Actual Storm Events Outperform Synthetic Design Storms
A Review of SCS Curve Number Applicability

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ABSTRACT

Two historic storm events occurred July 8, 1999, and August 19, 2003, over Las Vegas, Nevada, that met or exceeded 100-year frequency values with regard to rainfall depths in some areas and peak runoff levels in others. Although devastating in terms of loss of life and property damage, the two storm events provide a rare opportunity to compare synthetic design storms to actual rainfall events in the arid Southwest. Each storm, which occurred over a distinct watershed, is reconstructed using real-time data from a rain gage system maintained by Clark County Regional Flood Control District. Actual rainfall intensities are then compared to a standard 100-year, 6-hour rainfall distribution. The difference in "real" and synthetic storm intensities offers insight into why established 100-year rainfall depths and flowrates were exceeded during these two events. Actual precipitation depths and intensities are then input into HEC-1 Flood Hydrograph Package models to evaluate the sensitivity and applicability of SCS (Soil Conservation Service) curve number values for estimating runoff from developed and undeveloped watersheds in an arid environment. By comparing runoff levels recorded at stream gages in each watershed, this paper will show that SCS curve numbers effectively represent runoff from developed watersheds and overestimate undeveloped watershed runoff in an arid environment.

INTRODUCTION

The majority of Clark County, Nevada, is located in the Mojave Desert where the climate is arid with hot summers and relatively mild winters. Spring and fall are the driest seasons, mild general storms occur in winter, and intense, local thunderstorms occur during summer months. Mean annual precipitation ranges from less than 4 inches in southeast Clark County to over 20 inches in the Spring Mountains. Mean annual precipitation for Las Vegas Valley is just over 4 inches; about half of that total is generated by summer thunderstorms. Most major flood events that have occurred in Las Vegas Valley and surrounding areas were a result of heavy local thunderstorms.

Estimating storm events in Clark County is challenging for hydrologists and engineers because few long-term precipitation records are available. In addition, actual research of watershed response to rainfall in desert and semiarid environments has been minimal (McCuen, 2001). Therefore, to protect life and property from flood hazards, public agencies rely on widely used assumptions to quantify storm characteristics such as rainfall depth, intensity, losses, and runoff.

Although devastating in terms of loss of life and property damage, two recent storm events over Las Vegas provide a rare opportunity to evaluate current 100-year design criteria and hydrologic modeling practices suggested by local governments in Clark County. On July 8, 1999, and August 19, 2003, rainfall intensities and depths exceeded 100-year design values in some areas and 100-year peak flowrates in other areas. These widespread, dynamic events were recorded on a system of rain and stream gages in Las Vegas Valley. Using real-time data from numerous gages in two dissimilar watersheds, the storms were reconstructed to compare current design criteria with actual storm performance. This study also provides insight into the sensitivity and applicability of Soil Conservation Service (SCS) curve number values for estimating rainfall-runoff in arid and semiarid regions.

July 8, 1999 Storm Event

Two storm systems converged over Las Vegas Valley on July 8, 1999. The combined energy of the two systems caused intense rainfall over most of the Valley during a 3-hour period. Rainfall intensities measured 3 to 5 inches per hour during the storm's peak. Total rainfall depths recorded during the 3-hour event exceeded 3 inches at two rain gages, 2 inches at five gages, and 1.5 inches at twelve gages (Sutko, 1999). Flash floods generated by this event caused an estimated $20,500,000 in damage to public structures. Then-President Clinton declared a federal disaster area in Las Vegas Valley in response to Nevada governor's Declaration of Emergency.

The July 8, 1999 storm event is reconstructed over a 48-square mile portion of the roughly 150-square mile Flamingo/Tropicana watershed. In July 1999, almost 72 percent of the study watershed was undeveloped desert consisting of mountains and alluvial fan formations with sparse vegetation; the remaining area was urbanized. Soils in the study watershed are predominately alluvial fan materials categorized in Hydrologic Soil Group Type D, e.g., well-graded sands and gravels, silt, and caliche (cemented soils). At the time of the storm event, several miles of flood channel existed or were under construction. The 34 square miles of undeveloped desert drained into an existing detention basin (Upper Flamingo Wash Detention Basin) that discharged into an existing channel (Flamingo Wash). Downstream of the basin, urban runoff was conveyed into Flamingo Wash via streets or storm drains.

August 19, 2003 Storm Event

A very intense thunderstorm dropped up to 3 inches of rain within 90 minutes in northwest Las Vegas Valley on August 19, 2003. The most intense portion of the storm event was roughly centered over 49 square miles of the nearly 100-square mile Gowan watershed. Of the 15 rain gages in this study area, five recorded more than 2 inches of rainfall over a 5.6-square mile area.

On August 19, 2003, the southern 25.7 square miles of the study watershed was fully developed and densely populated with existing flood control facilities including storm drains, open channels, and detention basins. The north half was more sparsely developed. A majority of paved roads in the north portion did not have curb and gutter and the land sloped at a rate of 2% or greater toward the east. Undeveloped land consisted mostly of Hydrologic Soil Group Type B soils. Although relatively permeable, the steep alluvial slope, rainfall intensity, and rainfall volume resulted in flash floods that caused approximately $1,500,000 in damage to public facilities and an estimated $4,500,000 in damage to private structures.

Rain and Stream Gage System

Clark County Regional Flood Control District (CCRFCD) cooperates with the U.S. Geological Survey (USGS) and National Weather Service to maintain a hydrometeorological monitoring network in Clark County. To date, the network includes 139 ALERT (Automated Local Evaluation in Real Time) stations, all of which report rainfall data. The majority of stations, 106, are located in Las Vegas Valley and the remaining stations are located in other populated areas of Clark County. About 25 stations also report temperature, humidity, dewpoint, and wind data, and almost half of the stations collect water level information (Sutko, 2005). Eleven stations were located within or around the Flamingo/Tropicana study watershed area on July 8, 1999; all reported rainfall data and three reported water level information in Flamingo Wash. On August 19, 2003, 15 stations recorded rainfall in the Gowan study watershed and two reported water level information in two detention basins.

Clark County Standard Hydrologic Criteria

To standardize rainfall/runoff estimates, CCRFCD published procedures in their *Hydrologic Criteria and Drainage Design Manual* (Manual). The Manual, used throughout Clark County, defines a major design storm as having a 100-year return frequency and 6-hour duration.

For watershed areas greater than 150 acres, Soil Conservation Service (SCS) unit hydrograph or kinematic wave are two methods used in Clark County for determining stormwater runoff (CCRFCD, 1999). Both methods are based on physical characteristics of a watershed, which are relatively easily quantifiable from topographical maps, aerial photographs, land use, and soils information.

In Clark County, rainfall depths published in National Oceanic and Atmospheric Administration (NOAA) Atlas 2 are adjusted up based on analyses performed by United States Army Corps of Engineers (USACE), Los Angeles District, in 1988, and WRC Engineering, Inc., in 1989. The analyses found that NOAA values were not representative of rainfall depths observed and recorded since its publication in 1973. For example, NOAA Atlas 2 values are increased 43% for 100-year, 6-hour rainfall depths in Clark County (CCRFCD, 1999). In addition to increasing NOAA Atlas 2 point precipitation depths, a Depth-Area Reduction Factor (DARF) is applied to estimate average rainfall depth over a basin. Assumptions underlying depth-area adjustments are that storms are uniform, stationary, and most intense at the centroid of the storm.

To account for variation in rainfall intensity throughout a storm's duration, time-duration relationships in the form of mass rainfall curves were derived based on watershed area (USACE, 1988). Rainfall patterns represent light rainfall at the beginning of a 6-hour storm, intense precipitation during the middle two hours, and decreasing rainfall at the end of the storm. In Clark County, three of the five storm patterns published by USACE are used: Storm Distribution Number 3 (SDN 3) for watershed areas less than 8 square miles, SDN 4 for areas 8 to less than 12 square miles, and SDN 5 for watershed areas 12 square miles or greater (CCRFCD, 1999).

One of the physical parameters in the SCS unit hydrograph method is the SCS Curve Number. U.S. Department of Agriculture's National Resources Conservation Service, formerly SCS, produced a relationship between drainage characteristics of soil groups to a curve number (CN) based on soils studies. Data was compiled and published in a table that designers use to obtain CN values based on hydrologic soil group, land use or treatment, and antecedent moisture condition II (McCuen, 2001). CCRFCD recommends use of the SCS Curve Number method to calculate precipitation losses because of insufficient data to support other loss methods (CCRFCD, 1999).

METHODS AND DATA

Published HEC-1 Flood Hydrograph Package computer models employing the SCS unit hydrograph method were used for this study. The models, which originally encompassed full watersheds, were truncated to represent the study watersheds.

The Flamingo/Tropicana watershed has been modeled extensively by the USACE since 1959, as well as by the SCS and private consultants (USACE, 1988). The most recent [to the July 1999 event] HEC-1 model was prepared by G.C. Wallace, Inc. for a 1997 Flood Insurance Study Restudy of the Flamingo/Tropicana watershed. This model was selected because it represented existing conditions in the watershed two years prior to the storm. Once truncated, the 48-square mile study watershed contained 23 subbasins. To recreate watershed characteristics in July 1999, GIS information on parcels recorded in 1997 and 1999 provided a graphical tool to establish percent change in development within each subbasin. Aerial photographs taken August 6, 1997, and August 1, 1999 (Landiscor), were compared to determine land use types as well as to verify changes in topography within subbasins.

A 2001 HEC-1 model prepared by PBS&J for CCRFCD's *Las Vegas Valley Flood Control Master Plan Update* was used to recreate the August 2003 event. Analysis of the August storm occurred within a month of the event, therefore, watershed characteristics, observed flowpaths, and measured high water marks were physically available to evaluate the watershed. The model represented ultimate development with all planned flood control facilities constructed. The southern 25.7-square miles of the Gowan study watershed was fully developed and planned flood control facilities were constructed, so the model accurately represented half of the watershed in August 2003. The 49-square mile Gowan study watershed was divided into 118 subbasins.

Flood runoff was routed through urban subbasins using Kinematic wave method and Muskingum routing was used for undeveloped subbasins. Lag times were verified or adjusted if routing paths were altered due to development since the original HEC-1 models were prepared.

Real-Time Rainfall Evaluation

In July 1999, three of the 11 rain gages were interior to the Flamingo/Tropicana watershed, four were situated on the perimeter, and the remaining four were located outside watershed boundaries. Of the 15 gages recording rainfall over Gowan watershed, seven gages were interior, two were on the perimeter, and six gages were beyond the watershed boundaries. Based on the spatial orientation of rain gages throughout each watershed, Thiessen polygons were drawn to determine the relative weight of each gage within a subbasin. In the Thiessen Polygon method, any point in a watershed is assumed to equal the rainfall depth at the nearest gage (Chow, 1988). Hence, the influence of each gage is extended half way to the next gage in every direction. Subbasin area within a rain gage polygon was determined graphically and aerally averaged rainfall depths were calculated using actual gage data. Gage identification and recorded incremental rainfall data were input into each storm model, and applicable gage name and relative weight were added to subbasin records.

Once each storm was reconstructed from gage data, incremental and cumulative rainfall depths were compared to standard design storms. Figures 1 and 2 compare normalized sets of data for both rainfall events to an SDN 5 pattern, the pattern applied to watershed areas greater than 12 square miles. As shown in the figures, the actual storms peaked earlier within the standard 6-hour storm duration, exceeded standard 100-year rainfall depths, and were more intense than the standard storm pattern.

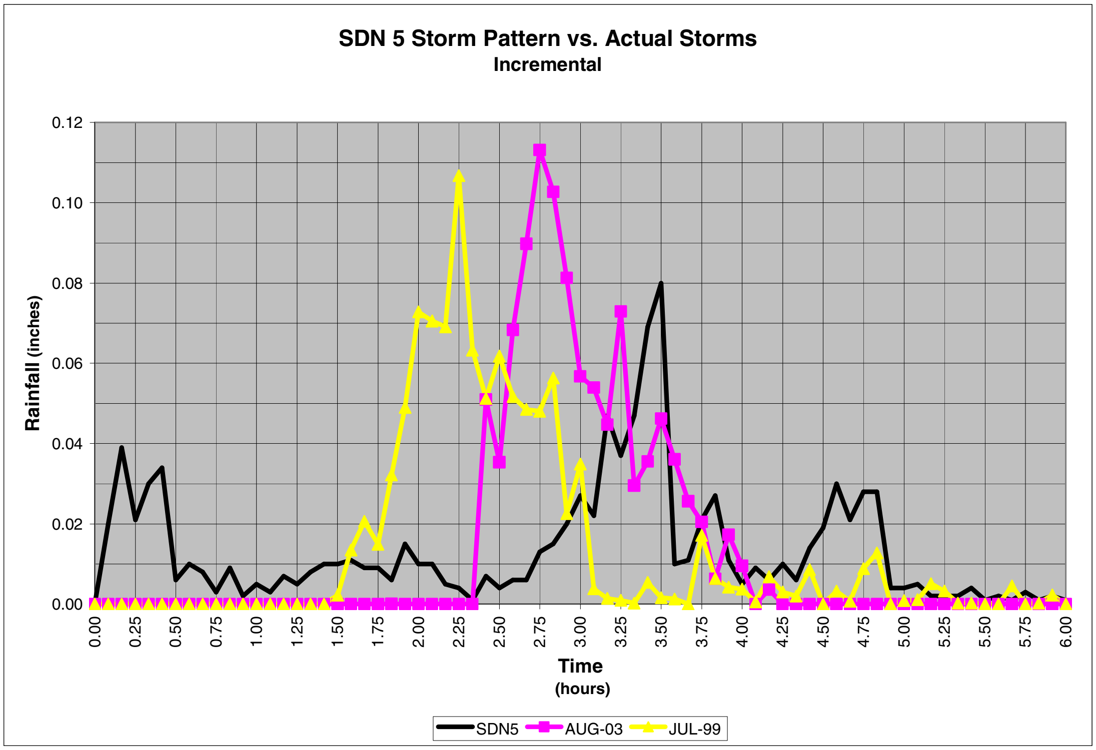

Figure 1 – Incremental rainfall comparison.

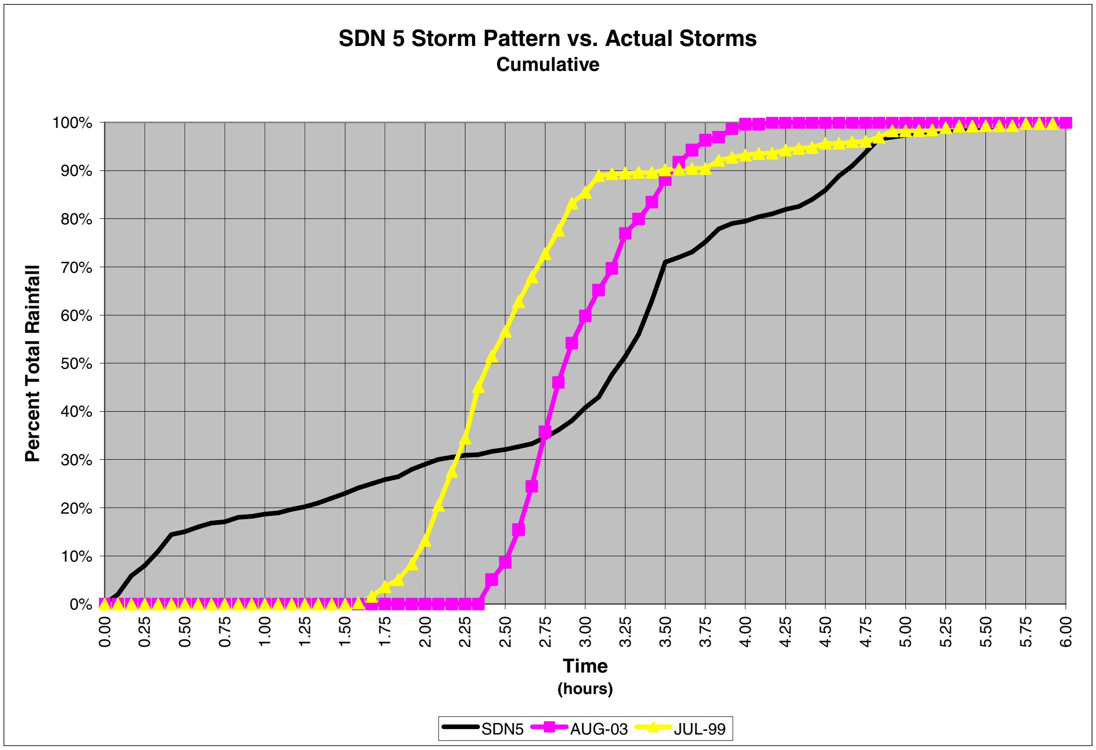

Figure 2 – Cumulative rainfall comparison.

Water Level Evaluation

Stream gages reported water levels based on rating curves previously input into the ALERT system employed by CCRFCD and USGS. Rating curves for stream gages were either developed by design engineers using hydraulic properties of the basin or channel, or by USGS. USGS physically measures channel cross-sections, flow depths, and flowrates during low flow conditions and extends the depth/flowrate relationship to estimate higher flow conditions (Sutko, 2002). Stream gages recorded water levels at the following locations in the study watersheds:

Flamingo/Tropicana Watershed

- Upper Flamingo Wash Detention Basin (UFWDB) – Upstream gage in study watershed with 34 square miles of undeveloped desert tributary.
- Torrey Pines – Located about 2 river miles downstream of UFWDB outlet on Flamingo Wash with 38 square miles tributary.
- Decatur – Located approximately 1.8 river miles downstream of Torrey Pines with 48 square miles tributary.

Gowan Watershed

- Gowan South Detention Basin (GSDB) – Upstream gage in watershed with 12.5 miles of highly urbanized area tributary via existing flood control facilities.
- Gowan North Detention Basin (GNDB) – Downstream gage in watershed with 49 square miles of urban area tributary via existing and future flood control facilities. In existing (August 2003) condition, 25.7 square miles of urbanized watershed were directly tributary.

In July 1999, USGS revised (increased) peak flowrates reported by gages at Torrey Pines and Decatur on Flamingo Wash based on field measurement of high water marks, which were then extrapolated from the gage rating curves (Tanko, 2002). A high water mark was also used to determine peak discharge rate from UFWDB outlet since gravel mining operations within the impoundment area made the original rating curve obsolete. Water was 5.5 feet deep at the 8' x 7' rectangular outlet. Assuming the outlet functioned as a weir below centerline and an orifice above centerline, it generated a peak discharge of approximately 470 cfs. High water marks verified gage water level reports for Gowan South and Gowan North detention basins.

Since stream gage information was reported in real time, it provided the means to determine time to peak and peak flowrate. These parameters were used to calibrate the storm models in addition to water level or depth.

ANALYSIS OF DATA

HEC-1 Flood Hydrograph Package computer models were prepared based on physical characteristics of the Flamingo/Tropicana and Gowan watersheds as they existed at the time of their respective storms using actual precipitation depths and intensities of those storms. Once initial model results were established, SCS curve numbers were adjusted to determine sensitivity of developed and undeveloped watersheds to this parameter. Identification and description of HEC-1 models follow:

Flamingo/Tropicana Watershed

- **FTBASE**: July 8, 1999 rainfall data recorded on rain gages in study watershed. Gage data aerally distributed by Thiessen polygon method. Watershed characteristics per July 1999 conditions.
- **FTBASE*x***: Where "*x*" represents SCS curve number point reduction for subbasins in FTBASE model to calibrate to stream gage data on Flamingo Wash. For example, FTBASE3 indicates CNs were reduced 3 points.

Gowan Watershed

- **GFUT**: August 19, 2003 rainfall data recorded on rain gages in study watershed. Gage data aerally distributed by Thiessen polygon method. Fully developed conditions over entire watershed with all planned flood control facilities in place. In absence of future facilities, runoff routed in accordance with observed flowpaths and slope of land.

Flamingo/Tropicana Hydrologic Model Results

Using actual rainfall depths and intensities of the July 1999 storm, the FTBASE model generated 2.5 times the flowrate (Qout) measured at UFWDB. At the Torrey Pines site, peak flowrate (Qp) was 50% higher in the model than measured, but the time to peak (Tp) was similar. Model peak flowrate at Decatur was 34% higher than measured and time to peak was slightly shorter in the model. Table 1 provides results of FTBASE and FTBASE*x* models.

Table 1 – Results of lowering CN values upstream of UFWDB.

FLAMINGO/TROPICANA MODEL CALIBRATION							
HEC-1 MODEL	UFWDB			Torrey Pines		Decatur	
	Qout (cfs)	Depth (ft)	Tp (hrs)	Qp (cfs)	Tp (hrs)	Qp (cfs)	Tp (hrs)
FTBASE	1210	19.7	5.6	1505	3.1	4010	3.0
FTBASE3	1125	17.0	5.6	1332	3.1	3795	2.9
FTBASE6	1050	14.6	5.5	1100	5.3	3771	2.9
FTBASE9	964	12.2	5.5	1014	5.3	3754	2.9
FTBASE12	868	9.7	5.4	919	5.3	3742	2.9
FTBASE15	766	7.5	5.4	816	5.3	3733	2.9
FTBASE17	682	6.1	5.4	787	3.0	3730	2.9
MEASURED DATA	**470**	**5.5**	**5.2**	**1000**	**3.0**	**3000**	**3.2**

Since the FTBASE model showed a greater disparity at UFWDB, curve numbers were reduced first in the 34 square miles of undeveloped desert upstream of UFWDB. These subbasins were homogeneous with respect to soil type and land use. Curve numbers were lowered 3 points per trial run in six FTBASE*x* models until time step errors occurred at 18 points. To eliminate time step errors, CN values were increased one point in the sixth run. In total, CN values for undeveloped subbasins were lowered 17 points thereby reducing the initial composite CN value from 84.5 to 72.3. Figure 3 shows UFWDB peak outflow approaching the measured flowrate as composite CN values changed upstream of the basin.

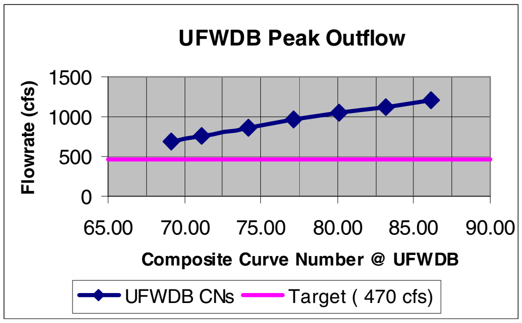

Figure 3 – Undeveloped desert subbasin CNs reduced by 3-point increments upstream of UFWDB.

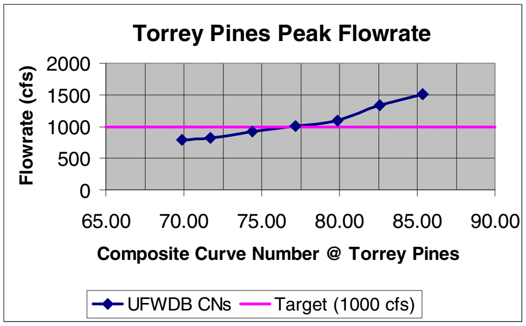

Figure 4 – Undeveloped desert subbasin CNs reduced by 3-point increments upstream of UFWDB.

Flowrates and times to peak at Torrey Pines were sensitive to UFWDB outflow as shown in Table 1 and illustrated in Figure 4. This is expected since only 4 square miles of watershed are directly tributary to Torrey Pines whereas UFWDB is attenuating runoff from 34 square miles 2 miles upstream. However, changes to UFWDB outflow do not have a significant effect on channel flowrate at Decatur. Since the FTBASE17 model was still over predicting flowrates at Decatur, CN values were adjusted in subbasins downstream of UFWDB while maintaining lowered CN values upstream of UFWDB.

Land use in the five subbasins directly tributary to Torrey Pines was dissimilar. Original CN values ranged from 66.3 to 89.2 representing a golf course community and densely populated master planned community, respectively. There was also vacant land with Type D soils. CN values were incrementally raised and lowered 6 points in the five subbasins upstream of Torrey Pines, however, outflow from UFWDB controlled peak values at this gage. As such, CN adjustment immediately downstream of UFWDB did not bring model results closer to measured results at Torrey Pines.

Nine subbasins encompassing 10 square miles drain to Decatur. Land use varies from vacant land to dense development, however, five subbasins closest to the gage site are fully developed. Individual subbasin CN values ranged from 74.4 to 91.5 for a composite CN value of 81.5. Curve numbers were reduced a total of nine points in the Decatur subbasins. Although time to peak held constant at 2.9 hours, peak flowrate showed a much greater sensitivity to CN reduction in the nine Decatur subbasins than it did to changes upstream of UFWDB. Peak flowrates began to drop below the target value of 3000 cfs after CN values were reduced 3 points. Figure 5 graphically shows peak flowrate response to CN changes upstream and downstream of UFWDB.

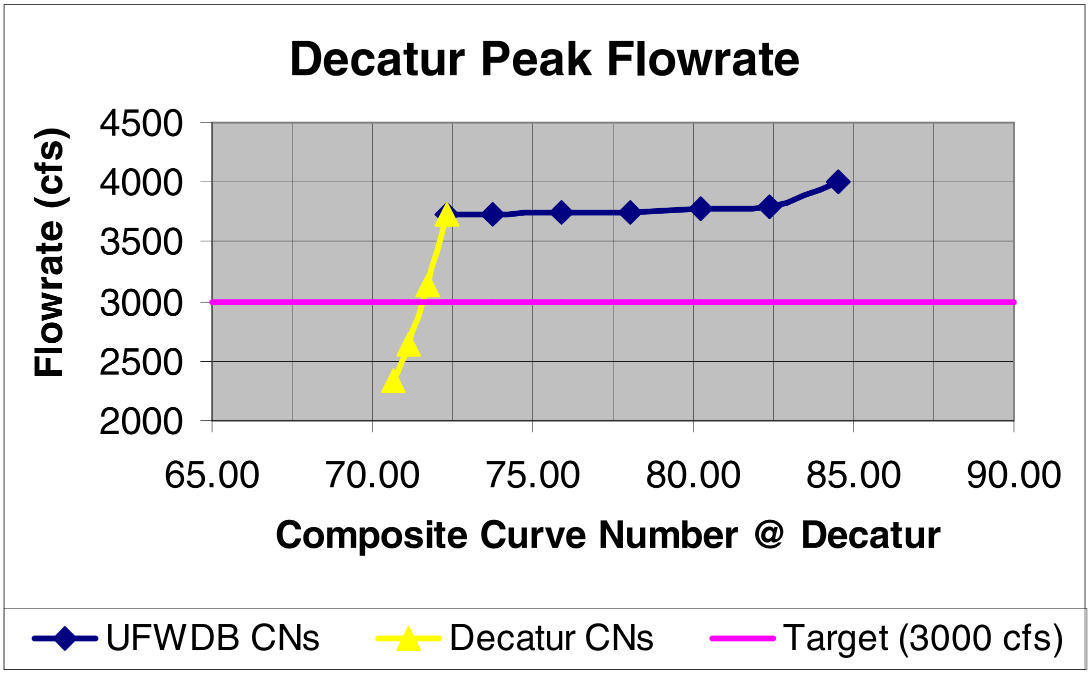

Figure 5 – Undeveloped desert subbasin CNs reduced by 3-point increments upstream of UFWDB, then CNs reduced in developed subbasins tributary to Decatur.

Gowan Hydrologic Model Results

Rain gage data from the August 19, 2003 storm event was modeled over a 49-square mile portion of Gowan watershed. The GFUT model assumes fully developed conditions with all flood control facilities in place. This was true in the southern part of the study watershed wherein 12.5 square miles of urbanized land drained to Gowan South Detention Basin (GSDB), and an additional 13.2 square miles drained to Gowan North Detention Basin (GNDB). Runoff was conveyed to the basins via existing storm drains and open channels. A composite CN value of 87.2 represented the densely developed residential and commercial subbasins in the southern 25.7 square miles of Gowan watershed.

Runoff from the remaining 23.4 square miles of sparsely developed subbasins bypassed the detention basins in the absence of future flood control facilities. To represent actual flow patterns of August 19th in northern Gowan watershed, flow was routed in roadways and earthen washes following natural topography.

The accuracy of the GFUT model was validated by comparing water level data recorded at the basin gages to stage distribution curves generated by the hydrologic model. Figures 6 and 7 illustrate that runoff reaching the two basins is effectively represented bythe GFUT model using CN values from 71.2 to 91.9 for the fully developed subbasins. Results are summarized in Table 2. Curve numbers were not adjusted in the GFUT model because the output corresponded to gage data for the fully developed portion of watershed. The sparsely developed areas were not directly tributary to a stream gage, and therefore, runoff bypassing the detention basins could not be validated.

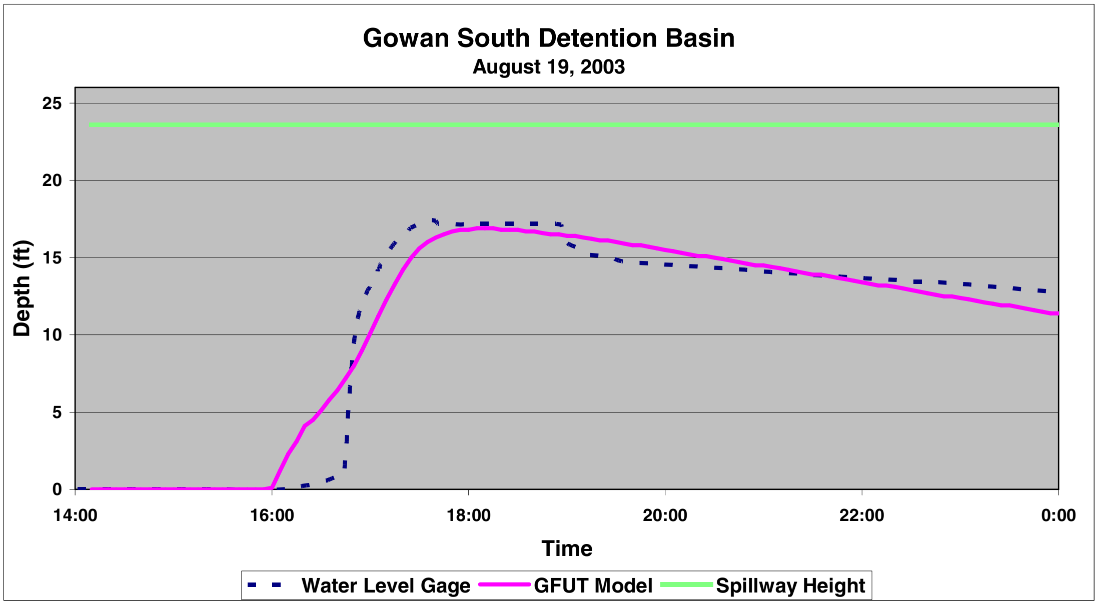

Figure 6 – GFUT model accurately represents fully developed watershed tributary to GSDB.

Table 2 – Hydrologic model results.

GOWAN MODEL CALIBRATION				
CHARACTERISTIC	**GSDB**		**GNDB**	
	Model	**Gage**	**Model**	**Gage**
Peak Stage (ft)	16.9	17.8	10.8	10.4
Peak Outflow (cfs)	407	418	365	341

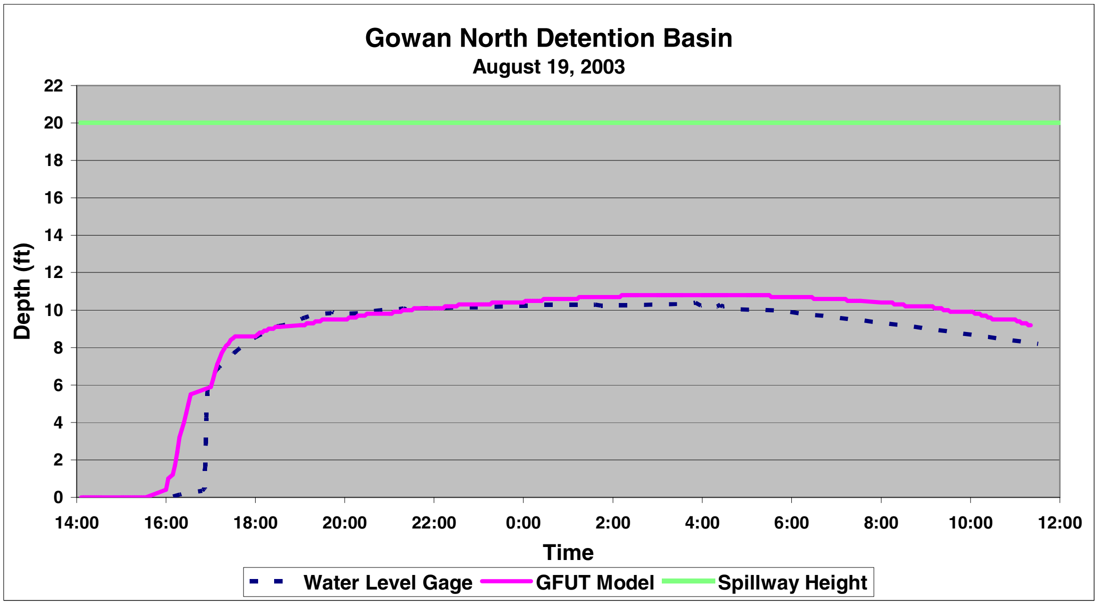

Figure 7 – GFUT model accurately represents fully developed watershed tributary to GNDB.

CONCLUSIONS

Two recent storm events over Las Vegas, Nevada, provide a rare opportunity to evaluate 100-year hydrologic design criteria adopted for use in this arid environment. Because the events were widespread, rainfall intensity and resulting runoff were recorded by a relatively large system of rain and stream gages. An analysis of the gage information generated during the storm events provides useful information by which to evaluate storm duration, rainfall intensity, watershed losses, and runoff.

On July 8, 1999, two storm cells converged over Las Vegas Valley causing intense rainfall during a 3-hour period. Using real-time information from 11 rain gages, the event is recreated over a 48-square mile portion of the Flamingo/Tropicana watershed, and then peak runoff is compared to stream gage data at three locations on Flamingo Wash. Another intense thunderstorm occurred August 19, 2003, dropping up to 3 inches of rain within 90 minutes in northwest Las Vegas Valley. This event is reconstructed using information from 15 rain gages within a 49-square mile portion of Gowan watershed. Peak water levels are provided by two stream gages located in Gowan South and Gowan North detention basins within the watershed.

Both storm events peaked earlier and higher than the standard 6-hour duration storm pattern used in Clark County. The standard 6-hour storm distribution begins with light rainfall for about two hours, increases in intensity during the middle two hours, and then tapers off during the last two hours. Neither the July 1999 nor August 2003 events started with light rainfall; intensities were high at the storms' onset and exceeded those in the standard distribution pattern (SDN 5). In lieu of questioning the standard distribution pattern, the actual events emphasize the need to examine multiple storm patterns and centerings in larger watersheds. Although the actual storms had shorter durations, the 6-hour duration appears appropriate for capturing all rainfall activity associated with typical local thunderstorms.

HEC-1 Flood Hydrograph Package computer models were used recreate the two historic storm events. Models of both study watersheds represented land use and flow patterns at the time of their respective storm events. To evaluate watershed losses, stream gage data was used to compare runoff generated by the hydrologic models using real-time rainfall depths and intensities from watershed rain gages.

When hydrologic model results exceeded measured flowrates at the Flamingo/Tropicana stream gages, SCS curve numbers were adjusted to calibrate to gage data. In July 1999, almost 72 percent of the Flamingo/Tropicana watershed was undeveloped desert in poor hydrologic condition. Curve number values were reduced 17 points in the undeveloped subbasins before model output began to converge on measured data at the first stream gage. Although model results still did not correspond to the lower two stream gages, CN adjustment in developed portions of the watershed tributary to these gages was not an effective means to fit reported data. Changes in CN values in subbasins tributary to the middle gage were overshadowed by detention basin outflow two river miles upstream; however, peak flowrate was highly sensitive to CN adjustment in developed subbasins tributary to the most downstream gage. By comparison, the August 2003 storm event occurred over a densely populated area of Gowan watershed, and hydrologic model results were remarkably similar to reported gage data. Curve number adjustment was not necessary in the developed subbasins tributary to Gowan South and Gowan North detention basins.

Based on analyses of the two storm events and watershed response of developed subbasins, evidence presented in this study indicates that tabulated CN values adequately estimate runoff losses from urbanized watersheds. Conversely, tabulated CN values appear to overestimate losses for undeveloped desert in poor hydrologic condition with Type D soils. This conclusion supports the theory developed by Hawkins (1978), which states that curve numbers could be relatively low in areas with high evapotranspiration rates and low antecedent moisture conditions (McCuen, 2001). In a study by Simanton et al (1996), they determined that tabulated CN values do not adequately account for infiltration losses in natural channels through larger subbasins. Subbasin areas ranged from 1.12 to 6.27 square miles in the undeveloped portion of Flamingo/Tropicana watershed. Thus, infiltration losses through the long, natural watercourses may justify lowering CN values nearly 20 percent.

This study evaluated one parameter of several that affect watershed response in a rainfall-runoff model. Further study on the effect of infiltration losses and subbasin size on SCS curve number selection should be initiated to validate Simanton’s work and the results presented in this study. Other variables inherent to the SCS Unit Hydrograph method should also be considered. Hydrograph lag times have a marked effect on flowrates and times to peak and routing parameters affect losses along flowpaths.

REFERENCES

Clark County Regional Flood Control District. *Hydrologic Criteria and Drainage Design Manual.* Prepared by WRC Engineering, Inc. and updated by Montgomery Watson. August 1999.

Clark County Regional Flood Control District. *Las Vegas Valley Flood Control Master Plan Update.* Prepared by PBS&J in association with G.C. Wallace, Inc., and Louis Berger Group. October 2002.

Chow, Ven Te, David R. Maidment, and Larry W. Mays. *Applied Hydrology*. McGraw-Hill, Inc., 1988.

G.C. Wallace, Inc. *Flood Insurance Study Restudy of Flamingo/Tropicana Washes Watershed*. Las Vegas, Nevada, October 1997.

Hawkins, R.H. "Runoff Curve Numbers with Varying Site Moisture," *Journal of Irrigation and Drainage*, ASCE. 104(IR4): 389-398, 1978.

Landiscor Aerial Information. *Las Vegas 1999 – 2000*, *Las Vegas 1997*, *Las Vegas 1991*, *Las Vegas 1988*, and *Las Vegas 1987 – 1988*. Las Vegas, Nevada.

McCuen, R.H. "Application of Curve Number Hydrology in Semi-Arid and Desert Environments." *Journal of Floodplain Management*, Vol. 2, No. 2, April 2001.

Simanton, J.R., R.H. Hawkins, M. Mohseni-Saravi, and K. Renard. "Runoff Curve Number Variation with Drainage Area, Walnut Gulch, Arizona," Trans. of the ASAE. 39(4):1391-1394, 1996

Soil Conservation Service. *National Engineering Handbook Section 4 Hydrology*. U.S. Department of Agriculture, Water Resources Publications, Littleton, Colorado. March 1985.

Sutko, Timothy E. "Rainfall Event Report July 8, 1999." Clark County Regional Flood Control District, July 30, 1999.

Sutko, Timothy E. Personal Interviews. April 8, 2002 and February 10, 2005.

Tanko, Daron J., Hydrologist, USGS. E-mail to Timothy E. Sutko and forwarded to author. March 25, 2002.

U.S. Army Corps of Engineers. *HEC-1 Flood Hydrograph Package Users Manual.* Hydrologic Engineering Center, Davis, California. September 1981, revised March 1987.

U.S. Army Corps of Engineers. *Hydrologic Documentation for Feasibility Study, Las Vegas Wash and Tributaries, Clark County, Nevada*. Los Angeles District, South Pacific Division. April 1988.