A Review of Infiltration Excess Overland Flow (IEOF): Terms, Models and Environmental Impact

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ABSTRACT

High precipitation rate usually give an impact on soil instability and streamflow volume that lead to hazard such as landslide, soil erosion and flood. However, such hazard might happen as a result of various factors including types of soil, soil structure, land used, human activities and surface and subsurface water flow. The major changes on flow rate might change the soil structure and flow direction due to high volume of precipitation with uneven dispersion, especially in hilly topography. The research on Streamflow Generating Process (SGP) has been advancing in order to understand the formation of stream resulting from both surface and subsurface flow comprising Infiltration Excess Overland Flow (IEOF), Saturation Excess Overland Flow (SEOF), Shallow Subsurface Flow (SSF), Direct Precipitation onto Stream Surface (DPOSS), percolation, evapotranspiration and ground water (GW). This paper will only focus on one of the process which is IEOF. Despite the apparent important of IEOF in determining changes in environment, relatively little is understood in the processes that occurred behind. The review aims to minimize the misconception on the terms that regularly used in IEOF studies such as overland flow, surface runoff, urban runoff and stormwater. The term used can make the meaning become misleading and give confusion to the readers. A numerous of terms used to explain the process in Hydrology does not pose problems for Hydrologist but effect the understanding of those who are from different field of background. Besides, this study also discussed on the current model that used in IEOF studies and the trend of integrated hydrological and Geographic Information System (GIS) model in solving IEOF problems. In addition, this paper also concentrates on one of the environmental issues that give impact to IEOF which is global warming.

Keywords: Streamflow Generating Process, Infiltration Excess Overland Flow, hydrology, Geographic Information System.

Academic Discipline And Sub-Disciplines

Hydrology, Geography and Environment

SUBJECT CLASSIFICATION

Subsurface water in Hydrology

TYPE (METHOD/APPROACH)

Literary Analysis

1.0 INTRODUCTION

High intensity short duration rainfall is much more likely to exceed the capacity of the soil to infiltrate water and result in overland flow than a longer less intense rainfall (Tarboton, 2003). Water from surface water input takes various pathways to reach the stream channel. Water from precipitation will infiltrate into the soil either will remain in the soil, percolate to ground water, infiltrate as subsurface flow, flow as overland water or directly enter the stream. Study on the pathway of the infiltrated water is important to enable further research related to streamflow is practicable. Kirkby and Chorley (1967) stated that the maximum hillslope water flow that might occur can be divided into zones consist of base of the slopes in hollows, in slope profile concavities and in areas of thin or less permeable soils. The surrounding terrain contributes to the rate of velocity of streamflow of an area. The steep surrounding terrain will produce greater runoff that moves downhill since the water from precipitation will have less time to infiltrate into the ground compared to the level terrain area. The path taken by water usually depends on the topography of the area and the resulting streamflow can give impact to both human and environment.

The movement of water in soil involves infiltration and redistribution process which critically depends on the hydraulic properties and the material of the soils it flow through. Infiltration can be simply defined as the water movement into the soil from the soil surface. Redistribution in the other hand comprises of exfiltration, recharge, capillary rise and interflow. Redistribution is the term used to describe the movement of water that infiltrated in the unsaturated zone of a soil. Exfiltration is the movement of water from the layer of the soil to the air in the process of evaporation, while recharge is
the water movement from the unsaturated zone in the soil to the saturated zone. Capillary rise in the other hand happen due to surface tension in the soil that force the water to move upward from saturated zone to unsaturated zone and interflow occur when the flow move downslope. The general terms which is used to describe the movement of water downward in unsaturated zone is percolation. All of the water movement on the surface or subsurface soil will end up either as a groundwater or flow into a stream.

The water movement in the soil or on the surface of the ground will end up in the stream. The process of by which the water flow before reaching the stream channel is called Streamflow Generating Process (SGP). Streamflow Generating Process consists of five main processes which are Infiltration Excess Overland Flow (IEOF), Saturation Excess Overland Flow (SEOF), Shallow Subsurface Flow (SSF), Direct Precipitation onto Stream Surface (DPOSS) and Percolation (Garen & Moore, 2005). Horton (1933;1945) argued that storm runoff was produced by Infiltration-Excess Overland Flow (IEOF). IEOF generate surface flow when the soil cannot absorb the excess water flow especially during high intensity storm until the soil become saturated to absorb water and immediately flow as runoff which is known as SEOF. However, the water can also produce shallow subsurface flow (SSF) that flow shallowly within the soil and redistribute soil moisture downslope. According to Dunne and Black (1970), the response of subsurface flow to rainfall was heavily damped by storage and transmission within the soil. The water will than exfiltrates from the aquifer to the stream as a ground water. IEOF which also known as Horton Overland Flow, shown in Figure 1. Further elaborations on IEOF processes were explained in the next subtopic.

![Fig 1: Infiltration Excess Overland Flow (also called Horton overland flow) (Image from Beven, 2000)](Image from Beven, 2000)

This paper will only focus on importance, related issues and trend of IEOF. There are many terms used to explain infiltration process which seemed to give the similar meaning. These circumstances prevent the process of understanding from occurring seamlessly. The terms that usually used for infiltration related studies are overland flow, surface runoff, urban runoff and stormwater. In order to get proper understanding on these topics, this paper reviewed and discussed on the brief explanation on each term and shows the differences between the terms used. Besides, the hydrological model and integrated hydrological and GIS model that used in IEOF related research were also discussed in this paper. Global warming is one of the environmental issues that affect the rate of infiltration of water into the soil. Therefore, this is the very interesting and suitable phenomena to be included as part of the discussion in this study. The next subtopic will explain in detail on the infiltration process especially on soil infiltration.

### 2.0 INFILTRATION

Prior to review further on IEOF process, knowledge and understanding on infiltration itself is essential. Infiltration is the process where ground surface water (eg: from precipitation or irrigation) seeps downward into the soil. The knowledge of infiltration is important as the process is indicating the ability of soils to allow the movement of water through and into the soil profile. The water that infiltrated in the soil stores temporarily that important for plant growth, root uptake and make the soil suitable for habitat of soil organisms. The soil that restricted the infiltration process will cause a stagnant of water on the soil surface that leads to poor soil aeration which then affects the root function, plant growth and nutrient availability. Stagnant of water on soil surface also destroy soil structure and increase detachment of soil particles. There are several practices that can help to improve water infiltration that helps to prevent soil from erosion, minimize soil compaction and disturbance and develop a good soil structure with continuous pore space (USDA, 2008). The example or practices are to increase the soil organic matter, manage crop residues well and also growing a vast area of vegetation cover.

In soil science, infiltration rate is a measured (inches per hour of millimeters per hour) of the rate at which the water from precipitation or irrigation is able to absorb in the soil. In the other word, infiltration rate is the velocity of water entering the soil. One of the most important factors that affect the process of rainfall-runoff is infiltration rate (Miyata, 2010) which related to the occurrence of Hortonian overland flow (Horton, 1933) where the volume is governed by the difference between infiltration rate and rainfall intensity. Infiltration calculated by using simplified equations such as Horton equation, Philip equation, Green-Amp equation, Richard’s equation, Finite Water-Content Vadose Zone Flow Method, Kostiakov equation and Darcy’s law. Infiltration rate depends on the level of saturation of the soil.

The rate can be determined by using infiltrometer. High precipitation that exceeds the rate of infiltration will cause runoff which associated with the saturated hydraulic conductivity of near-surface soil. Thus, the rate of infiltration is important to be measured especially at the hillslope area which exposed to landslide since runoff can be a part of triggering factor of this hazard. The rate of infiltration of water into the soil depends of soil texture, structure and moisture content. Different types of soil represent by different texture, structure and moisture content that required observation, field surveys and laboratory test to gather the information.
Every process has its own important parameters that are taken into account to identify required data. The essential parameters required in water infiltration research are capillary rise, porosity and hydraulic conductivity. The explanation on each parameter is as stated:

a. Capillary Rise

Capillary action is an important action for water movement which is flow in the narrow spaces of porous materials due to the forces like cohesion, adhesion and surface tension. The action is against the gravity forces. The water can move upwards where the groundwater can be pulled upward through capillary (small pores). The upward movement of water from different soil gives a result of different speed of movement. The water in sandy soil with a coarse textured quickly move the water upward but only cover a short distance while clay with a fine texture move the water slowly upward but cover long distance. According to Lu & Likos (2004) capillary rise can be defined as the unsaturated soil phenomenon that explain the pore water movement of water from lower to higher elevation is known as capillary rise which is driven by hydraulic head gradient acting across the curved pore air or pore water interface.

b. Porosity

Soil porosity refers to the amount of open spaces or pore between the soil particles that was form due to worms, roots and insects that can be filled by air or water. Nimmo (2004) stated that the porosity of a soil are depends on packing density, the breadth of the particle size distribution, the shape of particles and cementing. The porosity varies depending on the size and aggregation of the soil particles. Soil porosity is important because it give the soil an ability to provide water and oxygen for plant growth. Tightly packed soils have smaller porosities than loose, porous soil. The total porosity of the soil is the combination of pores of all sizes and shapes.

c. Hydraulic Conductivity

Hydraulic Conductivity known as one of the hydraulic properties of the soil which can be defined as a physical properties that measures the ability of material in order to transmit water through fractures and pore spaces in the available of an applied hydraulic gradient. Hydraulic conductivity is influenced by type of soil fluid, size of soil grain, structure of the soil grain and the relative amount of soil fluid (saturation) available in the soil matrix. Saturated hydraulic conductivity in the other hand is the term used to explain the water movement through the porous media for example soil. Saturated hydraulic conductivity can be defined as the flux of soil water per unit gradient of hydraulic potential when the soil is in saturated condition and it can give direct effects to soil erosion, deep percolation and surface water runoff (McKeague,1982).

Capillary rise, porosity and hydraulic conductivity are parameters that related to each others. Since infiltration involves the flow of the water in the soil, then this parameter should not be neglected. All of the parameters stated previously shows that the variability of soil properties make a different to the passage of water from the surface into the ground. The effect soil variability includes the time it takes for the water to infiltrate into the soil, the pattern of water flow and the direction of water flow. The next subtopic will discuss on overland flow, surface runoff, urban runoff and stormwater runoff which widely used in describing infiltration process in either papers or journal.

3.0 RELATION AND DIFFERENCE OF TERMS IN IEOF

There are many terms used to describe the study of the IEOF. Some of the terms are simple and easy to understand but there are a few terms that give a meaning which is ambiguous. A vague understanding is stems from a number of terms are used that have al most the same meaning. In hydrological studies generally and IEOF studies specifically the term that are frequently used are overland flow, surface runoff, urban runoff and storm runoff. The terms seems to be similar, however there are situation which suit each of its usage.

a. Overland Flow

Rainfall initiates the flow of water on the surface and underneath the soil. The accumulation of water on the surface of the soil when the rainfall intensity exceeds the rate of soil infiltration leads to the flow of the water down the slope under gravity and this process is known as overland flow (Miya ta, 2010). Infiltration-excess (Hortonian) and saturation-excess overland flow is two main type of overland flow where surface water runoff occur due to precipitation (Fagherazzi & Priestas, 2012). The different of these two types of overland flow is infiltration-excess occurs when the intensity of rainfall exceeds the infiltration rate of the soil and saturation-excess in the other hand happen when the water table reaches the ground surface (Dingman, 2002).

The generation of overland flow are due to surface roughness (Darboux, 2002) and in hillslope scale it is due to high spatial variability of the infiltration rate (Esteves & Lapetite, 2003). Darboux (2002), analyze the effects of surface roughness on overland flow in terms of flow pathways, runoff generation and model simulating depression filling. The relevant characteristics of the surface roughness were examined by using numerically generated surfaces. Spatial pattern of infiltration in hillslopes need to be considered as an essential parameter in order to determine spatial pattern of local overland flow generation and also for contribution of overland flow to storm runoff (Miya ta, 2010).

b. Surface Runoff
According to Berthier (2004) surface runoff is obtained from the computation of a surface water budget representing the interception process. Surface runoff is generated by two mechanisms namely infiltration excess runoff (Hortonian flow) and saturation excess runoff (Dunne flow) where different surface runoff generation mechanisms (that produce storm hydrograph) is due to spatial variability of soil properties, topography, antecedent soil moisture and rainfall (Liang & Xie, 2001). Distinction of both mechanisms is required to understand the basis of variable source area (VSA) hydrology.

According to the early study by Horton (1933), infiltration excess surface runoff happen when the rainfall intensity exceeds the soil's infiltration capacity while saturation excess surface runoff is due to waterlogged on the soil where the soil no longer possess storage for any additional rainfall (Dunne & Black, 1970; Dunne, 1983). For the landscape which is prone to VSA hydrology, climatic variables used to determined the nature and extend of surface runoff (Cooper, 2010).

c. Urban Runoff

Urban runoff refers to any storm water and non-storm water runoff where it is a surface runoff of rainwater created by urbanization. Urban runoff usually contributes to the major source of urban flooding and urban water pollution. EPA define urban runoff as a storm water that come from city street and adjacent domestic or commercial properties which carries various kind of pollutant into the sewer system and receiving water.

Alteration on urban soil contain a large number of infrastructural components (e.g trenches that act as a drains) influence the flow paths (Gustafsson, 1996). Most of the studies on urban runoff related to pollution where the urban runoff contaminates with chemical which abound in urban area. Quality and quantity of urban runoff influence by many factors. According to Maniquiz (2010) site and event parameters that have significant influence on urban runoff are antecedent dry period, total event rainfall, cumulative seasonal rainfall, annual average daily traffic and drainage area. Rainfall intensity and runoff volume during rainfall period influence the intensity, washed-off rate and the dilution effect of accumulated contaminants and their transportation to the receiving waters (Chui et al., 1982; Tsihrintzis & Hamid, 2001).

d. Stormwater Runoff

Storm water is defined as any water that originated from atmospheric moisture such as rainfall or snowmelt which fall onto either land, water or other surfaces. Whereas Stormwater runoff can be defined as a part of precipitation which the water flow across any surfaces towards storm drain system. Rainwater can be considered as a potential component to mitigate stormwater and can act as source control that can be include in residential drainage design as it can protect urban stream by reducing stormwater runoff volume and also the pollutants to reach downstream waterways (Water Sensitive Urban Design, 2005).

Woltemade (2010) stated that the divisions of rainfall water that run off and infiltrate into the soil are one of the most important hydrological process where the division is influence by soil permeability, antecedent moisture and land use. Urban development cause three types of significance ecological changes which are increase frequency of high flows, increase daily variation in streamflow and redistribution of water from periods of base flow to period of stormflow (Konrad & Booth, 2005). Lawn infiltration rates and also stormwater runoff is caused by soil disturbances like compaction in residential developments and excavation which give significant impact of rainfall-runoff process such as soil degradation and erosion (Woltemade, 2010).

Stormwater runoff is associated with urban areas, highly polluted (Aryal, 2010; Brezonik & 2002; Kim, 2005), stream toxicity that effect human and ecosystem (Joshi, 2010), channel erosion (Booth, 2002) decreased base flow (Ferguson, 1990), effect flora fauna of receiving water (Khaustagir, 2010) poor water quality (Carle, 2005) and reduced richness and abundance of fish species (Wang, 2001). The explanation on overland flow and surface flow previously clearly indicate that overland flow and surface runoff give the similar meaning where both of process occur when the rainfall intensity exceed the rate of soil infiltration. Besides, overland flow and surface runoff consist of two main type of flow namely infiltration-excess and saturation-excess. The only difference that can be found between overland flow and surface runoff was the use of the term whereas both give the same meaning.

The term stormwater runoff gives a huge contribution in the definition of urban runoff, Stormwater runoff is a part of precipitation and the water flow across any surface to the storm drain system. Urban runoff in the other hand refers to any storm of non-storm runoff where it creates surface runoff from rainwater which occurs in urban area. Urban runoff occurs in urban area and related to urbanization while stormwater runoff occurs anywhere. Both of the runoff initiate from the rainfall and can contribute to pollution because the runoff carries pollutant into the sewer system or storm drain system. Urban runoff known as a major source of urban flooding because urban area have a drainage system that can only accommodate a certain amount of water. If heavy rain falls, drainage system and shallow and narrow river in urban area cannot cope with the large amount of water that leads to urban flooding. Stormwater runoff and urban runoff gain a lot of attention as it brings a lot of environmental and health issues. Thus, many researches have been done including the effort to reduce stormwater volume (Water Sensitive Urban Design, 2005) for better water management. The next subtopic will review on the main focus of this paper which is IEOF.
4.0 INFILTRATION EXCESS OVERLAND FLOW (IEOF)

According to Horton (1933), the source of runoff during storm is the excess rainfall over infiltration capacity of basin surficial materials and the water infiltrate would become groundwater which was the source of baseflow. The infiltration capacity of the soil and the steepness, shape and roughness of the slopes in the catchment determine the height of the peak discharge, and hence the maximum fluid pressure which will be generated in the debris (Van Asch, 1999). IEOF also named as Hortonian overland flow as Horton originally introduces the idea of IEOF for storm hydrograph analysis and his finding is still relevant and used up until now. The idea is not only can be applied by hydrologist but also can be used in wide range of application that can be further develop.

IEOF only generate surface flow during high intensity storm unless the soil has a very low infiltration capacity, in which case lower intensity storm also generate subsurface flow (Garen & Moore, 2005). Different type of soil will have different infiltration rate. Silt and clay will generate more surface runoff as it has a slow infiltration rate compared to sand which have higher infiltration rate. The volume and rate of IEOF depends on the rate and soil hydraulic conductivity (Emmet, 1978). The hydraulic conductivity is one of the soil’s hydraulic properties that represents the measurement of the soil’s ability to transmit water through pore spaces or fractures where it depends on the structure of soil matrix, size of soil grain, fluid type and relative amount of soil fluid in the soil matrix. At a field scale, IEOF tends to increase down slopes as both surface and subsurface run-off from higher areas increases the hydraulic load, and hence the probability of overland flow in receiving areas (Nash, et. Al., 2002). Infiltration rate for soils in different part of the world is not the same example for most soil types in Ireland, the infiltration rate are sufficiently high to limit the risk of overland flow occurring (Diamond, 2003) and (Haygarth, 1999) suggested that IEOF that introduced by Horton (1933) is limited in Great Britain as the soil infiltration capacity is rarely exceeded. Different land used also give differ infiltration ability. According to Murai (1975) and M. Bonell (1978), forest have ability to accommodate rainfall intensities because the soils have sufficient infiltration capacities where previous studies by Dunne & Black (1970) and M. Bonell & Gilmour (1978) concluded that IEOF rarely occurred in forested catchment.

Van Asch and VanBeek (1999) reviews on the hydrological triggering system in land slide point out that surface runoff and high peak discharges is an important triggering mechanism for debris flow, while critical depth that can be determined by the cohesion of the soil and slope angle caused failure condition in shallow landslides where the moisture content in the soil become close to saturation that reduced the strength of the soil and the deeper landslide in most of the cases triggered by positive pore pressures on the slip plane induced by a rising ground water level. Lahmer et. al. (2001) shows the important regional water resource vulnerabilities to changes in both temperature and precipitation. The development of regional analysis for streamflow statistics has a relatively long and rich history and much of its development has benefited the advancement of regional estimation of rainfall-runoff model parameters for continuous streamflow simulation (Vogel, 2005). Darcy’s Law (1856) enable the prediction of outflow discharge at a slope base to be made. Darcy’s Laws required essential information of size and slope of the saturated wedge with the accurate determination of hydraulic conductivity for the soil (Anderson & Burt, 1978). 4.1 Current Hydrological Model Used In Ieof Studies

According to Borah (2009), watershed model mostly were developed during the 1960s-1980s where the model that most widely used nowadays are the ones having graphical user interface (GUI). Extensive developments of models build by expertise create more competition among supplier that caused the modification and upgraded versions done intensively. Most models are built with a specific function that can be easily handled and capable of providing the desired results. The hydrological model that will be discussed are Storm Water Management Model (SWMM), Storage Treatment Overflow Runoff Model (STORM), Distributed Routing Rainfall-Runoff Model (DR3M) and MUSIC.

a. Storm Water Management Model (SWMM)

Storm Water Management Model (SWMM) was first developed in 1971 and the current edition of this model is Version 5 with much improvements. This model is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas (EPA). The operation of subcatchment collection done within the areas on which rain falls and runoff is generated. The model mostly used in planning, design and analysis on stormwater runoff, combined sewer, sanitary sewer and drainage system. The model tracks simulation can determined quantity and quality of runoff together with the information on flow rate, flow depth and quality of water in each channel and pipe. There are various types of hydrological processes that lead to runoff especially in urban area. Among the process that considered by SWMM models are infiltration of rainfall into unsaturated soil layers, evaporation of standing surface water, time-varying rainfall, rainfall interception from depression storage and percolation of infiltrated water into groundwater layers (EPA, 2015)

Krebs (2012) applied high resolution SWMM model using parameter optimization for highly urbanized catchment by implementing methods of spatial analysis, EPA-SWMM model, Goodness of fit criteria and sensitivity analysis. Spatial analysis focuses on delineate catchment area by using network map data and subdivide catchment area to evaluate Low Impact Development (LID) scenarios. This high resolution simulation used to evaluate the effectiveness of LID tools and also green infrastructure in cost effective way. Topographical data and in-situ observation used to determine the flow direction within and between subcatchment. SWMM model is capable to integrate with Geographic Information System (GIS) that allow the database to be included in the model. In this study, the stormwater flow from the ground surface was stimulated through the system by using rainfall/runoff and the flowing routing model. Goodness of fit criteria focuses on
five criteria to conducted sensitivity analysis of the model performance that include Nash-Sutcliffe efficiency E, linear correlation coefficient, sum squared error (SSE), the per cent peak flow error (PFE) and the per cent volume error (VE). Sensitivity analysis was done to determine an optimal computation time step combination concerning both simulation and run-time and also to identify minimum number of key parameters for calibration model. Finally the key parameter was calibrated using generic multi-objective optimization algorithm NSGAII. The findings shows that the calibration addressing only the identified key parameters that lead to good results in investigated statistical measures for validation and calibration as it will reduce the number of calibration parameters.

SWMM model can evaluate situation within the model itself or also can be integrated with other system, tools or application to produce the result needed. Krebs (2012) also analyse the used of this model in previous study and he found out that the trend of this model are used to stimulate green roofing using Curve Number Method (CN) within SWMM (Palla et al., 2008), achieve reasonable prediction for prototype green roof under laboratory conditions (Alfredo et al., 2010), evaluate the redevelopment plan (Gambi et. al., 2011) and evaluate the benefits of a combination of LID tools by integrated the model with Best Management Practice Decision Support System (Jia et. al., 2012).

According to Smith (2010), The U.S EPA models created from a number of large program modulus which employed a method of surface water budget approach. One of it is the RUNOFF block that able to generate the runoff hydrograph from a sub-catchment where in MIDUSS the method of SWMM use the same method with limited to only support Horton or Green and Ampt infiltration equation.

b. Storage Treatment Overflow Runoff Model (STORM)

STORM was developed for the US Army Corps of Engineers in the 1970s (USACE, 1977) to compute stormwater runoff to a storage-treatment control by applying rational method at an hourly timestep. Outflow, overflow and utilization of storage are compute using a fixed treatment rate. One of the earliest used of this model is to estimate the combined sewer overflow for entire city (Heineman, 2005) and modification done where STORM’s core algorithms are incorporated into the NetSTORM program (Heineman, 2004) which provide upgrade function that includes linking multiple control structures within a STORM framework and processing and statistical analysis of precipitation data. Besides it can be incorporated into a dynamic-link library file (DLL) that allow STORM directly called from a single cell in a spreadsheet.

STORM can be used for preliminary sizing and treatment facilities for control of urban stormwater runoff. The impact of land use change on water quality and quantity also be evaluated.

c. Distributed Routing Rainfall-Runoff Model (DR3M)

An original version of DR3M was first introduced in 1978. DR3M is a watershed model that can be used to assess the routing of storm-water-runoff through a system or network of pipes or natural channels and is usually used to simulate small urban basins (USGS) and it used rainfall as input. The model can provide a detailed simulation of storm-runoff and the results of calculated daily soil-moisture. However, the model does not support simulation for interfow, baseflow, snow accumulation and snowmelt. Several data required to build DR3M model are daily evapotranspiration, precipitation, short interval precipitation and short-interval discharge.

USGS summarize the method used in DR3M and mention that the four component of rainfall-excess are pervious-area rainfall excess, soil-moisture accounting, impervious-area rainfall excess and parameter optimization. Green-Amp method and Kinematic wave theory are used where the function of Green-Amp equation is to calculate the infiltration and pervious area rainfall excess, while Kinematic theory used for channel routing and overland flow. The other procedure included in the model is Rosenbrock optimization that used to aid in calibrating soil moisture and infiltration accounting parameters.

MUSIC

CRCCH develop a model called MUSIC that widely used by land developer, consultants and water authorities that help them to design Water Sensitive Urban Drainage (WSUD) features in order to reduce hydraulic loading and at the same time improve stormwater quality that flow into urban drainage system. Three types of nodes known as source node, treatment node and receiving node are available nodes in MUSIC model (Khastagir & Jayasuriya, 2010). The model uses a tank to model the surface runoff generation from pervious and impervious areas. The conceptual daily rainfall-runoff model is shown in Figure 2. The conceptual model gives a clear explanation of the process from where the water come (precipitation) to where the water goes (impervious runoff, infiltration excess, saturation excess, baseflow and deep seepage).
4.2 Geographic Information System-Hydrological Integrated Model

Vegetation, soil and topographic characteristics of the catchment strongly influence the relationship of rainfall-runoff (Jain, 2004). The complex interaction of catchment characteristics and climatology leads to the generation on runoff which influence temporal and spatial variability of runoff (Jain & Singh, 2005). Temporal and spatial data required suitable techniques for better analysis that provide required results. Thus, the techniques that can cater both spatial and temporal data is Geographic Information System that well known as GIS. The ability of GIS Techniques in handling large database that describe heterogeneities in land surface characteristics is due to advance recent development of GIS (Julien et al., 1995).

Remote sensing often associated with GIS as one of the favored method for data acquisition where the techniques can help in providing spatial information in form of digital on soil type, land use, agriculture, and others at regular grid intervals with repetitive coverage. The integration of GIS and remote sensing technologies enable the means of identifying the physical factors which control the process of partitioning of rainfall into runoff and other components as well (Jain, 2004).

There are a few integrated GIS hydrology model that will be explain in this subtopics which include Philip Two-Term Infiltration Model, GWBasic Wits Rainfall-Runoff Erosion Model (GWBRafler), Kinematicwave–Philip Infiltration Watershed Model Using FEM, GIS and Remotely Sensed Data and Limburger Soil Erosion Model (LISEM).

a. Philip Two-Term Infiltration Model

Research that integrate GIS and hydrology was done by Jain (2004) that focus on modelling the distributed of rainfall-runoff by using the ability of grid or cell in handling the catchment heterogeneity in term of distribution information on slope, soil, landuse and rainfall. Philip two-term infiltration model was used to compute infiltration in a cell areas while the diffusion wave approximation of St Venant equation is used to described overland flow mechanics. St venant equation help in solving the depth flow and runoff numerically by the method of finite volume. The model was proven to simulate reasonably well the runoff hydrograph and can predict runoff over catchment and variation of the spatial distribution of flow depth realistically. However some of the parameter required calibration.

Raster-based GIS that used in this study divide the flow domain into an array of grid where each of the grids represents an area with average properties. The grid catchment illustrated in Figure 3.
The direction of the flow from one cell to the neighbouring cells is ascertained by using eight-direction pour point algorithm (Maidment, 1992) where the algorithm help to pick the direction with most steep descent among the eight permitted choices until cell-to-cell flow path is determined to the catchment outlet. DEM analysis in the other hand was done to compute and identify the upstream where the flow started and downstream where the flow directed to.

b. GWBasic Wits Rainfall-Runoff Erosion Model (GWBRafler)

GWBasic RAFLER (GWBRafler) is a hydraulic based model, developed by Wits University that used to simulate erosion and monthly runoff (Stephenson, 1992). The studies by Nyabeze (1999) showed that the GWBRafler was sensitive to saturated permeability, rill ratio, soil suction head and slope. A rainfall-runoff model and GIS technique present considerable advantages in order to integrate measurement, definition, and calculate parameter values for spatial features. In order to take up the estimated distribution of the critical parameters in GIS, a modified GWBRafler which is known as GIS_Rafler was introduced to enable the parameter can be estimated in GIS that lead can reduce the relationship among parameter and effort used to populated them (Nyabeze, 2003). The GISRafler can give better estimation of low flow that usually happen during drought conditions. Algorithm used and incorporated with GISRafler to estimate the parameter values from features cover areas that was measured in GIS.

c. Kinematicwave–Philip Infiltration Watershed Model Using FEM, GIS and Remotely Sensed Data

The research done by Venkata et al. (2008) give a good example of integrated GIS, remote sensing data and hydrological model of Kinematic Wave-Philip Infiltration Watershed to model the distribution of rainfall-runoff in water resources planning. The simulation of channel and overland flow were done by using finite element method (FEM) while Philip model act as determine infiltration estimation. Land use and land cover for the watershed was acquired by remotely sensed data while slope map and overland flow element connecting to channel element obtained by using GIS technique. Watershed distributed model are actually based on the complex physical theory and the unsteady flow equation solution where Kinematic wave model is one of unsteady flow phenomena as describe by St. Venant equations. Ponce (1992) stated that in the middle of 1950s, kinematic wave’s theory was introduced by Lighthill and Whitham. Nowadays the theory is widely used in surface runoff modeling. Kinematic wave equation (analytical solution) however does not tractable in handling realistic problems related to temporal and spatial variability in surface roughness, land use change, rainfall and infiltration. This situation is where numerical method of finite element method (FEM) and finite difference method (FDM) are needed to fulfill the deficiency of analytical solution. Finite element grid was used in order to prepare and generate the input file like element slope while GIS was used in gathering data on Manning's roughness. The integrated model proven to be useful to simulate events based rainfall-runoff for small and also medium ungauged watersheds.

d. LImburge Soil Erosion Model (LISEM)

LImburge Soil Erosion Model (LISEM) is one of the physical-based hydrological and soil erosion models that integrated in raster GIS is specially for planning and conservation purposes. The model was developed in 1991 by The Departments of Physical Geography of the Utrecht University, the University of Amsterdam, and the Soil Physics Division of the Winand Staring Centre in Wageningen. Integration with GIS enable the model to used remotely sensed data, easy application in larger catchment and user friendly because it could avoid conversion routines. The model have many processes incorporated including infiltration, rainfall, surface storage in micro-depressions, overland flow, vertical and lateral movement of water in the soil, transport capacity of the flow, channel flow, detachment of overland flow ad detachment by rainfall and throughfall. The studies done by Roo et al. (1994) applying these model and using Richard's equation to simulate lateral and vertical movement of water in the soil while a four-point finite-difference solution of Kinematic wave and Manning’s equation were used to get the distribution of flow routing.

5.0 THE IMPACT OF ENVIRONMENT TO THE INFILTRATION RATE OF WATER IN SOIL

The processes that occur in our environment are actually intertwined with each other. Many claim that global warming negatively impact hydrological cycle. However, the roots of the problems are due to economic and population growth that lead to changes of land-use and land-cover for which leads to four major direct impacts on water quality and hydrological cycle where they can lead to drought, floods, affect water quality and changes in river and groundwater regimes (Rogers, 1994). While the indirect impact of the changes are on climate and also the subsequent impact of the altered climate on the water. Besides, urbanization, one of the sign of economic and population growth has considerable as hydrological impact (Goudie, 1990) with reference to the influence of runoff nature, controlling rate of erosion and delivering pollutants to rivers. According to Weng (2001), urbanization started with the removal of trees and vegetation that reduce interception and evapotranspiration and also proliferate the stream sedimentation. The urbanization follow up by the development of settlement, buildings, shop houses, street, highways which give impact on lowering groundwater table, reduce infiltration, decreased base flow especially on dry period and increase stormflow. Due to these developments the time for runoff to occur will reduce which lead to potential of flood damage. In addition, the area equipped with sewers and storm drains escalate runoff (Goudie, 1990). This condition may indicate the effect of urbanization in urban area tends to cause different condition of rainfall-runoff than the classical hydrological cycles.

The finding from the synthesis report which is carried out by three Working Groups (WGs) of the Intergovernmental Panel on Climate Change (IPCC) give a wealth of information on the impact of global warming on water cycles including runoff. Temperature and precipitation changes leads to the changes of water availability and runoff (Barker, 2007). By mid of
century, the runoff predicted to increase by 10% to 40% at higher altitude and in tropical areas (populous areas in East and South-East Asia) while the runoff at mid-latitudes and dry tropics decrease by 10% to 30% because of decrease in rainfall and have higher rate of evapotranspiration. The area that projected to get lower effect of runoff need to face a reduce value of services that required water resources while the area that beneficial with increase annual runoff might be tempered by negative effects of seasonal runoff shifts on water supply, increase precipitation variability, flood risk and water supply.

Without warming, the water has certainly become an issue of global concern. However, global warming will contribute to water scarcity. There is no simple and easy ways to stop. The warming will continue for hundreds or thousands of years although the green house gas emission is terminated (Kanae, 2009).

Rising temperature, changing precipitation and increasing atmospheric CO₂ are some of the example of the concurrent changes in the driving forces of global change (Wan, 2007). The question on how soil respiration responds to the concurrent changes in weather and those drives and also how all of them interact with each other to impact soil respiration is still not clear (Norby & Luo, 2004) even many studies proven that the main effects of soil respiration are due to warming (Luo et al., 2001; L. E. Rustad et al., 2001) soil respiration of elevated CO₂ (Q. Liu et al., 2006; Craine et al., 2001) and changing soilwater availability or precipitation (Davidson, 1998; Davidson, 2000; Reichstein et al., 2005; Borken, 2006). C substrate, soil moisture and soil temperature have known as the fundamental parameters in predicting the responses of soil respiration to globe change (Cox, 2000; Reichstein et al., 2005; Trumbore, 2006) and controlling factors over soil respiration in terrestrial ecosystems (Raich, 2000; Rustad, 2000).

CONCLUSION

Studies of IEOF have certainly been carried out as early as around 1930s. The apparent changes that can be said is the method used in solving the problem related to IEOF. This review demystified the modeling techniques for the research in connection with IEOF. Most of the model used for hydrological studies applies Horton or Green and Ampt infiltration equation (SWMM) and for DR3M, Green-Amp equation and Kinematic wave theory were used. Horton equation, Green and Ampt infiltration equation and kinematic wave theories widely used in developing models of hydrology. GIS is no longer eccentric in associated study with hydrology. Philip Two-Term Infiltration Model, GWBasic Wits Rainfall-Runoff Erosion Model (GWBRafler), Kinematicwave–Philip Infiltration Watershed Model (Using FEM, GIS and Remotely Sensed Data) and Limburge Soil Erosion Model (LISEM) are some of the current available hydrology-GIS integrated models. Philip Two-Term Infiltration Model using St venant equation to solve the depth flow and finite volume method used to solve runoff where the contribution of GIS is the used of Raster-based GIS that divide the flow domain into an array of grid where each of the grids represents an area with average properties. GWBasic Wits Rainfall-Runoff Erosion Model (GWBRafler) in the other hand introduced GISRafler that able to estimate parameter in GIS that give better estimation of low flow that usually occur during drought condition. Kinematicwave–Philip Infiltration Watershed Model used finite element method (FEM), GIS and Remotely Sensed Data. Kinematic wave equation (analytical solution) does not tractable in handling realistic problems related to temporal and spatial variability in surface roughness, land use change, rainfall and infiltration which leads to the needs of numerical method of finite element method (FEM) and finite difference method (FDM) to fulfill the deficiency of analytical solution (Venkata et al., 2008). Last but not least is Limburge Soil Erosion Model (LISEM) integrated in rasper GIS is especially for planning and conservation purposes. Some of the hydrological and GIS integrated model also apply Kinematic equation but with added value of ability to integrated with GIS data. Richard’s equation, FEM, FDM, Manning’s equation, St Venant equation are used in Hydrology-GIS integrated model. The use of GIS in hydrological field, particularly for modeling study clearly shows that GIS helps to get a more detailed study and extensive as GIS is a method that has the potential to do research and analysis on environment. Besides, many tools available in GIS can help to give the variability to produce required results.

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REFERENCES


XXII. EPA, United State Environmental Protection Agency. Access on 10 June 2015 at: http://www2.epa.gov/water-research/storm-water-management-model-swmm


LXXIV. Weng, Q. (2001). Modeling urban growth effects on surface runoff with the integration of remote sensing and GIS. *Environmental Management*, 28(6), 737–748. doi.org/10.1007/s002670010258


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