3D GIS urban runoff mechanism: A new perspective using volumetric soft geo-object

Izham Mohamad Yusoff[1], Main Rindam[1]

[1]Geographic Section, School of Distance Education, Universiti Sains Malaysia, 11800 Minden, Penang.

Correspondence: Izham Mohamad Yusoff (email: izham@usm.my)

Abstract

With the enhancement of the current GIS data model into a 3D dynamic simulation form, the importance of urban runoff mechanism could be visualized significantly. Such enhancement provides a valuable step for urban runoff modelers by visualizing complex streamflow routing, overland flow, channel flow routing and runoff volume coverage information. Inclusion of Volumetric Soft Geo-objects (VSG) offers substantial effort towards representing 3D dynamic simulation of overland flow volume that hits the urban flood-plain areas, estimating channel flow capacity, routing and diversions to reduce urban flood disaster. The VSG are driven by a Kinematic Wave Routing and Green-Ampt method for simulating open channel flow and overland flow volume respectively using HEC-HMS hydrologic model. Basin model, sub-basin, reach and junction elements are extracted from Digital Elevation Model (DEM) with 5 meter resolution using HEC-GeoHMS programme within ArcView GIS software and HEC-HMS model. The comparison of simulated discharge volume using VSGs with observed 10 minutes interval discharge volume gave a reading of $R^2 = 0.88$ and a Nash-Sutcliffe coefficient of 0.82. Such 3D VSG visualization is useful in predicting potential location of flood disaster, landslide high risk spots, and informative. It is also valued as a realistic and sustainable hydrologic impact management instrument by contemporary GIS practitioners including hydrologists, environmentalists, town planners and other relevant scientists.

Keywords: 3D GIS, Green-Ampt method, kinematic wave routing, simulation, visualization, VSG

Introduction

Urban surface runoff is a complex process which includes surface infiltration, depression storage, overland flow, and rain-dependent inflow and infiltration. Various urban runoff models and methods have been developed and integrated with GIS to simulate the loss, transform and baseflow rate within basin 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 (Ward and Trimble, 2004; Olivera *et al*., 2006; Isenbies *et al*., 2007; Zhao et al., 2009). 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, roads and other hardscape objects in cities that needs to enhanced with visualization techniques. All these processes take place in the sub-catchments. The shapes, areas, and outlets of the sub-catchments will influence the accuracy of the predicted concentration times of urban surface runoff. Zhao *et al.* (2009) emphasized the accurate definition of real sub-catchments and the flow paths among them are of great importance in urban runoff modeling. Since the volume, rate, and velocity of runoff

from a particular rain event will depend upon the characteristics of the surfaces on which the rain falls, changes to these surfaces can significantly change the resultant overland flow volume, runoff rate and velocity (Wang *et al*., 2007). The process of urban stormwater runoff dispersion results from the dynamic change of spatial dimension, temporal dimension and attributes.

The emerging issues regarding dynamism has encouraged 3D GIS practitioners to represent changes to 3D data models, indexing 3D dynamic spatial layers and analyzing the influence of event based parameters (rainfall-runoff process as for this study) such as rainfall input, soil infiltration capacity, groundwater flow and increase in urban stormwater discharge within streamflow. Current GISs are not capable in the context of simulating 3D dynamic phenomena of urban runoff process due to the fact that insufficient conceptualizations of space and time compiled in existing GISs are not compatible with those in simulation models. Pouliot *et al*. (2003) and Stoter and Zlatanova (2003) stated that current GIS capabilities are not well adapted to represent and manage either geometry or topology of 3D spatial data. 3D continuous geo-information is usually modeled with raster structures, either directly with 3D grids (voxels) or with hierarchical grids such as octrees (Jones, 1989). This is due to the fact that raster structures are simple structures naturally stored and manipulated in a computer (with arrays of numbers) and hence a certain number of modeling tools are available. Lin *et al*. (2008) applied the Virtual Geographic Environment (VGE) concept based on GIS and Virtual Reality technologies for dynamic modelling atmospheric pollution dispersion phenomena in city clusters by maintaining an Octree to construct a view dependent representation of regular volume data, which resides under hybrid geometry types. Beni *et al*., (2007) proposed 3D dynamic data structure based on 3D Delaunay tetrahedralization that deals with objects and field representation of volume and space at the same time, and provides an on-the-fly interactive topological mesh for numerical simulation. These research approaches can be classified under rigid geo-objects, but soft geo-objects (i.e. streams, mudflows) are less represented. Shen *et al*. (2006) represented 3D simulation of soft geo-objects representing overland flow based on GIS flow element (FE) concept. However, the aspect of volumetric dynamic flow is not visualized. VSG method in this study renders to visualize urban runoff mechanism and providing GIS practitioners, hydrologists and geologist's inclusion accessing hydrological-soil impacts.

This paper enhances details of VSG modelling, emphasizing on urban runoff dynamism, simulation process, verification of simulated VSG results and 3D visualization techniques for simulating urban runoff process using soft geo-objects approach. Simulation is performed within basin boundaries driven by physically based Kinematic Wave Routing method and Green-Ampt infiltration equation for computing open channel flow and overland flow respectively using metaball approach. The concepts of 3D dynamic urban runoff simulation and VSG are explained in section 2. The experiment of determining VSG simulation for open channel flow and overland flow is highlighted in Section 3 and Section 4 respectively. Urban flood areas and 3D dynamic urban runoff simulation results are explained in Section 5, while conclusion is stated in Section 6.

3D VSG for urban runoff mechanism

Existing approaches represent 3D GIS modelling using 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). Modelling and simulation of physical phenomenon (e.g. flood) have been frequently applied to the analysis and understanding of phenomena, the testing of hypotheses and theories, the prediction of spatiotemporal systems behaviour under various conditions and scenarios (existing and simulated, often performed to support decision making), and to new discoveries of geospatial phenomena, enabled by the unique capabilities of computer experiments (Beni *et al*., 2007). In the past, simulation tools have generally been developed outside of GIS. However, these tools suffer from (1) insufficient spatial analytical component, (2) low performance of the spatial data's visualization

capability, and (3) non-conveniences in spatial data integration such as digital maps, satellite images and aerial photos (Bivand and Lucas, 1997).

An algorithm called the Flood Region Spreading Algorithm (FRSA) developed by Wang *et al*. (2007) explores the pseudo-intensity profile for potential flood spreading. The flood region search and merge process is conducted by a weighted cell region adjacency graph. The similarity measure associated with two neighbouring cells is found by firstly calculating the mean intensity value of all vertices associated with each cell, and then for the boundary between the two. The down cell will be flooded if and only if the flooded cells (up cell) mean value is greater than the down cell's mean value, and greater than the minimum value of the common boundary. A connected cell is identified as part of a flooded cell of the flood region if its elevation level is under a dam threshold of a neighbouring flooded cell. The process will be conducted in all eight neighbouring directions around the assessed cell. Flooded cells will be merged to become a large cell, and so on. The configured flood region consists of all flooded cells connected together and will then be used as a flooding field.

Beni *et al*. (2007) proposed a data structure based on 3D Delaunay tetrahedralization that can deal with discrete objects and continuous phenomena (field), which has the ability to represent both discrete objects and continuous phenomena, and to deal with static and dynamic 3D objects. Moreover, it can generate an optimal mesh for numerical simulation because it is an adaptive method; i.e. the size of the mesh elements depends on the distribution of the data points. In this mesh, after any change (event), local updates of topology are possible. Using this mesh, a fluid flow such as a flood and or a forest fire can be simulated within GIS if the Free-Lagrange method is used as the numerical model solution.

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. In this paper, adaptation of soft geo-objects data structure by including the aspect of volumetric 3D dynamic urban runoff and open channel flow provide the means to visualize the runoff volume spreading realistically. Inclusion of VSG for urban runoff visualization in the research can be related with such concept stated by Gold *et al.* (2004). This includes the runoff coverage expansion within saturated zone (dz/dt), volumetric runoff height change over the topographic landscape (dz/dx) and VSG boundary migration over time (dx/dt). Such changes may visualize the continuity as in soft topographic landscape or increased rainfall intensity, or discrete as in a riparian area or lakes.

Hence, the spreading (FRSA concept) and expansion (boundary migration) of volumetric urban runoff, their influences with buildings, roads and other hardscape objects are visualized through VSG, which is driven by the infiltrability of soil surface computed using Kinematic Wave Routing and Green-Ampt method. It enables dynamism of runoff direction by merging soft geo-objects of overland flow and open channel flow to visualize urban runoff process. Moreover, 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 3D 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 overland flow and open channel flow process within a structured framework. Therefore, modelling VSG simulation and visualization of urban runoff process involve simplification of a complex environment in order to improve understanding in a systematic manner.

Mathematical kinematic wave routing and green-ampt computation

Urban runoff process initially couples simulation with entering the changes by algorithms on a simulation model (e.g. rate of infiltration under different land use / soil type), followed by computer and modelling automation of the procedure (the visualization), or full simulation by defining mathematical functions that attempt to describe the behaviour of the process. In this study, 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; Feldman, 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.
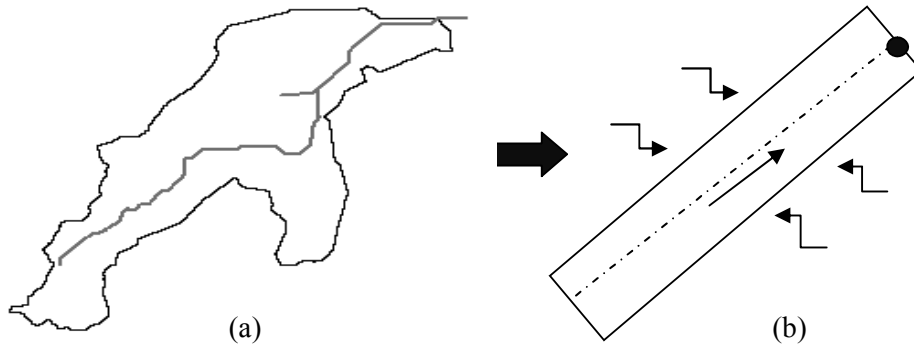

(a)   (b)

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 (2008). 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:

$$Sf = So - \frac{\partial y}{\partial x} - \frac{v}{g}\frac{\partial v}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial t} \tag{1}$$

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 (2).

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

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

$$Q = \alpha A^m \tag{3}$$

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 = prism storage and VB = 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 (4), Equation (6) is a kinematic-wave approximation of the equations of motion.

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

The Green-Ampt infiltration model is a physical model which relates the rate of infiltration to measurable soil properties such as the porosity, hydraulic conductivity and the moisture content of a particular soil based on simplified solutions to the Richards equation. The equation for infiltration under constant rainfall based on Darcy's law and assumes a capillary tube analogy for flow in a porous soil as follows:

$$f = K(H_o + S_w + L)/L \tag{7}$$

where K is the hydraulic conductivity of the transmission zone, H_o is the depth of flow ponded at the surface, S_w is the effective suction at the wetting front, and L is the depth from the surface to the wetting front. The method assumes piston flow (water moving down as a front with no mixing) and a distinct wetting front between the infiltration zone and soil at the initial water content. Smemoe (1999) stated basic Green and Ampt equation for calculating soil infiltration rate as follows :

$$f = K_s (1 + [\Psi\theta / F]) \tag{8}$$

where Ks is the saturated hydraulic conductivity, Ψ is average capillary suction in the wetted zone, θ is soil moisture deficit (dimensionless), equal to the effective soil porosity times the difference in final and initial volumetric soil saturations and F = depth of rainfall that has infiltrated into the soil since the beginning of rainfall.

Specific prediction capabilities of Kinematic Wave routing and Green-Ampt method would be vital to integrate GIS in terms of dynamic simulation and visualization to compute amount of open channel flow volume. The capability of GIS techniques to analyze infiltration and open channel flow as its characteristics mentioned by Bedient and Huber (2002), Ward and Trimble (2004), Brutsaert (2005) and Shen *et al*. (2006) are realized by producing VSG features driven by Kinematic Wave routing method to visualize urban runoff areas.

3D VSG urban runoff experiment

Description of the study area

The Pinang River basin lies between the Latitude of 5° 21' 32" to 5° 26' 48" North and Longitude from 100° 14' 26" to 100° 19' 42" East. Pinang River is the main river system in the Penang Island with the basin size approximated 51 km^2 which mainly comprises the urban areas of "George Town", "Air Hitam" and "Paya Terubong" as depicted in Figure 2. The basin consists of six tributaries- Sungai Pinang, Sungai Jelutong, Sungai Air Itam, Sungai Air Terjun, Sungai Dondang and Sungai Air Putih. Penang Island is located at the West Coast of the Peninsular Malaysia and experiences with convective storms generated by the inter monsoon seasons (Sumatra wind system) in the months of April/May and October/November. The South-West Monsoon (normally from May to September) produces less rain in the West Coast of the Peninsular whilst the North-East Monsoon, from November to March, carries longer and heavier rains to the East Coast of the Peninsular, North Sabah, and inland Sarawak (USMM, 2000). Penang Island is characterized by the equatorial climate, which is warm and humid throughout the year and has an average annual rainfall of more than 2477 mm; with the lowest monthly average around 60 mm for February and the highest around 210 mm for August and October. The Pinang river basin is highly developed area comprising more than 40 percent of urban areas in Penang Island. Pinang River basin has been selected to determine saturated and overland flow volume process due to continuity of development that had affected the physical characteristics of land use and soils; degrading water quality and increases water quantity 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".
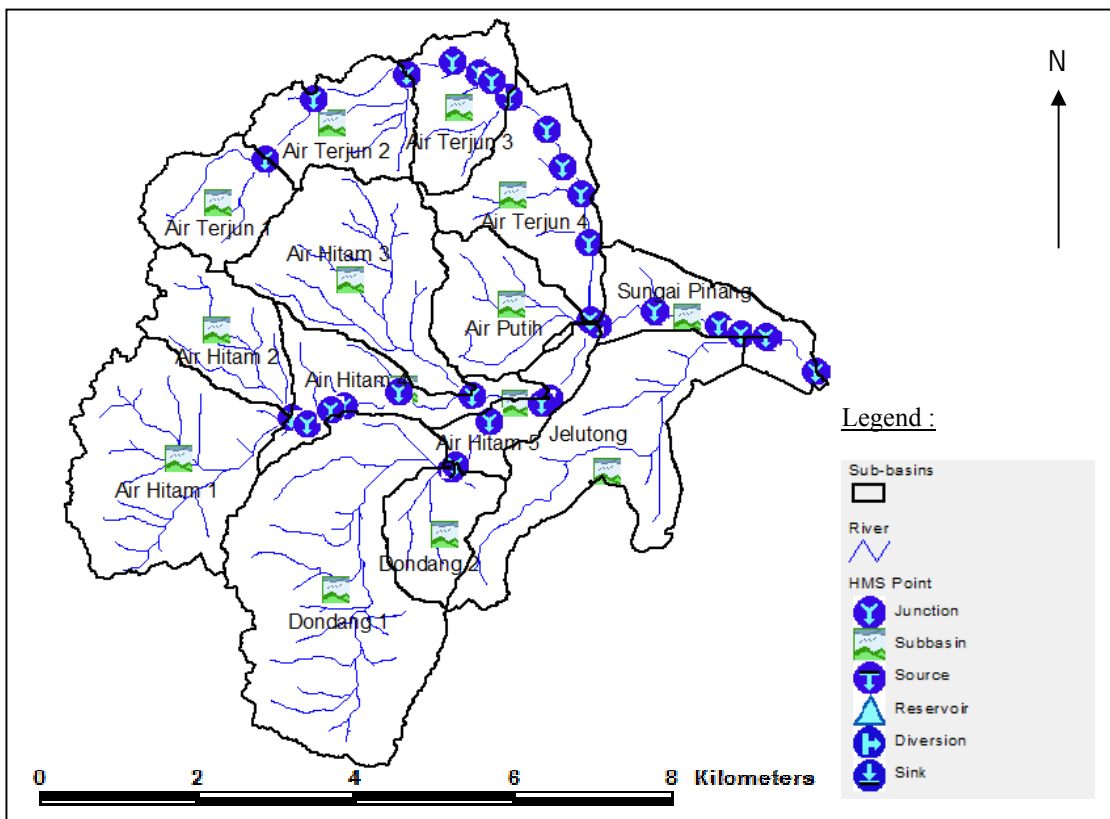

Figure 2. *Location of six tributaries of Sungai Pinang basin; Sungai Pinang, Sungai Jelutong, Sungai Air Itam, Sungai Air Terjun, Sungai Dondang and Sungai Air Putih.*

In this study, the procedure for linking GIS with flow routing parameter and 3D dynamic simulation of urban runoff process involves the following steps: (1) acquisition and development of GIS map data layers of Pinang River basin in Cassini-Soldner map projection; (2) pre-processing of Kinematic Wave Routing and Green-Ampt model input data; parameter and computation results within HEC-GeoHMS and HEC-HMS model and (3) post-processing of all dynamic flow volume components resulted from 3D VSG simulation for displaying overland flow, open channel flow volume and urban flood areas. The Green-Ampt and Kinematic Wave Routing parameters are linked into PC-based GIS package called ArcView GIS and commercial 3D modelling software to store and display dynamic VSGs for urban runoff modelling.

Integrating VSG with green-ampt and kinematic wave routing method

When simulating a flow (i.e. overland flow, streamflow, channel flow), to represent the continuum from the discrete samples, it is necessary to make a mesh. In fact, a mesh is a partition of the space by a set of elements such that the union of all elements completely fills the continuum. A set of rules should also be defined to assign some attributes based on the physical hydrologic equations and terrain properties to each node (x, y, z) in the mesh. VSG presents the continuous spreading of urban runoff with time, the soft geo-objects connection and influences with buildings, roads and other 3D hardscape objects. The distribution of VSG is rendered as a volume and reflects the dynamic by merging volumes of runoff, changes of

velocity and directions. However, dynamic VSG flow basis are identified by using eight neighbouring pixels (D8) introduced by O'Callaghan and Mark (1988) to determine flow direction and velocity based on slope gradient.
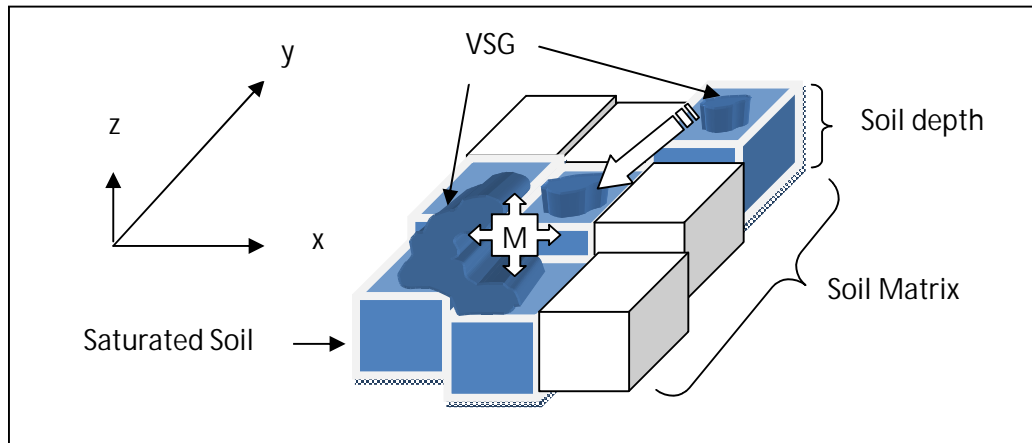

Figure 3. *VSG generated due to saturated soil layer, flows towards low elevation and merges (M)*

Generation of VSG are based on top soil infiltrability. Continuous precipitation input on saturated soil causes the stormwater exceeds the soil infiltrability using equation (7) and (8); and distributes VSGs, which carries values of overland flow (precipitation minus infiltration). Shapes of VSGs are proportional with the topographic surface of basin. The next simulation process consists of open channel flow driven by Kinematic Wave Routing method. VSGs are integrated with the method and shapes according to channel designation as quoted in equation (6). 3D dynamic simulation consists of merging VSGs (depicted in Figure 3) and visualizes overland flow, open channel flow and flow direction on top soils with time. As urban stormwater runoff decreases, VSGs are omitted due to re-infiltration of top soils. Additional textures on VSGs would deliver information such as the high and low infiltrated urban stormwater runoff, velocity of VSGs, overland flow and open channel flow within basin area.

The spread of VSG is visualized via the concept of FRSA worked by Wang *et al*. (2007). The saturated region, search and merge process is performed by a weighted cell region represented by VSGs. The similarity measure of infiltrated stormwater associated with neighbouring cells is identified by calculating the mean intensity value of all vertices associated with each saturated cell underneath VSG extent. The down cells will be covered with VSG if the maximum infiltration rate is exceeded. A connected cell is identified as part of a runoff cell of the surface runoff region. Flooded cells will be merged via metaball approach within 3D Studio Max software. Figure 4.6 illustrates the flow chart of VSG visualization.

Determining potential overland flow, open channel flow and urban runoff areas

Analysis is performed into two phases as illustrated in Figure 4. The first phase dealt with creating basin and meteorological models to be incorporated in HEC-HMS model by using the Geospatial Hydrologic Modelling (HEC-GeoHMS) program within ESRI's ArcView GIS software. Thus are obtained through hydrologic modelling by filling sinks, determining flow direction, flow accumulation, basin 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 and overland flow forecasting based on the resulted hydrograph as depicted in Figure 5.
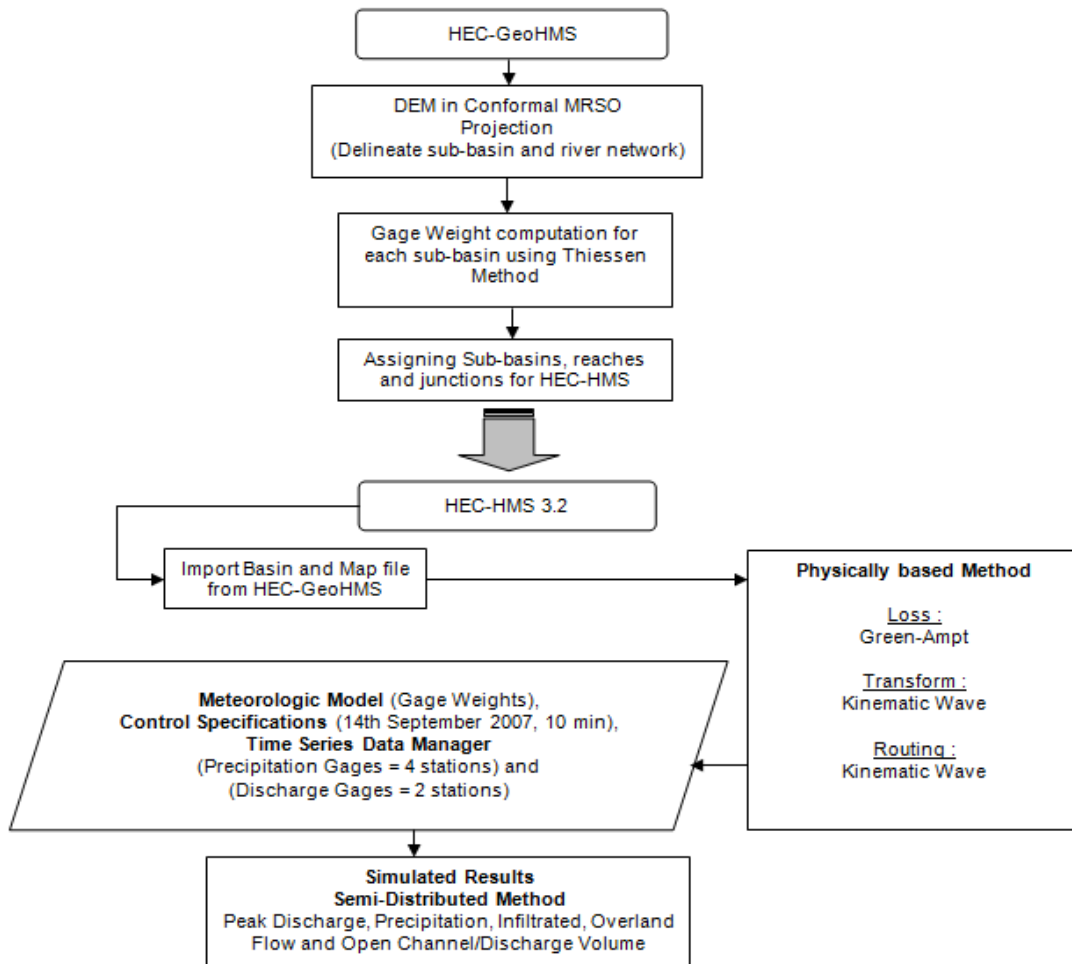
Figure 4. *Schematic diagrams for determining overland flow, open channel volume and flooded area*

To estimate open channel flow 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, and 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.
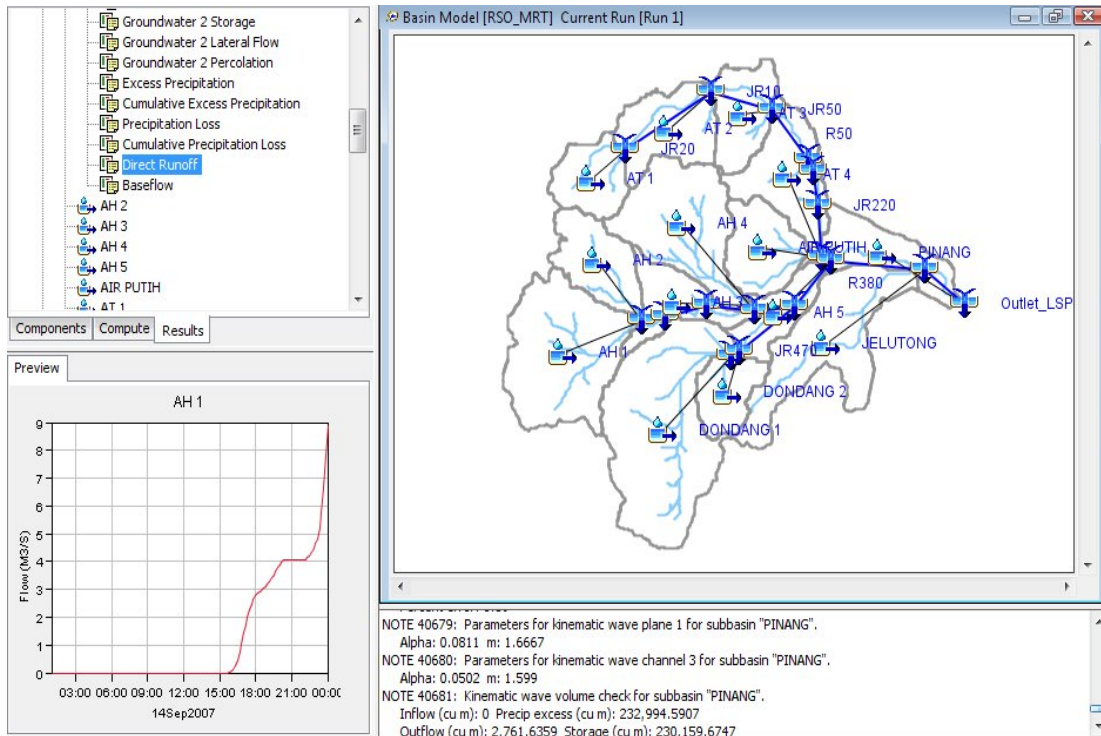
Figure 5. *Delineated sub-basin boundaries, reaches and junctions from HEC-HMS hydrologic model*

Computation and 3D dynamic VSG visualization of overland flow, open channel flow and urban runoff areas

Simulations of VSG are performed based on simulated overland flow based on equation (7) and (8), while open channel flow are simulated referring to equation (6). Total of open channel flow and overland flow within Pinang River basin are computed by subtracting precipitation volume with the infiltrated rainfall volume using the rainfall data recorded on 14th of September, 2007 with duration of 10 minutes interval. Figure 6 shows a flow diagram determining 3D dynamic VSG for urban runoff simulation represented by a fine cylinder.
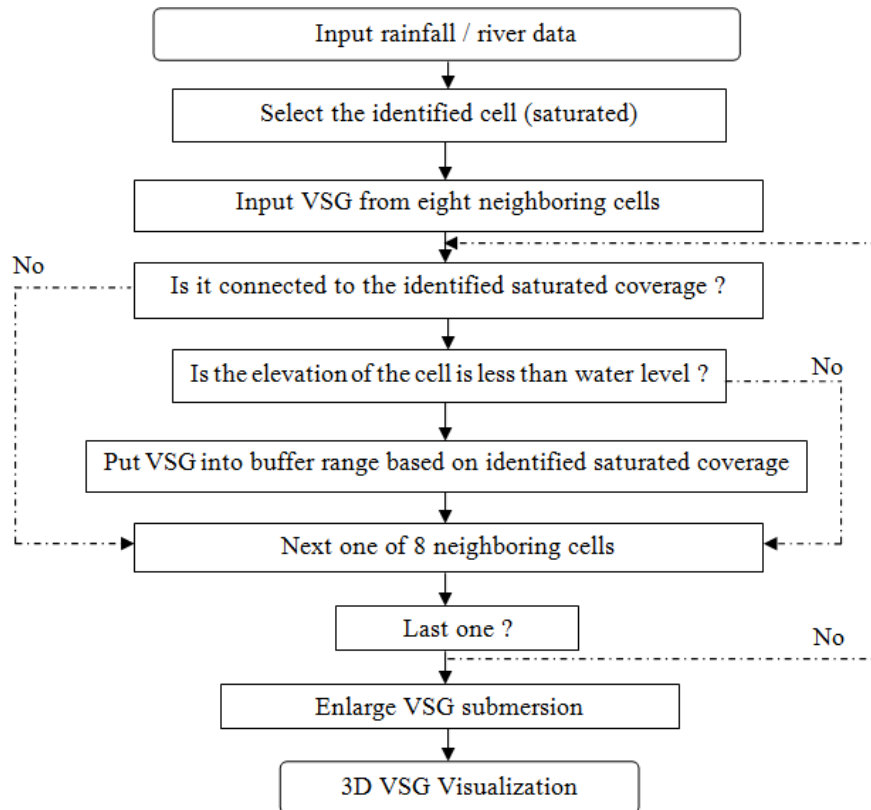
Figure 6. *Flow diagram for rendering 3D dynamic urban runoff VSG simulation*

Results and discussion

Potential urban runoff areas

The experiment on determining potential urban runoff area is illustrated in Figure 7. 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 are the major controls on the various urban runoff processes based on meteorological factors and physical characteristics as stated by USGS (2005).
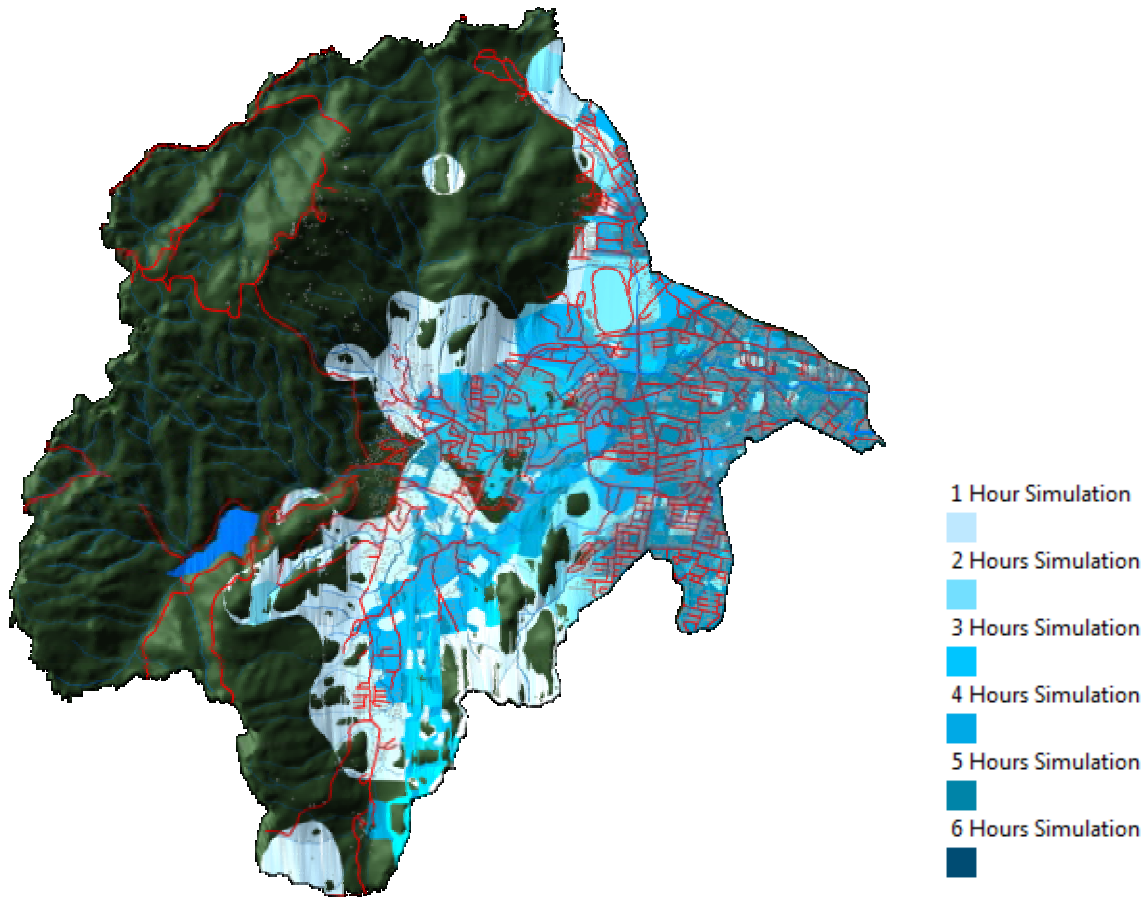
Figure 7. *Potential urban runoff area consists of overland flow and open channel flow within Pinang River basin based on 14th September 2007 rainfall data between 3.00 pm to 9.00 pm*

3D dynamic VSG simulation of overland flow, open channel flow volume and urban runoff areas

Approximately 5,114,100 m³ of precipitation volume were recorded within Pinang River basin. The estimated volume of rainfall infiltrated into soil is 1,197,000 m³. Total of overland flow and open channel flow volume simulated by VSG are estimated at 968,400 m³ and 1,718,000 m³ respectively. The results obtained are illustrated in Figure 8. Full summary of analysed overland flow and open channel flow volume using Green-Ampt and Kinematic Wave Routing method respectively for each sub-basin in Pinang River basin is stated in Table 1.
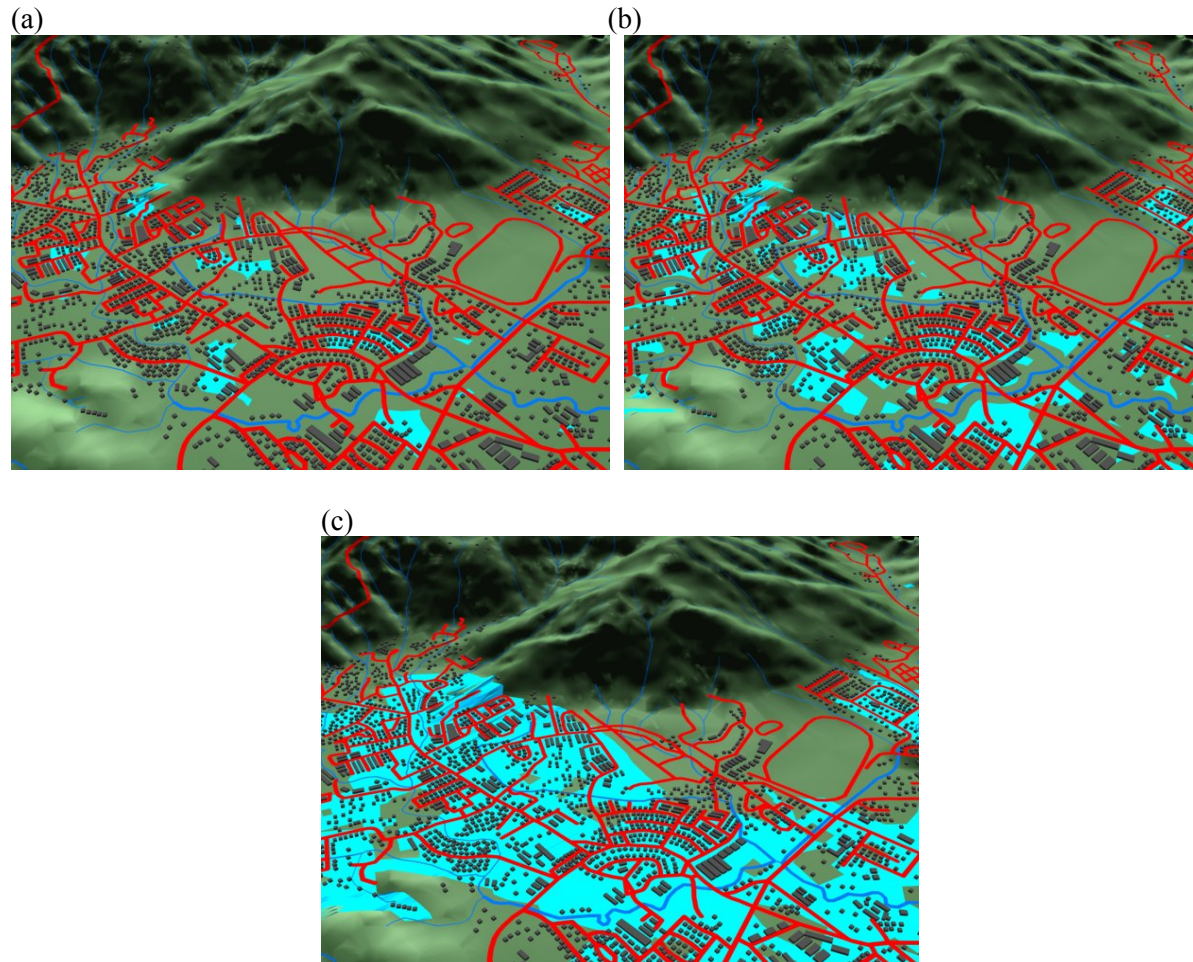
(a)

(b)

(c)

Figure 8. *3D dynamic VSG simulation for overland flow and open channel flow visualized at (a) 4.00 pm, (b) 6.00 pm and (c) 8.00 pm*

Figure 8 shows the visualization of 3D dynamic VSG simulation towards determining open channel flow and overland flow volume driven by physically based Kinematic Wave Routing and Green-Ampt method respectively using Cassini-Soldner projection. Continuous input from precipitation increases the height and coverage of overland flow and open channel flow volume, mainly on downslope and flat areas. The simulated VSG is proportional to the Kinematic Wave Routing method, Green-Ampt method and physical characteristics of equidistant Cassini-Soldner map projection, which results differential on the area, shape, flow path, slope and deformation of VSG. The outflow from all VSG are collected and merged into ordinary rendered settings and represents the overland flow volume, open channel flow volume and direction, flow discharge and flooded areas.

Figure 8 also illustrates the flooded area which lies in sub-basins of "Air Hitam 3", "Air Hitam 4", "Air Hitam 5", "Air Putih", "Jelutong" and "Pinang River". VSG visualizes flooded areas based on impervious area coverage, overland flow 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 urban flooding. Thus indicate the existing rivers and drainage systems lack of capability to shift runoff volumes from highly urbanized areas. The simulated results are then verified and compared with observed discharge volume as shown in Figure 9.
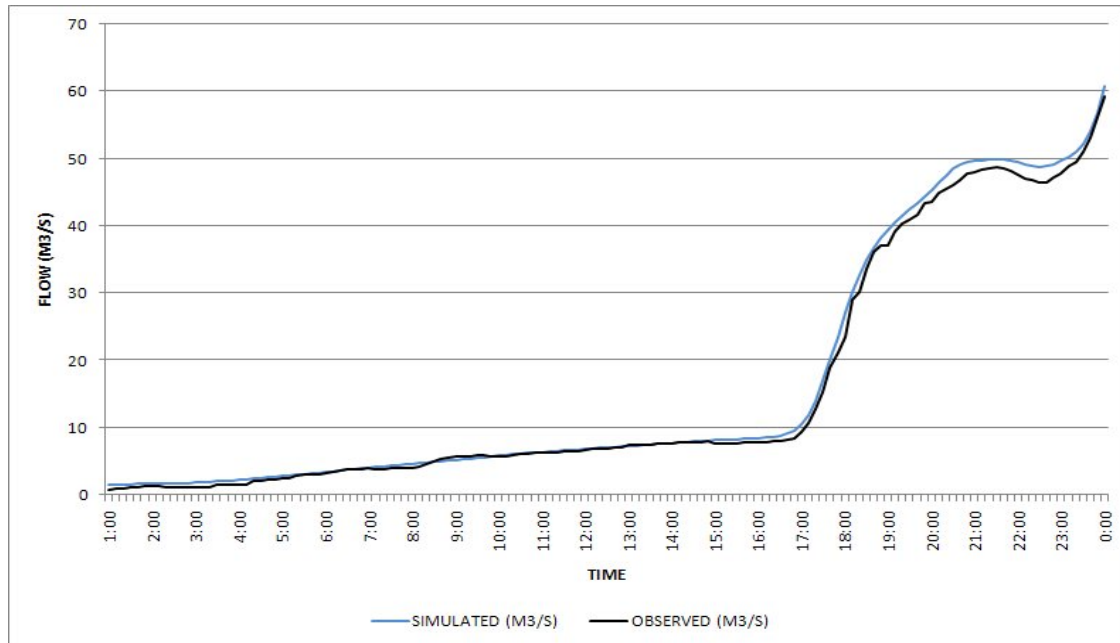
Figure 9. *Comparison of simulated discharge volume with observed discharge volume*

Simulated urban runoff discharge volume corresponded well with the observed measurements. Figure 10 illustrates R^2 error computed with observed streamflow at the outlet of the basin.
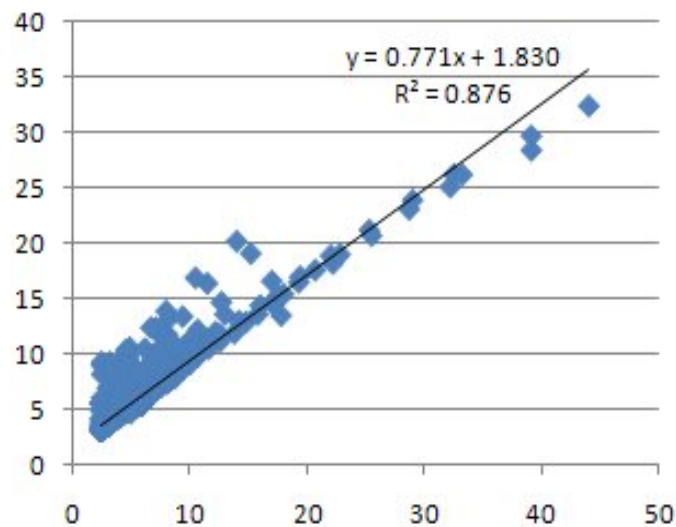

Figure 10. *R^2 of simulated discharge volume*

The comparison of simulated and observed discharge volume using 10 minutes interval gave an R^2 of 0.88 and Nash–Sutcliffe coefficient of 0.82 as the performance indicator of hydrologic process. The simulated results indicate that the 3D dynamic VSG urban runoff modelling indeed provides a valuable step for end-users envisioning complex volume information of flow routing, floodplain areas, affected buildings, land properties and appropriate flood disaster management.

Table 1. Simulated VSG urban runoff modelling results using Green-Ampt and Kinematic Wave Routing method

Sub-basin	Peak Discharge (M^3/s)	Precipitation Volume ($1000\ M^3$)	Infiltrated Volume ($1000\ M^3$)	Overland Flow 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	4.6	184.6	40.9	71.3	117.9
Jelutong	5.1	549.3	101.2	34.4	151.6
Pinang River	1.4	267.6	34.6	2.8	73.2
Total	-	5114.1	1197.0	968.4	1718.0

Differential of simulated and observed discharge volume are proportional with DEMs and plane flattening characteristics that alternates basin shape, size and distance. Thus would greatly affect the physical shape, distance, area and direction of VSGs and computation 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 overland flow generated in the study area. The 3D VSG simulation performed however does not account the water balance equation such as evapotranspiration losses, percolation, return flow, groundwater flow, shallow and subsurface flow.

Concluding remarks

This paper discusses the definition, mathematical expression and new perspective of 3D dynamic simulation of 3D GIS based urban runoff modelling using preliminary VSG approach by estimating the potential locations of open channel flow and overland flow volume within urban runoff areas driven by Kinematic Wave routing and Green-Ampt method respectively. The spatial layers of channel networks, streamflow, land use, soils and precipitation are all important sub-basin parameters that results significant changes of infiltrated urban stormwater, open channel flow and overland 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 VSG envisioning urban runoff process.

A thorough understanding need to be addressed in terms of physical geographic in flow routing process, determining the 3D GIS properties such as topological aspects, 3D spatial indexing, map projections, 3D generalization and coordinate systems before any urban runoff modelling and data processing can be performed. As for hydrological aspects, further investigation is needed for possible new criteria for visualizing VSG under multi layer adjustment by examining soil type and its properties, evapotranspiration, shallow flow, channel/macropores roughness and slope condition for numerous locations.

References

Bedient PB, Huber WC (2002) *Hydrology and floodplain analysis (3rd ed.).* Prentice Hall, New Jersey.

Beni LH, Mostafavi MA, Pouliot J (2007) 3D dynamic simulation within GIS in support of disaster management. Geomatics Solutions for Disaster Management, Lecture Notes in Geoinformation and Cartography. pp 165-184.

Bivand R, Lucas A (1997) Integrating models and Geographical Information Systems. In: Openshaw S, Abrahart R J (eds) *Geocomputation*, pp. 331-364. Taylor & Francis, London.

Brutsaert W (2005) Hydrology: An introduction. Cambridge University Press, New York.

Chaudhry HC (2008) *Open channel flow (2nd ed.).* Prentice Hall, New Jersey.

Chow VT (1959) *Open channel flow*. McGraw-Hill, New York.

Feldman RD (2000) Hydrologic engineering center – Hydrologic modelling system technical reference manual. US Army Corps of Engineers, California.

Gold CM, Chau M, Dzieszko M, Goralski R (2004) 3D geographic visualization: The marine GIS. In: Fisher PF (ed) *Developmants in spatial data handling - 11th International Symposium on Spatial Data Handling*, pp. 17-28. Springer.

Gong JY, Cheng PG, Wang YD (2004) Three-dimensional modelling and application in geological exploration engineering. *Computers & Geosciences* **30** (4), 391-404.

Isenbies MH, Aust WM, Burger JA, Adams MB (2007) Forest operations, extreme flooding events and considerations for hydrologic modeling in the Appalachians – A review. *Journal of Forest Ecology and Management* **242**, 77-98.

Jones CB (1989) Data structures for three-dimensional spatial information systems in geology. *International Journal of Geographical Information Systems* **3** (1), 15-31.

Lin H, Zhu J, Xu B, Lin W, Hu Y (2008) A virtual geographic environment for a simulation of air pollution dispersion in the Pearl River Delta (PRD) Region. 3D Geoinformation Sciences, Lecture Notes in Geoinformation and Cartography, pp. 3-14.

O'Callaghan JF, Mark DM (1988) The extraction of drainage networks from digital elevation data. *Computer Vision, Graphics Image Process* **28**, 328-344.

Olivera F, Valenzuela M, Srinivasan R, Choi J, Cho H, Koka, S, Agrawal A (2006) ArcGIS-SWAT: A geodata model and GIS interface for SWAT. *Journal of The American Water Resources and Association (JAWRA)* **42** (2), 295-309.

Pouliot J, Lachance B, Brisebois A, Rabeau O, Kirkwood D (2003) 3D geological modeling: Are GIS or CAD appropriate? *Proceedings of the International Society for Photogrammetry and Remote Sensing Workshop, WG II/5, II/6, IV/1 and IV/2 Joint Workshop on "Spatial, temporal and multi-dimensional data modelling and analysis",* Québec, Canada. 7 pp.

Shen DY, Takara K, Tachikawa Y, Liu YL (2006) 3D simulation of soft geo-objects. *International Journal of Geographical Information Science* **20**, 261-271

Smemoe CM (1999) The spatial computation of sub-basin green and ampt parameters. Unpublished.

Stoter JE, Zlatanova S (2003) Visualising and editing of 3D objects organised in a DBMS. EUROSDR Workshop: Rendering and visualisation. Enschede, The Netherlands.

USGS (2005) United States geological survey: Earth's water – Runoff. Available from: http://ga.water.usgs.gov/edu/runoff.html

USMM (2000) Urban stormwater management for Malaysia. Vol. 1 – 20. Department of Irrigation Drainage, Malaysia.

Wang C, Wan TR, Palmer IJ (2007) A real-time dynamic simulation scheme for large scale flood hazard using 3D real world data. 11th International Conference Information Visualization (IV'07), IEEE Xplore, pp 607-612.

Ward AD, Trimble SW (2004) *Environmental hydrology (2nd ed.)*. Lewis Publishers, Washington.

Zhao D, Chen J, Wang H, Tong Q, Cao S, Sheng Z (2009) GIS-based urban rainfall-runoff modeling using an automatic catchment-discretization approach: A case study in Macau. Environment Earth Science **59**, 465–472.