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Modeling of Storm Water Runoff for Kitwe CBD Drainage System Using SWMM Software

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Abstract: The 2007/08 rain season caused urban flash floods in urban districts of Lusaka, Central and Copperbelt Provinces. In the Copperbelt, Kitwe City town the flash flood was assumed to be caused by rapid urbanisation, faulty city drainage network and poor storm-water management. This meant that Local Authority of Kitwe City Council are required to mitigate and prevent the reoccurrence of urban flash flood, but this need assessment to determine the true cause of urban flash floods. In some countries the Storm Water Management Model (SWMM) is widely used for planning, analysing and designing storm water runoff and other drainage system in urban areas. SWM is a dynamic rainfall-runoff simulation model which is used for single event or long-term (continuous) simulation of runoff quantity and quality from urban areas.

This research was to model storm-water runoff for Kitwe Central Business District with the size of 0.146km², containing 115 storm-water inlets and 5 storm water outlets with SWMM software. The hydrological assessment for rainfall data and rainfall characteristics, land cover for drainage characteristics and usage of land as well as the hydraulic assessment for conveyance network elements were used.

Modelling and simulation was conducted using various situations as obtained on project site and these included completely blocked, partially and open drainage system situations, whereas, perfect condition was used to assess the operation of the software. After simulation, status report indicated that urban flash flood experienced in Kitwe CBD during the 2007/08 rainfall was due to lack of drainage maintenance.

Keywords: Urban flash floods, Storm Water Management Model, hydrological assessment, Hydraulic assessment, drainage maintenance and modeling/simulation

1. Introduction

The scope of the project is Kitwe Central Business District (CBD), bordered by Oxford, Chisokone, Obote and President Avenues. The site is approximately 350km north of Lusaka, the capital city of Zambian, 12°49'S, 28°12'E southern side of the equator and at an altitude of 1,295m above sea level. Geologically, the site general soil type is sandy and sandy clay loams and total project area 0.146km^2 (length 561 meters and width 262 meters). The current drainage design contains one hundred fifteen (115) storm-water inlets and five (5) storm water outlets.

The 2007/08 rain season caused urban flash floods in urban districts of Lusaka, Central and Copperbelt Provinces. In the Copperbelt, Kitwe City town the flash flood was assumed to be caused by rapid urbanisation, faulty city drainage network and poor storm-water management.

Developing a sustainable urban water management strategy is a complex challenge as it requires encompassing a broad range of technical, environmental and institutional issues which may operate over a variety of spatial and time scales. Worldwide regulatory practice now recognizes the need for legislative and administrative frameworks to address the environmental problems caused by impermeable urban surface. For example, German, United Kingdom agencies and organizations already have a basis for regional and catchment's scale planning which incorporates element of both basic and supplementary measures for the management of urban drainage. In Zambia, the Disaster Management Mitigation Unit ensures that all national development plans embrace all the aspects of disaster management through mitigation, prevention, preparedness, response relief, rehabilitation and construction (Disaster Management and Mitigation Unit, 2005). Thus in order for the Local Authority of Kitwe to mitigate and prevent the reoccurrence of urban flash flood, there is need to assess the likely causes of these flash floods and this may easily be done through a Storm Water Modelling (SWMM) system. Hence, the purpose of this research is to model storm-water runoff for Kitwe CBD using Storm Water Management Model (SWMM) software.

2. Theoretical Reviews

The natural or man-made factors including meteorological, hydrological and human influences tend to cause urban floods. However modification responses have been undertaken where the uses of empirical formulae in urban hydrology are being replaced with the developed application of mathematical simulation models of the rainfall- runoff process. According to Department of Environmental Programs (2003) the purpose of modeling effort is to determine the feasibility of using Low Impact Development (LID) storm water management practices to address storm water quality and storm water quantity issues and applying engineering analysis to analyse the hydrology by using the US EPA's RUNOFF block of the Storm Water Management Model (SWMM).

This means that the drainage area characteristics are needed to provide an estimated area of the impervious and pervious land surfaces. For example, the hydraulics of the Arthur Capper drainage systems was modeled using the EXTRAN block of the USEPA SWMM model, and its input data included ground surface elevations, pipe diameters, invert elevations, lengths and slopes. Additionally, Auckland Region Council (1999) developed a model which was recommended for use in storm water management design and suitable for assessing the effects of land use change. It was to model both frequent and extreme events applying to distribute or lumped catchments and simulating natural systems as well as engineered system such as pipe network. The main key features of the storm-water runoff model included; a standard 24hr temporal rainfall pattern having peak rainfall intensity at mid-duration, runoff depth calculated using Soil Conservation Service (SCS), rainfall-runoff curves, time of concentration estimated using an empirical equation and separate analysis of pervious and impervious components of urban catchments. According to Environmental Protection Agency (2010) storm water management model is a dynamic rainfall/runoff subsurface runoff simulation model which can be used for single events and long term continuous simulation of the surface hydrology quantity and quality for primarily urban areas. The model's simulated parameters for sub-catchments area include; surface roughness, depression storage, flow path length and slope, and for infiltration, the parameters included;

Horton equation, maximum/minimum rates and decay whilst for hydraulic/conduits parameter included; Manning's roughness, pipe diameter and shape.

3. Major parameters for storm water modelling

a) The hydrological compartment; rainfall data needed and possible means of analysing include rainfall characteristics such as correlation of rainfall records, partial duration series. Mostly the regression techniques and intensity-duration frequency (IDF) are used to analyse rainfall data and to determine the distribution of rainfall in time respectively. Also rainfall variability is used since the amount of rainfall that falls over a catchment varies with time.

b) The land cover compartment; sub catchments such as the drainage area, catchment width, the slope of the catchment and land use are considered. Also, the appropriate Manning's overland flow coefficients in are also used (see Table 1).

Table 1.0 Manning's overland flow coefficient (Source: McCuen, R. et al. (1996), Hydrology)

SURFACE	n	SURFACE	n
Smooth asphalt	0.011	Range (natural)	0.13
Smooth concrete	0.012	**Grass**	
Ordinary concrete lining	0.013	Short prarie	0.15
Vitrified clay	0.015	Dense	0.24
Cast iron	0.015	Bermuda grass	0.41

Additionally, depression storage was also considered and these included either the puddles or ditches in the surface of both pervious and impervious areas where rainwater are retained. Since meaningful observations of the magnitude of depression storage could not be obtained easily, individual depressions of appreciable area relative to the drainage basin under consideration were usually lumped with interception and treated as initial loss with respect to storm runoff (see Table 2).

Table 2.Depression storage (Source: ASCE, 1992 Design & Construction of Urban)

Land cover	Storage (mm)
Impervious surfaces	1.27 – 2.54
Lawns	2.54 – 5.08
Pasture	5.08
Forest litter	7.62

Furthermore, Horton's (equation 1) based on empirical observations is used to determine the maximum and minimum infiltration rates.

$$f_t = f_c + (f_o - f_c)e^{-kt} \quad \textbf{(1)}$$

Where; f_t= infiltration rate at time t;

f_o = initial infiltration rate or maximum infiltration rate;

f_c = constant or equilibrium infiltration rate after the soil has been saturated or minimum infiltration rate and,

k = decay constant specific to the soil.

c) The hydraulic compartment; modern drainage systems which collect runoff from impervious surface such as roofs and roads to ensure that water is efficiently conveyed to waterways through pipe networks. Common distribution appurtenances which receive surface-runoff from both road and side carriageways are sloped both laterally and longitudinally so that runoff water from both areas is constantly moving under gravity. At project site, conduits channels/pipes present included the either open/closed rectangular shaped curvets as well as the circular curvets. Additionally Inlets provided at the junction points to intercept the runoff before it can reach the pedestrian sidewalks and project site has Kerbs and gullies, whereas manholes were also considered as they provide for cleaning since runoffs are subjected to partial or complete clogging.

4. Estimating the surface runoff

Three methods that have gained particular credibility are the Rational/Lloyd-Davies method, the Department of Transport's Advice Note HA37/88 method, and the Transport and Road Research Laboratory (TRRL) hydrograph method (O'Flaherty, 2008). These methods cannot be described in detail as the SWMM software is automatically embedded with them. Though Rational method was used for modelling as it illustrated the factors that must be considered in surface runoff calculations as well as confined to relatively small drainage areas up to 80 hectares. Additionally, Manning's equation was used as it expresses the relationship between flow rates, cross sectional area, hydraulic radius and slope in all conduits.

5. Data collection

a) Hydrological compartment; rainfall data from three (3) Zambian Meteorological Departments namely Ndola airport, Mwekera and Kafironda meteorological stations for a period of 45 years.

b) Land covers compartment; storm runoff drainage system design and development maps were collected from the Kitwe City Council at Department of Engineering and Roads as well as Planning. The maps depicted the location of main drains, branches, subsidiary drains, sub-catchment areas, roads, discharging points and developmental area of the site. An infiltration capacity was obtained on site through the double cylindrical infiltrometer (Raghunath, 2006).

c) Hydraulic compartment; channel type, cross section, material and dimension of pipe and data on drainage appurtenances was collected. This was based on field inventory survey which included assessing the conditions of each storm water inlet and measuring of invert levels using surveying instrument to understand the runoff direction in the curvets.

6. Modelling and simulation

SWMM software was downloaded from the website: http://www2.epa.gov/water-research/storm-water-management-model-swmm to be used in modeling and simulation of storm water. Table 3 highlights the checklist of input data into SWMM software.

Table 3 Checklist of SWMM input data

Compartment	Main property	Model input
Hydrological	Rain gauge	➢ Intensity
Land Cover	Sub-catchment	➢ Area ➢ Width of overland flow path ➢ Average surface slope ➢ Per cent of impervious area ➢ Manning "n" of impervious and pervious area ➢ Depth of depression storage on impervious area and pervious area ➢ Percent of impervious area without depression storage.
	Infiltration	METHOD- HORTON ➢ Maximum and minimum rate ➢ Dry soils and dry time ➢ Decay constant
Hydraulic	Conduit	Shape and maximum depth (diameter) Length Manning's Roughness coefficient
	Inlet	Elevation of inlet invert

Simulation of modelled data was conducted using various situations obtaining on project site. Perfect condition, was used to test the software by assuming the operation of a commissioned drainage channel. Then, the simulation was conducted on three (3) critical conditions on site.

i) Simulation on completely blocked drainage system along Oxford/Zambia to Oxford/President Avenue. Note that the software does not recognise zero (0) digit on channel depth, an approximated digit of 10mm was used. Note that a surcharge was recorded at inlet DI-055 surcharged.

ii) Simulation on partially blocked drainage system along Oxford/Zambia to Oxford/Independence Avenue. A measured channel depth of 50mm was used. Note that the partial blockage had an effect on Inlet-002, Inlet-003 and Inlet-004 along the channel.

iii) Simulation on open drainage channel along Chisokone Avenue with solid waste dumped in it was also considered. Note a partially blocked scenario was considered for simulation with input channel depth of 20mm. Figure 8.3 shows the pictorial view the drainage network after simulation. It was noted that the system showed that partial blockage on drainage C-113 would result in overflowing of storm water.

After a successful simulation run, status report can be viewed in numerous ways. The status report contains useful summary information about the results of a simulation run. The full status report indicates results on node flooding and conduit surcharge summary in table form.

7. Conclusion

From the simulation conducted on perfect condition showed that 2007/08 rainfall had no effect on the flash flood experienced. Instead it can be concluded that the urban floods experienced in Kitwe CBD during the 2007/08 rain season was due to poor maintenance of drainage systems. This implies that the software can be used as an office field checking operation and if combined with a GIS it can be a very useful tool since the software has a map query which identifies objects on the study area such as surcharging nodes. Hence the impact of development project to the drainage system can be done easily by considering the percentage of impervious and rainfall patterns.

8. Recommendations

SWMM requires rainfall data; hence there is need for functioning meteorological stations placed either in town or at civil centre to monitor the rainfall pattern as well as rehabilitating the meteorological at the Copperbelt University.

SWMM has the ability to analyse the effect of water quality on drainage channel due to suspended solid waste carried in storm water. A project on water quality should be conducted to identify the effect of pollutants due to build up and wash off parameters.

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