Evaluating Urban Storm-Water Infrastructure Design in Response to Projected Climate Change

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Abstract: One of the goals of storm-water infrastructure design is to mitigate effects resulting from extreme hydrologic events. Projected changes in climate are expected to lead to an increase in the frequency and magnitude of extreme rainfall events for many regions. Accordingly, existing storm-water infrastructure may not meet design standards in future decades. The North American Regional Climate Change Assessment Program is currently disseminating high resolution climate data to facilitate climate change impact assessments. A simple framework is presented for assessment of storm-water infrastructure in response to climate change. First, the projected changes in the 6-hour, 100-year design-storm depth for a watershed in Las Vegas Valley, Nevada, are calculated from several climate scenarios by using regional frequency analysis. Climate model projections vary substantially for this region and time scale. Climate model performance is assessed by using gridded reanalysis data. The projected changes in design-storm depths are incorporated into an existing HEC-HMS model. The HEC-HMS simulation results indicate potential exceedences of current design standards for select storm-water infrastructure components under projected climatic change scenarios. **DOI:** 10.1061/(ASCE)HE.1943-5584.0000383.

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Introduction

One of the most significant effects of anticipated climate change is an increase in the frequency and severity of extreme hydrologic events in many regions (Christensen et al. 2007). Whereas projections of wetter or drier conditions vary for regions and seasons, an increase in the intensity of the hydrologic cycle is expected (Christensen et al. 2007). An increase in the frequency and magnitude of extreme rainfall events can lead to hydrologic effects, such as increased flooding and erosion (Olsson et al. 2009). Furthermore, in urban areas where land surfaces often have low infiltration rates, such hydrologic effects could be magnified (Semadeni-Davies et al. 2008).

Storm-water facilities can mitigate the effects of extreme precipitation events. In the arid regions of the southwestern United States, where ephemeral systems predominate, changes in climate could affect several aspects of storm-water management. Flood hydrographs in arid, ephemeral catchments typically have steep rising limbs (Levick et al. 2008). Increases in flash flooding frequency and magnitude could lead to exceedences of storm-water facilities' capacities and increases in total sediment transport (Guo 2006). Storm-water harvesting is sometimes used in the arid Southwest, and some detention basins are designed to retain water by infiltration. Changes in extreme-event characteristics could impact the design of storm-water facilities, and more specifically, changes in peak discharge and sediment transport could impact detention basin design (Semadeni-Davies et al. 2008). In addition, because of the infrequency of rainfall events in arid regions, substantial water quality concerns exist because of the buildup of contaminants (e.g., oil on pavements) during extended dry periods.

Hydrologic design and assessment for storm-water infrastructure in urban areas is often based on rainfall depths resulting from storms of a specific return period and duration (e.g., 6-hour, 100-year storms), which are calculated from historic data (Guo 2006). Hydrologic design based on the assumption that historic data will reflect future meteorological conditions may be erroneous (Mailhot and Duchesne 2010). Traditionally used methods to determine runoff (e.g., Ahmad and Simonovic 2005; Ahmad et al. 2009, 2010) for low-frequency events often do not take into account projected changes in climate and the corresponding potential changes in event frequency. Kalra and Ahmad (2009) argued that the planet is already in an unstationary climate and that these traditional design hydrologic methods are no longer applicable (Brown 2010; Milly et al. 2008).

Robust methods are needed to develop design standards that address projected climate change (Guo 2006; Mailhot and Duchesne 2010). At the same time, water management agencies and design engineers need simple methods for climate change assessment that are straightforward in application, allow the use of existing hydrologic models, and can be used for multiple locations with appropriate adjustments. Typically, urban storm-water studies are conducted by using surface hydrology models (e.g., Ahmad and Simonovic 2001, 2006; Mosquera-Machado and Ahmad 2007). Precipitation input for these models can be continuous time-series data or event-based data such as total rainfall depths. To assess the hydrologic effects of climate change, climate information, typically

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in the form of gridded data, should be incorporated into these models.

Global climate models (GCM) and regional climate models (RCM) produce climate projections on a coarse gridded scale. Hydrologic impact assessments of climate change should include multiple climate projections to address the inherent uncertainty in climate projections (Fowler et al. 2007; Kendon et al. 2008). The North American Regional Climate Change Assessment Program (NARCCAP) is in the process of providing multiple high resolution climate scenarios created from multiple RCMs for impact assessment on the North American continent (Mearns et al. 2009).

Linking gridded climate change projections with catchment-scale hydrologic analysis is not a straightforward task. Precipitation from climate models, available as gridded data, are areal averages and not point estimates (Chen and Knutson 2008). For spatial downscaling of gridded data to assess the effects of climate change, different dynamical and statistical downscaling methods are available (Fowler et al. 2007; Praskievicz and Chang 2009; Prudhomme et al. 2002; Kalra and Ahmad 2011).

As an alternative to complex downscaling methods, delta-change factors have been used to transpose projected future changes in climate onto point precipitation data (Andreasson et al. 2004; Diaz-Nieto and Wilby 2005; Hay et al. 2000; Mailhot et al. 2007). Differences in target precipitation totals between gridded historic and future projections are calculated, and these differences are then transposed onto point historic precipitation values. Depending on how the method is applied, this may involve the assumption that areal-to-point relationships of precipitation remain constant in future climates (Mailhot et al. 2007). In some studies, delta-change factors have been applied to precipitation time series (e.g., Andreasson et al. 2004; Hay et al. 2000; Olsson et al. 2009; Prudhomme et al. 2002). Alternatively, these factors can be applied to discrete totals, such as design-storm depths. Delta-change methods provide the required information for conducting hydrologic impact assessments on the basis of climate change and have the advantage of being simple to implement (Diaz-Nieto and Wilby 2005).

This work explores the projected changes in design-storm depths and the resulting effects on storm-water infrastructure design for an arid watershed in Las Vegas. Five NARCCAP data sets are initially used to project changes in design-storm depths. Using climate change projections from GCMs and RCMs that best reproduce historic precipitation statistics, delta-change factors are calculated and these factors are then applied to design-storm depths, enabling the analysis of storm-water infrastructure under different scenarios. The following two sections introduce the study area, data, and models. A subsequent section presents the methods used to link climate information, hydrologic information, and models. A review of delta-change factor calculations, climate model assessments, and hydrologic simulation results follows this section. The last section provides a discussion of the implications of this work on the impact assessment of climate change upon storm-water infrastructure.

Study Area

The Las Vegas Valley has undergone significant urban growth in recent years, and is located in the arid southwestern region of the United States. Climate change projections for the southwestern United States indicate decreased total rainfall during the summer and increased total rainfall in the winter; however, this does not preclude an increase in extreme rainfall event frequency or magnitude (Christensen et al. 2007). Madsen and Figor (2007) observed a statistically significant increase in the frequency of extreme precipitation events in the states of Arizona, Nevada, and New Mexico in recent decades. The Las Vegas Valley has endured several storms in the past 20 years that equaled or exceeded the depth criteria for the local storm-water design storm, the 6-hour, 100-year event. Two of these storms in particular, which occurred on July 8, 1999, and August 19, 2003, caused significant damage to private and public structures (Reilly and Piechota 2005). Not surprisingly, storm-water management is an important government service in this metropolitan area.

The Las Vegas metropolitan area and Las Vegas Valley lie within Clark County, Nevada. Fig. 1 provides a layout of the watersheds within the Valley. The latitude and longitude of McCarron Airport, located within the City of Las Vegas, are 36.1° N and 115.2° W, respectively. The total area of the Las Vegas Valley is approximately 1,600 km^2. Lake Mead, the primary source of freshwater for the area, lies to the east of the metropolitan area; the Las Vegas Valley drains to this water body. Most of the region's streams are ephemeral except for the Las Vegas Wash, which is a perennial stream primarily because of anthropogenic factors (e.g., wastewater discharge and excess landscape irrigation). The Pittman watershed, shown in Fig. 1, was selected for analysis in this study, and includes much of the southeastern part of the Las Vegas metropolitan area. The total area of the Pittman watershed is approximately 400 km^2.

The climate of this region is arid, with total precipitation averaging 114.0 mm annually. Monthly precipitation totals vary from 2.0 mm in June to 17.5 mm in February [National Oceanic and Atmosphere Administration (NOAA) 2011b]. Primary mechanisms of precipitation are summer convective events and winter frontal events.

Data and Models

This work uses climatic data sets from NARCCAP to project changes in precipitation depths for the Pittman watershed (Mearns et al. 2007). Climate projections are produced by using several different RCMs, which are driven with various GCMs. These GCMs have been used in Intergovernmental Panel on Climate Change (IPCC) studies (Mearns et al. 2009). As of June 2010, NARCCAP had disseminated results from four different RCM/GCM combinations for both historic and future simulations. In addition, one "timeslice" run was available, in which a GCM is run at a higher resolution, omitting the ocean model component to decrease computational demands. In the timeslice simulation, observed sea-surface temperatures and sea-ice boundaries replace the ocean model. Table 1 provides the abbreviations and names of the models used in this work.

All NARCCAP data sets have a 50 km spatial resolution and provide precipitation on a 3-hourly temporal resolution. Grid centers vary among the different RCMs. The time span is 30 years for both historic (1971–2000) and future (2041–2070) scenarios. Calendars vary for the models (no leap years, 360 day calendar). The emissions scenario is the special report on emissions scenarios (SRES) A2 (Nakicenovic et al. 2000).

To assess the performance of the NARCCAP model simulations for the target statistics, this work uses North American Regional Reanalysis (NARR) data provided by the National Centers for Environmental Prediction (Mesinger et al. 2006). Performance assessment involves comparing historic NARCCAP model simulation output with NARR data. Other studies have used Reanalysis data to assess historic gridded data sets from GCMs and RCMs (e.g., Wang et al. 2009). Reanalysis data are assumed to be gridded

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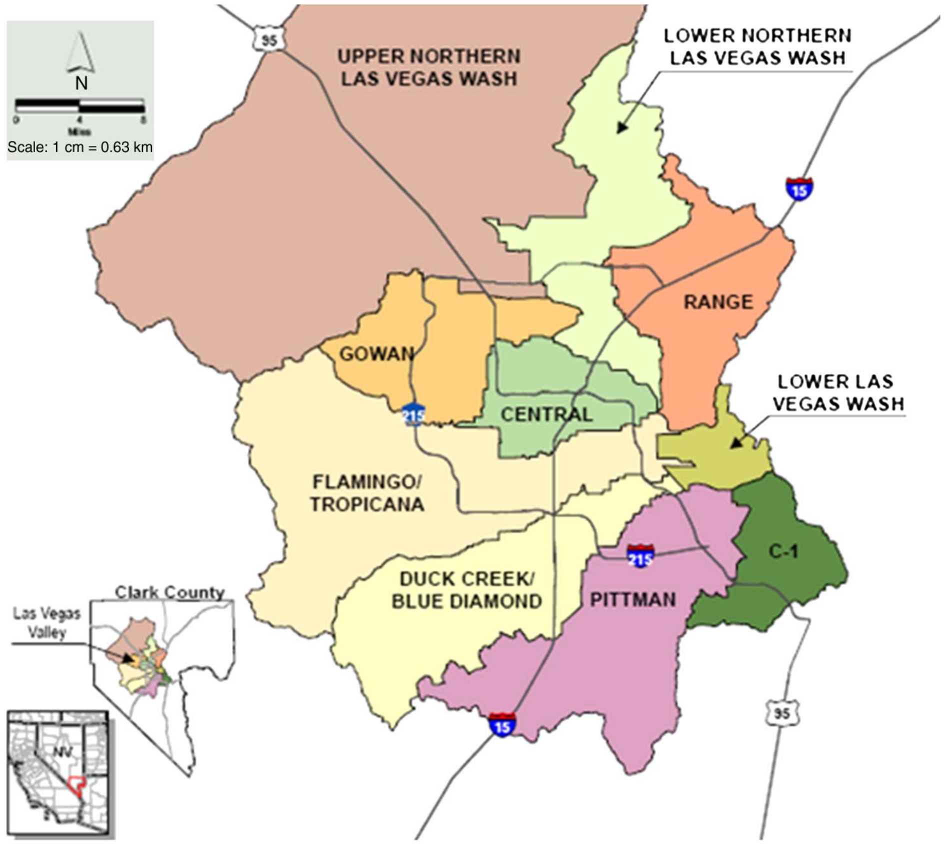

Fig. 1. Las Vegas Valley watersheds (CCRFCD 2008, with permission from Clark County Regional Flood Control District)

Table 1. NARCCAP Models (Adapted from Mearns et al. 2009)

NARCCAP RCM/GCM combinations		
RCM/GCM	RCM	GCM/Driver
CRCM/CGCM3	Canadian regional climate model	Third generation coupled
HRM3/HADCM3	Hadley Centre regional model 3	Hadley Centre coupled model, version 3
REGCM3/GFDL	University of California Santa Cruz regional climate model, version 3	Geophysical Fluid Dynamics Laboratory
REGCM3/CGCM3	University of California Santa Cruz regional climate model, version 3	Third generation coupled
Timeslice GFDL	None	Geophysical Fluid Dynamics Laboratory

estimates of historic weather observations, because they are constrained to historic temperature and precipitation observations (Kalnay et al. 1996). The NARR data have a 32 km resolution, smaller than the resolution of NARCCAP data. The NARR data have a 30 year temporal span (1979–2008) and are at a 3-hourly temporal resolution. This study uses only 22 years of NARR data from 1979–2000, because 2000 is the last year of the NARCCAP historic simulations.

The Clark County Regional Flood Control District (CCRFCD) manages storm-water infrastructure in the Las Vegas Valley and is responsible for developing comprehensive master plans for flood control. For master planning purposes, the Las Vegas Valley is divided into 10 watersheds, and a storm-water model is maintained for each of these watersheds. For the most recent master plan update, all watershed models were converted to the U.S. Army Corps of Engineers Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) from HEC-1 software. The models, model documentation, hydrologic design standards, and master plans are available from the CCRFCD. The design manual for storm-water infrastructure in Clark County is the Hydrologic Criteria and Drainage Design Manual (CCRFCD 1999) and the most recent master planning documents are the 2008 Master Plan (CCRFCD 2008).

The design standard for these storm-water facilities is the depth resulting from the 6-hour, 100-year event (6h100y). In the Pittman HEC-HMS storm-water model, each subbasin has a specified 6h100y point depth. These point depths are obtained from NOAA Atlas II estimates of the 6h100y depth (CCRFCD 1999; Miller et al. 1973), with each point depth multiplied by a factor to adjust values upward, reflecting the documented underestimation of design-storm values in Atlas II for this area (CCRFCD 1999). The scaled Atlas II 6h100y depths specified for the Pittman HEC-HMS model subbasins range from 7.04 cm to 8.71 cm; the area-weighted watershed mean 6h100y depth is 7.75 cm.

The HEC-HMS models apply a single depth area reduction factor (DARF) to all component depths to create area-averaged precipitation totals. Selection of a DARF value depends upon target component drainage area. For progressively larger areas, smaller DARFs are used. For this work, CCRFCD design guidelines determine DARF and hyetograph assignment (CCRFCD 2008). The

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Pittman storm-water model has a total of 1,034 hydrologic elements and 351 subbasins components. This HEC-HMS model has various basin models that differ on the basis of storm centering. Storm centering can be for the entire drainage area or alternatively for just a portion of the drainage area. If storm centering is on the more downstream section of a drainage area, the model diverts flow from upstream detention basins out of the watershed, while using a larger DARF to reflect the decreased total storm area (CCRFCD 2008).

Method

The method used in this study consists of multiple steps. Fig. 2 provides a schematic of the procedure. First, the 6h100y depths from the NARCCAP and NARR data sets are calculated. This is followed by assessment of the historic NARCCAP depths using NARR data. Finally, HEC-HMS is implemented for evaluation of the Pittman watershed storm-water infrastructure under climatic change. HEC-HMS results for different climate scenarios and historic runs were analyzed by determining maximum inflow, discharge, elevation, and storage amounts for select model components. Comparisons of the model output were made between different climate scenarios and with CCRFCD design standards. This work also includes a brief sensitivity analysis of DARFs.

Calculation of 6h100y depths from NARCCAP and NARR data involves a variant of regional frequency analysis using the method of *L*-moments from Hosking and Wallis (1997). In regional frequency analysis, calculation of extreme values for a single location uses "pooled" data sets, which include data from the location of interest and nearby locations to increase the sample size. Some studies have noted the disadvantages of using only data from a single grid for analyses (e.g., Brinkmann 2002; Kendon et al. 2008). Methods of regional frequency analysis similar to that used in this study have been used for analysis of gridded climate projections for extreme precipitation in other studies (e.g., Fowler and Wilby 2010).

For regional frequency analysis, this study uses output from the four grids with grid centers encompassing the centroid of the Pittman watershed (35.97° N, 115.12° W). Time-series data from a given NARCCAP grid and time period provides 30 years of data. First, an algorithm calculates the annual maximum series from 3-hourly time series for each grid and model combination. Annual maximum series have often been used in calculation of storm frequencies (e.g., Bonnin et al. 2006). The program determines the largest 6-hour precipitation total for each year by using a 6-hour moving window, which shifts incrementally across each 3-hourly value. To create standardized maxima for regionalization (pooling of data from multiple grids), each maxima was divided by the median of the 30 maxima for that grid (Fowler and Wilby 2010).

After pooling standardized annual maxima from the four grids for a given model run and time period, the algorithm fits a generalized extreme value distribution to each pooled set of standardized annual maxima. In NOAA's most recent publication, Atlas 14 (which has replaced Atlas II in the Southwest), different distributions were tested for representing the underlying distribution of annual maxima for different homogenous climate divisions (Bonnin et al. 2006). For the region including Clark County, the generalized extreme value distribution performed best for most locations and durations (Bonnin et al. 2006). This distribution has been used for estimating extreme precipitation storm totals from climate gridded data sets in other studies (Kharin and Zwiers 2000; Mailhot et al. 2007). To fit a generalized extreme value distribution to each pooled data set, the shape, scale, and location parameters were determined by using probability-weighted moments (Hosking and Wallis 1997). Unbiased estimators determined the *L*-moment and *L*-moment ratios. The algorithm then calculates the standardized 6h100y depth using these parameters. Finally, the algorithm rescales the standardized 6h100y depth by using the median of the grid that contains the centroid of the Pittman watershed to obtain the site (grid) specific 6h100y depth. After repeating this procedure for all data sets, delta-change factors were determined by dividing the future 6h100y depths by corresponding historic 6h100y depths.

To assess the NARCCAP data sets for the target statistics, this study compared the historic simulation 6h100y depths from NARCCAP, calculated for a 50 km grid resolution, to the NARR 6h100y depth, calculated at a 32 km resolution. Depth estimates for a 50 km resolution should be less than those at a 32 km resolution because area-averaged depth decreases with increasing total area. After determining the NARCCAP models that best reproduced historic precipitation, HEC-HMS was used to simulate storm-water infrastructure response for baseline and climate change scenarios. In the baseline scenario, no model parameters were modified to account for changes in climate. For the climate change scenarios, the delta-change factors calculated from the selected NARCCAP data sets were applied to all element depths in the HEC-HMS model.

Two detention basin elements were selected for analysis: Pittman East Detention Basin (PEDB) and Pittman West Detention Basin (PWDB). These detention basin elements were selected because they have some of the larger maximum storage and inflow design values in this watershed (CCRFCD 2008). These basins are located in different portions of the Pittman watershed. The element of the Pittman watershed with the largest drainage area was also selected for analysis. This is a junction last (JL) in the model that leads into the Duck Creek Wash, and is accounted for in another watershed.

The HEC-HMS simulation time was 24 h (beginning at 1:05) and the computation time interval was five minutes. The storm hyetograph runs for the first 6 hours of the simulation span. This analysis considered two basin models that differed according to storm centering. These two basin models are: (1) FULL, a storm centering for the entire watershed area, and (2) SC, a storm centering in the downstream portion of the watershed, excluding flow from most upstream detention basins (CCRFCD 2008).

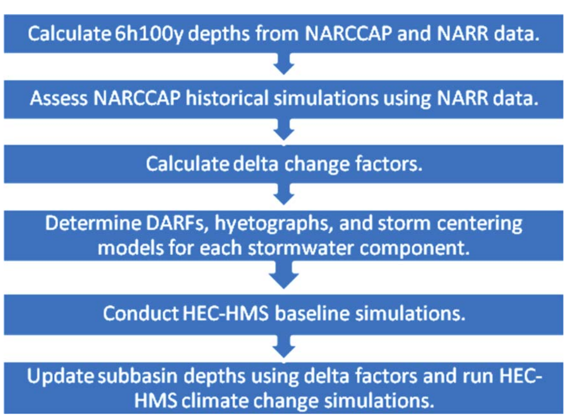

Fig. 2. Flowchart of methodology to evaluate storm-water infrastructure in response to projected changes in 6h100y depths

Results and Discussion

Initially, all four RCM/GCM combinations and the timeslice run were considered for storm-water infrastructure assessment. Historic

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and future 6h100y depths derived from all NARCCAP data sets and the NARR data set (historic only) are shown in the first two columns of Table 2. These values vary substantially. Fig. 3 is a scatterplot comparing NARCCAP 6h100y depths. In this plot, the *x*-axis indicates historic depth and the *y*-axis indicates future depth, both in centimeters (cm). The vertical line represents the NARR 6h100y depth, 3.83 cm. Three of the NARCCAP data sets [from model combinations Canadian Regional Climate Model/Third Generation Coupled Global Climate Model (CRCM/CGCM3), Hadley Centre Regional Model 3/Coupled Model Version 3 (HRM3/HADCM3), and Timeslice Geophysical Fluid Dynamics Laboratory (Timeslice GFDL)] produced historic 6h100y depths less than the NARR value, with points falling on the left side of the vertical line. This is expected because the spatial resolution of NARCCAP is coarser than that of NARR, and averaged storm depth decreases with increasing area.

Conversely, the other two NARRCAP data sets, both from the Univeristy of California Santa Cruz Regional Climate Model Version 3 (REGCM3) (from model combinations REGCM3/CRCM and REGCM3/GFDL) produced historic 6h100y depths greater than the NARR depth and were not used further. The 6h100y values for these two data sets exceeded not only the NARR value, but also the Atlas 14 point 6h100y value for the centroid of the Pittman watershed, 6.07 cm (NOAA 2011a).

The delta-change factors (the future 6h100y depth divided by the historic 6h100y depth) calculated for all NARCCAP data sets are shown in column three of Table 2. In Fig. 3, the 1:1 line separates delta-change factors into two categories. Points falling above the 1:1 line indicate a future increase in the 6h100y depth (delta change factor > 1.0), and points falling below the 1:1 line indicate a future decrease in the 6h100y depth (delta change factor < 1.0). Of the three selected data sets, the smallest delta-change factor, 1.24, and largest change factor, 3.02, were used for hydrologic analyses, designated as climate scenario 1.2 (CS1.2) and 3.0 (CS3.0). Delta-change factors less than 1.0 were derived from the two REGCM3 data sets.

Table 2. 6h100y Depths and Delta-Change Factors from NARCCAP and NARR Data

	NARCCAP 6h100y depths		
Model	Historic 6h100y (cm)	Future 6h100y (cm)	Delta change
NARR	3.83	—	—
CRCM/CGCM3	1.70	2.91	1.71
HRM3/HADCM3	2.90	8.77	3.02
Timeslice GFDL	3.37	4.19	1.24
REGCM3/CRCM	6.14	4.14	0.67
REGCM3/GFDL	11.33	8.75	0.77

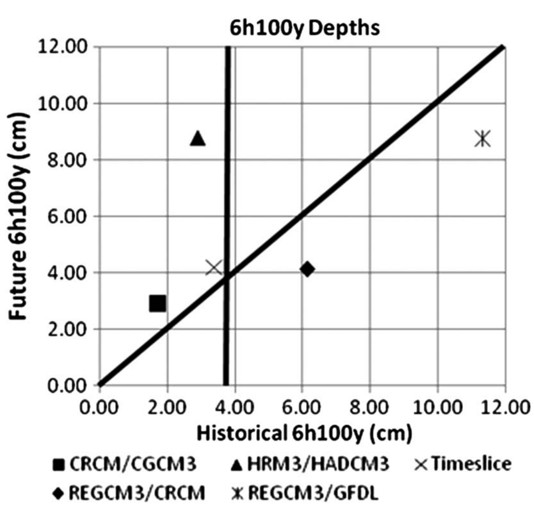

Fig. 3. Scatterplot of 6h100y depths from NARCCAP models: vertical line indicates the 6h100y depth from NARR; diagonal line is a 1:1 line; symbols below the 1:1 line indicate a negative delta-change factor, and vice versa

Hydrologic simulation results from two different basin models (FULL and SC) were compared to determine the greatest maximum values in inflow, discharge, elevation, and storage. For PEDB, a DARF of 0.725 was used with the FULL basin model for a drainage area of 85.0 km^2, while a DARF of 0.865 was used with the SC basin model for a drainage area of 24.1 km^2. The drainage area upstream of PWDB has no detention basins, and thus only the FULL basin model was used for PWDB with a DARF of 0.725 for a drainage area of 85.2 km^2. For JL, the FULL and SC basin models were both used, with a DARF of 0.58 for a drainage area of 347 km^2 in the FULL model and a DARF of 0.725 for a drainage area of 94.6 km^2 in the SC model. For a given climate scenario and model component, time series plotted and maximum values discussed in this section are only for those from the storm-centering model (FULL or SC) that produced the greatest maximum value (for inflow, discharge, elevation, or storage). This is because maximum inflow for one model component may be produced by the FULL basin model for one climate scenario and by the SC basin model for a different climate scenario.

For each detention basin, storage-discharge and elevation-storage functions are specified inputs in the HEC-HMS model. Diversion components have inflow-diversion functions specified. For two diversions and four detention basin model components in future simulations, the highest possible values specified for these functions were exceeded. None of the three components of focus in this study had function values exceeded. To allow the model simulations to complete, higher values were entered. These values were calculated by linearly extrapolating from the largest two paired values of the exceeded function.

Table 3 provides maximum inflow, discharge, elevation (stage), and storage results for both detention basins and maximum

Table 3. HEC-HMS Results for Inflow, Storage, Elevation, and Discharge

		HEC-HMS results			
Element	Unit	CS3.0	CS1.2	Baseline	Design
JL					
Discharge	m^3/s	2,377	277	219	219
PEDB					
Inflow	m^3/s	1,133	302	174	175
Discharge	m^3/s	1,125	35	28	28
Δ elevation	m	13.6	12.2	10.0	10.0
Storage	mcm	2.77	2.14	1.31	2.12[a]
PWDB					
Inflow	m^3/s	1,081	371	278	291
Discharge	m^3/s	1,078	232	7.2	7.2
Δ elevation	m	16.4	15.6	14.8	14.8
Storage	mcm	3.36	3.07	2.82	3.11[a]

Note: Units are meters (m), cubic meters per second (m^3/s), and million cubic meters (mcm). Design values for inflow, discharge, and elevation (stage) of detention basins for the 6h100y event are shown. Design storage value is for the spillway.
[a]Storage values are for storage at spillway, not 6h100y design values; only PWDB values account for sediment load.

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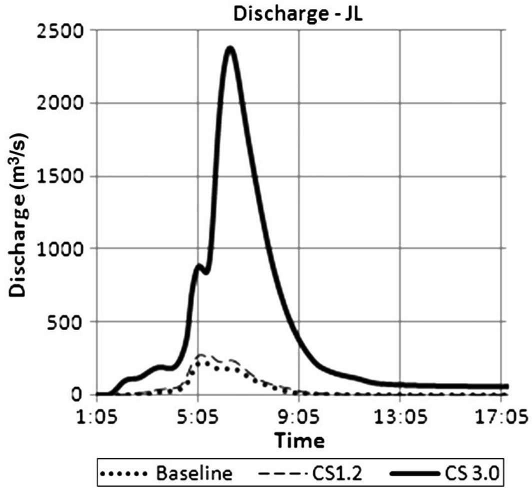

Fig. 4. Discharge (inflow) for the model component diverting flow into Duck Creek Wash (JL)

discharge (inflow) results for JL. Elevation is converted to change in elevation (Δ elevation) by subtracting the elevation at zero flow from the elevation output. Inflow, discharge, and elevation design values are for the CCRFCD 6h100y storm in Table 3. The storage values listed in the design column are not for the 6h100y storm, but for the storage at the spillway. For all three components, baseline simulation maximum values were close to design values for inflow, discharge, and elevation. This indicates that for baseline conditions, the HEC-HMS model produces the expected results. Small differences are expected because these design values are based on HEC-1 simulations.

Figs. 4–6 present graphical results from the HEC-HMS simulations. The discharge (inflow) for all simulations for JL are shown in Fig. 4. In this figure, maximum discharge values for the CS1.2 and baseline scenario were produced by the SC basin model, while the greatest maximum discharge value produced for the CS3.0 scenario came from the FULL basin model. A primary and a secondary maximum exist for all three curves. The secondary maximum for the CS3.0 scenario is approximately at the same time, 5:00, as the primary maximum for the other two scenarios, and vice versa for the maximum at approximately 6:30. These differences are likely because of the inability of upstream detention basins to attenuate storm-water discharge from the upstream portions of the drainage area in CS3.0 with the FULL basin model.

Figs. 5(a)–5(d) shows the results for PEDB for all three scenarios. The SC basin model produced higher maximum inflow values for the baseline simulation, whereas for all other variables and scenarios the FULL basin model produced higher maximum values. Time of maximum inflow, from Fig. 5(a), differs for all three scenarios. The earlier maximum for the baseline simulation, at 4:50, is likely caused by the different basin model, SC, and associated hyetograph, where less water drains from the upstream portion of the drainage area. The difference in time of maximums for CS1.2 (at 6:00) and CS3.0 (at 5:30), which both come from the FULL

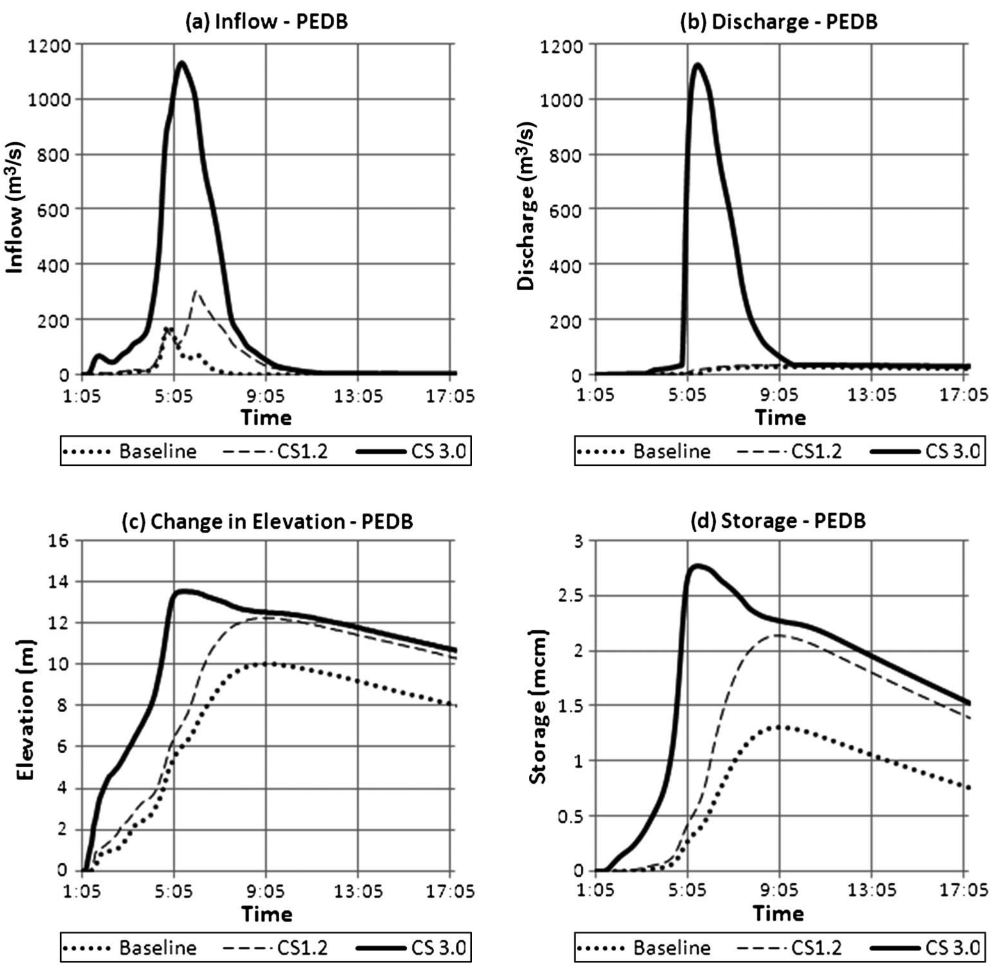

Fig. 5. Results for Pittman east detention basin (PEDB)

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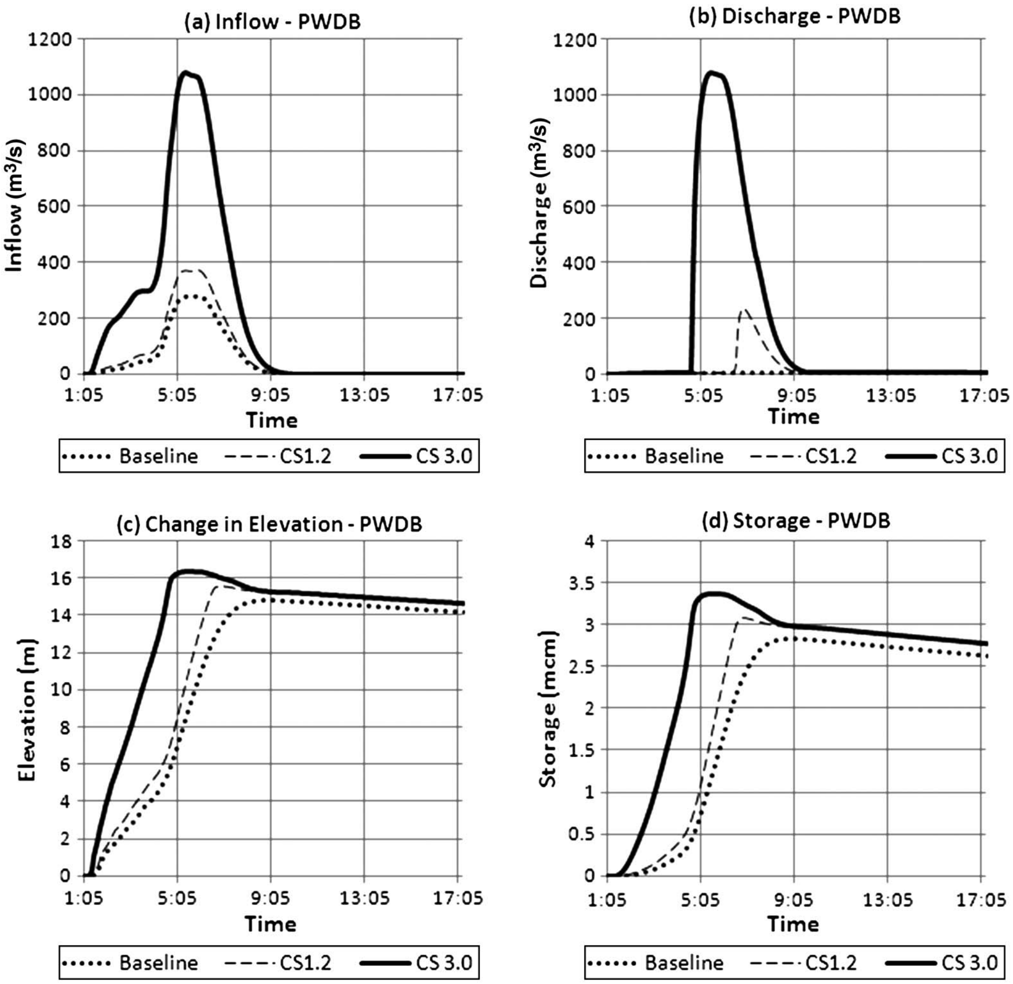

Fig. 6. Results for Pittman west detention basin (PWDB)

basin model, may be caused by a difference in time of failure of an upstream detention basin to attenuate discharge. The discharge curves behave differently among the three scenarios in Fig. 5(b) for PEDB. For the baseline and CS1.2 runs, the discharge curves are relatively flat. The discharge curve for CS3.0 has a sharp peak at approximately 5:30 close to the CS3.0 times of maximum inflow, change in elevation, and storage in Figs. 5(a), 5(c), and 5(d). In Figs. 5(c) and 5(d), the maximums of change in elevation and storage occur at approximately the same time, 9:00, for baseline and CS1.2 simulations. For the inflow and discharge plots, the relative change in magnitudes from baseline to CS1.2 was relatively smaller than the relative changes in magnitude from CS1.2 to CS3.0, whereas for change in elevation and storage, the differences in magnitudes between the three scenarios were relatively similar. These differences could be caused by overtopping of spillway elevation (different from stage elevation in Table 3), which does happen for CS3.0, but does not for CS1.2 and the baseline scenario. This hypothesis is consistent with the elevation-storage-discharge relationships in HEC-HMS. For these functions, a sharp increase in discharge occurs at the elevation and associated storage values for elevations greater than spillway elevation.

For PWDB, the trends for inflow, discharge, change in elevation, and storage shown in Figs. 6(a)–6(d) are similar to those of PEDB. Only the FULL basin model was used. In Fig. 6(a), the graph of inflow has two maximums for all three scenarios. Unlike PEDB, the PWDB discharge curve for CS1.2 has a sharp peak in Fig. 6(b). This may be related to the fact that spillway elevation was exceeded for PWDB in CS1.2, unlike for PEDB; examination of the elevation-storage-discharge relationships confirmed this. The plots of change in elevation and storage in Figs. 6(c) and 6(d) display progressively earlier maximum times with greater magnitudes.

Las Vegas Valley design DARFs are based on a 1988 study from the U.S. Army Corps of Engineers (USACE 1988). Analysis of this report and a 1984 study by the National Weather Service (Zehr and Myers 1984) for the arid Southwest reveal substantial variability in DARF determination for this region. These observations, considered in conjunction with possible changes in DARFs in future climate scenarios (Mailhot et al. 2007), indicate substantial uncertainty in DARFs for hydrologic analysis. A brief sensitivity analysis was conducted to assess how changes in DARFs would impact the HEC-HMS results. This analysis used PEDB, CS1.2, the FULL basin model, and focused on inflow only, which for this scenario equaled 302 cubic meters per second (m^3/s). The DARF, 0.725, was adjusted 10% upward and 10% downward. For a 10% increase in DARF (DARF $= 0.80$), the inflow increased to 374 m^3/s, an increase of 24%. For a 10% decrease in DARF (DARF $= 0.65$), the inflow decreased to 210 m^3/s, a decrease of 30%.

Summary and Conclusions

This work presented a method for assessing climate change effects on storm-water infrastructure design. The 6h100y depth was calculated for the Pittman watershed from several climate projections

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and NARR data. An existing HEC-HMS storm-water model, which has gone through extensive development, was used to evaluate the impact of changes in design rainfall depths upon select storm-water components.

Consistent with recommendations to use multiple climate projections for climate impact assessment (e.g., Fowler et al. 2007), several climate projections were considered for analysis. For each data set, a variant of regional frequency analysis was used to calculate the 6h100y depth. It is suggested that regional frequency analysis (using data from multiple grids) be used for calculating low-frequency storm depths from gridded data to increase sample size and reduce uncertainty in fitting distributions.

For assessment of the NARCCAP models, historic 6h100y depths were compared to the corresponding NARR value. Reanalysis data is considered to be gridded estimates of historic weather observations. The 6h100y depths derived from three of the data sets were less than the NARR 6h100y depth and were used in further analysis. Alternatively, the 6h100y depths derived from the two data sets that used the REGCM3 model exceeded both the NARR 6h100y depth and the Atlas 14 6h100y depth for the watershed centroid, indicating that these model combinations did not capture the target historic statistics for this location.

The change in 6h100y depth estimated from the five different model combinations ranged from a decrease of approximately 30% to a 300% increase. For the three selected models, the range was still substantial, from a 60% to a 300% increase. This wide variability makes it difficult to draw definitive conclusions about the future 6h100y rainfall depth in Las Vegas. However, considering differences among GCMs in spatial resolution, underlying physics, and boundary conditions, convergence is not expected at a high temporal resolution, especially in areas of complex topography. This variability highlights the often observed problem with quantifying changes in extreme events with gridded climate data (e.g., Fowler et al. 2005; Halenka et al. 2006; Kendon et al. 2008).

On the basis of HEC-HMS simulations, some current design standards will be exceeded in the Pittman watershed if the 6h100y depth is increased by a factor of 1.2. For the two climate scenarios modeled, four different variables (inflow, discharge, elevation, and storage) were assessed. For these four variables at the three components studied, maximum values increased by a factor ranging from 1.1 to 1.7 under CS1.2, except for discharge at PWDB where the increase was by a factor of 32.2. For CS3.0, the increase over CS1.2 maximum values ranged from a factor of 1.1 to 1.3 for elevation and storage, and increased by a factor of 2.9 to 8.6 for inflow and discharge. The exception to this is for discharge at PEDB where the increase was by a factor of 32.1. Generally, the greater increases for maximum discharge can be associated with changes in elevation-storage-discharge relationships assumed to reflect exceedence of spillway elevation.

The importance of storm centering in this HEC-HMS model was revealed. For example, for JL, the SC model produces greater discharge at earlier peak times (~5:00) for baseline and CS1.2, while the FULL basin model produced a greater discharge at later peak times (~6:30) for the CS3.0 scenario. The failure of upstream detention basins to mitigate flow, associated with elevation-storage-discharge relationships, likely played an important role, resulting in differences in timing and magnitude of maximums between storm-centering models.

The importance of DARFs was also demonstrated. Area-to-point relationships (such as DARFs) for precipitation may change, and a brief sensitivity analysis of DARFs was conducted. For one parameterization of the model for PEDB, a 10% DARF increase led to a 24% increase in inflow, while a 10% DARF decrease led to a 30% decrease in inflow. Design engineers should analyze DARF relationships and uncertainty in climate impact assessments, considering their importance illustrated here.

It is likely that design values will continue to be based on historic data. However, there is a need for more frequent updates of design-storm depths and DARFs to capture possible recent climate trends (for example, some CCRFCD design values are based on a 1988 study). The multiple exceedences of the 6h100y design values in the Las Vegas Valley suggest that updates may be warranted for this location. Other works have shown that the storm hyetographs used in this region should be reassessed (Reilly and Piechota 2005). To address climate change in design, more complex methods to calculate design-storm depths could be implemented. The partial duration series method (Madsen et al. 2002), where maxima are selected on the basis of a threshold and not limited to one per year, could be used to calculate the 6h100y value, potentially taking into account historic climate trends. Mailhot and Duchesne (2010) have addressed developing new design guidelines that address climate change, uncertainty, and unstationarity.

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