Urban Stormwater Management Model and Tools for Designing Stormwater Management of Green Infrastructure Practices

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Abstract. Urbanization is growing rapidly in Malaysia. Rapid urbanization has known to have several negative impacts towards hydrological cycle due to decreasing of pervious area and deterioration of water quality in stormwater runoff. One of the negative impacts of urbanization is the congestion of the stormwater drainage system and this situation leading to flash flood problem and water quality degradation. There are many urban stormwater management softwares available in the market such as Storm Water Drainage System design and analysis program (DRAINS), Urban Drainage and Sewer Model (MOUSE), InfoWorks River Simulation (InfoWork RS), Hydrological Simulation Program-Fortran (HSPF), Distributed Routing Rainfall-Runoff Model (DR3M), Storm Water Management Model (SWMM), XP Storm Water Management Model (XPSWMM), MIKE-SWMM, Quality-Quantity Simulators (QQS), Storage, Treatment, Overflow, Runoff Model (STORM), and Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS). In this paper, we are going to discuss briefly about several softwares and their functionality, accessibility, characteristics and components in the quantity analysis of the hydrological design software and compare it with MSMA Design Aid and Database. Green Infrastructure (GI) is one of the main topics that has widely been discussed all over the world. Every development in the urban area is related to GI. GI can be defined as green area build in the develop area such as forest, park, wetland or floodway. The role of GI is to improve life standard such as water filtration or flood control. Among the twenty models that have been compared to MSMA SME, ten models were selected to conduct a comprehensive review for this study. These are known to be widely accepted by water resource researchers. These ten tools are further classified into three major categories as models that address the stormwater management ability of GI in terms of quantity and quality, models that have the capability of conducting the economic analysis of GI and models that can address both stormwater management and economic aspects together.

1. Introduction

Urbanization is growing rapidly in Malaysia. Rapid urbanization has known to have several negative impacts towards hydrological cycle due to decreasing of pervious area and deterioration of water quality in stormwater runoff. One of the negative impacts of urbanization is the congestion of the stormwater drainage system and this situation leading to flash flood problem and water quality degradation. In the past, urban waterways have been limited to narrow river corridors with the channels canalised and concrete and other man-made materials forming the bed and banks of the river. At the same time, the waterways located in or near urban area are adversely influenced by solids in stormwater runoffs [1].

In the early 1970, simulation of water quantity has been growing rapidly by US Government Agency (US Environment Protection Agency). By using computer model, the mathematical relationships that represent the behaviour of the system are solved. There are two models in a hydrological model which are stochastic and determinstic model. Stochastic model is when a variable is considered as random...
variable that has probability distribution and it always produce a different response model. While deterministic model produces identical results when the same input parameter is inserted. From this deterministic model it could also be a stochastic model if the random variable replaced by their mean values. Both models may be classified into empirical or conceptual depending on whether the model is based on physical laws or not [2].

Most of the urban stormwater management tools or green infrastructure tools available in the market come in the software version. To compete with other well known softwares in the market, Department of Irrigation and Drainage (DID) Malaysia has come out with a prototype of MSMA Design Aid and Database software. This MSMA design aid and database software is developed guided by Manual Saliran Mesra Alam (MSMA 2nd Edition).

Green Infrastructure (GI) is one of the main topic that has been widely discussed all over the world. Every development in the urban area is related to GI. GI can be defined as green area build in the develop area such as forest, park, wetland or floodway. The role of GI is to improve life standard such as water filtration or flood control [3]. GI can offer a wide-ranging of ESS such as decreasing urban heat island, improve air quality, adaptation of climate change, improving the community liveability and improve the ethical values of community. Nevertheless, in site or locality scale, GI is normally defined as a key of managing the stormwater runoff by fine the solution how to make the water infiltrate into the ground or fine the way to reuse it in the daily life [4].

2. Urban Stormwater Model
Urban storm water models have been applicable for usage such as operational tools. Nevertheless, they are more frequently used as either planning or design tools. There are two basic modules of an urban storm water model which are [2].

i) Rainfall runoff modelling – The creation of surface and sub-surface runoff from rainfall, wash-off and build-up of pollutants from impervious surface.

ii) Transport modelling - Routing of flows and pollutants through the storm water infrastructure, for example storages, open channel and pipe network.

The illustration of link between these processes is in Figure 8.

![Figure 8: Overview of process incorporated in a storm water model [5].](image-url)
Rainfall simulation is a well-known type of simulation and has been used for a very long time almost a hundred years. Advances in technology and knowledge about rainfall and interaction between rain and land also depend on the rainfall simulator development. Now, there are different types of rainfall simulator used around the world. Rainfall simulation can also be used to study the influences of a certain management practice on the properties of a particular material, or it can be used to improve our knowledge about of processes, such as erosion, runoff and infiltration [6].

2.1. *Hydrological models*

In order to develop the hydrological model we need to use hydrological methods. In the hydrological method the Muskingum method, unit hydrograph, nonlinear storage and lumped continuity or storage models need to be considered. The spatial variability is going to be ignored in the problem and the hydrological method is only based on the conservation of mass [2]. Stormwater Management Software is commonly commercially available. Nevertheless, different software has provided different types of design facilities and modelling.

2.1.1. *Software name: DRAINS*

In January 1998, Watercom Pty Ltd released one multipurpose Window program called Storm Water Drainage System design and analysis program (DRAINS). Watercom Pty Ltd based in New South Wales, Australia. DRAINS is use for designing and analysing urban storm water drainage system and catchments. This software capable to model drainage systems of all sizes, from small to up to 10 km² by using sub-catchment with ILSAX hydrology and greater using storage routing model hydrology. DRAINS will simulate and convert the rainfall patterns to storm water runoff hydrographs by working through a number of time steps that befell during the course of a storm event. The simulation runoff will route through channel, networks of pipes and streams. The connections to CAD and GIS program, automatic design procedure for piped drainage systems and an in-built Help system is also include in this software.

In a single package, DRAINS can model the hydrological model using ILSAX, rational method and a storage routing models together with unsteady hydraulic modelling of systems of pipes, open channels and, and in the premium hydraulic model, surface overflow routes. The important functions that are not included in DRAINS are [7]:

(a) Continuous modelling over long periods including wet and dry conditions  
(b) Water quality modelling  
(c) 2-dimensional unsteady flow modelling  
(d) Life cycle cost

2.1.2. *Software name: MOUSE*

Based in Pennsylvania, USA, Urban Drainage and Sewer Model (MOUSE) is created as a comprehensive modelling system. This software is used for analysis of urban drainage and sewer systems including links to GIS. Other than that, MOUSE also used to simulate spatial variations in flows, water levels, sediment transport and pollution in pipes and open drains. Single or multiple events can be defined by the user and the time period up to several years.

Deterministic mathematical modelling tool is use as mathematical formulation of MOUSE model. With user defined the time interval MOUSE produces output a large number of variables. MOUSE has advantage in the aspect of no limits on the size of model area or number of input elements to be included in the simulation and capable to branched and looped network.

Continuous type of simulation is used in the MOUSE for nature of simulation. Besides that, this software also can predict the hydraulic deficiencies, overflow sites, flood inundation areas, and effect of real-time control. For rainfall-runoff model, the contributing area and hydrological losses are part of
model parameter. Topographic maps, drainage plans and aerial photos are an input requirement in MOUSE. The Input data requirement is in spread-sheet format [8].

2.1.3. Software name: InfoWork RS
InfoWorks River Simulation (InfoWork RS) is a hydrodynamic modelling software includes full solution modelling of open channels, floodplains, embankments and hydraulic structures. Using both event based and conceptual hydrological methods, the rainfall-runoff simulation is also available using geographical plan views, sectional view, long sections, spreadsheet and time varying graphical data in full interactive views of data [9].

The underlying data can be accessed from any graphical and geographical view. In addition to presentation of results in geographical plan, tables, cross section views and long section and model also provide animation showing how a flood event progress. Full flood-mapping capability is provided based on a sophisticated flood-interpolation model overlaid onto an imported ground model [9].

InfoWorks RS combine the advanced flow simulation engine, both hydrological and hydraulic models, GIS functionality and database storage within one single environment. The basic system architecture is an “Integrated Network Model” links data storage using a GIS to hydrologic/hydraulic modelling software suite embedded in InfoWorks RS [10].

2.1.4. Software name: HSPF
Hydrological Simulation Program-Fortran (HSPF) simulating the extended periods of time the hydrologic processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. HSPF uses continuous rainfall and other meteorological records to compute stream flow hydrographs. This software is used to simulate one or many pervious or impervious unit areas discharging to one or many river reaches or reservoirs. Any time series for frequency-duration analysis can be done. From 1 minute to 1 day at any time that divides equally into 1 day can be used. HSPF also can simulate any period from a minute to hundreds of years. This software is generally used to evaluate the effects of land-use change, reservoir operations, point or nonpoint source treatment alternatives, or flow diversions [11].

Programs which available separately, will support data in pre-processing and post processing for statistical and graphical analysis of data saved to the Watershed Data Management (WDM) file. The model contains hundreds of process algorithms developed from theory, laboratory experiments, and empirical relations from instrumented watersheds. HSPF simulated sediment routing by particle size, channel routing, reservoir routing, and constituent routing. Meteorological records of precipitation and estimates of potential evapotranspiration are required for watershed simulation. Physical measurements and related parameters are required to describe the land area, channels, and reservoirs [11]

2.1.5. Software name: DR3M
Distributed Routing Rainfall-Runoff Model (DR3M) is one of the storm water modelling. This software is created to simulate the storm runoff. It can simulate the routing storm either in system or pipes or natural channel. By using rainfall as an input, this software model the detail simulation of storm runoff according to user period time selected.

DR3M is commonly is used to simulating the storm runoff for small urban basins. To calculate the infiltration and pervious area rainfall excess the Green-Ampt equation is used. The disadvantage of this software is it does not simulate interflow and base flow of the basin. Daily precipitation, daily evapotranspiration, and short-interval precipitation are required for data requirement. To optimize and calibrate the model short interval discharge is needed [12].
2.1.6. Software name: SWMM
Developed in 1971, The USEPA Storm Water Management Model (SWMM) has been used for over 30 years and widely used as utilized model in detailed hydrological and hydraulic modelling of storm water and watershed of the catchment. This software is capable to simulate the precipitation movement from the ground surface through channel/pipe network. Single event and a long continuous period of event can be simulating by using SWMM. For a long time, SWMM version is a freeware and being maintained by several numbers of individual and organisation. Now, SWMM engine has been rewritten and known as a version SWIMM 5, SWMM 5 is maintaining by USEPA.

In this hydrological model concept, every sub-catchment in a basin is treated as non-linear reservoir with a single inflow or rainfall input and will produce the outflow or discharge in term of infiltration, evaporation and surface runoff. The development of a number of SWMM Graphical User Interface (GUI) wrappers such as MIKESWMM, XP-SWMM has been created through a year of revolution [13].

2.1.7. Software name: XP-SWMM
XP Storm Water Management Model (XPSWMM) is an inclusive software package for planning, modelling and managing sustainable drainage systems. This software is used to simulate the stormwater and sanitary sewer flows as well as treatment in typical LID (WSUD) systems. Hydraulically, flows are simulated in 1D channel and pipes and coupled to a 2D surface grid for comprehensive flood modelling and mapping.

Scientists, engineers as well as resource and asset managers use this software to simulate natural rainfall-runoff processes and the performance of engineered systems that manage our water resources. XPSWMM is used to develop link-node and spatially distributed models that are used for the analysis, design and simulation of storm and wastewater systems. XPSWMM also models flow in natural systems including rivers, lakes, and floodplains with groundwater interaction [14].

2.1.8. Software name: MIKE-SWMM
MIKE-SWMM is one of the SWMM Graphical User Interface (GUI) wrappers. In this MIKE-SWMM, the function is similar to SWMM which is to analyse the urban drainage system and sanitary sewers. Combination of hydrology, hydraulics and water quality, in MIKE-SWMM provides complete graphical and user friendly interface for user [15]. In this hydrological model concept, every sub-catchment in a basin is treated as non-linear reservoir with a single inflow or rainfall input and will produce the outflow or discharge in term of infiltration, evaporation and surface runoff [13].

2.1.9. Software name: QQS
QQS stand for Quality-Quantity Simulators. The advantage of this software is by using fine interval such as five minutes time interval this software capable to perform continuous or single event simulation. QQS is used to simulating the flows in channels or pipes using an implicit finite difference approximation of the kinematic wave equation, backwater analysis, storage routing and pipes under pressure. This software is suitable to use in urban area catchment to simulate it urban storm water modelling [5].

2.1.10. Software name: STORM
Storage, Treatment, Overflow, Runoff Model (STORM) is a modelling software that has been developed by US Corps of Engineers. This software is capable to simulate the runoff in the urban or rural catchment area in response to precipitation. STORM not only can be used for single event but it also can be used to simulate continuous model by using hourly time steps. Runoff of every sub-catchment will simply accumulate in one catchment by using hourly precipitation. To calculate hourly runoff unit hydrograph method, coefficient method and soil-complex-cover method can be chosen to use. Runoff is a linear relationship between runoff and the precipitation minus rainfall interception [5].
2.1.11. Software name: HEC HMS

In this study, Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS) the model that designed by US Army Corps of Engineers will be used to model the basic hydrological model [15]. This software is updated program from the HEC-1. The advantage of HEC-HMS compare to HEC-1 which is designed working with MS-DOS program, it designed for more function and run with a windows appearances [17].

The development from HEC-1 to HEC-HMS is one of the useful tool for the hydrologist because it is more user friendly [18]. HEC-HMS can be used to help set up the hydrological model system and also for simulating the rainfall-runoff process of a catchment [19]. Numerous methods are used to simulate surface runoff, by apply several methods in HEC-HMS model different result can be reached [19].

HEC-HMS is designed with four main components. Below is the list of main components in HEC-HMS [21]:

i) An advanced graphical user interface illustrating hydrologic system components with interactive features.

ii) A system for storing and managing data, specifically large, time variable data sets.

iii) An analytical model to calculate overland flow runoff and also channel routing.

iv) A means for displaying and reporting model outputs.

HEC-HMS can apply for both short term and long term simulations [22]

2.1.12. Software name: MSMA Design Aid and Database

MSMA Design Aid and Database is a computer design aid system that includes ecohydrological and ecostormwater design tool and data storage. This tool is used for the analysis of ecohydrological and ecostormwater variables that may indicate the risk for flash flood, polluted river water and mud flood at a designated site of interest, which is defined herein as data-collection on site.

MSMA Design Aid and Database is needed to provide available information to assess stormwater component database and design stormwater components. Design Aid is commonly described as an interactive computer program that integrates models and complex data to help managers make planning-level decisions for complex situations that may be rapidly changing and not well-defined in advance. In many applications, Design Aid provides a standard method to demonstrate the potential effectiveness (and limitations) of various levels of stormwater management and will therefore provide the necessary information for defensible recommendations for MSMA Design Aid and Database components which covers all aspects including concepts, detailed design and performances.

MSMA Design Aid and Database module framework covers six main components; Database, Hydrological component, Design Quantity Control, Design Quality Control, Conveyance component and Checking Tools component.
3. Summary of urban stormwater management software

From the urban stormwater management software that has been briefly mentioned above, the summary of the functionality and accessibility, characteristic and components in the quantity analysis of the hydrological design software that available in the market is compiled as shown in Table 1, Table 2 and Table 3.

Table 1: Functionality and accessibility of the representative models

| Urban Models   | Functionality | Accessibility |       |       |       |
|---------------|---------------|---------------|-------|-------|-------|
|               | Planning      | Operational   | Design | Public | Commercial |
| DRAINS        | ✓             | ✓             | ✓     | ✓     | ✓      |
| MOUSE         |               |               | ✓     | ✓     | ✓      |
| Infowork RS   | ✓             | ✓             | ✓     | ✓     | ✓      |
| HSPF          | ✓             |               | ✓     | ✓     | ✓      |
| DR3M          | ✓             |               | ✓     | ✓     | ✓      |
| SWMM          |               |               | ✓     | ✓     | ✓      |
| MIKE-SWMM     |               | ✓             | ✓     | ✓     | ✓      |
| QQS           |               | ✓             | ✓     | ✓     | ✓      |
| STORM         |               |               |       | ✓     | ✓      |
| HEC-HMS       |               |               |       |       | ✓      |
| MSMA Design Aid and Database | ✓ | ✓ | ✓ | ✓ | ✓ |

1, Flow balance only, 2, With EXTRAN module
Table 3: Components in the quantity analysis in representative models

| Urban Models | Model quantity component | Pipes | Open channel | Retarding basins | Others | Natural Streams | Rainfall runoff |
|--------------|--------------------------|-------|--------------|------------------|--------|-----------------|-----------------|
| DRAINS       | ✓                        | ✓     | ✓            | ✓                | ✓      | ✓               | ✓               |
| MOUSE        | ✓                        | ✓     | ✓            | ✓                | ✓      | ✓               | ✓               |
| Infowork RS  | ✓                        | ✓     | ✓            | ✓                | ✓      | ✓               | ✓               |
| HSPF         | ✓                        | ✓     | ✓            | ✓                | ✓      | ✓               | ✓               |
| DR3M         | ✓                        | ✓     | ✓            | ✓                | ✓      | ✓               | ✓               |
| SWMM         | ✓                        | ✓     | ✓            | ✓                | ✓      | ✓               | ✓               |
| XP-SWMM      | ✓                        | ✓     | ✓            | ✓                | ✓      | ✓               | ✓               |
| MIKE-SWMM    | ✓                        | ✓     | ✓            | ✓                | ✓      | ✓               | ✓               |
| QQS          | 3                        | ✓     | ✓            | 2                | ✓      | ✓               | ✓               |
| STORM        |                          |       |              |                  |        |                 |                 |
| HEC-HMS      | ✓                        |       |              |                  |        |                 |                 |
| MSMA Design Aid and Database | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |}

1, reservoir module; 2, weirs and pumps; 3 pressurised pipes; 4, gutter and pumps; 5, surcharges; 6, bridges; 7, overland flow.

4. GI Practice and the development of Modelling Tools

Among the twenty models that has been compared to MSMA SME, ten models were selected to conduct a comprehensive review for this study. These are known to be widely accepted by water resource researchers. These ten tools are further classified into three major categories which are:

1) Models that address the stormwater management ability of GI in terms of quantity and quality,
2) Models that have the capability of conducting the economic analysis of GI and
3) Models that can address both stormwater management and economic aspects together.

A literature review for each tool is conducted extensively by referring their user guides, design manuals, fact sheets, case studies, journal articles, conference proceedings and book chapters. Table 4 shows tools for green infrastructure modelling [23].

5. Modelling Tools that Address Stormwater Quality and Quantity

GI practices attempt to replicate the pre development scenarios of a site in order to reduce the runoff quantities and improve the runoff quality [24]. Three models which have the ability of predicting the responses of different GI practices on runoff management are discussed within this category. Table 5 shows the list of reviewed Modelling Tools.
| Modelling Tools | Reference and Case Studies | Supported GI Practices Comments | Comments |
|----------------|---------------------------|---------------------------------|---------|
| Environmental Protection Agency (EPA) Green Long Term Control- EZ Template | (Schmitt et al., 2010) | Green Roofs, Vegetated Swales, Bio Retention Basins, Permeable Pavements, Rain Barrels | • Planning tool for combined sewer overflow control.  
• Can be used in small communities. |
| Water Environmental Research foundation (WERF) BMP SELECT Model | (Reynolds et al., 2012) | Extended Detention, Bio retention, Wetlands, Swales, Permeable Pavements | • Examines the effectiveness of alternative scenarios for controlling stormwater pollution.  
• Water quality parameters that can be simulated are Total Suspended Solids, Total Nitrogen, Total Phosphorus and Total Zinc |
| Virginia Runoff Reduction Method (VRRM) | (Bork and Franklin, 2010) | Green Roofs, Downspout Disconnection, Permeable Pavements, Grass Channels, Dry Swales, Bio Retention, Infiltration, Extended Detention Ponds, Wet Swales, Constructed Wetlands, Wet Ponds | • Incorporates built-in incentives for environmental site design, such as forest preservation and the reduction of soil disturbance and impervious surfaces. |
| WERF BMP and LID Whole Life Cycle Cost Modelling Tools | (Reynolds et al., 2012) | Green Roof, Planters, Permeable Pavements, Rain Gardens, Retention Ponds, Swales, Cistern, Bio Retention, Extended Detention Basins | • Planning level cost estimation for GI practices.  
• Different spreadsheet tools are designed for different practices. |
| Modelling Tools | Reference and Case Studies | Supported GI Practices Comments | Comments |
|-----------------|---------------------------|---------------------------------|----------|
| Centre for Neighborhood Technology (CNT) Green Values National Stormwater Management Calculator | (Jaffe, 2011, Guo and Correa, 2013) | Green Roofs, Planter Boxes, Rain Gardens, Cisterns, Native Vegetation, Vegetation Filter Strips, Amended Soils, Swales, Trees, Permeable Pavements | • Allows the user to select a runoff reduction goal and select the combination of GI practices that provides the optimum runoff reduction in a cost effective way. |
| CNT Green Values Stormwater Management Calculator | (Kennedy et al., 2008, Wise et al., 2010, Jaffe et al., 2010) | Roof Drains, Rain Gardens, Permeable Pavements, Trees, Porous Pavements, Drainage Swales | • Tool which helps to get an approximation of financial and hydrologic conditions for a user defined site. |
| Chicago Department of Environment Stormwater Ordinance Compliance Calculator | (Emanuel, 2012) | Green Roofs, Planter Boxes, Rain Gardens, Native Vegetation, Vegetated Filter Strips, Swales, Trees | • Used to evaluate the opportunities of GI with regard to the guidelines of Chicago’s stormwater management ordinance. |
| EPA Stormwater Management Model (SWMM) | (Huber and Singh, 1995, Tsihrintzis and Hamid, 1998, Huber, 2001, Khader and Montalto, 2008, Rossman, 2010) | Bio Retention, Infiltration Trenches, Porous Pavement, Rain Barrels, Vegetative Swales, Green Roofs, Street Planters, Amended Soils | • Planning, analysis and design related to stormwater runoff, combined sewer overflows and drainage systems.  
• Complex model with variety of features. |
| Delaware Urban Runoff Management Model (DURMM) | (Lucas, 2004, Lucas, 2005) | Filter Strips, Bio Retention Swales, Bio Retention, Infiltration Swales | • Spreadsheet tool to assist GI design. |
| Modelling Tools                                      | Reference and Case Studies          | Supported GI Practices                                       | Comments                                                                 |
|-----------------------------------------------------|-------------------------------------|----------------------------------------------------------------|--------------------------------------------------------------------------|
| Stormwater Investment Strategy Evaluator (StormWISE) Model | (McGarity, 2006, McGarity, 2010, McGarity, 2011) | Riparian Buffers, Filter Strips, Wetland/Rain Garden, Bio Retention/Infiltration Pits, Rain Barrel/Cisterns, Land Restoration By Impervious Surface Removal, Permeable Pavements, Green Roofs | • Studies on GI projects based on pollutant load reduction and cost benefits. |
| Program for Predicting Polluting Particle Passage through Pits, Puddles, & Ponds (P8 Urban Catchment Model) | (Elliott and Trowsdale, 2007, Obeid, 2005) | Detention Tanks, Ponds, Wetlands, Infiltration Trenches, Swales, Buffer Strips | • Model the generation and transportation of pollutants through urban runoff and the effectiveness of GI for improving the water quality. |
| Long-Term Hydrologic Impact Assessment (L-THIA)     | (Tang et al., 2005, Bhaduri, 1998, Bhaduri et al., 2001, Engel et al., 2003) | Bio Retention/Rain Gardens, Grass Swale, Open Wooded Space, Permeable Pavement, Rain Barrel/Cisterns, Green Roof. | • Consists of calculations for Stormwater runoff and pollutant loading. |
| GI Valuation Tool Kit                               | (GiVAN, 2010)                       | Green Cover                                                   | • Evaluate the dollar value of environmental and social benefit of GI.    |
| RECARGA                                             | (Dietz, 2007, Atchison et al., 2006) | Bio Retention, Rain Garden, Infiltration                      | • Performance evaluation                                                 |
| Modelling Tools | Reference and Case Studies | Supported GI Practices Comments | Comments |
|-----------------|----------------------------|---------------------------------|----------|
| EPA System for Urban Stormwater Treatment Analysis and Integration (SUSTAIN) | (Lai et al., 2006, Lai et al., 2007, Lai et al., 2009, Lai et al., 2010, Shoemaker et al., 2013) | Bio Retention, Cisterns, Constructed Wetlands, Dry Ponds, Grassed Swales, Green Roofs, Infiltration Basins, Infiltration Trenches, Permeable Pavements, Rain Barrels, Sand Filters (Surface And Non-Surface), Vegetated Filter Strips, Wet Ponds | • Implementation planning for flow and pollution control. • Selects the most cost effective solution in stormwater quality and quantity management. |
| Model for Urban Stormwater Improvement Conceptualization (MUSIC) | (Wong et al., 2002, Deletic and Fletcher, 2004, Wong et al., 2006, Dotto et al., 2011) | Bio Retention Systems, Infiltration Systems, Media Filtration Systems, Gross Pollutant Traps, Buffer Strips, Vegetated Swales, Ponds, Sedimentation Basins, Rainwater Tanks, Wetlands, Detention Basins. | • Assists in decision making of GI selection for stormwater management in urban development. |
| Low Impact Development Rapid Assessment (LIDRA) | (Montalto et al., 2007, Behr and Montalto, 2008, Yu et al., 2010) | Green Cover | • Evaluates the effectiveness of green space in reducing stormwater runoff. |
| WinSLAMM (Source Loading and Management Model for Windows) | (Pitt and Voorhees, 2002) | Infiltration/Biofiltration Basins, Street Cleaning, Wet Detention Ponds, Grass Swales, Filter Strips, Permeable Pavement | • Evaluates how effective the GI practices in reducing runoff and pollutant loadings. • The cost effectiveness of practices and their sizing requirements also been modelled. |
| Modelling Tools | Reference and Case Studies | Supported GI Practices | Comments |
|-----------------|---------------------------|------------------------|----------|
| MSMA Integrated Stormwater Management | Eco-Friendly Integrated Green Technology Expert System for Sustainabl e Green Infrastructure (GENIUS) | Design Rainfall (Empirical Method & IDF Curve Creator), Design Runoff ( Rational Method, Rational Method Hydrograph Method, Time Area Method), Rainwater Harvesting (MSMA & SPAH), Detention Pond, On-site Detention, i) Water Quality Volume, Infiltration Facilities, Bioretention System, Water Quality Pond, Wetland, Erosion and Sediment Control, Green Roof Design, Greywater, Lined Drain Design, Composite Drain, Swale, Engineered Channel, Pipe Drains, Road Gutter, Inlet Spacing, Curb Opening Inlet, Porous Pavement, Checking tools (Bridge Afflux & Pollutant Loading) | • Build up with individual database.  
• Consists of calculations for Stormwater runoff and pollutant loading.  
• Bioretention System consists of permeable and impermeable type of system; complies with orifice and weir type of overflow structure, and can be editable due to the typical design measurements and coefficient values.  
• Erosion and Sedimentation Control supports with auto-calculation properties of the settling zone depth and width for sediment basin design, and also specially designed for all states in Peninsular Malaysia.  
• Green Roof Design complies with the US METHOD design manual standard, and provides editable function of the porosity coefficient values.  
• Infiltration Facilities consist of the trench and basin infiltration type including with design criteria table references.  
• Pollutant loading complies with editable function of the Event Mean Concentrations (EMC) values for each pollutant parameter and it also supports more than 50 sub-catchments in one calculation process.  
• Pipe Drain supports more than 50 units of pipe connection flows in one calculation process |
| Modelling Tools                                      | Owner                                                                 | Availability                                                                 | Intended Uses in GI Modelling                                                                 | Reference                                      |
|-----------------------------------------------------|------------------------------------------------------------------------|------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------|
| RECARGA                                             | University of Wisconsin-Madison, water resources group                 | Available to download freely http://dnr.wi.gov/topic/stormwater/standa... | To design and understand performances of bio retention, infiltration basins and rain gardens. | (Atchison and Severson, 2004)               |
| Program for Predicting Polluting Particle Passage   | William W. Walker, Jr., Ph.D. Environmental Engineer Massachusetts    | Available to download freely http://www.wwwalker.net/p8/                     | To predict the generation and transportation of pollutants in urban runoff and design GI to achieve Total Suspended Solids Reduction | (Walker Jr, 1990)                            |
| Pits, Puddles, & Ponds (P8 Urban Catchment Model)   |                                                                        |                                                                              |                                                                                            |                                               |
| EPA Stormwater Management Model (SWMM)              | United States Environmental Protection Agency                           | Available to download freely http://www.epa.gov/nrmrl/wswr/d/wq/models/swmm/ | To plan, design and analysis of the performances of different GI in runoff quality improvement and quantity reduction | (Huber et al., 1988, Rossman, 2010)          |
| Water Environment Research Foundation(WERF) BMP and | Water Environment Research Foundation, Alexandria                      | Freely available to download http://www.werf.org/i/a/Ka/Search/ResearchProf... | To evaluate whole life cycle cost for GI practices                                           | (Water Environment Research Foundation, 2009) |
| LID Whole Life Cycle Cost Modelling tools           |                                                                        |                                                                              |                                                                                            |                                               |
| The Green Infrastructure Valuation Toolkit          | Natural Economy North West UK                                          | Freely available to download http://www.greeninfrastructurew.co.uk/html/index.php?page=projects&GreenInfrastructureValuationToolkit=true | To evaluate the environmental and economic benefit of GI in monetary terms | (Natural Economy Northwest, 2010)           |
Continue Table 5…

| Modeling Tools | Owner | Availability | Intended Uses in GI Modelling | Reference |
|---------------|-------|--------------|------------------------------|-----------|
| Centre for Neighborhood Technology (CNT) Green Values National Stormwater Management Calculator | Center For Neighborhood Technology, Chicago | Free online assessment tool http://greenva
values.cnt.org/national/calculator.php | To compare GI cost, performance and benefits | (Center for Neighborhood Technology, 2009) |
| EPA System for Urban Stormwater Treatment and Analysis Integration Model (SUSTAIN) | United States Environmental Protection Agency | Freely available to download http://www.epa.gov/nrmrl/wswrd/wq/models/sustain/ | To develop implementation plans for flow and pollution control, evaluate cost effectiveness of GI | (Lai et al., 2007) |
| Model for Urban Stormwater Improvement Conceptualization (MUSIC) | eWater, Australia | Proprietary software http://www.ewater.com.au/products/ewater-toolkit/urban-tools/music/ | To evaluate GI practices in order to achieve stormwater quantity reduction, quality improvement and cost effectiveness. | (Wong et al., 2002) |
| Low Impact Development Rapid Assessment (LIDRA) | eDesign Dynamics, New York | Open Source Web Based tool http://www.lidratool.org/database/database.aspx | To study runoff cost reductions with GI | (Yu et al., 2010) |
| WinSLAMM (Source Loading and Management Model for Windows) | PV & Associates USA | Proprietary software http://winslamm.com/winslamm_updates.html | To study the quality of urban runoff and the role of GI in runoff quality improvement | (Pitt and Voorhees, 2004) |
| Modeling Tools                              | Owner                   | Availability                     | Intended Uses in GI Modeling                                                                 | Reference |
|--------------------------------------------|-------------------------|----------------------------------|---------------------------------------------------------------------------------------------|-----------|
| MSMA Integrated Stormwater Management Eco Hydrology Design Aid and Database System (MSMA SME Design Aid and Database System) | HTC & UNITEN            | To be described by Co-Inventor (JPS/UNITEN)                                                | • To design and understand performances of bio retention, wetland, green roof and etc.  
• To evaluate GI practices in order to achieve stormwater quantity reduction and quality improvement  
• To study the quality of urban runoff and the role of GI in runoff quality improvement  
• To plan, design and analysis of the performances of different GI in runoff quality improvement and quantity reduction | -         |
Conclusion

In general, urban stormwater management model is the standard tool used to help engineer to simulate the hydrological process. There are many models with the different applications range from small catchment to a large catchment have been developed. Every software has its own specific characteristics and respective applications. Several models are used to model gauged and ungauged study area. Each model has several disadvantages such as lack of user friendly characteristics, large data requirements and nonappearance of clear declarations of their boundaries. In order to overcome these imperfections, it is required for the models to include rapid advances in remote sensing technologies. New distributed models can be developed for modelling gauged and ungauged basins by applying the new technologies. One of the challenges is regarding the use of large quantity of data and hence new facilities are to be included for the efficient storing, managing and manipulation of the large data. Each software manufacturer should be required to provide a clear statement of their border and issued a corresponding guide and enlighten the dominant physical process. A different way than model evaluation required for accurate prediction. Parameters measures will reflect the causes of errors in modelling. To avoid adverse effect on model calibration the modeller need to have proper knowledge about subsurface flow pathways and hydraulic characteristics. In general, the development of MSMA Design Aid and Database is complete, with all components in place. The MSMA Design Aid and Database have met the two main purposes. First, to assist in solution development of MSMA Design Aid and Database components and integrated stormwater management based on expert data and user input and second is to provide better understanding on the MSMA Design Aid and Database components which cover all aspects including concepts, detailed design and performances

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