

Figure 3. Normalized incremental free surface displacement



Figure 4. Dependence of free surface displacement with captured air mass for varying conditions of L_{es}/D_t

Figure 5 presents the evolution of air releasing through the shafts for cases in which the amount of captured air varied significantly. The figure presents the symmetric plane views of the air motion at different times and the cross-section views of the shaft station, similarly to what is presented in Figure 1. It is noticed the small shaft extrusion length difference $\Delta L_{es}/D_t=0.05$ between the cases resulted in much larger air discharge into the shaft.

A comparison of the simulated pressure head results at the horizontal conduit centerline, immediately below the vertical shaft, is presented in Figure 6. Pressure head results are normalized by the vertical length of the shaft L_{shaft} . With the shaft

lower rim extension, magnitude of the pressure head oscillation can be significantly declined, and particularly when $L_{es}/D_t>0.35$, the oscillation turns to be small enough to be ignored for practice. Consistently with results from previous experimental investigations on the release of large air pockets, pressure head results were much smaller than the elevation of the maximum free surface during the air pocket release process.



Figure 5. Evolution of air releasing through different L_{es}/D_t conditions



Figure 6. Normalized shaft bottom pressure head at the springline level

Conclusions

Some operational problems in stormwater systems are created by the presence of air phase that is entrapped during rapid filling conditions of these systems. Among these problems is the displacement of water in vertical shafts created by the uncontrolled release of air through these structures when they are pressurized. In some cases this air release may lead to stormwater geysering events, with deleterious impacts that include public health issues, structural damage, among others.

The present work evaluated an alternative to perform geometric changes in dropshafts and prevent uncontrolled air release via extending the lower rim of the shaft toward the centerline of the conduits. Since air pockets occupy at most the upper half of conduits as they propagate in stormwater systems, the goal is to prevent significant air discharge in smaller dropshafts, which could cause geysering. Rather, by creating these extensions in dropshafts, the fraction of discharged air can decrease to a point in which the displacement is no longer noticed, as is indicated on the numerical simulation results presented in the present work.

This investigation will be completed with more detailed CFD simulations and some experimental data collection illustrating the benefits of positive L_{es}/D_t . The idea is to assess to what extent such extensions can control air discharge in shafts with other D/D_t ratios, as well other air pocket volumes. Also, it is important to assess what are the impacts of such extensions in terms of energy losses in the conduits when flow is pressurized.

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Coupling HEC-RAS and HEC-HMS in Precipitation Runoff Modelling and Evaluating Flood Plain Inundation Map

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Abstract

The climate change and land use change have raised the challenges associated with increased runoff and flood management. The risks associated with flooding have been increasing with development in flood plain and changing climate resulting in increase in inundation of flood plain. The current study will help to evaluate the extent of flood plain in the study area – copper slough watershed (CSW) in Champaign, Illinois; utilizing the known precipitation and land use. The study of CSW is taken into account, as this is the largest watershed of Champaign City and had undergone major land use change increasing the flooding issues in the region. The conducted research utilizes the hydrologic engineering center - hydrologic modelling system (HEC-HMS) and Hydrologic Engineering Center – River Analysis System (HEC-RAS) as the modelling tool to develop runoff and floodplain inundation evaluation model for known precipitation. The model also incorporates Aeronautical Reconnaissance Coverage Geographic Information System (ARCGIS) extensions- HEC-GeoRAS and HEC-GeoHMS for the spatial analysis of the watershed. The hydrologic analysis is performed using HEC-HMS while the hydraulic modeling is done using HEC-RAS. Forcing the model with forecasted precipitation can also help with flood warning system by generating pre-flood inundation maps.

Keywords: Rainfall-Runoff Model, HEC-HMS, HEC-GeoHMS, HEC-RAS, HEC-GeoRAS.

INTRODUCTION

The changing climate in the past century is quite convincing based on several studies (IPCC, 2014a; Carrier et al., 2016). In the period from 1951 to 2012, global temperature increased at the rate of $0.8 \,^{\circ}$ C to $0.14 \,^{\circ}$ C (IPCC, 2014a). Climate change has led to increasing temperature in some places while increasing precipitation and streamflow at the other places (Kalra and Ahmad, 2011, 2012; Pathak et al., 2016a). The changing climate is a driver that induces the shifts in hydrological regimes by changing different parameters of hydrologic cycle such as precipitation and evaporation (Middelkoop et al., 2001; Kalra et al., 2013 a&b; Pathak et al., 2016b). Change in precipitation that results in changes in streamflow can hence be linked to change in climate indices (Tamaddun et al., 2016a; Sagarika et al., 2014). Streamflow changes in US has been

attributed to ocean climatic variability in some studies highlighting the impact of climate change (Sagarika et al., 2015a,b). The impacts of variation in climate differs regionally inducing droughts in some region while in other region intensifying precipitation and runoff (Middelkoop et al., 2001; IPCC, 2014b; Tamaddun et al., 2016b). In addition to climate change, the changes in land use and urbanization increase the non-pervious area resulting in increasing the runoff from the watershed by reducing the infiltration (Parker, 2000; Sohn et al., 2015; Thakali et al., 2016). Thus, the flood events are accompanied by the change in land use and intensification of storms due to climate change. The study conducted by Red Cross in 2010 (WDR, 2010) suggests 99 million peoples affected by flood hazards worldwide. Assessments of flood affected areas resulting from extreme precipitation and changing land use can be helpful in better understanding the flood events (Ahmad and Simonovic, 2006; Mosquera-Machado and Ahmad 2007; Dawadi and Ahmad 2012).

Assessment of the extent and depth of floods has been one of the prime goals for the water resource managers for making policies for mitigation of flood impacts. Such an assessment is also critically important to inform the public and policy makers and garnering their support for making such policies and structuring a suitable governance (Paz et al, 2013; Maheswari et al., 2014; Dhakal and Chevalier 2015, 2016). Physical models take into account the underlying parameters of the system being simulated and are able to simulate the results based on the changes in the key driving parameters. Motivated with the conducted literature review, current study develops the physical model to mimic the rainfall runoff event with the aid of hydrologic and hydraulic feature of Hydrologic Modelling System (HEC-HMS) and Hydrologic Engineering Center - River Analysis System (HEC-RAS), respectively. Previously, Knebl et al., (2005); Yuan and Qaiser (2011) and Tahmasbinejad et al., (2012), have coupled HEC-HMS and HEC-RAS modelling tools. Current study couples these tools with Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) extensions, Geographic hydrological model extension (HEC-GeoHMS) and Geographic River Analysis extension (HEC-GeoRAS) for generating the input model data from the available data in digital format for HEC-HMS and HEC-RAS, respectively.

Precipitation is the only source of runoff and flood in the one or other form but the transformation of the runoff from precipitation is governed by the parameters such as land use, soil type, evaporation, and storage. HEC-HMS deals with the basic water balance equation taking into account major parameters that governs runoff and is capable of modelling rainfall runoff event. While, HEC-RAS can simulate the runoff hydraulics through the channel based on the channel morphology and can generate the extent of the inundated region. Coupling these two models can assess the inundated region for a known storm event. Further, the calibrated coupled model can be used for future flood plain mapping with the future rainfall data and land use scenarios.

STUDY AREA AND DATA

Illinois receives average annual precipitation of around 48 inches and flooding is a major hazard of this state. Copper Slough Watershed (CSW) is situated in central region of Illinois in terms of latitude. Most of the region of CSW falls in the Champaign city with high imperviousness and

moreover three interstate highways are also located in this watershed resulting the high runoff per unit area for a given storm event. Taking above mentioned aspects into consideration CSW is incorporated as the study area in the current research. The precipitation data for the watershed was abstracted from the USGS station 05590050. The precipitation station along with the CSW is shown in Figure 1. The discharge data from the watershed along with the gage heights were obtained from the same USGS station as precipitation data. The area of the delineated watershed with the outlet at the selected gaging station was obtained to be 15.92 sq.km. The terrain data, soil type and land use data is tabulated in Table: 1 along with the website from where they were abstracted.



Fig: 1. Study area of Copper Slough Watershed with 7 sub basins, streams, and USGS rainfall and runoff gaging station.

Table: 1 Input Data for the rainfall runoff model along with the source from where they were abstracted.

SN	Data	Data source
1.	1/9 arc second Digital	United States Geological Survey (USGS) National map viewer.
	elevation model	Website: https://viewer.nationalmap.gov/basic/
	(DEM)	
2.	Land use data 2011	National Land Cover Database (NLCD) website: www.mrlc.gov
3.	Soil type Data	Soil Survey Geographic Database (SSURGO) Website:
		http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx
4.	Rainfall, Runoff,	USGS station site inventory for station ID 05590050
	Gage Height data	Website: http://waterdata.usgs.gov/nwis/inventory

METHODOLOGY

The model structure is shown in Figure 2 showing the coupling of the model components used in the study. First the runoff is obtained from the precipitation data with HEC-HMS model. The obtained runoff is then simulated in HEC-RAS. The output of HEC-RAS is then exported to HEC-GeoRAS for flood plain mapping. In this section first, HEC-HMS modelling approach along with the generation of input file of HEC-HMS with HEC-GeoHMS is discussed followed by the modelling approach in HEC-RAS and generating HEC-RAS inputs with HEC-GeoRAS is briefly described. Lastly, the section also elucidates the mapping of the flood plain with HEC-RAS results in HEC-GeoRAS.



Fig: 2. Modelling structure of rainfall-runoff model for generating floodplain inundation map incorporating HEC-HMS, HEC-RAS along with Arc-GIS extensions HEC-GeoHMS and HEC-GeoRas.

The input data for HEC-HMS was generated with HEC-GeoHMS which incorporates spatial analyst and other features of Arc-GIS. Digital Elevation Data was used in HEC-GeoHMS for generating drainage paths and sub basins along with other features such as sub basin slope and area, drainage path slopes, and longest flow paths of sub basin. These parameters were then used as input for HEC-HMS. The generated HEC-HMS model is shown in Figure 3. The runoff of CSW is mainly generated by the precipitation, thus the base flow of the watershed was neglected. Soil Conservation Service (SCS) curve number is implemented for the precipitation loss calculations. The curve number for each sub basin was generated with the land use and soil type data. The land use data obtained from NLCD were reclassified in Arc-GIS into four major groups based on Land Cover Institute (LCI) as tabulated in Table: 2. While runoff transformation from precipitation was conducted using SCS unit hydrograph method and the routing of the flow from the outlet of each sub-basin to the outlet of entire watershed was achieved using Muskingam-Cunge method.

Table: 2. Reclassified CN look up table for Copper Slough watershed based on classifications of USGS Land Cover Institute (LCI) 2001.

		Type of Land Use					
SN	Soil Type	Water	Medium Residential	Forest	Agriculture		
1	А	100	57	30	67		
2	В	100	72	58	77		
3	С	100	81	71	83		
4	D	100	86	78	87		



Figure: 3. HEC-HMS model for Copper Slough Watershed showing modelled sub-basin, junction, reach, and sink.

While generating HEC-RAS geometric input data using HEC-GeoRAS first, the Triangular Irregular Network (TIN) data was obtained from the available USGS DEM data using 3D analyst of Arc GIS. After generating TIN, the river was digitized in HEC-GeoRAS. Figure 4. shows the digitized river geometry for the CSW upstream to the USGS station 05590050 in HEC-GeoRAS. For this, the layers were created for stream centerlines, bank lines, flow path lines, and (cross section) XS cut lines. In editor mode each layers were then digitized. The attributes for all layers were computed and the data was then exported to HEC-RAS. GIS data was then imported in HEC-RAS from the geometry window of HEC-RAS. The cross sections generated in GIS were observed as stations numbers from downstream station to upstream station in the cross section editor window of HEC-RAS (Tate, 1999). HEC-RAS model was then run for different observed discharges and gage heights from USGS stations 05590050 at the downstream of the river reach. The calibration was conducted by changing the manning's n to get the simulated depth of flow same as the depth measured at the gaging station. The calibrated model was then validated for different events that were used for calibration. The simulated runoff from HEC-HMS was then used in the calibrated and validated HEC-RAS model to generate the inundation extent and the water surface elevation. The flood plain map showing the inundation extent was generated with HEC-GeoRAS by exporting the HEC-RAS results to HEC-Geo RAS.



Figure: 4. Digitized geometry of the simulated Copper Slough River length in HEC-GeoRAS using TIN. Green lines show the crossections, red lines are the river bank lines, and blue lines represent centerline of stream and flow path lines.

RESULTS AND DISCUSSION

The results of simulated runoff for the precipitation event were obtained from HEC-HMS and the flood plain model was generated with the aid of HEC-RAS and HEC-GeoRAS. The water surface profiles, discharges and velocities along with Froude number at different cross sections were obtained with the aid of HEC-RAS

HEC-HMS results

Based on the land use data and the soil type data the computed weighted area curve number for each sub basin of CSW is shown in Table 3. The simulated runoff obtained using curve number for the storm of 25th June 2015 was lower than the observed value demanding the calibration of the model. The lower prediction in the runoff can be explained as the change in land use since 2011 resulting the change in lag time and time of concentration due to the variations in curve number. The model was calibrated to reduce the error in lag time by changing the curve number. Manning's n of the reaches were also tweaked for the calibration and for the model it was observed that the model was more sensitive to the curve number than the values of manning's n considered for all reaches. The calibration of the model was done for the 8th July 2015 storm and the validation was conducted for the storm of 25th June 2015. The calibration and validation period was selected with the recent peak events so, the recent changes in the physiology of the watershed could be taken into account. The model simulated runoff for the storm events 8th July 2015 and 25th June 2015 was reported to be 6.7 m³/s (236.6 cfs) and 16.1 m³/s (568 cfs), respectively. While the corresponding observed discharge was 6.7 m^3 /s (181cfs) and 20.08 m^3 /s (709cfs). The calibrated curve number is reported in Table 3. The simulated discharge for 25th June 2015 is used as an input for HEC-RAS. The results obtained from HEC-HMS can be further refined by considering the base flow and other sources of runoff except rainfall. Different loss