5-21-2017

Response of Climate Change on Urban Watersheds: A Case Study for Las Vegas, NV

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Abstract

The current research is a partnering effort between Southern Illinois University Carbondale and City of Las Vegas to assess the vulnerability to drought, extreme heat, and extreme precipitation. This study focuses on precipitation and uses different climate scenarios from the high-resolution North American Regional Climate Change Assessment Program (NARCCAP) climate model data to evaluate the existing stormwater infrastructure of the Gowan watershed in the Las Vegas valley. Six NARCCAP models considered in the study have shown the Gamma distribution as the best fitted from Kolmogorov Smirnov best fit test. Delta change method is adopted to quantify the effect of climate change on storm depth. U.S. Army Corps of Engineers HEC-HMS model is used to evaluate the changes in peak flow, storage, and outflow within the watershed. The findings of the analysis show that the drainage facility of the study area is vulnerable to the related climate change impacts. This study helps to quantify the effect of climate change on design storm depth of urban watershed.

Introduction

The impact of changing climate on regional hydrology has led to altering the intensity, amount, type and frequency of precipitation (Solomon, 2007; Dawadi and Ahmad 2012; Pathak et al., 2016a, b). IPCC concluded that there would be increased precipitation intensity in future which ultimately increases the risk of flooding (Bates et al. 2008; Sagarika et al., 2015a, b). In many regions of the world increasing trends on these extremities were already seen (Christensen et al., 2007; Kalra and Ahmad, 2011, 2012; Sagarika et al., 2014). Even the regions where there is decrease in total annual rainfall has shown an increase in shorter duration storms due to climate change (Dopdato et al., 2011). Intense precipitation increases the peak runoff (Lemmen and Warren, 2004; Tamaddun et al. 2016a, b), which is responsible for downstream damages with serious socio-economic and ecological impacts. Almost half of the world population lives in urban areas and the trend of the urbanization is increasing rapidly in recent twenty years (Cohen, 2006). This urbanization impacts storm water drainage facilities because it reduces infiltration due to increase in impervious surface increases runoff (Semadine-Davies et al., 2008; Ghimire et al., 2016).

Urban water drainage facilities are designed on the basis so that the peak discharge after development should not exceed the predevelopment condition (Crohshey, 1986). To meet this purpose detention basins are designed and implemented. Climate change has increased the probability of more frequent exceedence of design storm (Kalra et al., 2013a,b). This results in flooding because design capacity of detention basins is exceeded. This study gives the in-depth analysis of such case for the study area. Using available mid-20th century data for the design storm depth may not represent the present frequency of the rainfall (Rosenberg et al., 2010). In past different statistical approaches for the frequency analysis has been proposed. Single statistical approach may not be appropriate for each hydrological dataset (Ahmed and Tsanis, 2016). This study aims to get the particular statistical distribution method appropriate for the study area among twenty-seven statistical methods using Kolmogorov Smirnov best fit test.

North American Regional Climate Change Assessment Program (NARCCAP) provides precipitation depth on high resolution climate scenarios from multiple Regional Climate Model (RCM) and Global Climate Model (GCM) (Mearns et al., 2009). Six pairs of RCM-GCM models provided by NARCCAP are used for the study. The precipitation data provided by NARCCAP are areal average gridded data (Chen and Knutson, 2008). Some study applied delta change factor for the effect of climate change on design storm depth (Forsee and Ahmad, 2011). While some study applied it on rainfall time series to get future time series (Prudhomme et al., 2002). For the study, the climate change impacted rainfall depth is obtained using delta change factor. U.S. Army Corps of Engineers Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) used in this study is one of the best computer model for the storm water hydrology of urban areas (Akan and Houghtalen, 2003).

The objective of this study is to find the localized best frequency distribution to calculate the future design storm depth of the study area under changing climate. The study uses the data from NARCCAP. Six sets of NARCCAP RCM-GCM paired model data were analyzed for twenty-seven statistical methods using Kolmogorov Smirnov best fit test. The best fitted statistical method is used to calculate storm depth for specific duration. Delta change factor, which is the ratio between future and historic storm depth for particular intensity and duration, from NARCCAP model data is applied to the storm depth from historic data to calculate future design storm depth. Thus obtained future design storm depth is applied to the existing hydrologic model of the study area developed using HEC-HMS. Hydrological outputs of one of the frequently flooding detention basin were analyzed and compared with baseline scenario.

Study Area

The study area selected in the current study comprises of the Gowan watershed, which is one of the ten watersheds in the Las Vegas valley. Though the climate of the valley is characterized as semi-arid, flooding in the valley is frequent in past 20 years. Clark County Regional Flood Control District (CCRFCD) is responsible for the overall planning of the flood control within the valley. Most of the watershed falls under the City of Las Vegas jurisdiction. CCRFCD maintains jurisdiction of the Gowan Watershed and is responsible for programming flood control funds. The City of Las Vegas is responsible for prioritization of proposed flood control design and construction projects within the watershed. The total area of the Gowan Watershed is 216 km^2. Drainage facilities within the watershed consist primarily of detention basins connected by conveyance facilities. The study area has undergone significant urban growth in recent years (Singer, 2004). Figure 1 shows the study area within the Clark county and City of Las Vegas.

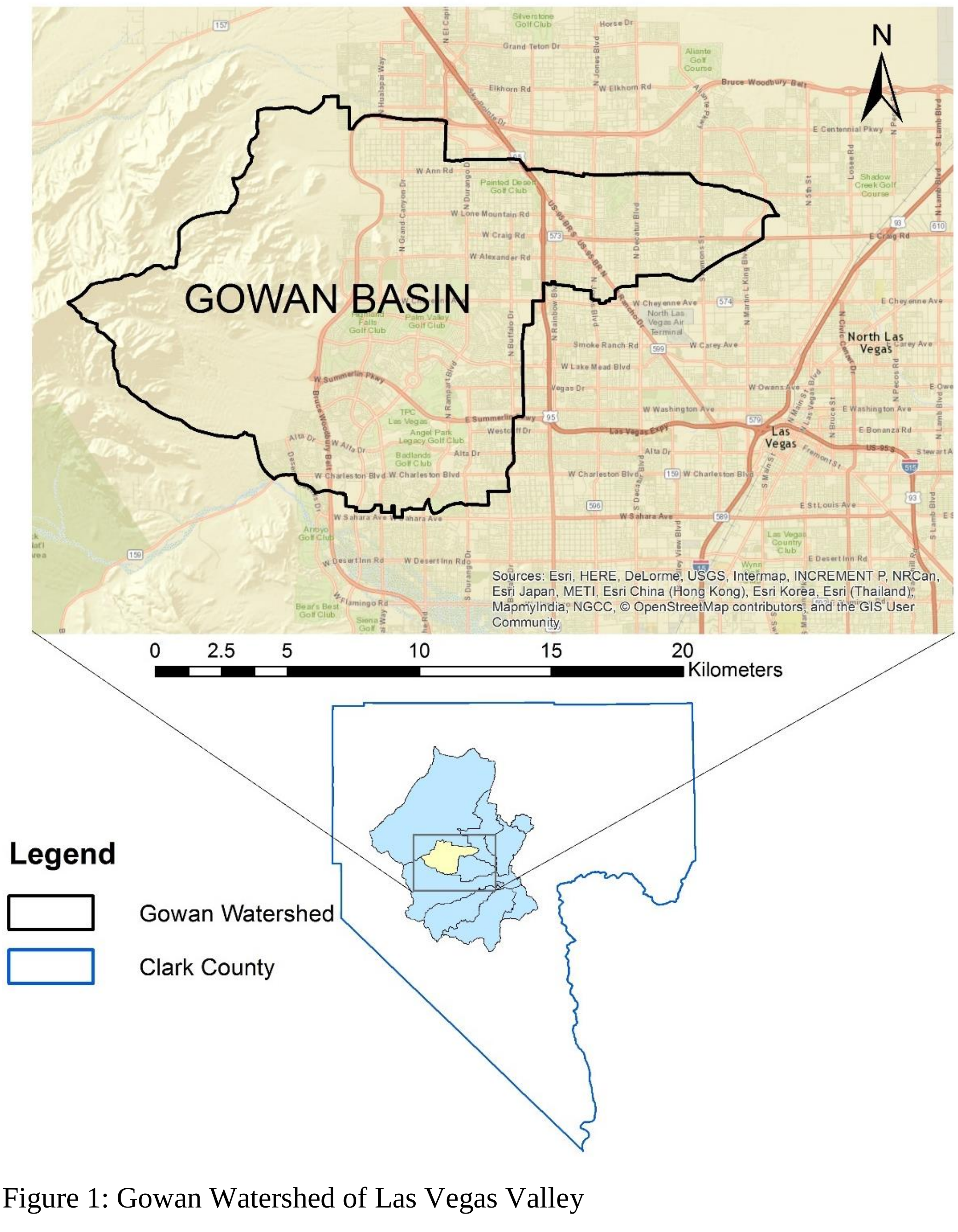


Figure 1: Gowan Watershed of Las Vegas Valley

Data and Model

The NARCCAP model dataset has 3hr data time series for the present and future and is available in NetCDF file format. Six combinations of RCM-GCM paired NARCCAP model data were used for the study. The data sets contains historic/present data from 1970-2000 and future projection data from 2040-2070. These 3hr temporal datasets are spatially gridded in 50km resolution. A2 emission scenario of greenhouse gas and aerosol concentration described in the Special Report on Emission Scenario (SRES) is used to produce the data of each NARCCAP model (Music and Caya, 2007). The NARCCAP RCM-GCM paired model used for the study are listed on Table 1. HEC-HMS Hydrological model of the Gowan watershed prepared by CCRFCD (2008) is used for estimation of the peak discharge and operation of the detention basin.

Table 1: Models used for study with their abbreviation.

Model (RCM-GCM)	RCM	GCM
CRCM-CCSM	Canadian Regional Climate Model	Community Climate System Model
CRCM-CGCM3	Canadian Regional Climate Model	Third Generation Coupled Global Climate Model
HRM3-GFDL	Hadley Regional Model 3	Geophysical Fluid Dynamics Laboratory
HRM3-HadCM3	Hadley Regional Model 3	Hadley Centre Coupled Global Climate Model
RegCM3-CGCM3	Regional Climate model version 3	Third Generation Coupled Global Climate Model
RegCM3-GFDL	Regional Climate model version 3	Geophysical Fluid Dynamics Laboratory

CCRFCD had prepared hydrologic model of each of the Clark county watershed in HEC-1. The HEC-1 model of the study area was converted to HEC-HMS due to its graphical user interface capability (CCRFCD, 2008). This HEC-HMS model of study area was prepared based on future expansion and landscape design. The model consists of sub-basin, drainage facility, reach, junctions, detention basin and outlet.

Method

The analysis performed to achieve the desired objective is twofold i.e. (1) frequency analysis and delta change factor calculation and (2) Hydrological analysis.

Frequency analysis and delta change factor calculation

From the 3hr NARCCAP model set available on Network Common Data Form (NetCDF) file format data was extracted. 3hr data series was converted to the 6hr data series using 6hr window (Bedient and Wayne, 1988). For historic and future time frame the annual maximum is calculated. Initial spin up period data for present data before 1971 and for future data before 2041 were omitted, thus only data available for 30 years of time frame from 1971-2000 for present and 2041-2070 for future was used. Frequency analysis were performed on the data using twenty-seven statistical distribution. Kolmogorov Smirnov test for best fit was applied among the twenty-seven statistical distribution. The scientific basis of the distributions are presented by Kozanis et al.

(2010). Grillakis et al. (2011) has used the similar statistical approach effectively to access the climate change impact on a small watershed. The best fit distribution method was adopted to calculate the present and future design depth for each NARCCAP model data. The delta change factor is determined with the ratio of future to present 6hr 100yr depth.

Hydrological analysis

Existing HEC-HMS model prepared by CCRFCD (2008) is used for the hydrological analysis of the study area. The model contains sub-basin, junction, detention basin and reach as the hydrological unit. Each sub-basin has storm depth assigned based on storm distribution. The calculated delta change factor was applied to the storm depth of the existing HEC-HMS model of the study area. The model was run from 01:05AM, Jan 01 to 02:00AM, Jan 09 with computation time interval of 5 minutes. The hydraulic parameters such as inflow, storage, change in elevation and outflow were considered for the comparison between design storm depth and climate change adopted storm depth. The outputs of the model were analyzed for one of the detention basin named SUM5DB, which was over flooded during past 20 years of extreme events. A comparison on output from HEC-HMS model using climate change adopted storm depth and design storm depth were carried out.

Result and Discussion

Total six pairs of RCM-GCM paired model data were considered for the assessment. Statistical fitting using Kolmogorov Smirnov test was carried out for the present and future datasets of each model. The best fitted statistical distribution for each model dataset is presented in Table 2.

Table 2: Best fit distribution for NARCCAP model data for 6hr duration

Distribution	CRCM-CCSM	CRCM-CGCM3	HRM3-GFDL	HRM3-HADCM3	REGCM3-CGCM3	REGCM3-GFDL
Normal						
Normal (L-Moments)						
Log Normal						
Galton						*
Exponential						o
Exponential (L-Moments)						
Gamma	*	*			*	
Pearson III						
Log Pearson III						
EV1-Max (Gumbel)						
EV2-Max						
EV1-Min (Gumbel)						
EV3-Min (Weibull)						
GEV-Max				*	o	
GEV-Min						
Pareto			o			

GEV-Max (L-Moments)						
GEV-Min (L-Moments)		○	*			
EV1-Max (Gumbel, L-Moments)						
EV2-Max (L-Moments)						
EV1-Min (Gumbel, L-Moments)						
EV3-Min (Weibull, L-Moments)	○			○		
Pareto (L-Moments)						
GEV-Max (Kappa Specified)						
GEV-Min (Kappa Specified)						
GEV-Max (Kappa Specified, L-Moments)						
GEV-Min (Kappa Specified, L-Moments)						

Note: The symbol * is for present and ○ is for future best fit respectively

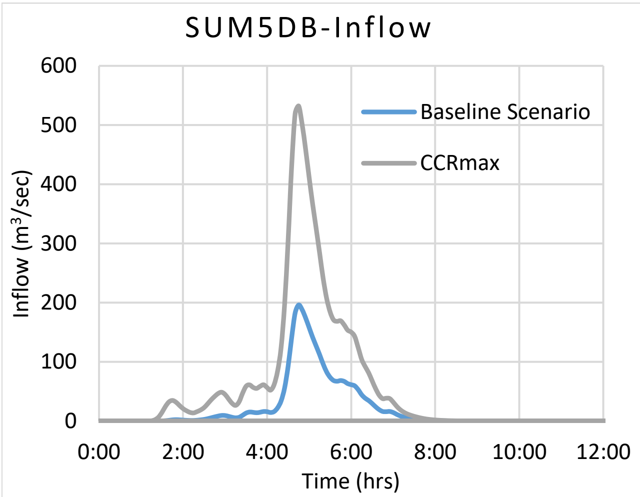
From Table 2, Gamma distribution was selected for 3 times, which is the 25% of the total selection. While, GEV-max, GEV-Min (L-moments) and EV3-Min (Weibull, L-Moments) were selected twice and Galton, Exponential and Pareto distributions were selected for once. From the result the Gamma distribution is the best fit and hence, selected for the further analysis and calculation of the storm depth for present and future storm depth. The delta change factor for each model were presented on Table 3. The maximum change on future datasets were seen on the HRM3-HADCM3 model with delta change factor 2.2.

Table 3: Present & Future 6hr 100yr depths with delta change factor for NARCCAP models

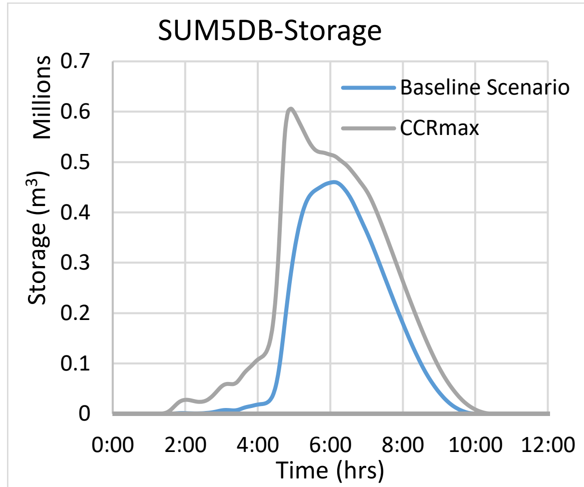
Climate Model	Present 6hr 100yr depth (mm)	Future 6hr 100yr depth (mm)	Delta Change Factor
CRCM-CCSM	20.98	22.72	1.08
CRCM-CGCM3	17.13	21.56	1.26
HRM3-GFDL	99.67	122.12	1.23
HRM3-HADCM3	29.70	65.43	2.20
REGCM3-CGCM3	40.38	41.13	1.02
REGCM3-GFDL	61.95	110.98	1.79

The delta change factor with highest value was adopted to the existing HEC-HMS model of the Gowan watershed. The output from HEC-HMS model for inflow, storage, change in storage elevation and outflow were presented on Figure 2 (a), (b), (c) and (d) respectively for baseline and maximum climate change scenario. The peak inflow for SUM5DB is increased to 532.3 m^3/s under climate change condition from 198.3 m^3/s design condition. Similarly, the storage is increased from 473656.0 m^3 for design value to 606008.7 m^3 for climate change condition. The peak outflow is increased from 60.96 m^3/s to 469.9 m^3/s from design condition to climate change condition. The peak for each scenario is reported on Table 4. The results show the climate change consideration increase the storm depth and the functioning of detention basin would be greatly affected. For climate change condition, the peak inflow at SUM5DB was observed at 4:45AM, while peak storage, maximum change in storage elevation and peak outflow was observed at 4:55AM Jan 01.

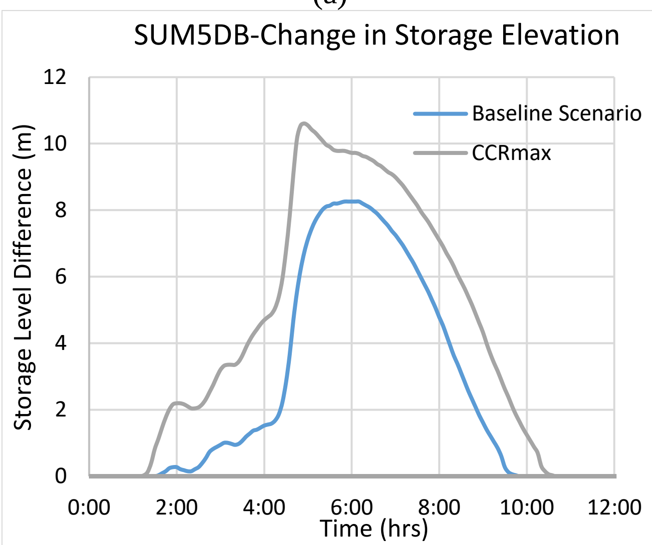
For baseline scenario, the peak inflow, peak storage, maximum change in storage and peak outflow were observed at 4:45AM, 6:00Am, 5:50AM and 6:00AM respectively.



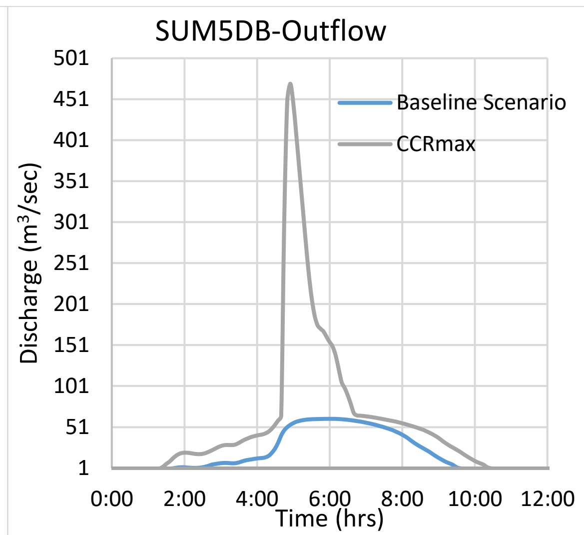
(a)



(b)



(c)



(d)

Figure 2: Hydrological Modeling outputs for Summerlin Detention Basin (SUM5DB) for baseline and maximum climate change scenario.

Table 4: Hydrological modeling output for SUM5DB detention basin

Scenario	Peak Inflow (m^3/s)	Peak Storage (m^3)	Maximum Change in elevation (m)	Peak Outflow (m^3/s)
Design	198.26	473656.00	8.23	60.96
Baseline	196.09	460088.04	8.26	61.06
CCR_{max} (2.2)	532.27	606008.72	10.61	469.93

The 6hr 100yr present and future design depth that were calculated for each NARCCAP model as given in Table 3. Each NARCCAP model data were derived from different RCM-GCM combination model. Each model gives different delta change factor which was used to access the climate changed future storm depth estimation. Using delta change method is simple to use than other complex downscaling methods. Among the six pair of NARCCAP model datasets, the HRM3-HADCM3 has high delta change factor value. Thus only this model is considered and analyzed further. Although the minimum value of the delta change factor is found to be 1.02. Thakali et al. (2016) also found the same model producing maximum delta change factor for Flamingo and Tropicana watershed, which is adjacent to the Gowan watershed.

Baseline simulation was run to simulate the condition of the design value. Although the watershed model was originally developed in HEC-1 and later converted to HEC-HMS, the HEC-HMS results for baseline scenarioare very close to the design conditions such as peak inflow, storage, maximum change in elevation and peak outflow as represented on Table 4. This represents the HEC-HMS model is functioning appropriately in comparison with HEC-1. Hydrological simulation run on HEC-HMS has shown the drainage facility and detention basin selected for the study exceeded the capacity. Best management practice could be the effective way to decrease the risk of flooding (Gautam et al., 2010).

Conclusion

Statistical analysis and hydrological analysis were the two phases of the study. Best fitting among the twenty seven statistical distribution using Kolmogorov Smirnov best fit test was carried out; an existing hydrological model of the Gowan watershed in HEC-HMS was used for modelling. First, best fit distribution method was identified and the method was used to calculate 6hr 100yr storm depth for historical and future data of six RCM-GCM paired NARCCAP model. Delta change factor with highest value is selected to represent maximum climate change effect on storm depth. The hydrological modelling on HEC-HMS was carried out to access the effect of climate change on existing drainage facility of the Gowan watershed. Following findings were made from the study:

- Gamma distribution is the best fitted model for the six sets of NARCCAP model among twenty-seven distribution.
- Appropriate method of distribution vary spatially, so best method shall be find out to calculate the design storm depth.
- HRM3-HadCM3 has the highest delta change value among the six different models.
- This study shows the drainage facility existing at the study area were unable to handle the storm water resulting from the climate change condition as per NARCCAP climate model data of HRM3-HadCM3.
- The design storm depth for the future is going to increase. The peak inflow, peak storage, maximum change in elevation and peak outflow will achieve quicker than design condition.
- For 2.2 times increase in peak inflow there will be more than 7 times increase in outflow of the detention basin. This implies small increment in storm depth will increase outflow exponentially.

- The drainage facilities of the Gowan watershed are vulnerable to the extreme storm due to climate change.

This study reflects a possible way of incorporating the climate change effect on design storm depth of an urban watershed. Climate change affects not only the storm depth but also its frequency and pattern. Present design basis of urban stormwater infrastructures are based on the stationarity of the rainfall, which was invalidated (Gilory and McCuen, 2012; Carrier et al., 2016). Besides climatic factors there are anthropogenic factors, such as urbanization, deforestation, and land use change which amplify the flooding (Pokhrel et al., 2012). Peak flow is considered as the design parameter in most of the drainage facility is going to increase due to climate change and along with other anthropogenic factors. To cope with the natural variability, design engineers and policy makers should consider the possible changes. The study gives the general idea of the effect of climate change on design storm depth and effect on urban drainage facility along with possible way of incorporating it in design.

Acknowledge

We wish to thank the North American Regional Climate Change Assessment Program (NARCCAP) for providing the data used in this paper. We would like to thank CCRFCD for the access to the documents and hydrological model. We would like to express our gratitude to the office of Vice Chancellor for Research at SIUC for providing support to conduct this research work. Thank you also to the Thriving Earth Exchange program, which made the collaboration between Southern Illinois University and the City of Las Vegas possible.

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