5.4 DEVELOPMENT OF A SCIENTIFICALLY DEFENSIBLE DESIGN STORM FOR SOUTH BOULDER CREEK

John F. Henz* and William J. Badini
HDR Engineering, Inc.
Denver, Colorado

1. INTRODUCTION

The climatology task has provided a detailed insight into the precipitation mechanisms and occurrences within the South Boulder Creek basin. Five integrated tasks were completed that culminated in the development of a South Boulder Creek "scientifically defensible" Design Storm (SDDS). The SBC SDDS makes use of existing observational databases, which were not available until the past ten years, to enhance the temporal and areal definitions of the design storm.

2. PREMISE OF A DESIGN STORM

The basic premise of a design storm's utility is that a design storm of a given frequency will produce a simulated runoff peak and volume having the same return frequency. Thus, a 100-year design storm should produce a 100-year runoff and volume. Typically, design storms have been developed by statistical analysis of long term point precipitation records with little regard for the runoff consequences (Urbonas, 1979). It is crucial that the design storm be linked quantitatively to the basin's runoff response.

Another inherent weakness of the standard design storm is that it lacks true definition of the storm's areal coverage in a basin and the temporal distribution of the rainfall producing the runoff (Urbonas, 1979). Typically, these factors are "backed into" by synthetic modeling efforts. Lacking both quantitative storm areal and temporal distributions from observations, many contemporary design storm approaches have been based on a combination of long term precipitation point records and sophisticated analysis and modeling efforts.

However, the SBC design storm has addressed these key weaknesses and is based on a strong local and regional observation base and related basin response modeling. The SBC design storm proposed is based on the integration of four key basin evaluations:

1. statistical South Boulder Creek precipitation record evaluation and analyses to provide the storm magnitude and return frequencies and antecedent moisture characteristics,
2. enhanced radar analysis of regional, historical 100-year storms to refine the areal coverage and temporal rainfall of observed Front Range 100-year thunderstorms,
3. observed topographic impacts on SBC storm placement and development on precipitation distribution within the basin and,
4. paleo-hydrologic basin-specific evidence of past flooding events.

3. KEY DIFFERENCES IN THE SDDS

Traditional design storms rely heavily on creative analyses of precipitation records or historically developed storm types from other parts of the country. The SBC design storm builds on the standard design storm approach by using standard statistical analyses of precipitation observations to develop the quantitative definition of storm return frequencies. The SBC design storm enhances the standard design storm's statistically-based temporal and areal precipitation distributions by the integration of areal and temporal storm characteristics derived from National Weather Service's (NWS) WSR-88D Doppler radar storm observations.

Application of the 1993-2003 WSR-88D database has refined the areal and temporal distributions of storms not available from precipitation records. The key characteristic of the radar storm observations is the 5-min to 6-min temporal resolution of the storm intensity over a roughly 0.5 by 0.5 mile resolution of the storm's areal coverage. Current rain gage based observations lack this temporal and areal resolution.

Thus, the definition of the SBC design storm is based on observed storm characteristics. These analyses address the inherent weaknesses of most design storms. Most standard design storms rely only on point or network precipitation analyses and statistically generated precipitation characteristics. The SBC design storm has been customized for the SBC basin.

The basin modeling tasks provide insights into the runoff characteristics generated by the design storm to provide a bridge between the basin design storm and its runoff characteristics. The detailed modeling approach used provides a direct link between the design storm precipitation and its related runoff.

Instead of a typical, conservative uniform rainfall distribution and design storm application, the SBC design storm is based on the integrated, climatological analysis completed for this study. Based on the SBC storm climatology it evolved into two customized design storms: a 72-hour general storm and a 24-hour thunderstorm. These two design storms reflect the primary meteorological causes of flooding in SBC basin. We refer to these design storms as our “scientifically defensible” Design Storm (SDDS) for South Boulder Creek.

3. SOUTH BOULDER CREEK BASIN

The City of Boulder, Colorado has been identified as having one of the largest potentials for loss of life to flash flooding within Colorado (CWCB, 2003). Boulder is lined to the west by a series of foothills canyons that drain into the City. The three primary foothills watersheds from north to south include Four Mile Creek, Boulder Creek and South Boulder Creek. (See Figure 1)

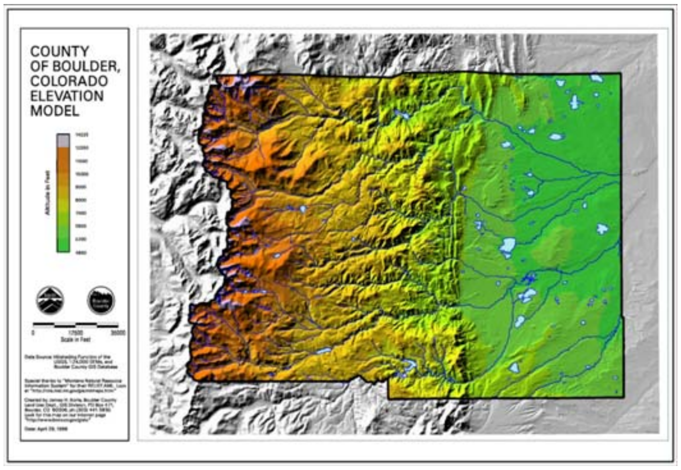


Figure 1 South Boulder Creek in Boulder County, Colorado

Figure 1 Sout
Colorado

South Boulder Creek’s physiography may play a role in its flooding history. Note in **Figure 2** that the South Boulder Creek basin (outlined in black) has three distinct sections:

1. The **lower** basin is flat with a **northeast-southwest** orientation with most of the basin’s elevation below 6,000 feet. The lower basin ends abruptly at the Flatiron’s interface.
2. The **middle** basin shows a distinct **southeast to northwest** orientation with elevations rising from near 6,000 feet to over 9,000-10,000 feet along the basin’s north and south boundaries. This portion of the basin extends one to two miles west of Gross Reservoir.
3. The **upper** portion of the basin faces an almost due **east-west** orientation and extends from about 8,500 feet up to over 13,000 feet along the Continental Divide.

4. SPECIFIC SDDS TASKS

The primary tasks were to provide a quantitative and scientifically defensible basis for the development of a South Boulder Creek (SBC) design storm and provide realistic rainfall input for use in the calibration of the hydrologic modeling of the SBC basin. These primary tasks required the accomplishment of the following specific subtasks:

1. Develop a quantitative description of the meteorological causes of and the rainfall patterns flooding events in the SBC basin.
2. Update the NOAA Atlas II precipitation frequency analysis by adding the precipitation events observed in the basin from 1973 to present.
3. Develop radar-rainfall reconstruction of key storm events for use in basin model calibration efforts. The radar-derived and ground-truth rainfall data provided enhanced temporal, areal and intensity information not available from limited rain gage only data.
4. Evaluate WSR-88D observations of 100-yr or greater to obtain areal and temporal storm characteristics.

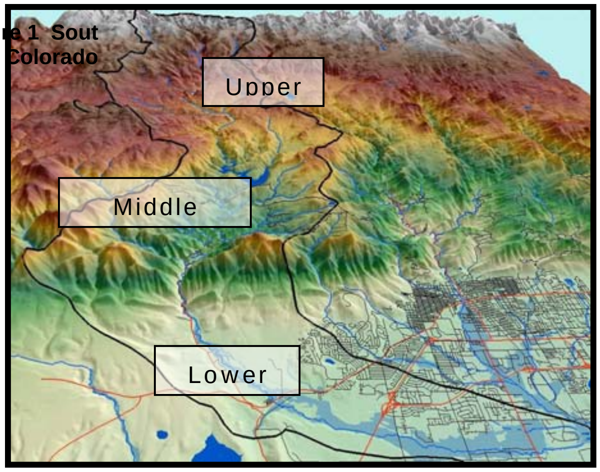


Figure 2 3-D View of South Boulder Creek looking west

The role of the first subtask was to identify the major flooding events that impacted the basin, quantify, to the degree possible, the precipitation pattern that produced the flood and identify the meteorological causes of the event.

The updating of NOAA Atlas II precipitation frequency data provided an additional 30 years of historical perspective on the magnitude of rainfall events affecting the basin. Together, these subtasks provide a strong historical foundation on which to understand the causes of SBC flooding and its frequency.

The third subtask provided a quantitative link for use in determining the runoff response of the basin to major precipitation events. Reliable temporal distribution, areal coverage and intensity of precipitation are required input into any hydrologic model. Selection of two recent rainfall events from 1998 and 1999 allowed use of the National Weather Service's WSR-88D Doppler radar in concert with the existing SBC Flood Detection Network of weather stations, rain gages and stream gages to develop the detailed precipitation definition needed for successful modeling.

The final sub-task required the identification and analyses of 100-yr or greater precipitation events that were observed by National Weather Service WSR-88D Doppler radars to occur in similar physical locations to South Boulder Creek along the Front Range of Colorado. The installation of WSR-88D's in Cheyenne, WY, Watkins, CO and Pueblo, CO occurred during 1993-1994. The storm search period covered 1994-2003.

Finally, the integration of the results from the prior four steps is used to craft a scientifically defensible design storm that is based on the cumulative knowledge gained from local and regional flooding events. This comprehensive approach is a basin-specific representation of the meteorology for South Boulder Creek rather than relying on statistically-derived regional procedures.

5. SBC FLOOD CLIMATOLOGY

A detailed review of flooding on Boulder County, Colorado, Colorado and neighboring state identified that to primary causes of flooding appeared to impact Boulder County and South Boulder Creek, specifically. From 1890 to 2004 7 general storms and 14 thunderstorm events were related to significant Boulder Creek or SBC flooding.

The most significant general storm events occurred in May 1894 and May 1969 and produced the most wide-spread flooding damage and coverage. The deadliest flash flooding event produced by thunderstorms occurred on September 2, 1938 and killed 7 people on South Boulder Creek. This flood also produced the largest recorded flood peak on SBC. Thus both general and thunderstorm events were deemed to be important to the development of the SDDS.

6. UPDATING NOAA ATLAS II VALUES

This task involved calculating the updated values of precipitation DDF in Boulder County for the stations originally used in the creation of NOAA Atlas II Volume III – Colorado, 1973. The observation stations, data sources and the statistical techniques used to derive the values were detailed in a preceding section. The addition of 30 years of precipitation data lowered the value of the 24-hour, 100-year storm at the Boulder gage from 5.03 inches to 4.69 inches. The lower value, however, was not recommended for acceptance since the Boulder gage is not accepted as being representative of precipitation in the South Boulder Creek basin.

A comparison of the limited periods of record for the Hawthorne and Gross Reservoir gages in SBC basin to the Boulder gage record was reported earlier in this report. Since both the Hawthorne and the Gross Reservoir gages are in the SBC basin, a ratio adjustment technique was applied to each using the longer record Boulder gage to develop comparable 24-hour, 100-year values at each site. The results were shown in Table 4. The ratio adjustment of the 24-hour, 100-year value for the Boulder gage computes a 24-hour, 100-year value of 5.41 inches for the Hawthorne gage and 5.02 inches for the Gross Reservoir gage.

These values are presented in Table 1 below along with values for the Boulder-updated and Boulder-NOAA Atlas II 24-hour, 200 year and 24-hour, 500-year precipitation events. Note that utilization for design of the Boulder-updated gage values resulted in an under-estimation of the 24-hour, 100-year values if the Hawthorne and Gross Reservoir values are representative of SBC 100-year events. Due to this uncertainty, the Boulder-NOAA Atlas II values were used for development of the SBC SDDS.

Table 1 - Comparison of Boulder, Hawthorne and Gross Reservoir gage return frequency values

Station	**24-hour, 100-year**	**24-hour, 200-year**	**24hour, 500-year**
Hawthorne	5.41"		
Gross Reservoir	5.02"		
Boulder-updated	4.69"	5.14"	5.74"
Boulder-NOAA Atlas II	5.03"	5.40"	6.05"

Table 1 summarizes agency design storm characteristics. The table presents the preferred

A second review was made of the gages to determine how many times the Boulder 100-year, 24-hour NOAA Atlas II value of 5.03” had been equaled or exceeded at any of the four Boulder gages closest to SBC. The gages were the Boulder, Boulder 2, Hawthorne and Gross Reservoir gages. The only 24-hour storm value that equaled or exceeded the 24-hour, 100-year event of 5.03” was the 5.22” reported at Hawthorne during the September 2, 1938 flooding event. **Table 2** shows the peak 24-hour values reported at each site.

Table 2 - Listing of Boulder, Boulder 2, Hawthorne and Gross Reservoir gage values for peak observed 24-hour and 72-hour precipitation events for period of record

Station	Peak 24-hour value	Peak 72-hour value	Other 24-hour of interest
Boulder	4.80”, 7-31-1919	6.37”, May 5-7, 1969	3.51”, 5-17-1995
Hawthorne	5.22”, 9-02-1938	7.48”, May 5-7, 1969	4.09”, 5-07-1969
Gross Reservoir	4.15”, 4-03-1986	6.17”, Mar 18-20, 2003	3.47”, 8-05-1999
Co-op Observer-SBC	NA	13.05”, May 5-7, 1969	NA

Note that the Hawthorne gage value of 5.22” on September 2, 1938 reported on the night of the Eldorado flood was the only observation that exceeded or equaled the NOAA Atlas II 24-hour, 100-year event value of 5.03 inches. Figure 3 below shows the location of the analyzed rain gages used ion this evaluation.

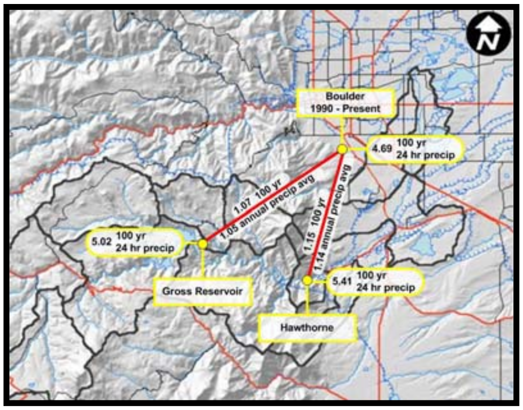


Figure 3 SBC Precipitation Gages

Of additional interest is the 4.09” observed at the Hawthorne gage on May 7, 1969 during the 1969 flooding event. Apparently the Hawthorne gage, discontinued in 1973, was the only gage to record both the 1938 and 1969 event rainfall magnitudes. By comparison both the Boulder and the Boulder 2 gages showed peak responses in 24-hour precipitation to other events and the peak values were lower.

7. RAINFALL-RUNOFF CALIBRATION

A primary disconnect in most design storms is the lack of a basin calibrated rainfall-runoff relationship. The SBC SDDS relied on the re-construction of rainfall from two key events.

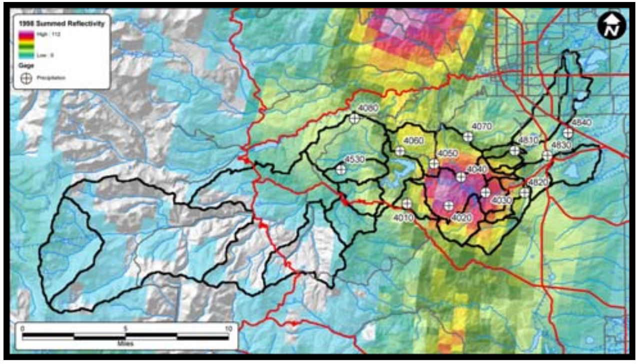


Figure 4 Radar-derived rain for July 8, 1998

The July 8, 1998 thunderstorm event produced damaging but not widespread flooding on the middle SBC basin. The August 3, 1999 event produced general rain across the entire basin. Use was made of a flood detection network to ground-truth the radar reflectivity-rainfall relationship for both cases. Figure 4 above shows the radar-derived rain for July 8, 1998 and Figure 5 shows the radar reflectivity rainfall relationship achieved an r-squared of 0.886.

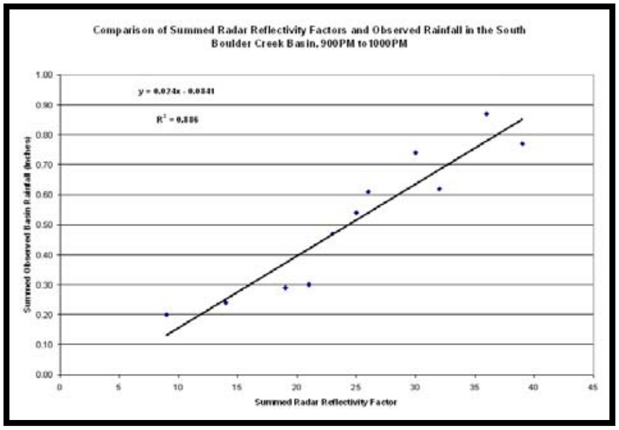


Figure 5 Radar reflectivity-rainfall relationship for July 8, 1998 in SBC.

The radar-derived rainfall was converted using GIS techniques into a grid of 1km by 1km and used to develop sub-basin averaged rainfall. The temporal distribution was developed using a combination of the basin ALERT rain gages and radar reflectivity profiles. The rainfall field was used as input into a basin hydrologic model to calculate runoff and describe the floodplain through use of a linked hydraulic model.

8. 100-YR THUNDERSTORM SDDS

Traditional design storms rely heavily on creative analyses of precipitation records or historically developed storm types from other parts of the country. The SBC design storm builds on the standard design storm approach by using standard statistical analyses of precipitation observations to develop the quantitative definition of storm return frequencies. The SBC design storm enhances the standard design storm's statistically-based temporal and areal precipitation distributions by the integration of areal and temporal storm characteristics derived from National Weather Service's (NWS) WSR-88D Doppler radar storm observations.

Application of the 1993-2003 WSR-88D database has refined the areal and temporal distributions of storms not available from precipitation records. The key characteristic of the radar storm observations is the 5-min to 6-min temporal resolution of the storm intensity over a roughly 0.5 by 0.5 mile resolution of the storm's areal coverage. Current rain gage based observations lack this temporal and areal resolution.

The size and areal characteristics of the 13 100-year storms identified above provide a solid basis for defining the SBC SDDS. The first characteristic is length to width ratio. NOAA Atlas II defined this ratio as 2.4:1 and Henz, (2003) reported a ratio of 3:1 in an evaluation of extreme eastern Colorado precipitation events. The ratios of the storms evaluated in this study ranged from 1.17:1, on July 12, 2000, to 3.1:1 on August 31, 2001 as shown in **Table 3**. The average of the 13 storms was a 2.14:1 ratio and this value was rounded to SDDS value of 2:1.

Table 4 shows individual and average areal characteristics of the storms including:

1. Storm length and width
2. Area of precipitation of 2.0" to 3.5" in square miles
3. Area of precipitation greater than 3.5" in square miles
4. Storm total area of precipitation greater than 2.0"

These characteristics provide areal definition to the SBC SDDS. It is interesting to note that the average size of the storm rainfall area of greater than 3.5" is only about 8 square miles in size and the area of 2.00" or more is about 23 square miles. The relatively small size of these 100-year storms explains why basins and rain gages are hit so seldom by these events.

Table 4 - Thunderstorm length vs. width axis ratios for the 13 Northern Front Range 100-year precipitation events, 1994-2003

Storm Date	Length(miles)	Width(miles)	Axis Ratio
8/10/1994	7.00	3.80	1:84
6/2/1997	10.20	3.40	3:1
6/6/1997	12.80	6.00	1.64:1
7/30/1997	6.40	4.80	1.38:1
7/30/1998	6.00	3.60	1.67:1
8/10/1998	3.40	2.40	1.42:1
9/1/1998	6.20	3.40	1.82:1
8/4/1999	7.20	3.60	2.19:1
7/16/2000	5.00	3.60	1.39:1
8/16/2000	5.80	1.40	4.14:1
7/12/2001	5.60	4.80	1.17:1
8/31/2001	6.20	2.00	3.1:1
6/18/2003	6.00	2.60	2.73:1
AVG. RATIO			**2.14:1**

Table 3 - Thunderstorm size characteristics for the 13 Northern Front Range 100-year precipitation events, 1994-2003

DATE	Length of Storm (miles)	Width of Storm (miles)	Square miles of > 2.0" - 3.5"	Square Miles of > 3.5"	Total Square Miles Of > 2.0"
8/10/1994	7.00	3.80	17.40	4.35	21.75
6/27/1997	10.20	3.40	17.40	14.50	31.90
6/7/1997	12.80	6.00	36.25	20.30	56.55
7/30/1997	6.40	4.80	21.75	5.80	27.55
7/31/1998	6.00	3.60	10.15	7.25	17.40
8/10/1998	3.40	2.40	8.70	2.90	11.60
9/1/1998	6.20	3.40	15.95	5.80	21.75
8/4/1999	7.20	3.60	14.50	8.70	23.20
7/17/2000	5.00	3.60	11.60	7.25	18.85
8/16/2000	5.80	1.40	5.22	2.90	8.20
7/12/2001	5.60	4.80	11.60	8.70	20.30
8/31/2001	6.20	2.00	6.80	4.80	11.60
6/18/2003	6.00	2.60	14.50	11.60	26.10
Average	6.75	3.5	14.67	8.16	22.83

A comparison of the areal coverage of the square miles of rainfall of 2.0”-3.5” to rainfall of greater than 3.5” supports the observed tight gradient of rainfall over short distances during strong rainfall events. Six of the thunderstorm events were multi-cell storms and seven storms were single cell storms.

The SBC SDDS used the relationships determined in **Tables 3 and 4** to guide the areal precipitation distribution of the thunderstorm design storm as shown in **Figure 5**. The SBC thunderstorm SDDS has the following observationally-derived characteristics:

1. Length of 7 miles and width of 3.5 miles for a 2:1 ratio (main cell, greater than 1”),
2. Areal coverage of 23 square miles with rainfall of 2” or more,
3. A multi-cell storm, and
4. Covers just over 8 sq. miles of rainfall greater than 4 inches with the 5.03”, 24-hour, 100-year precipitation maximum falling within the 4 inch isohyetal line.

These radar-derived characteristics are not standard design storm methodology but address the most significant design storm short-comings of poor areal and temporal observation of precipitation described by Urbonas, (1979).

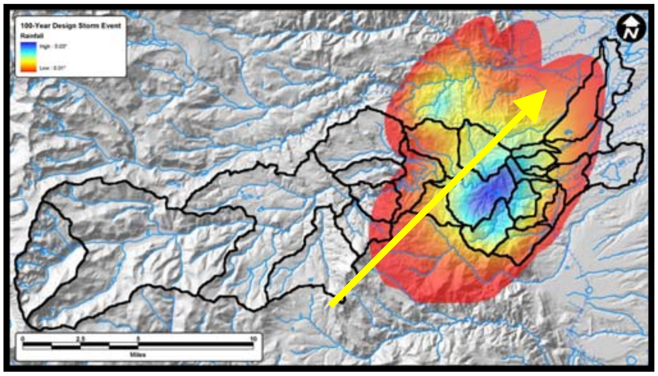


Figure 2 - Areal precipitation distribution for the 24-hour, 100-year thunderstorm SDDS

It is interesting to note that all the 100-year thunderstorm events in **Table 5** had durations of 6 hours or less for precipitation. The duration of each event was cross-checked against the Level III maximum radar reflectivity values that corresponded closest to the event location. The value of the point radar reflectivity (dBZ) of the identified central point was used to derive the temporal reflectivity pattern.

The actual reflectivity value of that point was converted to a scale that only included reflectivity values equal to or greater than 40 dBZ. Lower reflectivity values are not associated with thunderstorm rainfall thresholds. Some leeway was allowed for values where the point was near the divider between radar ‘bins’, and subjective averages were used if these situations existed.

Based on the 13 events, the 360-minute temporal distribution shown in **Table 5** was developed. The rainfall is equally divided by 5-minute time steps within each 30-munite block. The “slow start” to the precipitation event over the first 30 minutes is reflected in development of the storm updraft. While high reflectivity values may be present during this updraft time, little precipitation has been observed.

Table 5 - Thunderstorm SDDS temporal precipitation distribution based on the 13 Northern Front Range 100-year precipitation events, 1994-2003

Time Interval	Precipitation amount	Accumulated	Percent Accumulation
0	0	0	0
30	0	0	0
60	1.00	1.00	20
90	1.00	2.00	40
120	0.30	2.30	46
150	0.50	2.80	56
180	0.50	3.30	66
210	0.50	3.80	76
240	0.25	4.05	80
270	0.25	4.30	85
300	0.25	4.55	90
330	0.25	4.80	95
360	0.23	5.03	100

This 6-hour precipitation period is embedded within a specific 24-hour period with the preferred time for the precipitation during the afternoon or early evening hours. As noted earlier, antecedent moisture of up to 20-25% of the observed precipitation is reasonable based on observations. It should be noted that the application of the 24-hour, 100-year precipitation of 5.03” into a preferred 6-hour period is not meant to imply that this value is a 6-hour, 100-year storm. Rather it is a concession to the observation that summer thunderstorms tend to last less than 6 hours and it is a conservative SDDS alternative to test the basin response.

9. 100-YR GENERAL STORM SDDS

The design general storm makes use of the observations of precipitation from the May 4-7, 1969 event to provide detail on the areal precipitation distribution in South Boulder Creek during a significant flooding event. Instead of the uniform distribution of precipitation across the basin as prescribed by a standard design storm, the SBC SDDS recognizes that the 1969 storm presents an excellent proxy for the uneven orographic distribution of precipitation across the SBC basin. The temporal distribution of precipitation for this event makes use of the Boulder recording gage and is consistent with the distributions found in long duration, low intensity upslope precipitation found in Front Range general storms.

Storm totals in SBC basin ranged from 4-6 inches in the lower basin to over 13 inches in the middle basin. Lesser amounts were observed in the upper third of the basin where most of the precipitation fell as snow. The 1969 general storm was preceded by 72-hour precipitation total of 1.25” in the Hawthorne gage which was 20 percent of the storm total Hawthorne precipitation of 6.24 inches.

A GIS-based precipitation distribution analysis was used to develop an areal distribution of rainfall in the SBC basin for the 100-year event. Using the peak 72-hour precipitation value (maximum grid cell) observed during the 1969 event, the entire rainfall grid was converted to a percent-of-maximum value. This percentage value was used to normalize the grid and facilitate develop of multiple design storm recurrence interval rainfall grids.

This process should provide a realistic simulation of the orographic impacts of topography on precipitation distribution and intensity during a general storm event. **Figure 6** shows the areal precipitation distribution for the 72-hour, 100-year general SDDS.

The normalized precipitation pattern described above was used to distribute the 7.02” 72-hour, 100-year event for a general storm across the SBC basin. The peak rainfall grid cell value is assigned the 7.02” value and the remaining rainfall grid cell values are calculated as a percent of this maximum value.

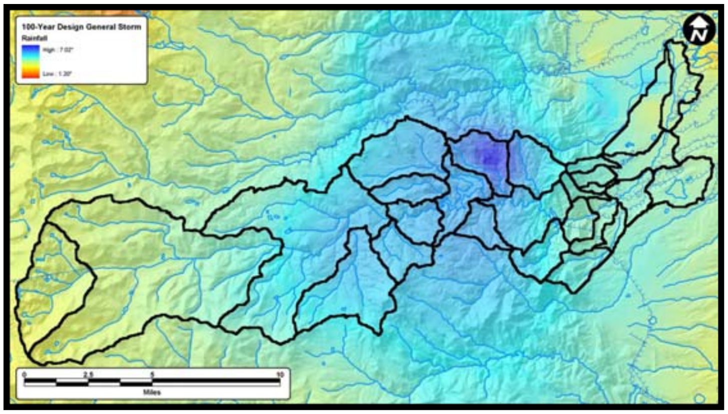
The observed storm mass curve for the 1969 event from Midnight, May 4 to Midnight, May 7 was used as the model for the temporal distribution of the event. The time distribution of this 72-hour period was used to distribute the precipitation in each of the rainfall grid cells. Observations were not available to differentiate temporal distribution differences within the SBC basin so this “uniform temporal distribution” was chosen as the best alternative.

Thus the 72-hour, 100-year general storm SDDS is based heavily on the orographically influenced areal and temporal distributions of the 1969 flooding event. The reliance on an observed key historic event to provide the temporal distribution varies from the standard design storm use of SCS curves of temporal distribution and a uniform areal precipitation distribution. However, the use of an observed event that was similar to the design 100-year, 72-hour event in quantitative values provides a more realistic and scientifically defensible definition to a general storm in SBC.

The key definition of the 72-hour general storm includes the following components:

1. The quantitative value of the 72-hour, 100-year storm is an elevation and basin coverage adjusted value of 7.02 inches.
2. The areal coverage of the precipitation in the basin is based on a normalized distribution from observed precipitation during the 72-hour May 4-7, 1969 event.
3. The temporal distribution of the precipitation is based on the hourly 72-hour precipitation values recorded at the Boulder, Colorado gage during the May 4-7, 1969 event.

Figure 6 - Areal precipitation distribution for the



72-hour, 100-year general SDDS

9. CONCLUSION

The South Boulder Creek “scientifically defensible” design storm uses a combination of observational data bases to describe the areal and temporal distribution of precipitation. While relying on NOAA Atlas II techniques and updates of gaged precipitation to determine the magnitude of the 100-yr, 24-hr design storm, WSR-88D Doppler radar observations were used to define the temporal and areal characteristics of the design storm.

The climatology task provided a detailed insight into the precipitation mechanisms and occurrences within the South Boulder Creek basin. Five integrated tasks were completed that culminated in the development of a South Boulder Creek “scientifically defensible” Design

Storm (SDDS). The SBC SDDS makes use of existing observational databases, which were not available until the past ten years, to enhance the temporal and areal definitions of the design storm.

Table 17 summarizes agency design storm characteristics. The table presents the preferred methodology used by each agency to describe the temporal, areal and quantitative value of the basin design storm.

Note the heavy institutional reliance on NOAA Atlas II by all agencies despite the fact that this information source and methodology was written in the early 1970's with a limited database.

Table 3 - Summary of design storm methodology and information sources uses by key agencies

Agency	Frequency	Temporal	Areal	Methodology	Use
FEMA	NOAA Atlas II	NOAA Atlas II	NOAA Atlas II	CWCB State Criteria Manual	US
CWCB	NOAA Atlas II	NOAA Atlas II/SCS	NOAA Atlas II	NOAA Atlas II	Colorado
UDFCD	NOAA Atlas II and DEN obs	NOAA Atlas II and DEN obs	NOAA Atlas II and UDFCD tables	Urban Drainage Storm Criteria Manual Vol 1 and 2	Denver Metro
SBC SDDS	NOAA Atlas II Update and SBC precipitation stations	NWS WSR-88D radar observations, NOAA Atlas II, SBC FDN	NWS WSR-88D radar observations (T-storm) and 1969 observed precipitation (Gen. storm)	GIS use of observations, NOAA Atlas II,	SBC

FEMA and CWCB rely the heaviest on NOAA Atlas II though CWCB has developed its own criteria manual for use by jurisdictions and organizations charged with developing design storms. While FEMA strongly supports the use of NOAA Atlas II methodology, CWCB notes that it will defer to local jurisdictions that develop their own design storm criteria and methodology as long as it is published and reviewed.

The most creative enhancement of the NOAA Atlas II methodology for design storms is evidenced in the Urban Drainage Storm Criteria Manual, Vol 1 and 2 developed by the UDFCD. The UDFCD design storm methodology is heavily biased to small urban watersheds of less than 75 sq miles and heavily urbanized. UDFCD has modified the NOAA Atlas II methodologies by relying heavily on the analyses of 73 key storm precipitation events that occurred from 1898 to 1969 and were measured in the Denver Post Office and Stapleton Airport National Weather Service recording gages.

All 73 storms occurred between April 30 and October 13 and appear to be all thunderstorms. The longest storm duration was 2.5 hours on May 9, 1957 and the greatest amount of precipitation was 2.05 inches. This storm sample serves as the basis and is biased to “leading intensity storms” that produce most of their rainfall in the first 30-60 minutes of the storm. UDFCD develops a temporal precipitation distribution based on these storms.

CWCB and FEMA rely on NOAA Atlas II for guidance on the areal distribution of precipitation with a general acceptance of applying a standard areal reduction factor and a uniform distribution in the basin of the new value. UDFCD develops its own areal reduction/increase table but provides only limited justification for the table. UDFCD indicates that its procedures and methodologies are best suited for use in small urban catchments of 20 sq miles or less in size. Thus the agency design storms rely heavily on point rainfall observations and standard agency analyses of these observations appropriate to the size of the basin.

By contrast the SBC SDDS appears to be similarly observationally driven with strong adherence to NA II methodology, especially for frequency recurrence calculations. However, the SBC SDDS makes use of enhanced data sets, new technologies such as radar and GIS, to make the methodologies more applicable to a large, 135 sq mile, watershed located along the plains-mountain interface.

The primary design storm difference is the SBC SDDS reliance on radar observations to define the areal and temporal precipitation distribution observed within thunderstorms and the use of the detailed rainfall observations assembled by the Bureau of Reclamation during the May 1969 flooding event to specify the areal general storm precipitation distribution. GIS applications were used to objectively analyze and apply these observations to areal and elevation basin distributions. Additional use was made of the South Boulder Creek Flood Detection Network (FDN) and radar observations to define the temporal and areal distribution of rainfall for basin calibrations studies.

The NOAA Atlas II precipitation frequency updates relied on NOAA Atlas II methodology on the same sites used in the NOAA Atlas II analyses. However, use was made of partial series observations at Hawthorne and Gross Reservoir to enhance the definition of recurrence frequencies in the South Boulder Creek basin while relying on the long term observations taken at the Boulder gage. These enhancements followed standard analyses techniques.

Finally, the thunderstorm and general SDDS placement strategy for the areal storm footprint was based on the integration of the following factors:

- observed historic storm wind patterns,
- basin topographic effects on precipitation distribution
- paleo-hydrologic evidence of severe flooding locations, and
- modeling maximization of the basin runoff.

In essence, the SBC SDDS used new technologies to address the limitations faced by NOAA Atlas II-based methodologies in defining objectively and realistically the areal and temporal distributions of precipitation in a large foothills basin. These enhanced observation sets allowed the SBC SDDS to develop both a general storm SDDS and a thunderstorm SDDS for application to the basin modeling.

The SBC thunderstorm SDDS has the following observationally-derived characteristics:

1. Length of 7 miles and width of 3.5 miles for a 2:1 ratio (main cell, greater than 1”),
2. Areal coverage of 23 square miles with rainfall of 2” or more,
3. A multi-cell storm, and
4. Covers just over 8 sq. miles of rainfall greater than 4 inches with the 5.03”, 24-hour, 100-year precipitation maximum falling within the 4 inch isohyet.

The SBC thunderstorm SDDS relied on NWS WSR-88D observations of 100-year, 24-hour precipitation events that were observed by rain gages and areally defined by the Storm Total Precipitation Product (STP). Radar reflectivity 5-min observations were used to determine the temporal distribution of the precipitation.

Historical storm analyses of general storms that produced 4.00 inches of precipitation or more along the Colorado Front Range and Boulder rain gages indicated that the peak 24-hour annual precipitation events were part of a 72-hour general storm 80 percent of the time. Thus the general SDDS was determined to be a 72-hour event.

The key definition of the 72-hour general storm includes the following components:

1. The quantitative value of the 72-hour, 100-year storm is an elevation and basin coverage adjusted value of 7.02 inches.
2. The areal coverage of the precipitation in the basin is based on a normalized distribution from observed precipitation during the 72-hour May 4-7, 1969 event.
3. The temporal distribution of the precipitation is based on the hourly 72-hour precipitation values recorded at the Boulder, Colorado gage during the May 4-7, 1969 event.

REFERENCES

Colorado Water Conservation Board, 2003: Colorado Flooding Threats, Flood task Force Web page, accessed October, 20, 2003.

Tomlinson, E.M., J. F. Henz and R. A. Williams, 2003: Technical Review for the Probable Maximum Precipitation (PMP) Site Specific Study for Cherry Creek Reservoir, Dept. of Nat. Res., Colo. Water Con. Board, Denver, CO, 131pp.

Urban Drainage & Flood Control District, 2001: Urban Storm Drainage Criteria Manual, Vol. 1 and 2, Denver Regional Council of Governments, Denver, Co.

Urbonas, Ben, 1979: Reliability of Design Storms in Modeling. Presented at International Symposium on Urban Storm Runoff, University of Kentucky, Lexington, KY, July 23-26,1979, 13pp.