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VOLUMETRIC SOFT GEO-OBJECTS FOR GIS BASED URBAN RUNOFF MODELLING

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ABSTRACT

Monsoon and flash flood have been dominating the entire urban areas in Peninsular Malaysia, such as in Penang, upper Kinta Valley, Malacca Basin, East Coast of Kelantan, Terengganu, Pahang and Johor. From the larger scale view, global warming causes uncertainties of receiving rainfall amount in Malaysia. Improper urban development planning and increased number of impervious area causes hazardous impact towards urbanized land use properties within basin. Complexities of constructed buildings, road networks and urban landscape makes difficulties for flood mitigation and rehabilitation planning towards reducing flood disaster. Thus require of a new dimension representing urban flood modelling realistically. Concepts of urban runoff process need to be reviewed in order to sustain the existing environmental condition. Inclusion of volumetric soft geo-objects would offer substantial effort towards representing stormwater flow that hits the flood-plain areas, estimating channel flow capacity, routing and diversions to reduce urban flood disaster realistically. This study aims to perform dynamic simulation of urban runoff process by accounting direct runoff and open channel flow volume visualized using volumetric soft geo-objects within 3D environment. The volumetric soft geo-objects are driven by physically based Kinematic Wave routing method. Basin model, sub-basin, reach and junction elements are extracted from Digital Elevation Model (DEM) using HEC-GeoHMS and HEC-HMS model. Hydrologists, Town planners, Environmentalists and local authorities could find the results are useful to evaluate the effectiveness of flood management control, sustainability for long-term development purposes, stream restoration, rehabilitation and relocation of construction projects.

Keywords: GIS, SEOF, TWI, AMC, Map Projection

1.0 INTRODUCTION

The spatially distributed hydrologic modelling serves an efficient method to identify hydrological impacts due to urbanization on land cover. GIS is capable of handling spatial data organization, visualization, querying, analyzing and helpful in the context of hydrologic simulation and modelling (e.g. floods, subsurface flow and evapotranspiration) (Drummond et al., 2007). Greene (2002) stated GIS is the only effective technology that allows for the visualization of emergency or disaster situation. By placing the accurate physical geography of flood disaster event on a computer monitor aligned with other relevant features, events, conditions and threats, GIS enables hydrologists, environmentalists and town planners, police and fire forces to make decisions based on the simulated rainfall-runoff event. Moreover, GIS has given benefits to expand various kinds of simulation basis, spatial representation and temporal representation models to visualize results based on site specific measurements and experiments for urban runoff modelling (Garbrecht et al., 2001; Dingman, 2002; Goodchild, 2003). Precipitation is one of the major basin-scale phenomenons in the hydrologic cycle. A streamflow derives integrated results from various upland flow sources in response of precipitation and other water inputs. At present, the large variation and behaviour of drainage basins causes difficulties to produce general relationships to identify and quantify the physical geographic characteristics that results the simulated hydrograph in urban areas (Brutsaert, 2005). Urban runoff occurs from the portion of rainfall, irrigation water or wastewater that does not infiltrate into the soil and reaches streams and channels (ranging from the large permanent streams to the tiny rills and rivulets) by travelling over the surface of the soil (Bedient and Huber, 2002; Ward and Trimble, 2004). It also exists on compacted soils, removed topsoil and particularly obvious on paved urban areas. Urbanized watershed often covered with impervious areas resulting increase of more frequent surface runoff and severe flooding, causes the rainfall-runoff process changed evidently. Thus include increase of flood crest value, runoff coefficient, stormwater quantity and short duration of flood crest occurrence. United Nations has made a call to highly rank the urban flood disaster issues on national agendas due to the steady increase in urbanization (Grothe et al., 2005).

Many river basins in Malaysia are now under intense pressure from urban, industrial, and infrastructural development where downstream receiving water bodies such as rivers, lakes, ponds, reservoirs, and estuary and coastal waters have become sensitive to increased rates and volumes of runoff and pollutant discharge. Urbanization increases the percentage of impervious area in a watershed, thus the urban runoff in a post-development area becomes greater than in that in pre-development area particularly in the western states of the Peninsular Malaysia. The problems become even more aggravated by frequent intense rainfalls, the physiological nature of basins and the pattern of urbanisation with relatively poor urban services. Department of Irrigation and Drainage, Malaysia (DID) estimates the costs of damage due to the flood event in year 2004 to be over than RM2.5 billion. Various urban runoff models and methods have been developed and integrated with GIS to simulate the loss, transform and baseflow rate within watersheds such as SCS Technical Release (TR-55), Storage Treatment Overflow Runoff Model (STORM), Distributed Routing Rainfall-Runoff Model (DR3M), MIKE-SHE, AGWA, Soil and Water Assessment Tools (SWAT), Kinematic Runoff and Erosion Model – KINEROS and Storm Water Management Model – SWMM. These models can be used to access the runoff rate, analyze an existing network of interconnected stormwater management facilities, designing new components such as underground storm sewers, detention ponds, ditches, channels and street-side curbs of an existing system, but practically yielded only limited success. The urban runoff has become complex due to the complicated structures and distributions of the buildings in cities that needs to cope with visualization techniques.

Recently, GIS have started to penetrate from 2D basis spatial hydrologic information system towards 3D applications and most recently from static manner (3D) towards dynamic systems that incorporate a temporal element, which is the 4D (Drummond et al., 2007). Modelling dynamic urban runoff simulation provides decision makers to analyze and predict natural disasters (e.g. flash floods, landslides, water pollution) to reduce related damages. Maidment et al. (2005) linked HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) and HEC-RAS (Hydrologic Engineering Centre-River Analysis System) with ArcGIS in a case study of flood simulation for Rosillo Creek in San Antonio, Texas due to limitation of analyzing and modelling multidimensional data sets within GIS software. Although commercial GIS softwares are valuable representing 2D spatial features, it did not support dynamic and probabilistic modelling. Existing approach represents 3D GIS modelling into three geometry types; the surface-based (e.g. grid modelling); volume-based (e.g. tetrahedron network (TEN) modelling) and hybrids (e.g. TIN-Octree modelling) (Gong et al., 2004). These approaches can appropriately visualize rigid geo-objects such as mountains, roads, and buildings, but soft geo-objects are less represented. Shen et al. (2006) developed a method for representing 3D simulation of soft geo-objects representing overland flow based on GIS flow element (FE) concept, which can be performed using particle system and metaball approach. Adaptation of soft geo-objects method by including the aspect of volumetric dynamic flow towards urban runoff simulation would offer beneficial contribution towards reducing flood in urbanized areas. Visualization techniques in this study provide the means to improve the urban runoff process determination and allowing hydrologists, environmentalists and other professional's inclusion within the decision-making process. Moving from a 2D map to a 3D landscape image of urban flood modelling provides a valuable step for end-users envisioning complex flow routing information.

This paper describes the visualization techniques for simulating urban runoff process dynamically using volumetric soft geo-objects. Simulation is performed within catchment boundaries driven by physically based Kinematic Wave routing method using metaball approach. The concepts of georeferencing for 3D dynamic urban runoff simulation and volumetric soft geo-objects are explained in

Section 2. The experiment of determining volumetric soft geo-objects simulation for direct runoff and open channel flow is highlighted in Section 3. Determination of urban flood area is explained in section 4, 3D dynamic urban runoff simulation results are visualized in Section 5, while the conclusion is stated in Section 6.

2.0 GIS FOR URBAN RUNOFF MODELLING

The powerful usage of GIS techniques is the ability to perform spatial analysis. Proper assignation of map projection would be vital to implement GIS techniques to compute amount of urban runoff generated in a spatial extent of catchment. GIS is capable to serve urban runoff modellers to input data and present the output of flow routing process, impacts and has been applied in various urban stormwater management based application such as rainfall runoff modelling, water quality monitoring and assessing non-point source pollution. There are two main factors that determine urban runoff formation and behaviour, the meteorological and physical characteristics (USGS, 2005; Christopherson, 2005). Malaysia is located in tropical rain forest climate, where rain occupies the precipitation type. The rainfall intensity, rainfall amount and rainfall duration are tightly connected. High intensity of rainfall will distribute large rainfall amount in a short period of runoff duration. Moisture condition of a soil would determine the total urban runoff volume generated (precipitation minus infiltration).

Table 1: Lists of urban runoff formation factor

Meteorogical Factors	Physical Characteristics
Type of precipitation (rain, snow, sleet, etc.)	Land use.
Rainfall intensity.	Vegetation.
Rainfall amount.	Soil type.
Rainfall duration.	Drainage area.
Distribution of rainfall over the watersheds.	Basin shape.
Direction of storm movement.	Elevation, Slope,
Topography.	
Antecedent precipitation and resulting soil moisture.	Direction of orientation,
drainage network patterns.	
Other meteorological and climatic conditions that	Ponds, lakes, reservoirs,
sinks, etc. in the basin, which prevent or alter runoff from continuing downstream.	

Source : Modified from USGS, (2005)

Obviously, urban flood disaster management can be planned efficiently through GIS, provided the urban runoff datasets need to be precise, accurate and actual positioned (Firchau et al., 2005). Natural disasters (i.e. flash floods, earthquake, Tsunami) pose a threat to population, human assets and environment. Moreover, urban areas are particularly vulnerable due to the interaction between people, buildings and transportations. Urban flood management initiatives intent to include general public within the decision-making process through consultations, but remains a difficult task because of dynamic complexities of land surface. Identifying present or historic patterns of urban runoff process may less appropriate due to changes in driving forces and climate influences.

Current GIS commercial software is used for handling aspects of 2D and 2.5D of TIN and raster surfaces with single z values on each point data. Advanced GIS software could represent well with 3D objects on surfaces, but to access true volumetric analysis specialist domain-specific packages are required (Drummond et al., 2007). Existing GIS products are in a very static map-based analysis and successfully implemented for managing natural and physical resources as assets. However, urban runoff process is fuzzy, uncertain and dynamic. Successful of simulating GIS based urban runoff process may require multi-dimensional space-time modelling. There are some encouraging signs of ArcGIS software to support some dynamic simulation capabilities through scripting (Drummond et al., 2007). Volumetric soft geo-objects for GIS based urban runoff modelling describe the visualization techniques for simulating urban runoff process dynamically within Pinang River basin.

2.1 Dynamic GIS based Urban Runoff Visualization

The land use surface is a dynamic zone, representing at any time a net balance between changing processes and landforms, with complex scale-dependent interactions. Current policy initiatives in Malaysia, such as Urban Stormwater Management (USM) recognize this dynamism and are encouraging longer planning horizons as well as to improve urban stormwater runoff process. Dynamic representation of geographic features and time in GIS had been included to provide prediction, changes and future behaviour since 1980 and early 90s. Several researchers proposed event-based models (Worboys, 2005) which move from geographic feature identification and location characterization to an explicit focus on changes. Appropriate temporal data streams from monitoring and sensor networks provide tremendous scientific values but are not fully exploitable due to difficulties in integrating across the heterogeneous spatial and temporal sampling regimes and assimilating across a large multi-variant space. GIS have been useful tools for investigation of spatial patterns but have suffered from a lack of abilities to explore the dynamic aspects of urban runoff phenomena. The Kinematic Wave routing method provides the foundation of dynamic direct runoff and open channel flow process. Such routing method requires new visualization techniques to fully address the spatial detail of water shape movement and changes.

Furthermore, the method allows interpretation of routing and channelizing uncertainties through the use of different urban flood management strategies in combination with climate change patterns. Combination of visualization techniques and simulation model is provided by a GIS, which allows querying of the model data, integration with other datasets using a common format and transfer between the modules used for visualization. By developing urban runoff simulation, specific analysis can potentially provide a replicable, rational and transparent method to explore the complex processes of the direct runoff and open channel flow process within a structured framework. Therefore, modelling simulation and visualization of urban runoff process involve simplification of a complex environment in order to improve understanding in a systematic manner. However, some discrepancy or deficiency is inevitable due to the resulted information could not exact the replication of real world.

2.2 Georeferencing for Dynamic Urban Runoff Visualization

Implementing GIS based urban runoff application need careful understandings in terms of selecting appropriate georeferencing systems while entering spatial data (Snyder, 1983; Galati, 2006). In planning series of map of a limited area, one of the first decisions to be made is choice of a map projection (Loxton, 1980). Galati (2006) stated the main component of any GIS usage is the adaption of georeferencing systems to retrieve the actual positions of each features on the real world. It is about how coordinates tie the real world into its projected electronic image in the computer. Information regarding georeferencing and its transformation are the main key points that civil engineers, hydrologists and town planners lack while using GIS approach (Garbrecht et al., 2001). Loxton (1980) stated the represented spatial features with more than 10 km^2 on projected map are distorted. Cartographers have long complained about the poor quality of the output from GIS, which generally today is not due to limitation of the GIS itself, but to lack of understanding cartographic principles by users (Forrest, 2003).

There are two types of ellipsoid used as reference for georeferencing purposes in Peninsular Malaysia; the Modified Everest ellipsoid for existing Malayan Revised Triangulation (MRT) system and Geodetic Reference System 1980 (GRS80) ellipsoid for the newly Geocentric Datum of Malaysia (GDM2000) system (Kadir et al., 2003). Both systems derive the Malaysian Rectified Skew Orthomorphic (MRSO) and Cassini-Soldner coordinate system for mapping in Peninsular Malaysia. The physical characteristics of MRSO coordinate system is to preserves shape of spatial features for mapping topographic layers, while Cassini-Soldner preserves distances between spatial features for mapping cadastral lots based on origin within each state in Malaysia (Wan Abdul Aziz et al., 1998). Considering georeference influences for urban runoff modelling would benefit the actual GIS core concepts and its applications.

In this study, the MRSO map projection is used since it provides an optimum solution in the sense of minimizing distortion of spatial objects whilst remaining conformal for Peninsular Malaysia. As urban runoff process depends significantly with soil properties and land use, improper assignation of the actual position of each spatial object causes distortion on the shape, areas, distance and direction of its original position (Wan Abdul Aziz et al., 1998) of each soil and land use properties. Thus would result influences on terrains, flow direction, direct runoff and open channel flow volume represented by volumetric soft geo-objects. Such cases may derive inaccurate urban runoff simulation results.

2.3 Volumetric Soft Geo-objects for Urban Runoff Modelling

According to Shen et al. (2006), geo-objects can be represented by two approaches; the soft geo-objects which displays streams, channels, fire and mudflows; and rigid geo-objects which displays buildings, roads, bridge and mountain. Simulating soft geo-objects can be performed using particle system, which uses small particles as basic elements representing soft geo-objects; and the metaball approach, which displays different formation when more metaball collide each other. Shen et al. (2006) introduced soft geo-objects concept by performing GIS FE based on pixel imagery and controlled by geoscientific models. The GIS FE concept has position, velocity and direction but neglects volume. Hence, this paper intent to model urban runoff process dealt with calculation of total direct runoff and formation of open channel volume towards existing streams and drainage systems. Inclusion of volumetric soft geo-objects, which controlled by physically based Kinematic Wave routing method under conformal based MRSO map projection would provide proper usage of georeference concept, guidelines of enhanced visualization of the current land use and soil surface, designation of channel capacity and diversion to improve future urban flood impact assessment. Volumetric soft geo-objects are simulated using metaball approach, which visualize continuous surface that is formed when various overland flow sources meet. The contribution from all volumetric soft geo-objects are collected and merged into ordinary rendered settings and represented in shape of volume, flow direction and flow discharge.

2.4 Mathematical Kinematic Wave Routing Method Computation

The Kinematic Wave routing method represents a sub-basin (a) as a wide open channel (b) with inflow to the channel equal to the excess precipitation as illustrated in Figure 1 (Ward and Trimble, 2004; HEC-HMS, 2000). It solves the equations that simulate unsteady shallow water flow in an open channel to compute the watershed runoff hydrograph. The method represents the sub-basin as two plane surfaces over which water runs until it reaches the channel. The water then flows down the channel to the outlet. At a cross section, the system would resemble an open book, with the water running parallel to the text on the page (down the shaded planes) and then into the channel that follows the book's center binding. The kinematic wave routing model represents behaviour of direct runoff on the plane surfaces and flow in the sub-basin channels.

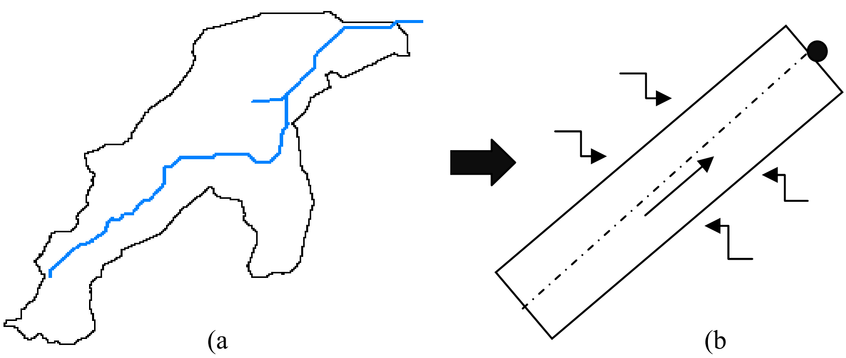

Figure 1: Simple watershed with kinematic-wave model representation.

Direct runoff and open channel flow is computed based on the concept of overland flow mentioned by Chow (1959) and Chaudhry (1993). The centre of overland model computation depends on the equation of open channel flow, which is the momentum equation and the continuity equation.

In one dimension, the momentum equation is :

$$Sf = So - \frac{\partial y}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{1}{g}\frac{\partial V}{\partial t} \quad (1)$$

where Sf = friction slope; So = bottom slope; V = velocity; $\frac{\partial y}{\partial x}$ = pressure gradient; $\frac{V}{g}\frac{\partial V}{\partial x}$ = convective acceleration and $\frac{1}{g}\frac{\partial V}{\partial t}$ = local acceleration. The energy gradient can be estimated using Manning's equation as in (2).

$$Q = \frac{CR^{2/3}Sf^{1/2}}{N}A \quad (2)$$

where Q = flow, R = hydraulic radius, A = cross-sectional area and N = a resistance factor that depends on the cover of the planes. Equation in (2) can be simplified to :

$$Q = \alpha A^{m} \quad (3)$$

where α and m are parameters related to flow geometry and surface roughness. The second critical continuity equation is

$$A\frac{\partial V}{\partial x} + VB\frac{\partial V}{\partial x} + B\frac{\partial y}{\partial t} = q \tag{4}$$

where B = water surface width; q = lateral inflow per unit length of channel; $A\frac{\partial V}{\partial x}$ = prism storage; $VB\frac{\partial V}{\partial x}$ = wedge storage and $B\frac{\partial y}{\partial t}$ = rate of rise. The lateral inflow represents the precipitation excess, computed as the difference in precipitation losses. With simplification appropriate for shallow flow over a plane, the continuity equation reduces to:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \tag{5}$$

By combining equations (3) and (5), Equation in (6) is a kinematic-wave approximation of the equations of motion.

$$\frac{\partial A}{\partial t} + \alpha m A^{(m-1)}\frac{\partial A}{\partial x} = q \tag{6}$$

In this study, the overland flow element is represented as a wide rectangular channel of unit width; $\alpha = 1.486S^{1/2} / N$ and $m = 5/3$. N is referred as runoff roughness factor.

Proper information delivery and prediction capabilities of Kinematic Wave routing method parameters would be vital to integrate GIS techniques in terms of dynamic simulation and visualization to compute amount of direct runoff and open channel flow volume. The capability of GIS techniques to analyze urban runoff as its characteristics mentioned by Bedient and Huber (2002), Ward and Trimble (2004), Brutsaert (2005), Shen et al. (2006) and HEC-HMS (2000) would produce certain features of volumetric soft geo-objects simulation driven by Kinematic Wave routing method to visualize urban runoff areas.

3.0 MODELLING 3D DYNAMIC URBAN RUNOFF VISUALIZATION

3.1 Study Area

The Pinang River basin is located between Latitude from 5° 21’ 32” to 5° 26’ 48” and Longitude from 100° 14’ 26” to 100° 19’ 42”. Pinang River is the main river system in the Penang Island with the catchment size approximated 52 km^2, as illustrated in Figure 2. Pinang River basin has been selected to determine direct runoff and open channel flow volume process due to continuity of development that had affected the physical characteristics of land use and soils; degrading and increase the water quality and water quantity respectively of the entire basin. Moreover, flash flood and water pollution is the main problems occurred in highly urbanized area such as Georgetown, Jelutong and Air Hitam.

In this study, the procedure for linking GIS and flow routing parameter components results involves the following steps: (1) acquisition and development of GIS map data layers of Pinang River basin in MRSO projection; (2) pre-processing of Kinematic Wave routing model input data, parameter and computation results within HEC-HMS model and (3) post-processing of all flow routing components results to the 3D simulation for volumetric soft geo-objects displaying direct runoff, open channel flow volume and flooded areas. The Kinematic Wave routing parameters are linked into PC-based GIS package called ArcGIS and commercial 3D modelling softwares to store and display dynamic GIS based urban runoff visualized from volumetric soft geo-objects simulation results.

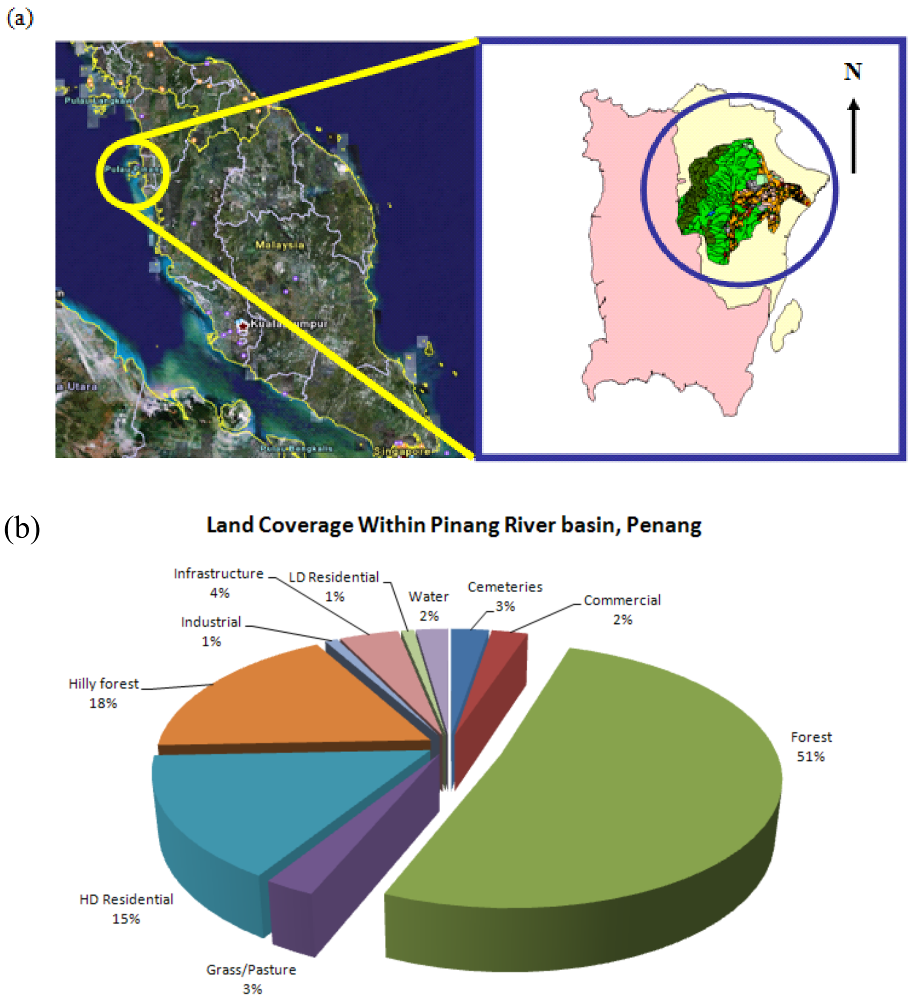

Figure 2: Location of Pinang River basin (a) and its land use for 2007 (b)

Digital topography map with 1 : 25 000 scale is used to extract layers of Buildings, Contours, DEMs, Road network and River networks. The land use and soil map is used to evaluate the soil condition at the place of interests. In this study, the rainfall data of 14th September 2007 with duration of 10 minutes interval is used to determine direct runoff and open channel flow generated from urban areas. Topographic information such as slope, aspect, flow length, contributing area, drainage divides and channel network can be reliably extracted from DEM with 5 meter grid resolution.

3.2 Determining Potential Direct Runoff, Open Channel Flow and Flooded Areas

Analysis is performed into two phases as illustrated in Figure 3. The first phase dealt with creating basin and meteorological models to be incorporated in HEC-HMS model by using the Geospatial Hydrologic Modelling Extension (HEC-GeoHMS) within ESRI's ArcView GIS software. Thus are obtained through hydrologic modelling by filling sinks, determining flow direction, flow accumulation, watershed delineation and streamflow network extraction using DEM of 5 meter resolution. The next phase comprises simulation of precipitation-runoff processes in HEC-HMS model for identifying urban drainage, flow forecasting and flood damage reduction based on the resulted hydrograph.

To estimate direct runoff using kinematic wave routing method, each sub-basin is described as a set of elements that include overland flow planes, collector and sub-collector channels; and the main channel. The overland flow planes consists information regarding its typical length, representative slope, overland flow roughness coefficient, area represented by plane and loss model parameters. The collector and sub-collector channels required inputs of area drained by channel, representative channel length, channel shape, dimensions of channel cross section, channel slope and representative of Manning's roughness coefficient. The main channel comprises information of channel length, channel shape, dimensions of cross section, channel slope, representative Manning's roughness coefficient and identification of inflow hydrograph. These information are obtained through HEC-GeoHMS Geospatial Hydrologic Modelling.

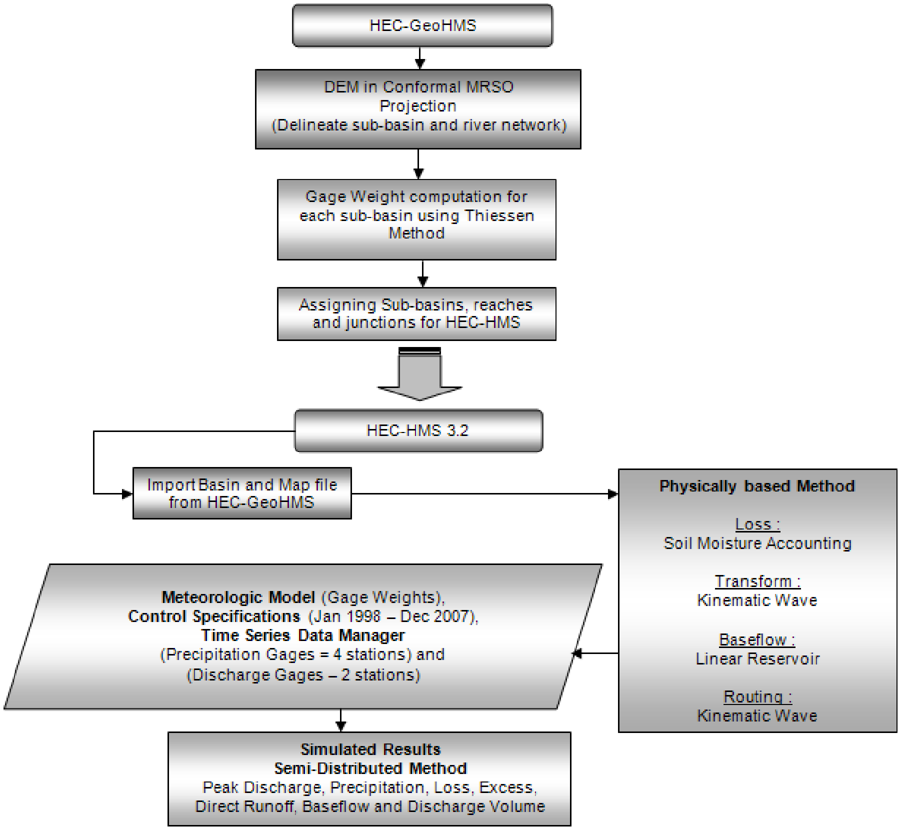

Figure 3: Schematic diagrams for determining direct runoff, open channel volume and flooded area

3.3 Computation and 3D Dynamic Visualization of Direct Runoff, Open Channel Flow and Flooded Areas

Simulations of volumetric soft geo-objects are performed based on simulated direct runoff and open channel flow by referring to equation (6). Total of direct runoff and open channel flow within Pinang River basin areas are computed by subtracting rainfall volume with the infiltrated rainfall volume using the rainfall data recorded on 14th of September, 2007 with duration of 10 minutes interval. Figure 4 shows a flow diagram determining 3D dynamic volumetric soft geo-objects for urban runoff simulation represented by a fine cylinder.

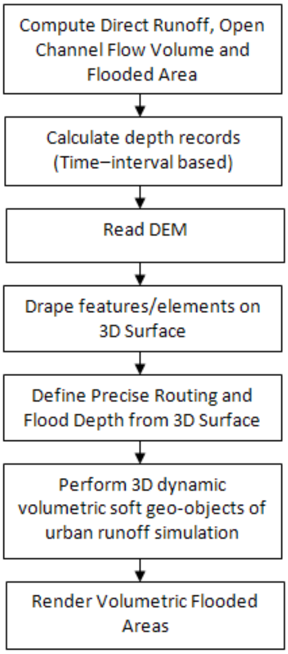

Figure 4: Flow diagrams for rendering 3D dynamic urban runoff volumetric soft geo-objects simulation

4.0 POTENTIAL URBAN RUNOFF AREAS

The experiment on determining urban runoff area is illustrated in Figure 5. The urban runoff area (shaded with black) is based on 14th of September 2007 precipitation data.

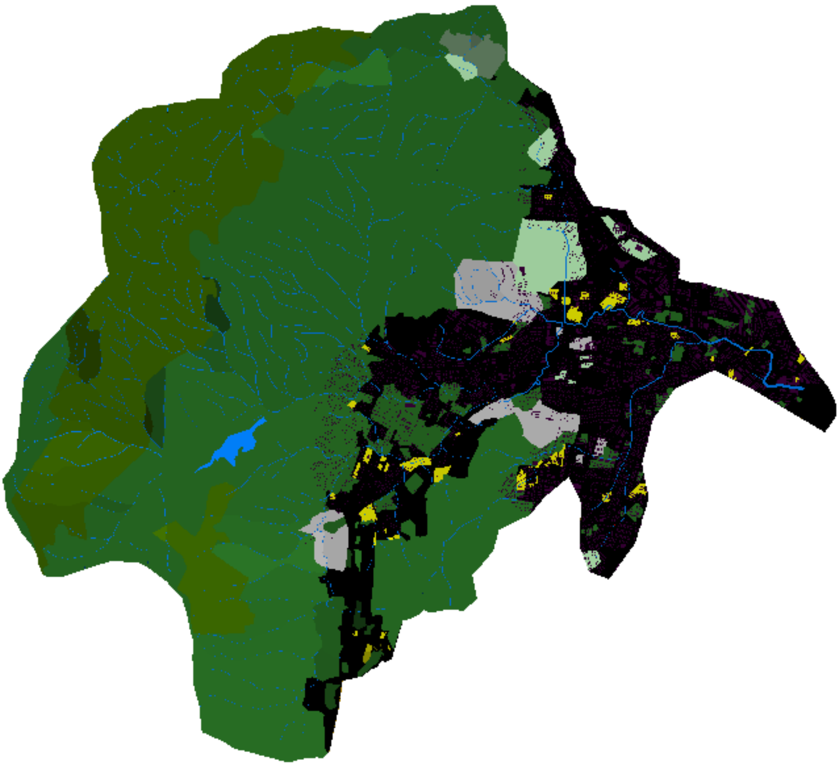

Figure 5: Potential urban runoff area consists of direct runoff and open channel flow within. Pinang River basin based on 14th September 2007 rainfall data

Approximately 11.59 km^2 of urban runoff areas are identified. Most of the urban runoff coverage lies in areas of Georgetown, Paya Terubong, Air Hitam, Air Terjun River, Kebun Bunga, Green Lane and partly in Gelugur and Jelutong. The location of urban runoff area lies on the sub humid to humid regions, which is the major controls on the various urban runoff processes based on climate data, land use, soil topography and rainfall characteristics as stated by (Tarboton, 2003; Ward and Trimble, 2004).

5.0 3D DYNAMIC SIMULATION OF DIRECT RUNOFF, OPEN CHANNEL FLOW VOLUME AND FLOODED AREAS

Approximately 5,114,100 m^3 of precipitation volume were recorded within Pinang River basin. The estimated volume of rainfall infiltrated into soil is 1,197,000 m^3. Total of direct runoff and open channel flow volume simulated by volumetric soft geo-objects are estimated at 968,400 m^3 and 1,718,000 m^3 respectively. The results obtained are illustrated in Figure 6 and 7. Full summary of analysed direct runoff and open channel flow volume based on Kinematic Wave Routing method for each sub-basin in Pinang River basin is illustrated in Table 2.

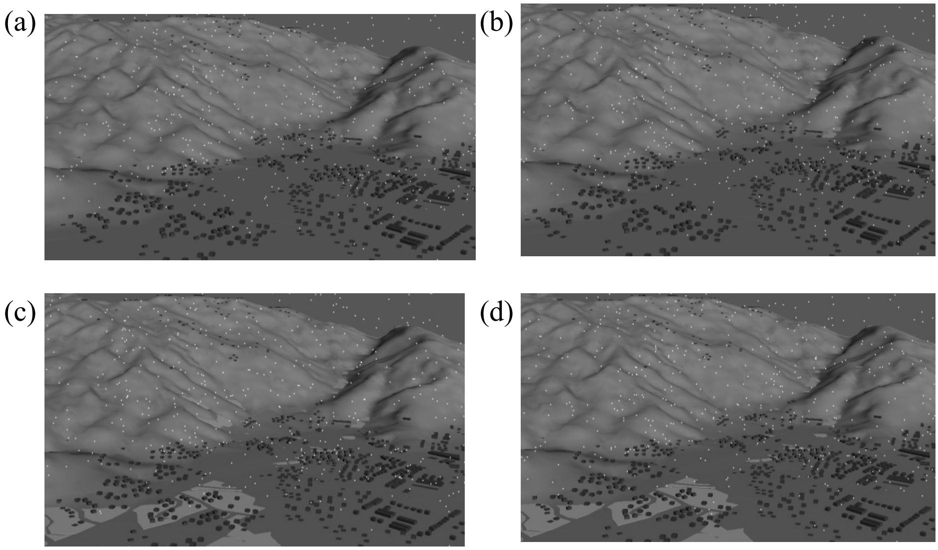

Figure 6: 3D dynamic volumetric soft geo-objects for direct runoff and open channel flow simulation visualized at (a) 1 hour, (b) 6 hours, (c) 12 hours and (d) 18 hours precipitation time within Pinang River basin, Penang.

Figure 6 shows the visualization of dynamic volumetric soft geo-objects simulation towards determining direct runoff and open channel flow volume driven by physically based Kinematic Wave Routing method under MRSO projection. Continuous input from precipitation increases the height and coverage of direct runoff and open channel flow volume, mainly on downslope and flat areas. The simulated volume is proportional to the Kinematic Wave Routing method and physical characteristics of conformal MRSO projection, which results differential on the area, shape, flow path, slope and deformation of volumetric soft geo-objects. The outflow from all volumetric soft geo-objects are collected and merged into ordinary rendered settings and represents the direct runoff volume, open channel flow volume and direction, flow discharge and flooded areas.

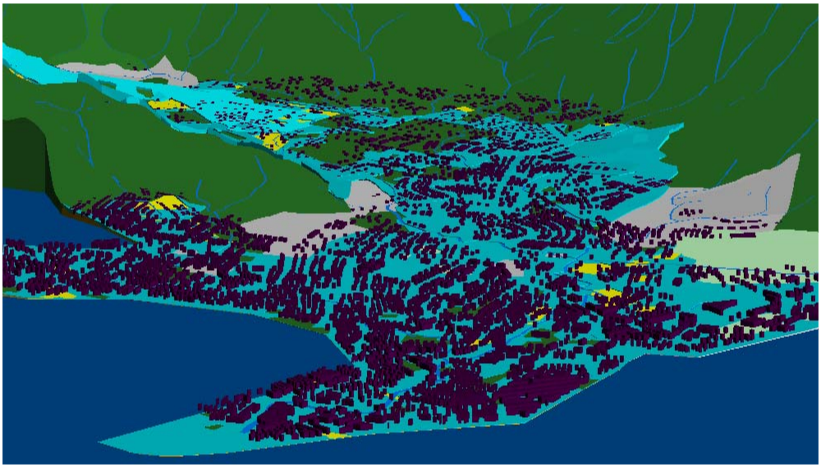

Figure 7: Flooded Areas based on Kinematic Wave Routing method within urban area

Figure 7 illustrates the flooded area which lies in sub-basins of Air Hitam 3, Air Hitam 4, Air Hitam 5, Air Putih, Jelutong and Sungai Pinang. Volumetric soft geo-objects visualize flooded areas based on impervious area coverage, direct runoff and channel flow that spill out from the existing drainage and streamflow pattern. Constructions of shop lots, apartments and widened road network increases the land cover with impervious areas, which is the main factor contributing to flood disaster. Thus indicate the existing rivers and drainage systems lack of capability to shift runoff volumes from highly urbanized areas. The simulated results are then compared and validated with observed discharge volume as shown in Figure 8.

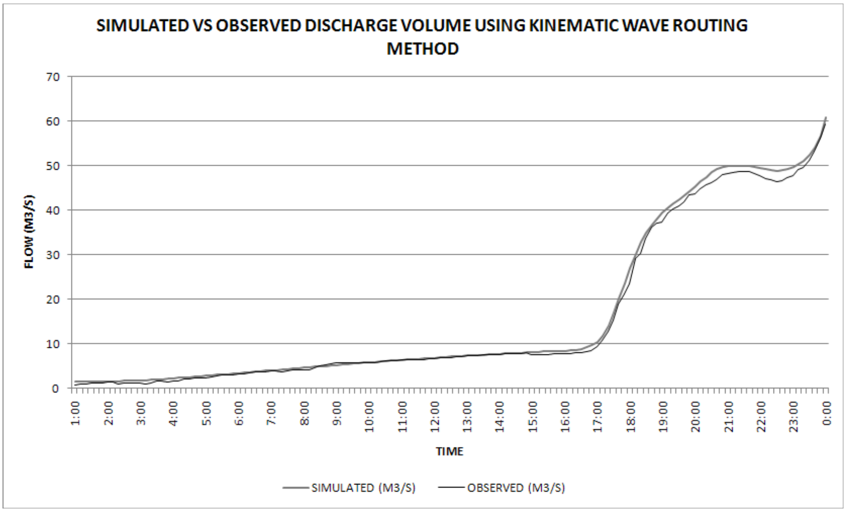

Figure 8: Comparison of Simulated Discharge Volume with Observed Discharge Volume using Kinematic Wave Routing Method

The comparison of simulated discharge volume with the observed 10 minutes interval discharge volume gave an R^2 of 0.91 and a Nash–Sutcliffe coefficient of 0.87. The simulated results indicate that the 3D dynamic urban flood modelling using volumetric soft geo-objects indeed provides a valuable step for end-users envisioning complex information of flow routing, floodplain areas, affected buildings, land properties and appropriate flood disaster management.

Table 2: Simulated urban runoff modelling results using Kinematic Wave Routing method.

Calculations / Sub-basin	Peak Discharge (M^3/s)	Precipitation Volume (1000 M^3)	Loss Volume (1000 M^3)	Direct Runoff Volume (1000 M^3)	Open Channel / Discharge Volume (1000 M^3)
Air Hitam 1	9.9	640.6	241.5	100.2	150.0
Air Hitam 2	6.9	271.8	83.8	83.4	114.2
Air Hitam 3	5.5	228.4	29.1	85.3	116.3
Air Hitam 4	12.9	516.9	71.8	128.6	200.1
Air Hitam 5	1.5	182.7	18.2	12.3	31.1
Air Putih	4.0	266.4	26.5	42.4	67.4
Air Terjun 1	4.2	214.0	71.5	61.2	89.0
Air Terjun 2	7.2	309.9	90.1	81.3	115.8
Air Terjun 3	7.7	243.5	31.0	125.3	158.0
Air Terjun 4	9.1	360.8	50.1	99.9	159.0
Dondang 1	5.8	877.6	306.7	40.0	174.4
Dondang 2	4.6	184.6	40.9	71.3	117.9
Jelutong	5.1	549.3	101.2	34.4	151.6
Sungai Pinang	1.4	267.6	34.6	2.8	73.2
TOTAL	**-**	**5114.1**	**1197.0**	**968.4**	**1718.0**

Alternation of basin shape, size and distance due to conformal based MRSO map projection would greatly affect the physical shape, distance, area and direction of soft geo-objects and calculations of total infiltrated precipitation onto ground surface, change of physical soil parameters (soil porosity, conductivity, path of subsurface flow, return flow) with different soil types; and amount of direct runoff generated in the study area. The modelling performed however does not account the water balance equation such as evapotranspiration losses, percolation, return flow, groundwater flow, shallow and subsurface flow. Physical characteristics of MRSO projection causes different values of infiltrated stormwater, overland flow volume and flow direction by volumetric soft geo-objects.

6.0 CONCLUDING REMARKS

This paper discusses the definition, mathematical expression and representation of 3D dynamic simulation of GIS based urban runoff modelling using volumetric soft geo-objects approach by estimating the potential locations of direct runoff, open channel flow volume and flooded areas, which is driven by Kinematic Wave routing method. The spatial layers of channel networks, streamflow, land use, soils and precipitation are all important sub-basin parameters that results significant changes of infiltrated stormwater, direct runoff and open channel flow volume at various location within urbanized areas. Although the method involves some identifiable sources of uncertainty, the results nevertheless provide an initial indication of the volumetric soft geo-objects envisioning urban runoff process.

3D dynamic simulation of urban runoff within GIS delivers better understanding of observed phenomena as well as the representation and management of all steps of the process. Performing volumetric soft geo-objects simulation offers the possibility of visualizing affected areas, minimizing complexities of buildings and road network, reducing economical and social losses realistically. A thorough understanding need to be addressed in terms of physical geographic in flow routing process, determining the GIS properties such as map projections, scale and coordinate systems before any urban runoff modelling and data processing can be performed. A map can be drawn at any scale, but it is unclear to what extent existing hydrologic models can be applied at different map projections and scales in the mean of using GIS.

Further investigation is needed for possible new criteria for visualizing volumetric soft geo-objects for multi layer adjustment by examining soil type and its properties, evapotranspiration, shallow flow, channel/macropores roughness and slope condition for numerous locations. For practical purposes, better algorithms need to be incorporated with the suitable physical characteristics of map projections for an actual use of GIS application over a region. The results obtained would benefits the relevant agencies such as Department of Irrigation and Drainage (DID), Department of Environmental (DOE), Department of Town Planning (DOTP) and Department of Minerals and Geosciences (DMG) to determine urban flood risk zones, areas of prompt to produce large direct runoff volumes, careful monitoring of NPS runoff pollutant loading, proper development plan and constructions, monitoring water quantity and quality of river networks for analysing long-term flood disaster management towards urbanized areas.

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