Urban Stormwater runoff under changing climatic conditions

Ranjeet Thakali[1], Ajay Kalra[1], and Sajjad Ahmad[2]

[1]Department of Civil and Environmental Engineering, Southern Illinois University, 1230 Lincoln Drive, Carbondale, IL 62901-6603, United States

[2]Department of Civil and Environmental Engineering and Construction, University of Nevada, 4505 S. Maryland Parkway, Las Vegas, NV 89154-4015, United States

ABSTRACT

The urban stormwater systems are more vulnerable to the effects of climate change on hydrologic cycle. This study used the Climate information from the climate model data for the Las Vegas Valley. The Generalized Extreme Value method with the aid of L-Moment was used for the determination of change in design storm in the climate model predicted future climate. An existing HEC-HMS model with 6hr-100yr design storm information was implemented using the projected climate change information. The hydrologic simulations resulted in exceedance in the selected existing stormwater infrastructures, which were designed as per the current design standard.

Keywords: **Rainfall-Runoff, Climate Change, HEC-HMS, L-Moment, Design Storms**

INTRODUCTION

The population of the world is growing exponentially since the end of the 18th century when the industrial revolution started (Wu et al., 2011). A report, (UN, 2004), from the United Nations estimated that by the end of the 21st century the world population would become stable at around 9.1 billion but the population of the urban areas will still be increasing. Development pressure because of the increased population upsurges the urbanization. Urbanization results in the increase in the impervious area altering the natural hydrology (Kalra & Ahmad 2011). Altered hydrology due to the urbanization is particularly associated with the decrease in infiltration and increase in the runoff (Ghimire et al., 2016).

Moreover, recent years have witnessed the significant change in the climatic condition that affects the natural cycle of hydrology. The changes in the intensity and frequency of the precipitation are attributed to the climate change (Intergovernmental Panel on Climate Change, 2014; Pathak, Kalra & Ahmad, 2016a, Tamaddun, Kalra & Ahmad, 2016a). Present changes in the climate is primarily driven by the various anthropogenic activities (Kalra & Ahmad 2012; Carrier, Kalra & Ahmad, 2016; Sagarika, Kalra & Ahmad, 2014). Climate studies have predicted to continue change in the climate in the future as well (Kalra et al 2013; Sagarika, Kalra & Ahmad, 2015a; Sagarika, Kalra & Ahmad, 2015b;

Kalra et al., 2012). In the changing climatic condition, the urbanization results in the magnified effects in the stormwater by increasing runoff quantity (Berggren et al., 2011; Tamaddun, Kalra & Ahmad, 2016b; Pathak, Kalra & Ahmad, 2016b; Mosquera-Machado and Ahmad 2007). As a result, numerous recent studies (Grum et al., 2006; Mailhot et al., 2009; Forsee and Ahmad 2011) have focused on the evaluation of climate change impacts on the stormwater infrastructure so as to identify vulnerable points and reduce flooding.

It is expected that the change in rainfall intensity due to the climate change would surpass the operational capacity of existing stormwater system. The current design standards for stormwater infrastructure are based on using observed data for the calculation of design storms. However, the future climate may not replicate the present climate resulting in the inadequate design of the stormwater system (Thakali et al., 2016). The objective of this research was to examine the impact of change in design storm due to climate change on the existing urban stormwater systems.

STUDY AREA AND DATA

This study was performed in one of the watersheds, Flamingo and Tropicana, within Las Vegas Valley of Nevada, United States of America. The watershed's drainage and flood control infrastructures are programmed and managed by Clark County Regional Flood Control District (CCRFCD). The total area of the Flamingo and Tropicana Watershed is approximately 220 square miles. The stormwater infrastructure primarily consists of detention basins connected by the open channels. Figure 1 depicts the Flamingo and Tropicana along with the other watersheds of the Las Vegas Valley.

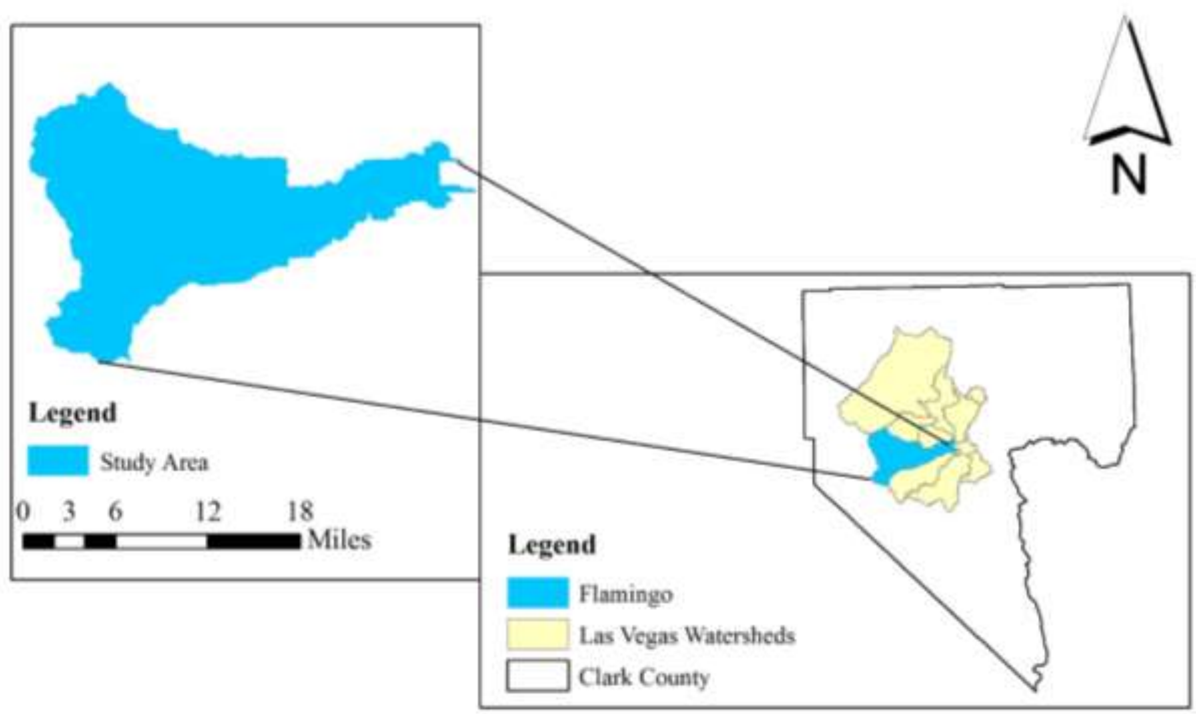

Figure 1: A map showing the study area.

The precipitation data were used from the datasets of North American Regional Climate Change Assessment Program (NARCCAP) (Mearns et al., 2007) and North American Regional Reanalysis (NARR) (Messinger et al., 2006) climate models. NARCCAP data are available for 1970 to 2000 for historic and 2040 to 2070 for future scenarios and NARR data are historic data and available for 1979 to 2016. NARCCAP and NARR datasets have same temporal resolution of 3 hours. The spatial resolution of NARCCAP data is 50 km, and that of NARR data is 32 km. Table 1 lists the combinations of global and regional NARCCAP climate models implemented in this study.

METHODOLOGY

The steps adopted in this include the calculation of design storm, 6 hour duration 100 year return period (6hr-100yr), from the NARCCAP and NARR datasets. CCRFCD design manual, CCRFCD 1999, suggested 6hr-100yr event for the design depth of the drainage system for the region of Las Vegas City. The NARR design storm was employed to evaluate the design storms from the NARCCAP datasets. The screened NARCCAP design storms were used in the existing Hydrologic Engineering Center's Hydrological Modeling System (HEC-HMS) model for the Flamingo and Tropicana watershed. The results for hydrological modeling for the different climate scenarios were compared with the CCRFCD design values. Figure 2 demonstrates the steps of the procedure followed in this study.

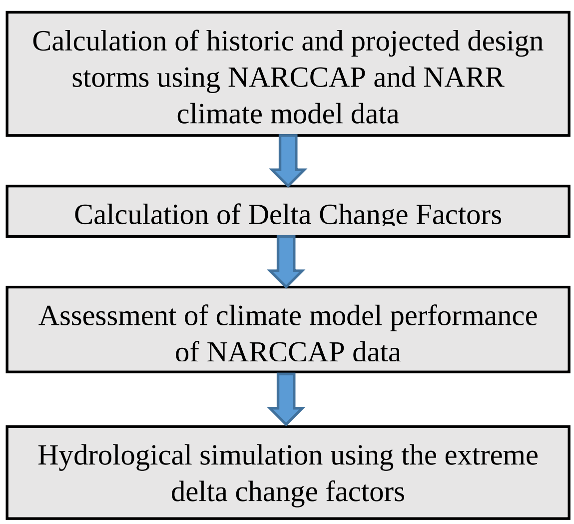

Figure 2: Flow chart of the procedures used in the study.

The 6hr-100yr design depths for the historic and projected NARCCAP and historic NARR datasets were estimated using the L-moments with generalized extreme value (GEV) approach from Hosking and Walls, 1997. The statistical calculation of design depth includes the regional frequency analysis using the surrounding four grid of the watershed. This approach was similar to the method followed by Fowler and Wilby 2010 for projection

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of extreme precipitation using gridded climate model data. The NARR historic design depth was used for the assessment of NARCCAP climate model performance.

The NARCCAP gridded data are courser and cannot be used directly in the drainage design which uses the point rainfall. These data need to be downscaled in order to implement in the hydrological modeling. Delta change factor method is a simple and straightforward as compare to other sophisticate downscaling methods. The delta change factors were calculated for the NARCCAP model combination by taking the ratio of future design depth and historic design depth.

An existing HEC-HMS model for the Flamingo and Tropicana watershed was used for the hydrological modeling. CCRFCD had developed the hydrological models for all the watershed within its jurisdiction and used them for the design of existing stormwater infrastructure (CCRFCD, 2013). The calculated delta change factors were implemented in the model and based on modeling output the comparison among the climate change scenarios (CCS) and the current design parameters (baseline-scenario) were made.

RESULTS AND DISCUSSION

The design depths for the historic and future NARCCAP datasets and historic NARR were calculated using the L-moment statistical approach (Table 1). The depths for the different NARCCAP datasets varied from each other. This is due to the inherent differences in the GCM and RCM used in each combination (Wehner, 2013). The NARCCAP historic 6-hr100yr depths were assessed with the NARR historic depth and the NARCCAP models which resulted in greater design depth than the NARR historic depth were eliminated for the further analysis. The spatial resolution of the NARR data are higher than the NARCCAP data; so the NARCCAP models should result in the less design depth as gridded climate models take area-averaged precipitation for the particular grid. Six NARCCAP models, CGCM3/WRFG, HaDCM3/ HRM3, CCSM/CRCM, CGCM3/CRCM, Time slice GFDL, and Time slice CCSM resulted in the historic depth less than NARR historic depth and were selected for the further study. Table 1 shows the calculated design depths for the climate models and delta change factor, which is the ratio of future and historic design depth. The statistical results were plotted in the stacked bar diagram, Figure 2. The horizontal line represents the NARR historic depth and the NARCCAP models which resulted in historic depths above the line were eliminated.

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Table 1: The calculated 6hr-100yr historic and future depth for the NARCCAP and NARR data sets along with the delta change factors for the NARRCAP climate model combinations.

Model Combination GCM/RCM	Historic 6hr-100yr depth (in)	Future 6hr-100y depth (in)	Delta Change Factor
NARR	1.17	-	-
CGCM3/CRCM	0.62	0.94	1.53
CGCM3/ RCM3	1.51	1.35	0.89
CGCM3/WRFG	1.07	1.47	1.37
CCSM/CRCM	0.81	0.91	1.12
CCSM/WRFG	1.46	1.54	1.06
CCSM/MM5I	1.40	1.64	1.17
HaDCM3/ HRM3	1.15	2.15	1.86
HaDCM3/ MM5I	1.63	2.17	1.33
GFDL/ HRM3	3.37	3.49	1.04
GFDL/ RCM3	2.10	2.33	1.11
GFDL/ECPC	2.37	3.10	1.30
Time slice GFDL	1.08	1.55	1.44
Time slice CCSM	0.95	0.99	1.05

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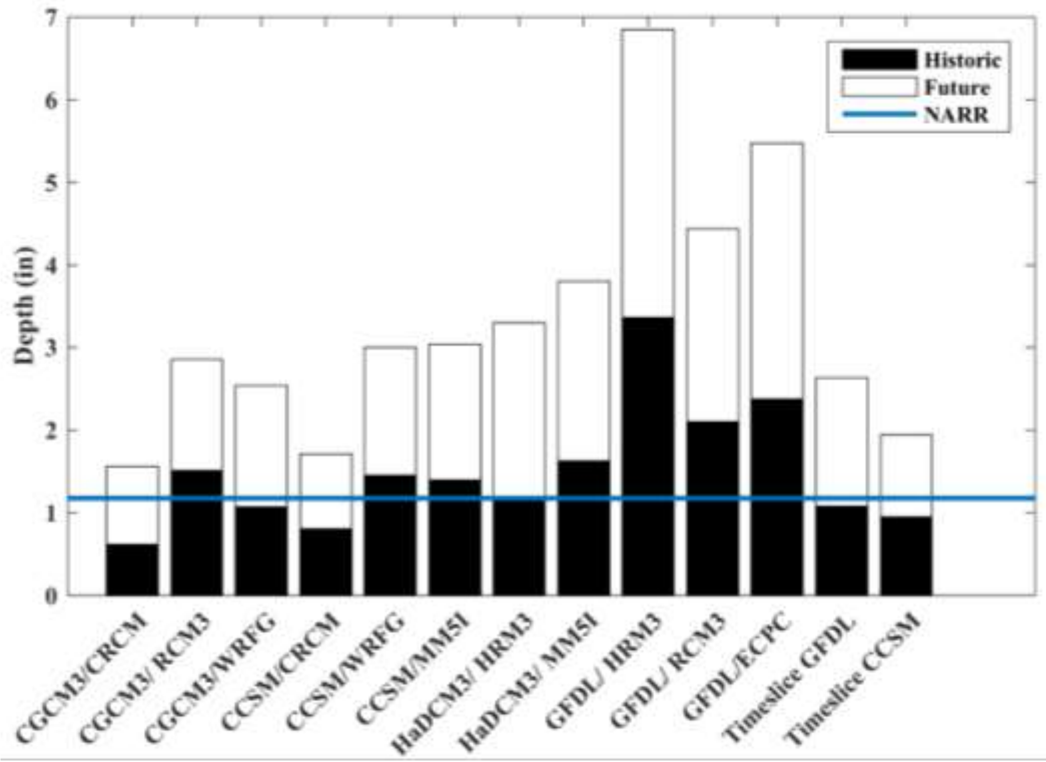

Figure 3: Stacked bar plot of historic and future design depth from the NARCCAP datasets and the NARR dataset. The horizontal line represents the calculated NARR design depth.

The value of delta change factor varied substantially for each NARCCAP model. The minimum and the maximum delta change factor among the six selected NARRCAP models were taken for the hydrologic modeling. The minimum value was 1.05 from Time slice CCSM model and the maximum value was 1.86 from HaDCM3/ HRM3 model. The HEC-HMS simulation includes three different scenarios, minimum (CCS 1.05), maximum (CCS 1.86) and the baseline scenario. Baseline scenario outputs are from the simulation of the existing HEC-HMS model without making any changes.

Lake Detention Basin (LAKEDB) was selected for the analysis of modeling outputs of different scenarios. Detention basin uses inflow, change in elevation, outflow, and storage values for the design. Table 2 shows the simulation values for design, baseline, CCS 1.05, and CCS 1.86 scenarios. The slight difference in the design values and the baseline simulation were found. CCRFCD used the HEC-1 model during the design of the existing stormwater infrastructures thus the conversion of HEC-1 model to the HEC-HMS model is responsible for the difference in design and baseline values. Figure 3 shows the time series plot of the hydrological parameter of the LAKEDB.

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Table 2: Hydrological modeling outputs for the Lake Detention Basin (LAKEDB) for different scenarios.

Scenario	Inflow (cfs)	Change in elevation (ft)	Outflow (cfs)	Storage (ac-ft)
Design	1975.86	25.69	96.06	165.00
Baseline	1968.09	25.69	86.52	165.20
CSC 1.05	2128.06	35.01	96.41	179.30
CSC 1.86	4792.56	259.51*	326.66	409.30

*It should be noted that detention basin was hypothetically extended to demonstrate water elevation for CSC 1.86. In reality detention basin will fail and surrounding area will be flooded.

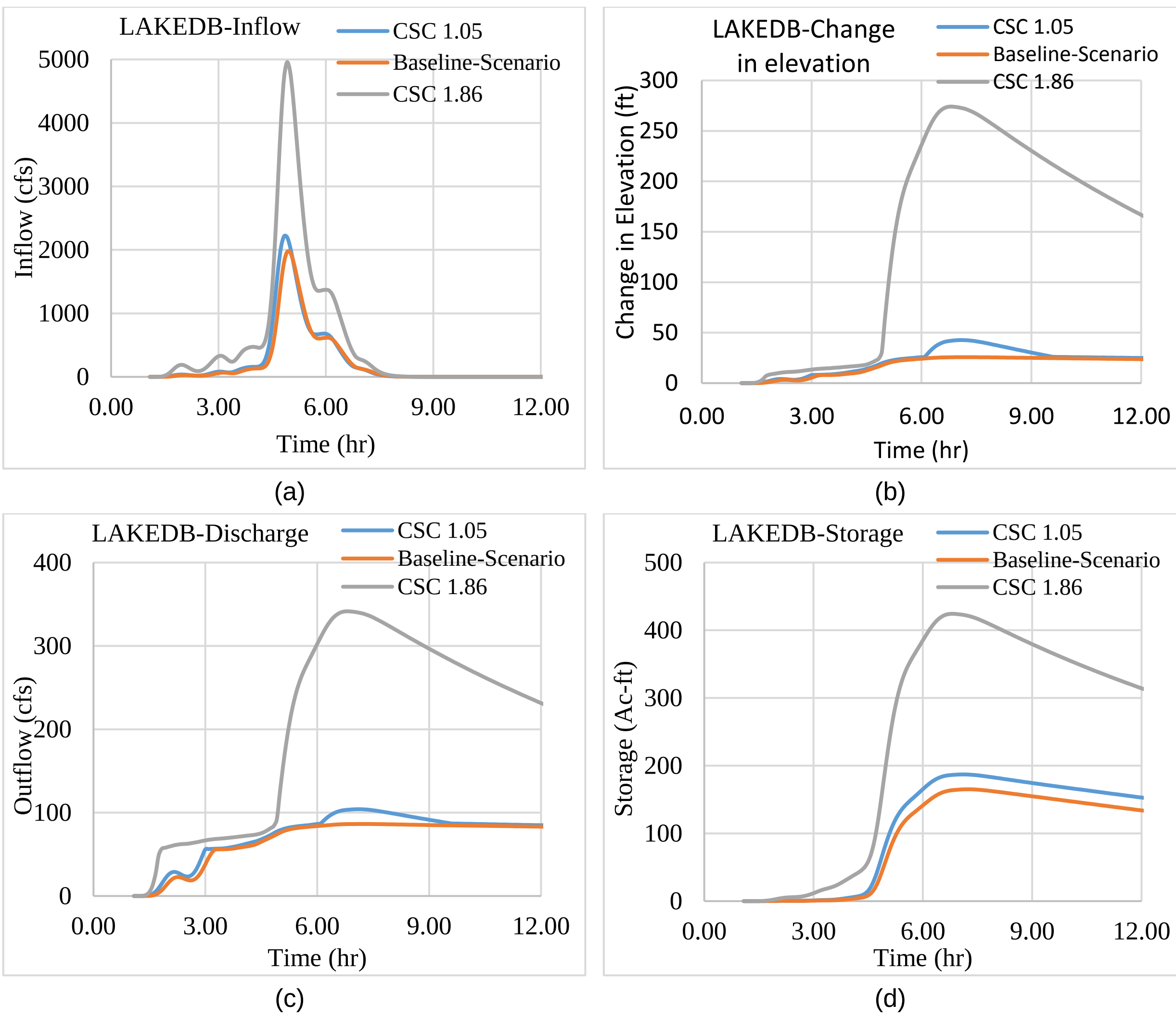

Figure 3: HEC-HMS outputs, inflow, change in elevation, discharge, and storage, of Lake Detention Basin (LAKEDB) for climate change scenarios, CCS 1.05 and CCS 1.86 and baseline scenario.

CONCLUSIONS

This study used the climate information from the climate models in the design of the stormwater system. The method purposed in this paper assessed the existing stormwater infrastructure of the Flamingo and Tropicana watershed. Based on the analysis following conclusions were drawn.

1. Different combinations of GCMs and RCMs in the NARCCAP climate experiment projecting different future climate.
2. A range of the potential projected future climate scenarios should be considered in the design and management of the stormwater infrastructures to address uncertainty.
3. Current flood control facilities may not be able to convey the projected flow due to changing climate.
4. Existing design standard for the stormwater may not be valid in the future climate.
5. This study proposed a method to evaluate urban stormwater infrastructure in the changing climate.
6. The finding and methods used in this study may be helpful for engineers and decision makers in designing, and evaluating stormwater infrastructure in response to climate change.

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