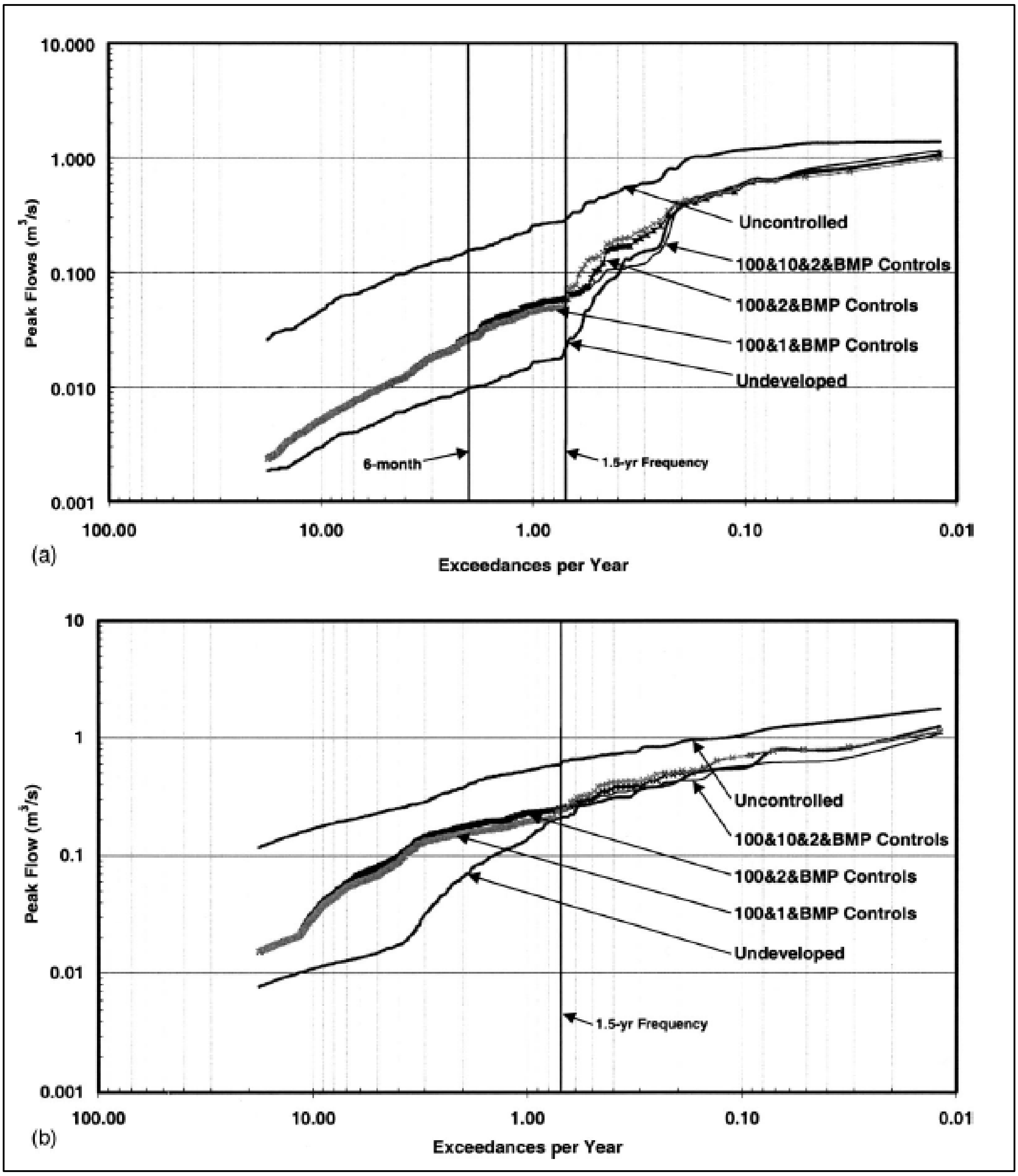

Figure 2.7: Effects of multiple extended detention basins configuration in (a) Fort Collins and (b) Atlanta (Nehrke and Roesner, 2004)

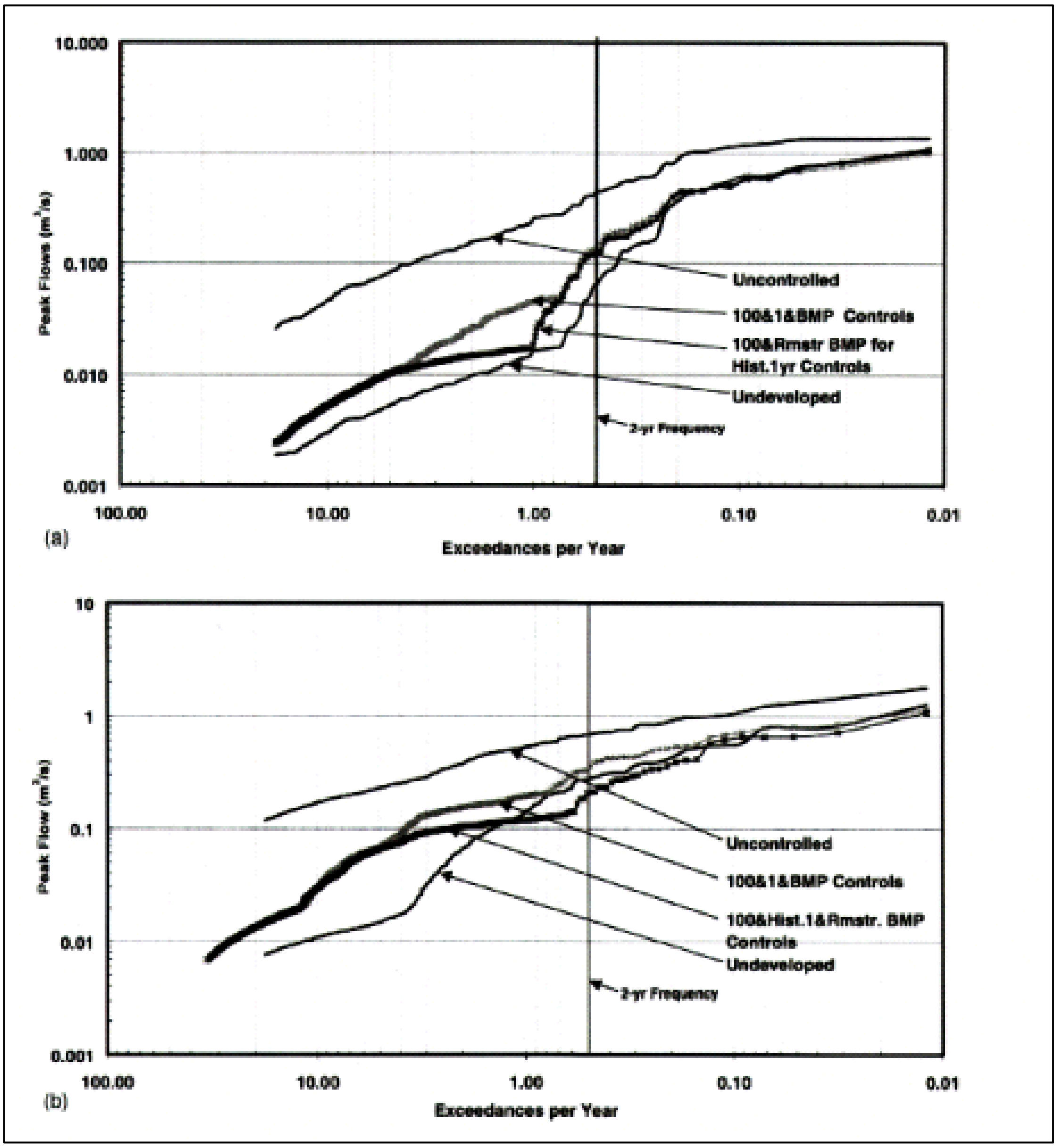

Figure 2.8: Effects of extended detention basin designed to historical levels in (a) Fort Collins and (b) Atlanta (Nehrke and Roesner, 2004)

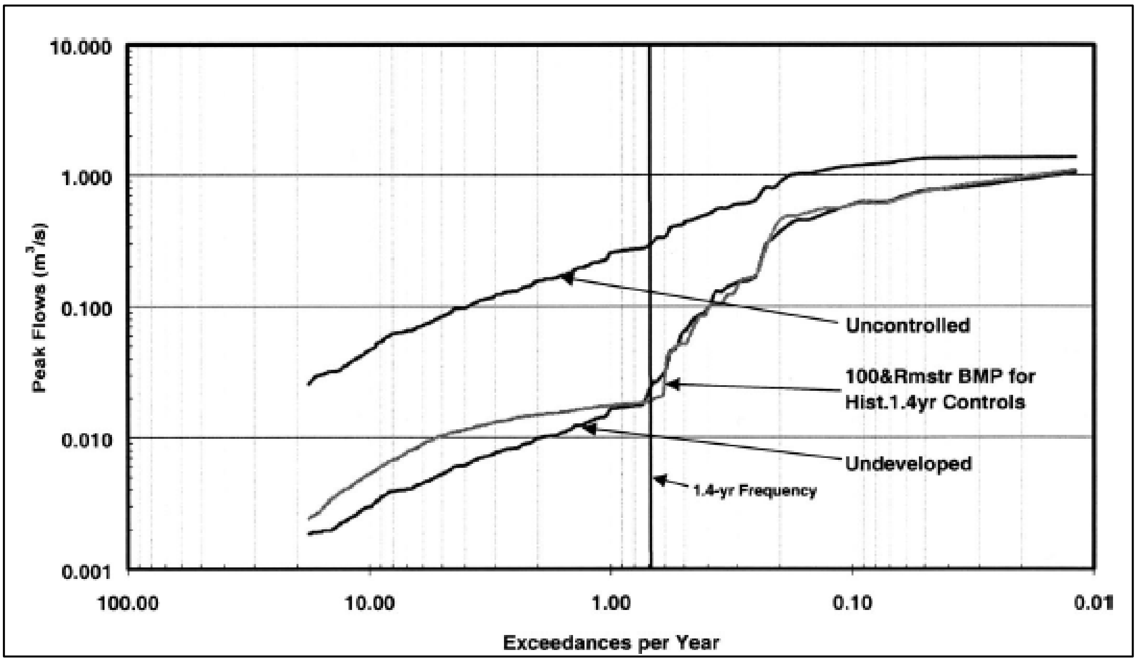

Figure 2.9: Effects of extended detention basin designed to 1 - 4 historical levels in Fort Collins (Nehrke and Roesner, 2004)

The preceeding figures show that for both Fort Collins and Atlanta, flow control alone is effective for storms larger than smallest design storm, but for smallest design storms, the flow-frequency curve wanders back toward the uncontrolled curve, showing that runoff from very frequent storms is essentially uncontrolled. Better control by showing attenuation in peak flows for the higher-frequency storms than the flood control only when the BMP orifice is placed. The BMP was sized to capture 85% of the annual runoff volume with drowdown time of the 24 h. Generally, the combination of stacked orifice was capable of controlling the peak flows over the range of design storms.

From the results, it seemed that 100/2/BMP configuration might be sufficient to achieve the desired control of the postdevelopment flow frequency curve to match the predelopment curve. Although the predevelopment curve can be reproduced in the developed state, the flow –duration curve for the developed state must be shifted to the right. However, it is believed by Nehrke and Roesner (2004) that through the appropriate use of runoff controls and properly designed BMPs can control the urban runoff and protect urban headwater streams geomorphically and ecologically.

For swale, Fiener and Auerswald (2006) had mentioned that the efficiency of grassed waterways (GWWs) in reducing runoff has been investigated only in few studies. Thus, they had carried out a study on GWWs using a model at the Lauterbach watershed, an area of approximately 16.7 km^2, located in North Rhine-Westphalia, Germany.

The study area was modeled according to a modified SCS curve number (CN) technique according to SCS standard procedures by calculating runoff travel time and replacing the empirical equation for shallow concentrated flow along drainage lines by proposed Manning's equation and using the graphical discharge method. The idealized cross-section of GWW was shown in Figure 2.10.

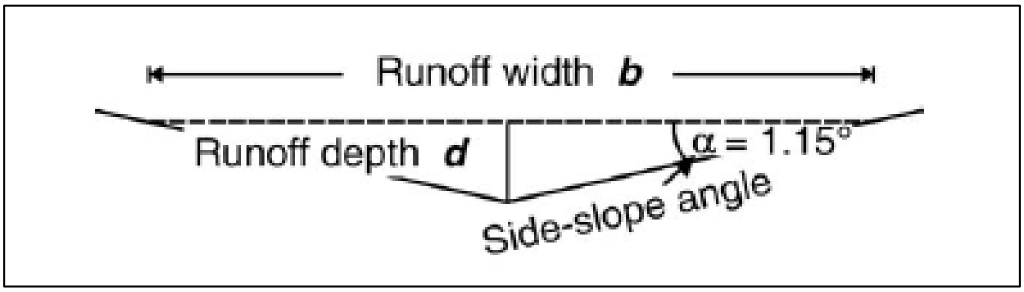

Figure 2.10: Idealized cross-section of modeled grassed waterways
(Fiener and Auerswald, 2006)

The approach was modified to take into account: (i) the seasonal variation in runoff generation in draining fields and (ii) the location of a GWW in a watershed as well as its high infiltration capacity and hydraulic roughness, which prolongs runoff travel time after the end of a rain event. The model was tested under two land use as shown in Figure 2.11 (land use dominated by arable lines and diversified land use).

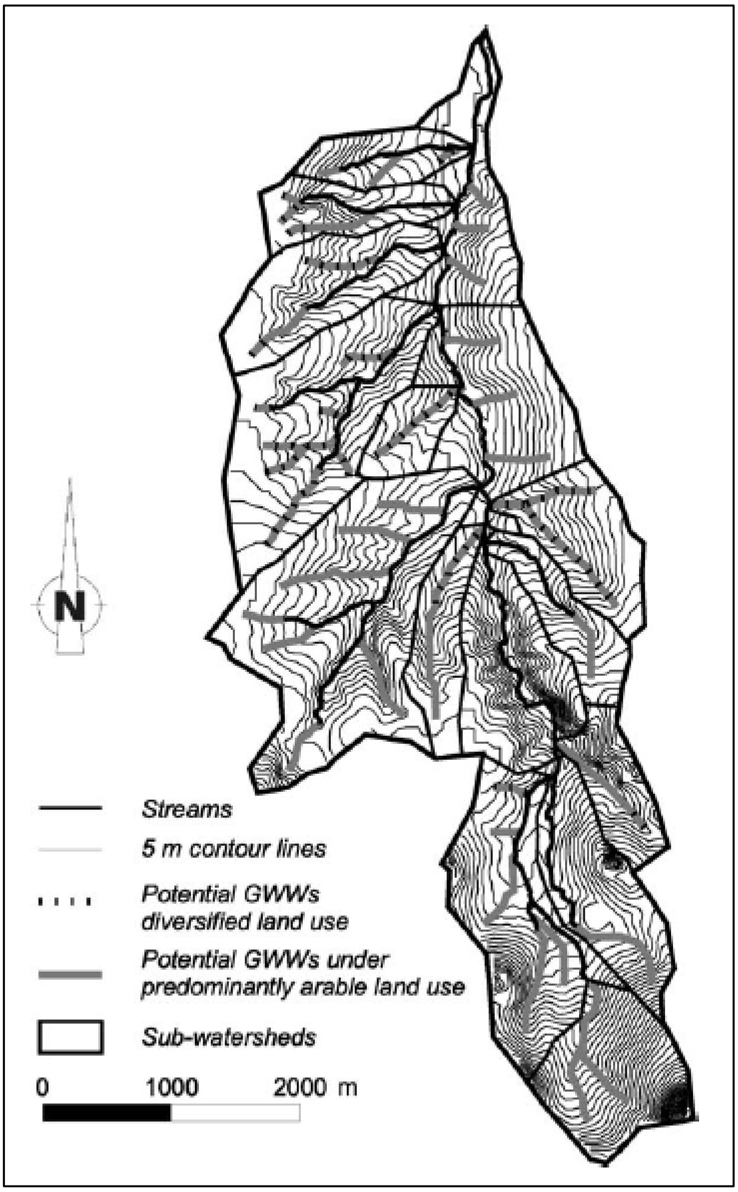

Figure 2.11: Potential grassed waterways (GWWs) in the Lauterbach watershed under predominantly arable land use in all sub-watersheds and diversified land use (Fiener and Auerswald, 2006)

The simulation used two summers period (one prior to and one after small grain harvest) and one winter condition at recurrence times of 2, 10, 20 and 50-year ARI. The results were shown in Figures 2.12 and 2.13.

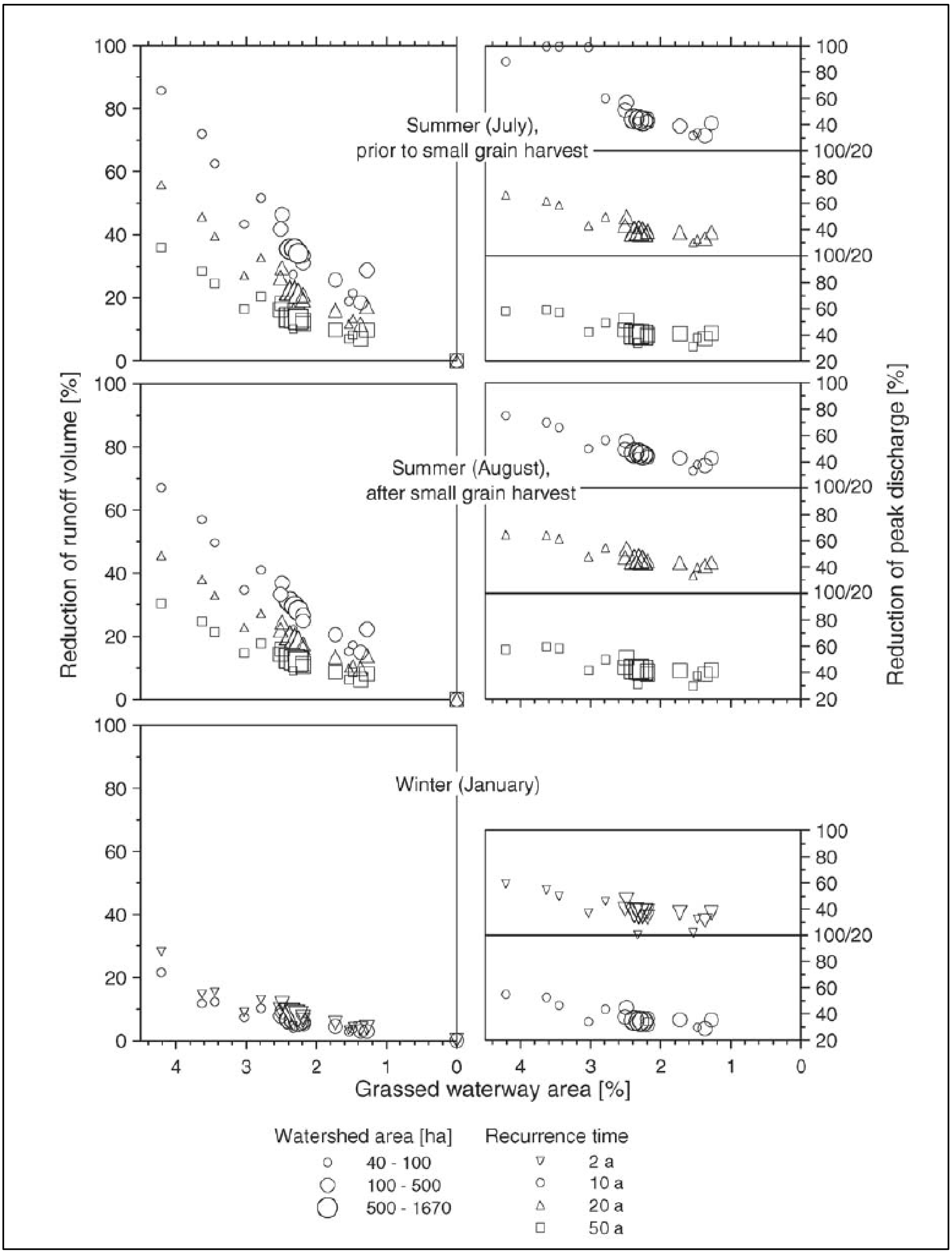

Figure 2.12: Modeled reduction of runoff volume (left) and peak discharge (right) for 24-h storms for a predominantly arable land use [grassed waterways assumed in all sub-watersheds; note: for summer storms recurrence times of 10-50-yr (no runoff in case of 2-yr storms), while for winter events recurrence times of 2-10-yr are presented; winter storms >10-yr are excluded due to unknown vegetation behavior (Fiener and Auerswald, 2006)]

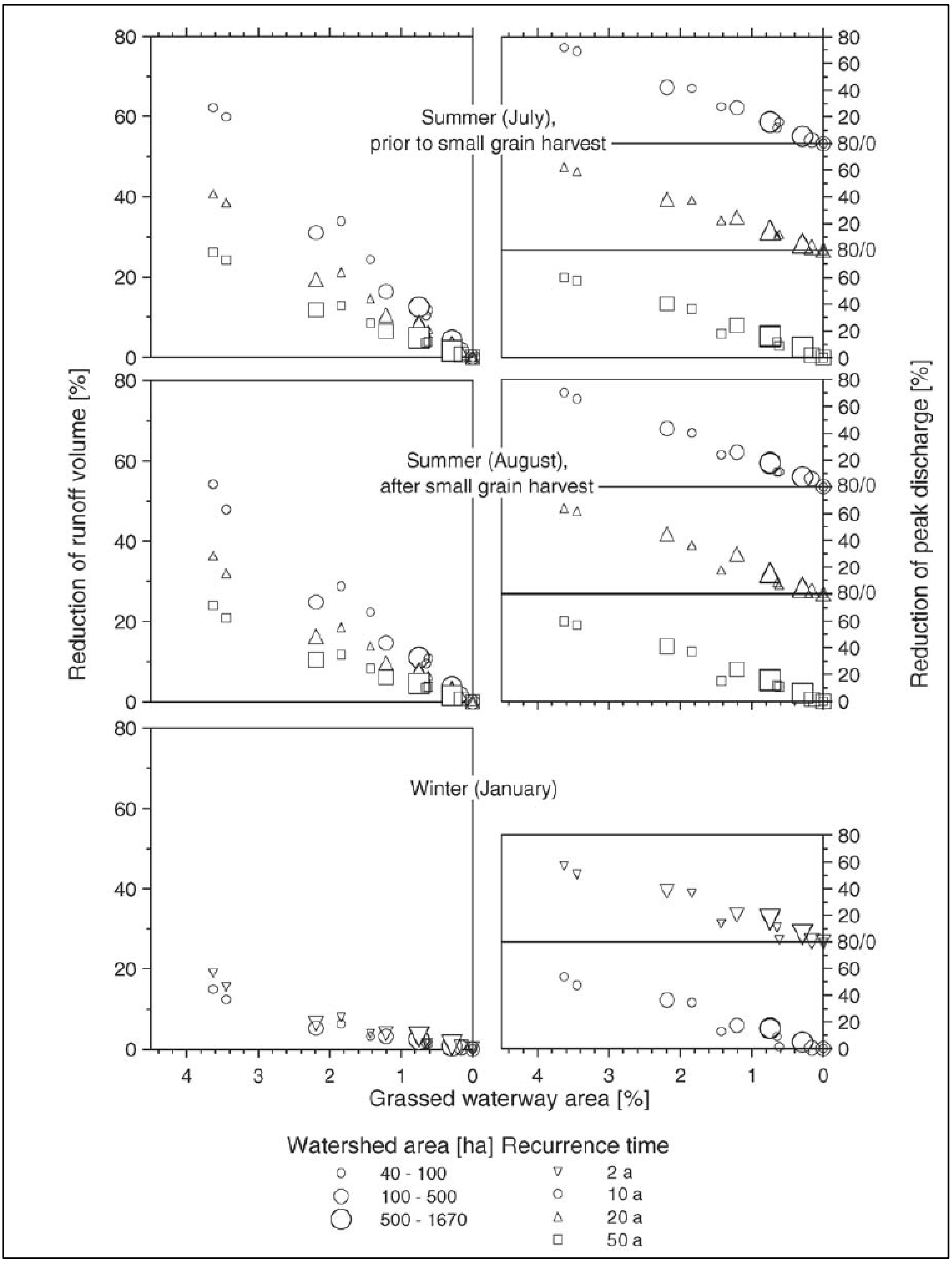

Figure 2.13: Modeled reduction of runoff volume (left) and peak discharge (right) for 24-h storms for a diversified land use [grassed waterways assumed where ever possible due to topography and land use; note: for summer storms recurrence times of 10-50-yr (no runoff in case of 2-yr storms), while for winter events recurrence times of 2-10-yr are presented; winter storms >10-yr are excluded due to unknown vegetation behavior (Fiener and Auerswald, 2006)]

From Figures 2.12 and 2.13, GWWs show a large reduction in runoff volume and peak discharge in a pre-dominantly small area arable land use, but the efficiency had no remarkable effect on runoff reduction with an increasing watershed size of similar GWWs area.

Besides that, reduction in the runoff and peak discharge decreased with higher storm size due to high amounts of inflow into the GWWs. Other than watershed size and type of storm, a proper designed and well managed of GWWs especially to keep their vegetation in good condition and to shape and maintain their cross section flat-bottomed are of major importance (Fiener and Auerswald, 2006).

2.3 Stormwater Management Modelling

To a greater understanding on the modeling, Guo (2001) had carried out a study at Chigago, Illinois on the hydrologic design of the flood control detention ponds with 35% of 250 ha is an urban catchments area. Using a 50-year hourly historical rainfall record (1948-1997) from Midway Airport in Chigago (excluded data from November through March each year), the study assumed that the statistical characteristics of the rainfall remain the same in the future. The approaches using: (1) design storm approach; (2) continuous simulation approach; and (3) analytical probabilistic approach.

The design storm approach for various durations are developed through statistical analysis shows peak discharges which extremely sensitive to storm duration. In continuous simulation approach, the historical rainfall data are used directly in Stormwater Management Model (SWMM) (Huber and Dickinson, 1988). For the analytical probabilistic approach, Guo and Adam (1998) assumed that exponential distributions were well approximated to the observed frequency distributions. The exponential probability for rainfall event, volume, duration and inter-arrival time can be used to represent the complete spectrum of future rainfall condition. Thus, for rainfall data, only the statistical analysis in supporting the analytical probabilistic approach is used. Spreadsheet application is used by Guo and Adam (1998) as an alternative for the hydrologic design of the flood control detention ponds.

The results are presented by showing a comparison between two approaches; (1) analytical probabilistic and continuous simulation; and (2) analytical probabilistic and design storm modeling. In design, it is important to determine the storage volume generated using the approaches adopted. The results are shown in Tables 2.1 and 2.2.

Table 2.1: Detention Volume using the Analytical Probabilistic Approach (Guo, 2001)

Calculations Using the Analytical Probabilistic Approach

Required Storage-Discharge Table		**Resulting Peak Discharge Rate Return Period**
Storage Volume (m^3)	Discharge Rate (m^3/s)	Return Period (years)
0	0.000	0.0
42000	6.853	2.0
60900	9.137	5.0
91200	13.706	25.0
96650	17.361	50.0
98690	21.929	100.0

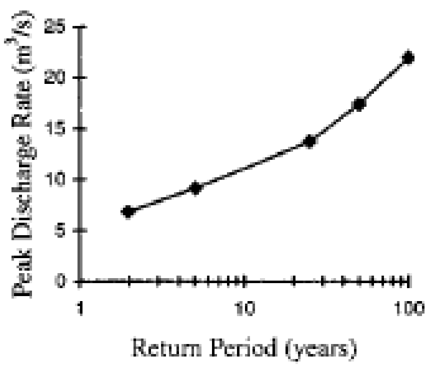

Table 2.2: Comparison of Flood Control Detention Volume Requirements Determined Using Different Methods (Guo, 2001)

Approach used	Detention volume required to satisfy level 1 control (X 1000 m^3)	Detention volume required to satisfy level 2 control (X 1000 m^3)
SWMM with 3-h storm peaking at 1st quartile	170	144
SWMM with 3-h storm peaking at 2nd quartile	178	155
SWMM with 6-h storm peaking at 1st quartile	173	144
SWMM with 6-h storm peaking at 3rd quartile	211	184
SWMM with 24-h storm peaking at 3rd quartile	113	26
HEC-HMS with 3-h storm peaking at 1st quartile	211	185
HEC-HMS with 3-h storm peaking at 2nd quartile	226	207
HEC-HMS with 6-h storm peaking at 1st quartile	212	186
HEC-HMS with 6-h storm peaking at 3rd quartile	254	229
HEC-HMS with 24-h storm peaking at 3rd quartile	136	49
Analytical Probabilistic Approach	175	154

From Tables 2.1 and 2.2, the storage volume determined using the design storm approach can vary significantly depending on which model and design storm are used. When excluded the results from the 24-h storms, the design storm approach with storm durations of 3 or 6 hours shows that for control level 1, the maximum difference can be 41% of the average value; while for control level 2, the maximum difference can be 47% of the average value. Generally, the storage volume determined from the analytical probabilistic approach is within the range determined from the design storm approach with storm durations of 3 or 6 hours (Guo, 2001). The study on the peak discharge simulated, the results are shown in Figures 2.14 to 2.16.