Areal Reduction Factors for the Colorado Front Range and Analysis of the September 2013 Colorado Storm

Bill Kappel, Doug Hultstrand, Geoff Muhlestein Applied Weather Associates, LLC - Monument, Colorado

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Outline

- Study
- Review of September 2013 Rainfall Event
- Areal Reduction Factor (ARF)
 - Calculation
 - NOAA Atlas 2
 - Site Specific
- 2013 Basin Specific ARFs
- 24-hour ARFs for Colorado Front Range
- Summary



Study was initiated due to areal limitations associated with the NOAA Atlas 2 ARF curves

• NOAA Atlas 2 ARF curves extend from 1-sqmi to 400-sqmi.

• For Phase I of the CDOT September 2013 Flood Study, the NOAA Atlas 2 ARFs were used since drainage area sizes analyzed were less than 400-sqmi.

• For Phase II of the CDOT September 2013 Flood Study, the NOAA Atlas 2 ARFs required an update specific to each basin because the drainage area sizes were larger than 400-sqmi.



 CDOT Flood Hydrology Committee tasked Applied Weather Associates to:

Derive 24-hour ARFs for the Front Range of Colorado for area sizes of 1- to 1000-sqmi.

 Derive basin specific ARFs for the September 2013 rainfall event for four basins (Boulder Creek, St. Vrain Creek, Big Thompson River, and Thompson River basin).

• The Phase II 24-hour ARF curve extends out to 1,000-sqmi

The Storm: Storm Toll

- ☐ Fatalities: 10 (most in a Colorado flood since 1976)
- Counties impacted: 20
 Damaged homes: 16,000-plus
 Destroyed homes: 1,882
 Damaged businesses: 750
- Destroyed businesses: 200



- □ Miles of state highways damaged: 200
- Economic toll: \$2-3 billion

The Storm: Stats

□ Optimum combination of monsoon moisture, instability and slow-moving storm system produced record-breaking rainfall over Colorado during September 8-17, 2013

□ Up to 20" of rain in 7 days – exceeded 1,000-year recurrence interval in places

During the period Sep. 10th - 15th,
 the Boulder, CO NWS Office issued
 64 Flash Flood Warnings

□ Wet anteceded conditions, saturated soils and burn scars lead to amplified flooding





Water vapor Sept. 12, 2013

The Storm: 168-hr Annual Exceedance Probability



http://www.nws.noaa.gov/oh/hdsc/

The Storm: 24-hr Annual Exceedance Probability



estimates for the Justice Center gauge.

The Storm: Flood Damage



Big Thompson Canyon west of Loveland, CO

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The Storm: Flood Damage



Big Thompson Canyon (taken by Noel Bryan)

South Platte River in Weld County, Colorado near Greeley

Storm Precipitation Analysis System (SPAS)



Radar-only tended to underestimate the rainfall
Gauge-adjusted radar-precipitation preformed much better.

> 6-8" vs. 18-20" actually measured



The Storm

Classified as an upslope synoptic event associated with an area of low pressure to the east/southeast causing the air to flow into the Front Range (upslope) from the Midwest and Southern Plains.



SPAS 1302: Big Thompson-Buckhorn Calibration



ARFs: Background

NOAA defines an ARF as the <u>ratio between area-averaged rainfall</u> to the maximum depth at the storm center

The most common sources for generalized ARFs and depth-area curves in the United States are from the NOAA Atlas 2 and the U.S. Weather Bureau's Technical Paper 29



ARFs: Methods

 AWA calculated ARFs using a storm centered depth-area approach based on gridded hourly rainfall data from the Storm Precipitation Analysis System (SPAS)

Used SPAS hourly precipitation grids for calculation



Figure 1 Illustration of Decay of Rainfall Depth from the Storm Center.

2013 Basin Specific ARFs

The hourly gridded rainfall data, based on gauge adjusted radar data, were used to derive basin specific ARFs

• Four basins located along the Colorado Front Range were used to derive the 24-hour basin specific ARFs.

Boulder Creek Big Thompson River St Vrain Creek Thompson River

Calculated the point maximum (1-mi²) 24-hour rainfall within each basin (storm center)

• The maximum average basin 24-hour rainfall depth for standard area sizes (1-, 10-, 25-, 50-, 100-, 200-, 300-, 400-, and 500-mi²) up to the basin total area were calculated



Colorado Front Range ARFs

 Nine storms used to derive regional ARF values for Colorado Front Range

Each storm event utilized in this analysis represented meteorological and topographical characteristics that were similar to each other and similar to the September 2013 event



Colorado Front Range ARFs

The point maximum (1-mi²) 24-hour rainfall selected as storm center

The maximum average 24-hour rainfall depth for standard area sizes were calculated

										M	ax	HM	R 55A			
ID	SPAS ID	St	torm Loo	cation	Dates			Latitude Longitude		Precipitation		CL	CLASS		55A SUBUNIT	
1	1211	Gibson	Dam, M	Г	Jun. 6-8, 1964			48.3541 -113.3708		-113.3708	19.16		Orographic		Or	ographic "A"
2	1251	251 Lake Maloya, NM			May 17-21, 1955			37.0090 -104.3410		14	14.82		Orographic		ographic "E"	
3	1252	252 Waterton Red Rock, AB			June 14-21, 1975			49.0875 -114.0458		14.46		Orographic		Or	ographic "A"	
4	1253	3 Big Elk Meadow, CO			May 3-8, 1969			40.2700 -105.420		-105.4200	20.01		Orographic		Or	ographic "C"
5	1302	Northea	ist Colora	ado	Sep.	8-17, 20)13	40.0150 -105.2650		20.41		Orographic		Or	ographic "C"	
6	1320	Calgary	, AB		Jun.19-22, 2013			50.6350 -114.8550		13.78		Orographic		Or	ographic "A"	
7	1325	Savaget	ton, WY		Sep. 27-Oct. 1, 1923		43.8458		-105.8042	17	.56	Nonorographic		: Min. N	Min. Nonorographic "A"	
8	1335	Warrick	, MT		Jun. 5-10, 1906		48.0791 -1		-109.7041	13.69		Orographic		Orographic "A"		
9	1338	Spionko	op Creek,	, AB	Jun. 4-7, 1995		49.1708 -114.162		-114.1625	14.48		Orographic		Orographic "A"		
				4254	4050	4050	4000			1						
			1211	1251	1252	1253	1302	1320	132	5 1335	1338					
		Area	ARF	ARF	ARF	ARF	ARF	ARF	AR	F ARF	ARF	Avg	Max	85%	.+1 StDev	
		1	1.00	1.00	1.00	1.00	1.00	1.00	1.0	0 1.00	1.00	1.00	1.00	1.00	1.00	
		10	0.96	1.00	0.98	0.87	0.88	0.99	0.9	8 0.98	0.94	0.95	1.00	0.98	1.00	
		25	0.93	0.97	0.96	0.78	0.84	0.98	0.9	6 0.96	0.92	0.92	0.98	0.96	0.99	
		50	0.90	0.93	0.92	0.71	0.81	0.96	0.9	2 0.95	0.90	0.89	0.96	0.93	0.97	
		100	0.88	0.87	0.86	0.61	0.77	0.90	0.8	6 0.92	0.86	0.84	0.92	0.88	0.93	
		150	0.86	0.79	0.82	0.60	0.74	0.87	0.8	2 0.89	0.83	0.80	0.89	0.85	0.89	
		200	0.85	0.77	0.79	0.59	0.70	0.84	0.7	9 0.87	0.79	0.78	0.87	0.82	0.86	
		300	0.81	0.67	0.74	0.54	0.69	0.79	0.7	4 0.82	0.73	0.73	0.82	0.77	0.81	
		400	0.79	0.67	0.71	0.53	0.64	0.73	0.7	1 0.79	0.67	0.69	0.79	0.73	0.77	
		500	0.76	0.58	0.69	0.52	0.62	0.73	0.6	9 0.75	0.66	0.67	0.76	0.71	0.75	
		1000	0.70	0.54	0.66	0.45	0.55	0.69	0.6	6 0.63	0.57	0.61	0.70	0.65	0.69	

2013 Basin Specific ARFs

2013 storm event basin specific ARFs rapidly decrease

1		1
Basin	Area (mi²)	ARF
Boulder Creek	446	0.352
St. Vrain Creek	982	0.384
Big Thompson River	630	0.357
Thompson River	827	0.355
Thompson River	827	0.355



Colorado Front Range ARFs



The final equation used to represent Colorado Front Range 24-hour ARFs is:

 $ARF_{85\%} = 0.646 + 0.354 * \exp(-kA)$

where $ARF_{85\%}$ is the 85% confidence ARF, k is a decay coefficient (0.00374), and A is storm area in square miles.

Summary



Take Home Messages

□ The derived ARFs create significantly larger reductions in point rainfall as compared to NOAA Atlas 2.

□ The final 24-hour $ARF_{85\%}$ curve compared well to the four basin specific 24-hour ARF curves for the September 2013 event

□ The updated ARF values produce more realistic and representative point to areal reductions

Thank you!

Bill Kappel Chief Meteorologist/President Applied Weather Associates <u>billkappel@appliedweatherassociates.com</u> 719-488-4311



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Summary

 Derived ARFs created significantly larger reductions in point rainfall as compared to NOAA Atlas 2.

• Because results of the Phase I CDOT September 2013 Flood Study were not being changed as part of this work, a smooth transition between NOAA Atlas 2 24-hour ARF and the derived 24-hour $ARF_{85\%}$ was needed for Phase II basins.

• The largest basin used in Phase I was 315-mi^2 and the smallest basin used in Phase II was 446-mi^2 . In order to maintain consistency between Phase I results and Phase II results, a linear transition was applied between NOAA Atlas 2 315-mi² ARF value and ARF_{85%} 500-mi².

Summary

Based on the areal limitations of NOAA Atlas 2, the larger point precipitation reductions based on $ARF_{85\%}$, and maintaining consistency with Phase I study the linear transition between NOAA Atlas 2 315-mi² ARF value and $ARF_{85\%}$ 500-mi² was chosen for application of Phase II of the CDOT September 2013 Flood Study.

 In addition, application of this transition in the hydrologic modeling for the four basins investigated showed good agreement and acceptable results. The final 24-hour ARF_{85%} curve is compared to the four basin specific 24-hour ARF curves for the September 2013 event

Data Mining, "Bucket Survey" & Field Survey

Over 2,600 rainfall reports collected during virtual "bucket survey"

METSTAT September 8-17, 2013 Colorado Rainfall Measurement Form Today's Date & Time: Your email address (for follow-up questions only) LOCATION OF RAINFALL MEASURMENT Dam name, location or address: BAIN GAUGE INFORMATION Measuring device (nin gauge, bucket, bottle, etc): Other important gauge information (holding capacity, exposure, etc.): _ RAINFALL MEASURMENT DETAILS Time Remarks (inches) (local time) This information will be used for developing a compressive and detailed rainfall analysis using the Precipitation Analysis System through a collaborative effort with MetStat, Applied Weather A and the Colorado Climate Center. The analysis will provide the hydrologic engine ering community a valuable dataset for or tions while ensuring public safety. If you have any e email or call Tye Parzybok at tyep@metstat.com or (970) 640-6401. THANK YOU! Please mail or scan-and-email this form to MetStat. Inc. tyen@ or 320 E. Vine Drive, Ste. 101, Ft. Collins, CO 80524

CLIMATE

▼ General

Resources

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Meteorology

Storm Totals

Accumulation

Satellite/Rada V Climatol Extremes

Historic Flood

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Streamflow R Evapotranspi **V** Pictures Boulder Big Thompso Park

Drought

Timeline

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Links Contact Us

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SPAS: Daily to Hourly Precipitation

• To achieve an hourly time step at ALL stations, its necessary to convert daily & supplemental stations into estimated hourly stations.

In the past, timing of daily measured data was accomplished by associating each daily station with <u>a single</u> nearby hourly station.

• SPAS, however, uses several hourly stations to time each of the daily stations, thereby allowing the hourly precipitation distribution to be unique at each daily station.



• This provides more representative spatial and temporal detail.

SPAS-NEXRAD



Storm Rainfall Analysis

Determine hourly Z-R based on concurrent radar and station data

ZR Relationship - SPAS #1302



Apply ZR to radar data (initial precip. grid)



Storm Precipitation Analysis System (SPAS)

Compute bias (residual) at all stations



Interpolate bias adjustments



Storm Precipitation Analysis System (SPAS)

Add initial to bias to create final <u>grid</u>

Good correlation between observed value and modeled value



1.5

SPAS 1302 DAD Zone 1- Boulder/NW Domain

STORM 1302 - SEP. 8 (800 UTC) - SEP. 18 (700 UTC), 2013 MAXIMUM AVERAGE DEBTH OF PRECIPITATION (INCHES)																	
	Duration (hours)																
Area (mi²)	1 3 6 12 18 24 36 48 72 96 120 144 168 192 216 240														Total		
0.4	2.59	4.83	7.25	9.46	11.21	12.44	15.04	16.24	16.89	18.2	18.93	20.23	20.41	20.41	20.41	20.41	20.41
1	2.52	4.72	6.49	9.18	10.94	12.08	14.31	15.32	15.8	17.64	17.95	18.93	19.13	19.13	19.13	19.13	19.13
10	2.2	4.31	5.57	7.23	9.15	10.64	12.79	14.33	14.73	16.27	16.42	17.94	18.23	18.24	18.33	18.33	18.33
25	1.97	3.9	5.15	6.75	8.66	10.08	12.32	13.68	14.35	15.56	15.7	17.18	17.51	17.53	17.61	17.61	17.61
50	1.67	3.33	4.5	6.5	8.27	9.8	11.85	13.04	13.79	14.84	15.25	16.35	16.86	16.87	16.98	16.98	16.98
100	1.26	2.85	4.31	6.24	7.74	9.32	11.29	12.41	13.15	14.4	14.48	15.59	16.13	16.13	16.2	16.2	16.20
200	1.06	2.59	3.98	5.79	7.07	8.46	10.61	11.8	12.42	13.49	13.77	14.75	15.21	15.36	15.36	15.36	15.36
300	1.03	2.42	3.86	5.38	6.79	8.31	10.18	11.26	11.95	12.92	13.18	14.19	14.71	14.74	14.75	14.75	14.75
400	0.89	2.27	3.66	5.22	6.25	7.78	9.71	10.72	11.35	12.03	12.28	13.09	14.04	14.2	14.22	14.23	14.23
500	0.85	2.12	3.49	4.87	6.1	7.54	9.33	10.27	10.91	11.85	12.07	12.96	13.55	13.64	13.79	13.81	13.81
1,000	0.59	1.72	2.99	3.91	5.12	6.61	7.97	8.73	9.27	9.93	10.15	11.34	11.41	12.04	12.26	12.28	12.28
2,000	0.44	1.32	2.29	3.29	4.06	5.35	6.49	6.88	7.74	8.43	8.44	9.62	9.67	10.45	10.5	10.51	10.51
5,000	0.24	0.64	1.09	1.94	2.41	2.99	4.05	4.46	5.29	5.83	6.92	7.58	7.75	8.16	8.2	8.24	8.24
10,000	0.14	0.41	0.75	0.98	1.23	1.58	2.32	3.51	3.96	4.46	5.29	5.74	5.94	6.23	6.26	6.3	6.30
16,014	0.1	0.29	0.54	0.85	1.11	1.53	2.14	2.54	2.91	3.37	3.95	4.31	4.54	4.65	4.67	4.68	4.68



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CoCoRaHS Data



- 2,635 Stations

- 1,237 CoCoRaHS

168-hr Annual Exceedance Probability



48-hr Annual Exceedance Probability



Flood Damage



Big Thompson Canyon west of Loveland, CO

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Radar-only tended to underestimate the rainfall
Gauge-adjusted radar-precipitation preformed much better.

> 6-8" vs. 18-20" actually measured



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The Storm



MODIS Sept. 7, 2013

The Storm



MODIS Sept. 13, 2013

SPAS 1302: Big Thompson-Buckhorn Calibration



Flood Damage: Estes Park



Flood Damage: Estes Park



Flood Damage: Fall River



The Storm: Water Vapor



Water vapor Sept. 11-12, 2013

The Storm: Precipitable Water

1.75 Max 99th +3S D +2SD 1.50 75th 50th 25th -2SD 1.25 Min 1.00







106°W

105°W

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The Storm: 24-hr Annual Exceedance Probability



The Storm: 24-hr Annual Exceedance Probability



ARFs: Background

Several site specific ARFs and depth-area curves are referenced in:

NOAA Technical Report 24 (Meyers and Zehr, 1980) for the semi-arid southwest

 the NOAA Technical Memorandum Hydro- 40 (NOAA Hydro-40, 1980) for the semi-arid southwest

City of Las Vegas, Nevada (Gou, 2011)

Fountain Creek Watershed Colorado (Carlton Engineering, 2011)

Storm Precipitation Analysis System (SPAS)



ARFs: Methods

Two common methods for deriving ARFs:Geographically Fixed and Storm Centered

Geographically Fixed:

originate from rainfall statistics
relate the precipitation depth at a point to a fixed area
storm center has an arbitrary location relative to the measurement array
Sometimes the measurement array captures the storm center, sometimes the array captures the edge of the storm

$$ARF_{Fixed} = \frac{\frac{1}{n}\sum_{j=1}^{n}\hat{R}_{j}}{\frac{1}{k}\sum_{i=1}^{k}\left(\frac{1}{n}\sum_{j=1}^{n}R_{ij}\right)},$$

Storm Centered:

 do not have a fixed area in which rain falls but changes dynamically with each storm event

 the representative point is the center of the storm, defined as the point of maximum rainfall

$$ARF_{center} = \frac{\overline{R}_i}{R_{center}} \,,$$