Colorado Flood Threat Bulletin – 2017 Final Report

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PREPARED BY:

Dewberry

990 S. Broadway

Denver, CO 80209

PREPARED FOR:

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

C/O Kevin Houck
1313 Sherman St., Room 721
Denver, CO 80203
Phone: 303-866-3441
Fax: 303-866-4474

Contents

Contributors

Dmitry Smirnov, PhD
Project Meteorologist
dsmirnov@dewberry.com
303.951.0644

Dana McGlone
Staff Meteorologist
dmcglone@dewberry.com
720.943.5923

Brad Workman
Staff Meteorologist
bworkman@dewberry.com

Sam Crampton, PE
Principle in Charge
scrampton@dewberry.com
678.537.8622

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2017 Colorado Flood Threat Bulletin

Final Report

1) INTRODUCTION

In 2017, the Colorado Water Conservation Board (CWCB) made a 5-year award of the Colorado Flood Threat Bulletin program (hereafter, Program) to Dewberry. Dewberry has been the provider of this service for the CWCB since 2012. While we are committed to continuously improving all aspects of the Program, the core features remain the same due to their acceptance by end-users. The Program runs from May 1 through September 30 and requires (i) the daily issuance of a Flood Threat Bulletin (FTB) describing and visualizing the flood threat in Colorado, (ii) the twice weekly issuance of a 15-day Flood Threat Outlook (FTO), highlighting periods of rapid snowmelt, locally heavy rainfall, or conversely the development of drought conditions due to lack of precipitation and (iii) a daily State Precipitation Map (SPM; previously called State Total Precipitation) product that recaps the past 72 hours of hydrometeorological conditions across the state. In 2017, all forecasts were developed by Dewberry meteorologists Dmitry Smirnov (FTB, FTO, SPM), Dana McGlone (FTB, FTO, SPM) and Brad Workman (FTB, FTO, SPM). Archived forecasts are available through the Program's website www.coloradofloodthreat.com. Dmitry Smirnov served as the project manager for Dewberry, while Sam Crampton served as Principle-in-Charge.

This objective of this Final Report is to: (i) perform a rigorous validation of forecast performance, (ii) summarize weather conditions during the 2017 operational season, (iii) document all additional services provided, and (iv) measure Program viewership.

Daily Flood Threat Bulletin (FTB)

The FTB is designed for daily issuance during the contract period by 11:00 AM. In practice, many forecasts are issued well before the 11AM deadline to provide as much lead time as possible to end-users. The FTB outlines the daily threat of flooding across the State, the nature of the threat and the time period in which the threat of flooding would be the greatest in a County-specific manner. Additional information includes a characterization of the threat of attendant severe weather (tornadoes, high winds, hail) and the probability and intensity of thunderstorm rainfall rates and/or total amounts. Table 1 summarizes the five-tier category system that is used to characterize the flood threat: None, Low, Moderate, High and High Impact.

Table 1: Description of the five category threat system.

THREAT	DESCRIPTION
NONE	No flood threat is expected.
LOW	Low probability (<50%) that isolated/widely scattered flooding will occur. If flooding occurs, low impact/severity flooding is anticipated.
MODERATE	Moderate probability (50-80%) of flooding occurring.
HIGH	High probability (>80%) of flooding occurring.
HIGH IMPACT	High probability (>80%) of *high-impact* flooding due to a combination of factors including, but not limited to: high population density, antecedent rainfall and/or long-term duration.

Of particular concern for flash flooding are fresh wildfire burn areas that occur nearly every year somewhere in the state. There were many wildfires during the unusually active 2016 season, with at least 15 burn areas being officially recorded in the databases of Federal, State and Local agencies. Ideally, each fire burn area would be the subject of a dedicated flood threat. In practice, limited resources imply the need to focus on the most impactful burn areas: those with relatively large scale (which corresponds to a higher runoff threat) and in close proximity to high population and/or major roads. Three such areas were specially monitored during the 2017 season: the Beulah Hill, Junkins and Hayden Pass burns with acreages of 5,200, 18,800 and 16,600 acres, respectively (also see Figure 1).

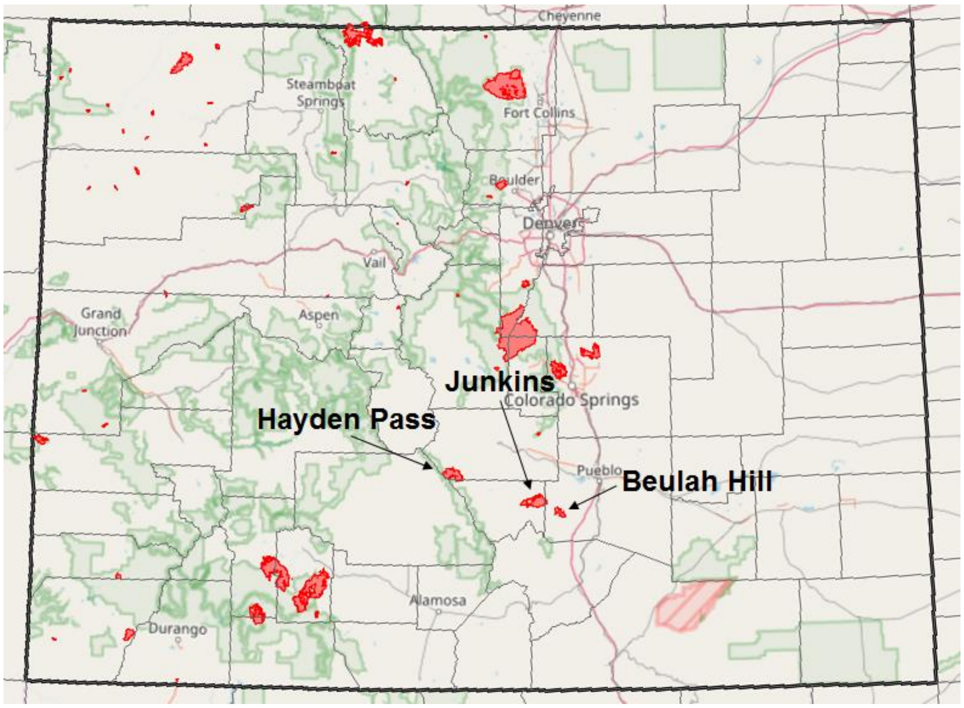

Figure 1: Wildfire burn areas that were shown on the daily FTB map during 2017. The Junkins, Hayden Pass, and Beulah Hill burn areas received dedicated flood threat forecasts on threatening days.

A notable upgrade to the FTB during 2017 was the inclusion of multiple daily updates, as warranted during situations with a particularly threatening and/or rapidly evolving flood threat. This extra feature was used on four occasions on July 7, 12, 26 and 27.

The threat of flooding is conveyed to the user community through the use of graphics and text. The graphical component to the product includes a map of the State of Colorado with county boundaries and a color-coded threat to succinctly illustrate the range of flooding threats across Colorado. The evolution of this presentation to a more communicative graphical form enhanced the spatial and temporal threat areas visualization. All forecasts continued to be archived in a blog-style manner available on the product's website.

Flood Threat Outlook (FTO)

The FTO is a bi-weekly product issued on Mondays and Thursdays by 3PM to address the 15-day threat of flooding across the state. This product addresses both the extended threat of flooding (snow-melt and precipitation driven) and a precipitation outlook by river basin. The FTO continued to be structured in an event-based manner, where rainfall was partitioned by its forcing feature and presented in a timeline. An example of a threat "timeline" is shown in Figure 2 from the June 5th FTO.

FTO 06-05-2017: Roller Coaster Start To Summer

June 5, 2017 by Dima Smirnov ·

Issue Date: Monday, June 5th, 2017
Issue Time: 3:00PM MDT
Valid Dates: 6/6 – 6/20

Next 15 Days	Tuesday 6-Jun	Wednesday 7-Jun	Thursday 8-Jun	Friday 9-Jun	Saturday 10-Jun	Sunday 11-Jun	Monday 12-Jun	Tuesday 13-Jun	Wednesday 14-Jun	Thursday 15-Jun	Friday 16-Jun	Saturday 17-Jun	Sunday 18-Jun	Monday 19-Jun	Tuesday 20-Jun
Precipitation	EVENT #1						EVENT #2								
Snow melt															

No Apparent Threat | Elevated Threat | High Threat
LEGEND

Figure 2: Example of an FTO headline showing the threat "timeline".

State Precipitation Map (SPM)

For the first part of 2017, Dewberry provided a continuation of the State Total Precipitation (STP) service through visualization of NWS Stage IV 24-hour gridded Quantitative Precipitation Estimates (QPE). A major overhaul of the STP product, which involved renaming to the State Precipitation Map (SPM) was completed during July 2017. The SPM product expanded the QPE to include 48 and 72-hour accumulation as well as maximum 1, 3 and 6 hour precipitation over the past 24 hours. The new QPE, called MetStorm Live, was obtained from sub-consultant MetStat Inc. (see Section 4). Data was visualized through the use of a custom built, Dewberry-hosted webmap using Mapbox API. An example of the SPM is shown in Figure 3.

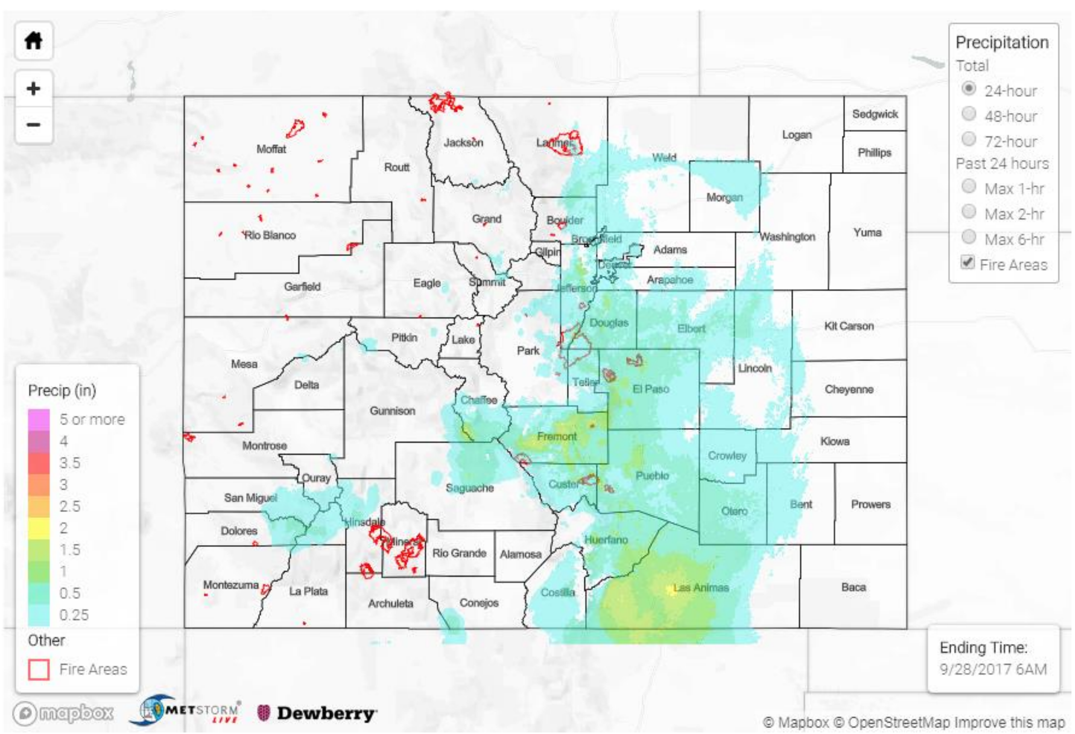

Figure 3: Example of SPM from September 28, 2017.

In addition to the map-based visualization, Dewberry forecasters provided text-based summaries of recent hydrometeorological conditions (including extreme rainfall, flooding, debris slides, hail, wind, tornadoes and wildfire activity). The discussions were often supplemented with highlights using CoCoRaHS, COOP sites, Urban Drainage and Flood Control District's ALERT rain gages, SNOTEL data and NWS Local Storm Reports.

Performance metrics

Table 2 shows the final year to date number of all products provided, and the percent provided on time. Out of 350 total products delivered, 347 were delivered on-time or ahead of time. The three late products were: May 11 FTO (5 minutes late), July 13 FTB (5 minutes late) and September 18 FTO (50 minutes late). Note that Table 2 also shows September performance since there was no monthly Progress Report for September.

Monthly Progress Reports were prepared for May through August and sent to the CWCB Project Manager no later than 2 weeks after the end of the month. To avoid duplicated effort, a progress report was not prepared for September because all necessary information is contained within this Final Report.

Table 2: On-Time performance metrics for all issued products (SPM, FTB and FTO).

		Products to Date	Products on Time	Products Late	Percent on Time			Products to Date	Products on Time	Products Late	Percent on Time
September	SPM	30	30	0	100%	YTD	SPM	153	153	0	100%
	FTB	30	30	0	100%		FTB	153	152	1	99%
	FTO	8	7	0	88%		FTO	44	42	2	95%
	TOTAL	68	67	0	99%		TOTAL	350	347	3	99%

2) VERIFICATION METRICS

a) Data Sources and Methodology

The daily FTB flood threat forecasts were verified on their ability to both (i) identify days when flood threats were realized and (ii) specify the approximate location of the potential flooding. Dewberry continued to place substantial effort on verification to increase robustness and, in turn, improve future forecasts. In fact, this year's verification was very likely the most stringent of our tenure with notable improvements (compared to 2016) including: creation of comprehensive daily validation maps (see Figure 5), the use of more quality controlled rain gages and more effort spent on manual day-by-day quality control to ensure that a threat is properly classified. The data sources and methodology used to verify 2017 forecasts are described below.

Observational Data Sources

a) Daily precipitation accumulation reports from about 850 CoCoRaHS observers across Colorado. This data is generally reported in the morning and encompasses the previous 24-hours. We use only reports that are received from 6AM to 9AM to ensure that measurement is consistent with the forecast period. Questionable observations were noted and discarded based on comparison with other data.
b) Natural Resources Conservation Service (NRCS) SNOTEL hourly precipitation, which was aggregated into daily accumulation at approximately 65 high-elevation sites across Colorado.
c) The University of Utah's MesoWest hourly precipitation data, which has many contributing networks. The majority of the data came from: Colorado Agricultural Meteorological Network (CoAgMet), Climate Reference Network (CRN), Hydrometeorological Automated Data System (HADS), Interagency Remote Automatic Weather Stations (RAWS) and Soil Climate Analysis Network (SCAN). Hourly data was aggregated into 24-hour totals, and questionable observations were noted and discarded based on comparison with other data.

d) NOAA Stage IV gridded precipitation data (hereafter Stage IV), which is a publicly available hourly product based on a radar-estimated, gage-adjusted technique using all National Weather Service NEXRAD radars and many quality controlled rain gages. The horizontal resolution is about 4 km (2.6 miles). In addition to using the 24-hour total precipitation, maximum 1- and 2-hour amounts were calculated to better understand the nature of the precipitation.
e) Local storm reports (LSRs) obtained from the four NWS offices that are responsible for Colorado: Boulder, Pueblo, Grand Junction and Goodland (KS). Reports were only included if they contained the following phrases: “Heavy Rain”, “Flash Flood”, “Flood” or “Debris Slide”. Reports involving the term “Heavy Rain” were retained only when the magnitude of rainfall exceeds 0.50 in. Similar to CoCoRaHS data, reports of 24-hour accumulation were only retained if the report ending time was between 6AM and 10AM. If a “Heavy Rain” report did not specify a magnitude, it was dismissed unless the observer’s note contained a specific reference to flooding.
f) NWS warning and advisory shapefiles (obtained from Iowa State University), including metadata such as when the product was issued. Only flash flood warning, riverine flood warning and areal flood advisory products were included in the analysis.

Verification methodology
To determine if a flood threat was accurate, a “Flood Day” classification system was developed to describe whether flooding and/or rainfall intensity capable of causing flooding was observed. **A Flood Day is defined as a binary variable: it is either 1 when flooding and qualifying rainfall intensity is observed, or zero otherwise**. Note that, in practice, flooding often goes undocumented, and that adding a measure based on rainfall intensity ensures a more comprehensive treatment of the issue. Given the large variance in the rainfall-runoff relationship across Colorado (see Appendix B), more than one rainfall threshold is required. Thus, a Flood Day is hereby defined when one of following two criteria is met:

1) Gridded or observation based 24-hour rainfall exceeds (see Figure 4):
    a. 1.00 in. west of the 1,600 meter (5,250 foot) contour over the eastern plains
    b. 1.50 in. east of the 1,600 meter (5,250 foot) contour over the eastern plains

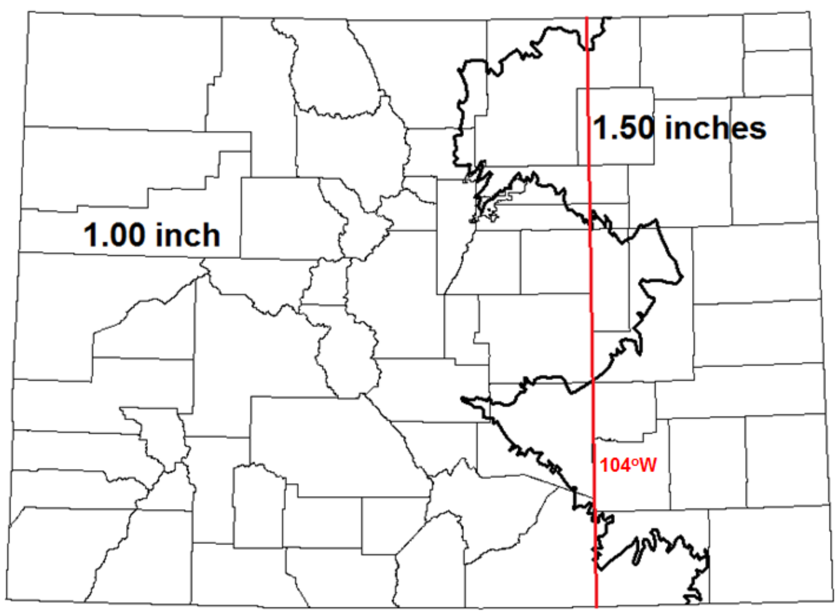

Figure 4: Colorado county map with thick black line showing the 1,600 meter (5,250 foot) elevation contour line east of the Continental Divide, which acted as the demarcation in rainfall-runoff sensitivity. To the east, a rainfall threshold of 1.50 inches

per day was used to denote a "Flood Day"; to the west, it was 1.00 inch. For reference, the red line shows the existing demarcation line (the 104ºW parallel) that was used through 2016.

2) A qualifying NWS Local Storm Report (LSR) report described is received. For more information, see item (5) under Observational Data Sources, above.
3) An NWS flash flood **warning** is issued that day. An NWS **advisory**, alone, does not qualify as a "flood-day".
4) If a Flood Day is based solely on the Stage IV product, the areal coverage of qualifying rainfall must exceed 50 square-miles for each storm center. This helps to eliminate days with localized, marginal rainfall that is unlikely to cause flooding.

Despite the desire to create a purely objective Flood Day index, there are numerous reasons where the protocol above may yield an erroneous Flood Day classification. Thus, after objective calculation of Flood Day using the protocol above, a manual quality control procedure was completed to account for the overriding conditions shown in Table 3. Note that multiple conditions could be met on any given day, reiterating the importance of having a manual quality control. In total, there were 13 days where overriding conditions were used.

Table 3: Conditions warranting a change in the objective Flood Day classification.

Condition	Label	Outcome	# Occurrences
Snowfall results in a qualifying 24-hour precipitation total, but minimal runoff does not support flooding.	Snow (SNOW)	Flood Day = 0	0
Long-duration low intensity precipitation causes qualifying 24-hour precipitation total but runoff does not support flooding.	Low Intensity (LI)	Flood Day = 0	4
There is no rainfall but antecedent conditions and/or snow melt cause riverine flooding.	Riverine (RIV)	Flood Day = 1	7
Hail likely causes an overestimate in Stage IV resulting in qualifying precipitation totals.	Hail (H)	Flood Day = 0	2
The area of qualifying Stage IV precipitation exceeds 50 sq. mi. but is spread out over multiple (independent) areas, limiting flooding potential.	Multiple areas (AREA)	Flood Day = 0	2

In addition to conditions in Table 3, there were four times when a Flood Threat was issued only for one or more burn areas shown in Figure 1. At present, there is no protocol on how to validate such a forecast since flood threat rainfall thresholds for burn areas (which are substantially lower than surrounding areas) were not established at the start of the season. Thus, burn area forecasts were labeled as "BURN" in Appendix B for information purposes only. This issue will be resolved during 2018 when each burn scar that qualifies for special monitoring will be assigned a rainfall threshold, and communicated to users before the start of the season. It is important to note that the accuracy of burn scar flood threats will likely be lower, possibly significantly, than other forecasts due to the difficulty in forecasting for such a small area. For example, the Junkins burn scar, the largest of the three that were specially monitored during 2017, is only about 30 sq. mi., which is smaller than the ~250 sq. mi. scale at which current forecasts begin to show skill.

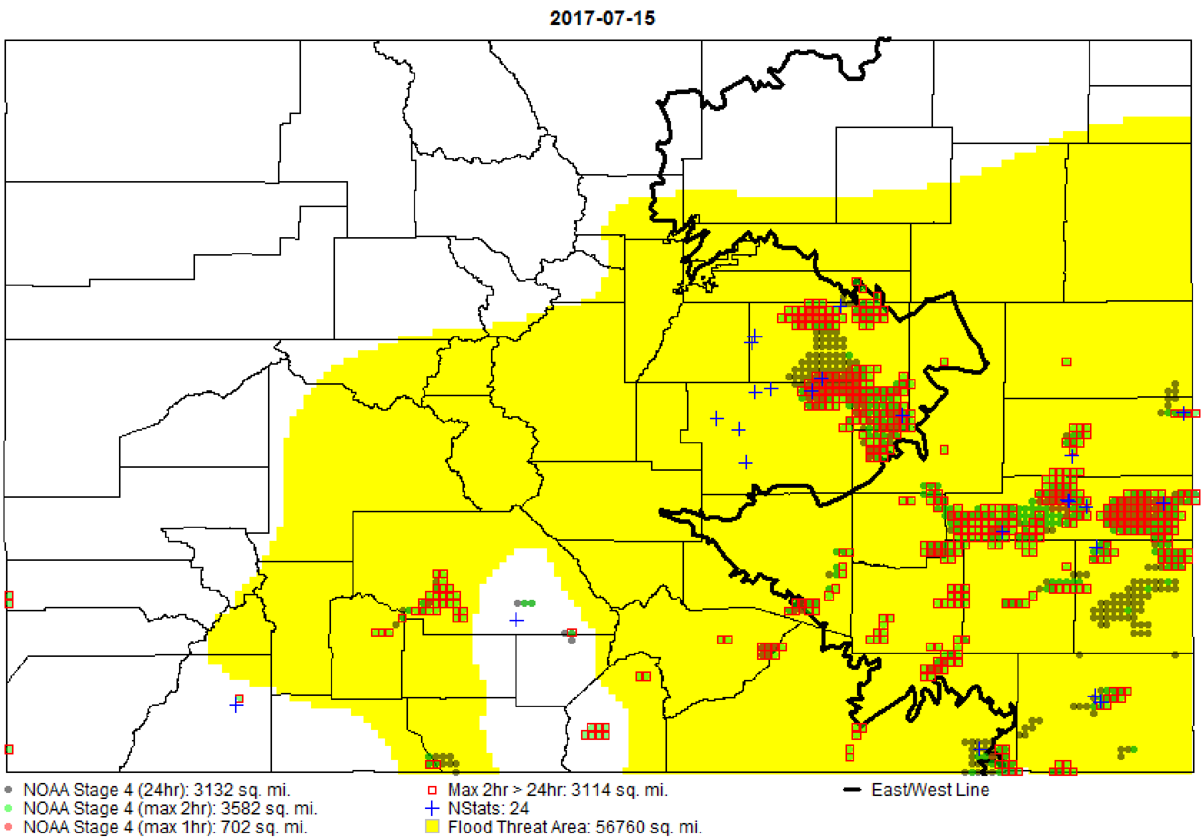

Figure 5: Example of daily validation map from July 15, 2017 showing qualifying NOAA Stage IV pixels (gray dots), rain gages (blue crosses) and threat area (yellow color fill). For reference, qualifying Stage IV maximum 1-hour (red dot) and 2-hour (green dot) estimates are also shown, but note these were not objectively used in defining a "Flood Day". Red squares denote areas where maximum 2-hour Stage IV estimates exceeded the 24-hour estimate, an indication of the potential existence of hail and/or very high radar reflectivity. Note that the threat area does not distinguish between different threat levels.

b) Results

Appendix A contains the Verification Worksheet that was used to assess forecast performance. Note that on four days, an afternoon forecast update required the issuance of an updated threat map. To be consistent with previous seasons, the analysis herein does NOT include these updates and measures performance based on the initial flood threat map only. In future years, the updated forecasts may also be included in the validation.

As there is no single number that can comprehensively measure forecast accuracy, Table 4 shows the five metrics that are used in this report, all based on the contingency table approach shown in Table 3. In brief, there are two possible outcomes when a Flood Day forecast is issued: (i) a Flood Day is observed (case a in Table 3), a "Hit", (ii) a Flood Day is not observed (case c in Table 3), a "False Alarm". There are two additional scenarios that complete the set of all outcomes. First, if a "Flood Day" is not forecasted, but is observed, this results in a Miss (case b in Table 3). Second, if a non-Flood Day is forecasted and a non-Flood Day is observed, this also results in a "Hit", although a dry one (case d in Table 3). Historically, the CWCB has always advocated for minimizing the Miss rate, which, given the uncertainties with heavy rainfall forecasting, necessarily results in a higher False Alarm rate. As shown in Table 4, target numbers for each metric have been established in 2017 based on values accepted as reasonable within the forecasting community.

Table 4: Contingency table showing the four possible outcomes of forecasting and observing a Flood Day.

		Flood Day Forecasted	
		Yes	**No**
Flood Day Observed	**Yes**	**(a) Hit**	**(b) Miss**
	No	**(c) False Alarm**	**(d) Hit (Dry)**

Table 5: Description of metrics used for validating forecast accuracy.

Metric	Abbreviation	Calculation (see Table 4)	Summary	Goal
Accuracy or "Hit" rate	Hit %	$\frac{a+d}{a+b+c+d}$	Measures probability that Flood Days and non-Flood Days are accurately forecasted. Perfect forecast value is 100%.	>75%
Probability of Detection	POD	$\frac{a}{a+b}$	Measures probability of accurately forecasting Flood Days. Perfect forecast value is 100%.	>75%
False Alarm Rate	FAR	$\frac{c}{c+d}$	Measures probability that a Flood Day is forecasted but a non-Flood Day is observed. Perfect forecast value is 0%.	<20%
Miss Rate	Miss %	$\frac{b}{a+b}$	Measure probability that a non-Flood Day is forecasted but a Flood Day is observed. Perfect forecast value: 0%. Note the sum of the Miss % and POD equals 1.	<15%
Bias	Bias	$\frac{a+c}{a+b}$	A ratio of total number of Flood Days forecasted compared to those observed. Perfect forecast value is 1.0.	N/A

Table 6 shows the individual monthly and yearly aggregated forecast verification during the 2017 season. **Over the course of the season, forecast performance achieved or exceeded each of the four targets established in Table 5**. With an overall hit rate of 86%, forecast performance continued to be well above the 75% target. The Probability of Detection was also high, at 86%, above the target of 75%. The False Alarm Rate was 15%, which also achieved the target of less than 20%. Finally, the Miss Rate was 14%, or just under the target of below 15%. Out of the 10 misses over the course of the season, seven had qualifying Flood Day area of less than 250 sq. mi. implying relatively localized areas of heavy rainfall. The May 18 snow event was conservatively classified as a Miss even though the runoff was marginal and most rivers stayed below Minor flood stage. Those that did enter Minor flood stage receded to lower levels quickly. Overall, the Miss classification during this event can be described as a representative example of the rigor with which the validation process is done.

Looking at the month-to-month performance in Table 6, there was some variability in the performance as can be expected due to smaller sample sizes. For example, during September, all four Flood Days were correctly forecasted, resulting in a 100% Probability of Detection. Meanwhile, in August, five of 21 Flood Days were not forecasted, resulting a POD of 76% and a relatively high Miss Rate of 24%. June had the highest False Alarm Rate due to instances where the atmospheric ingredients were present for heavy rainfall, but storms never materialized. Research regarding reducing the False Alarm Rate is ongoing.

Table 6: Summary of forecast performance, by month and in total. Red font indicates performance did not meet program targets.

Forecast / Observed	May	Jun	Jul	Aug	Sep	Total
(a) Flood / Flood	13	8	23	16	4	64
(b) No Flood / Flood	2	2	1	5	0	10
(c) Flood / No Flood	2	6	0	0	4	12
(d) No Flood / No Flood	14	14	7	10	22	67
Total Days	31	30	31	31	30	153
Hit %	90%	73%	97%	87%	87%	86%
POD	87%	80%	96%	76%	100%	86%
FAR	13%	30%	0%	0%	15%	15%
Miss %	13%	20%	4%	24%	0%	14%

Table 7 shows the yearly performance summaries, from 2012 through the present. Overall, 2017 was one of the more accurate, if not the most accurate year when all measures are taken collectively. The combination of minimizing both the False Alarm Rate and Miss Rate can be elusive and was accomplished in 2017. Nonetheless, ongoing research is targeting further reductions in these measures in the future.

Table 7: Summary of yearly forecast performance since 2012. Note that the validation procedure was significantly enhanced in 2014, which makes it difficult to compare pre-2014 statistics to 2014-present.

	Hit %	POD	FAR	Miss %	Threats Issued	Flood Days	Bias
2012	86%	84%	18%	16%	65	64	1.02
2013	84%	85%	13%	15%	83	85	0.98
2014*	76%	73%	18%	27%	75	84	0.89
2015	77%	78%	25%	22%	85	88	0.97
2016	84%	88%	21%	12%	93	91	1.02
2017	**86%**	**86%**	**15%**	**14%**	**76**	**74**	**1.03**

Table 8 shows the forecast performance as a function of threat level. A robust forecast system should show higher skill as the threat level increases due to more confidence that flooding will be realized. Indeed, Table 8 shows this to be the case. While Low threat forecasts verified about 70% of the time (consistent with 2015 and 2016), **Moderate and High threats verified 100% of the time they were issued**. Despite the relatively high number of days with a High threat (5), there were no days when a High Impact threat was issued.

Table 8: Accuracy as a function of threat level.

	Observed Flood Day	Observed Non-Flood Day	Total Days
Low	28 (70%)	12 (30%)	40
Moderate	31 (100%)	0	31
High	5 (100%)	0	5
High impact	0	0	0
Total	64 (84%)	12 (16%)	76

3) CHARACTERIZATION OF FORECAST PERIOD WEATHER

Overview

The 2017 operational season, spanning from May 1 to Sep 30, can be best characterized as warm and relatively dry for the western portion of the state, and cool and wet over southeastern Colorado (Figure 6). However, this does not do justice to the record wet season experienced in parts of the Arkansas River basin. During July, isolated parts of the basin received over 10-15 inches of rainfall over a prolonged active stretch, or up to 5 times their normal rainfall during the period. Using NOAA Atlas 14 guidance, this equated to a 1 in 100-500 year event, depending on location. Interestingly, despite these impressive statistics, riverine flooding was almost completely avoided because the precipitation was temporally and spatially distributed in a way to limit runoff.

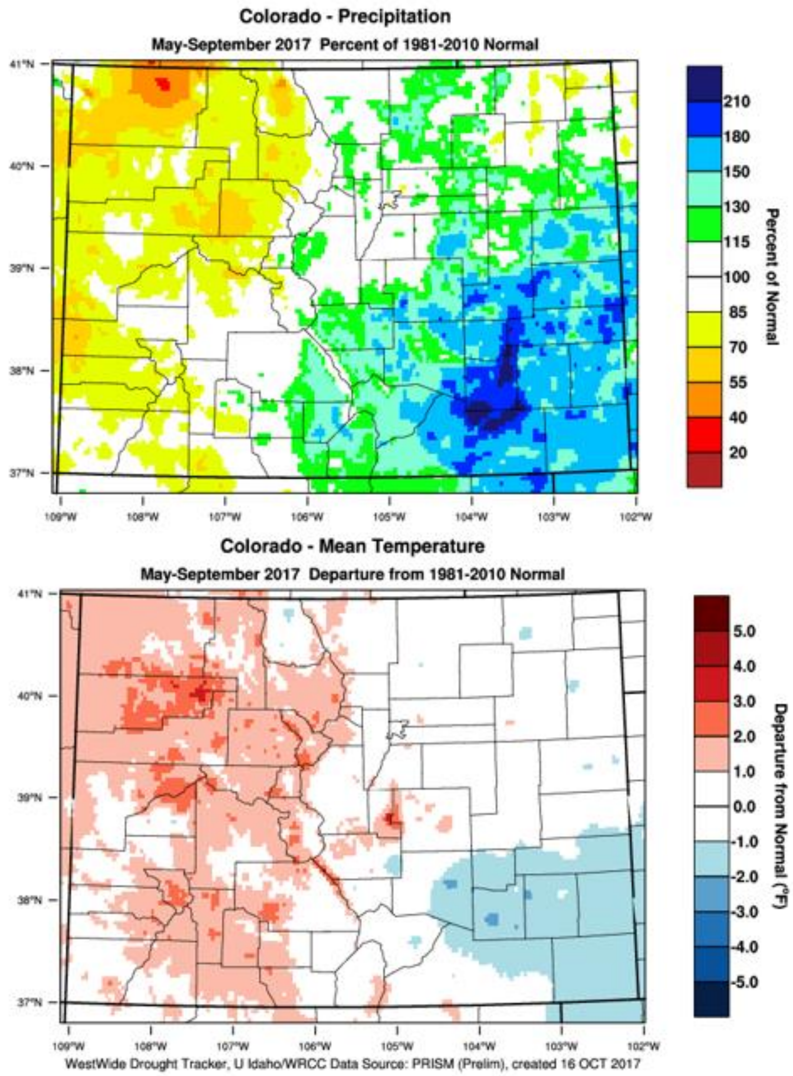

Figure 6: Precipitation (top) and temperature (bottom) anomalies for May-September 2017 using PRISM data. Source: Desert Research Institute.

Over the 153-day operational season, heavy rainfall activity took a downturn in 2017 compared to previous years. Table 7 shows that 74 Flood Days were observed this season, which is about 10% below the 2012-2016 average of 82 days. Appendix C shows the number of flood threats issued for a given locale. The most active region was most of southeast Colorado where isolated regions over the Palmer Ridge had Flood Threats issued on over 60 days (almost 1 threat for every 2 days). Notably, Appendix C shows the fire scars near Pueblo experienced a very active season with numerous days providing heavy rainfall in the area. A secondary maximum was found over the San Juan mountains, where up to 30 days had a Flood Threat. These active regions are consistent with the climatology of summertime precipitation in Colorado.

Figure 7 shows the daily number of rain gage reports over 1 and 2 inches of rainfall, along with the area exceeding Flood Day thresholds as measured by the Stage IV gridded product. There were 58 days where at least 1 station measured a qualifying precipitation amount (see “NStats” column in Appendix A). There were 47 days where at least two stations measure qualifying amounts, and 19 days where at least 10 stations measured qualifying precipitation. There were four days (May 17-18, July 26 and September) where over 100 gages measure qualifying precipitation, though it should be noted that the May event was associated with a single snow storm and thus only the latter two events are truly indicative of widespread heavy rainfall. In terms of Flood Day area (panel c), there were 22 days where over 1,000 sq. mi. were noted. There were six days where Flood Day area exceeded 5,000 sq.

mi., indicative of widespread heavy precipitation: two events were in May, two in July, one in August and one in September. While the 2017 season had below normal flood days on a statewide-level, southeast Colorado experienced a very active flood season.

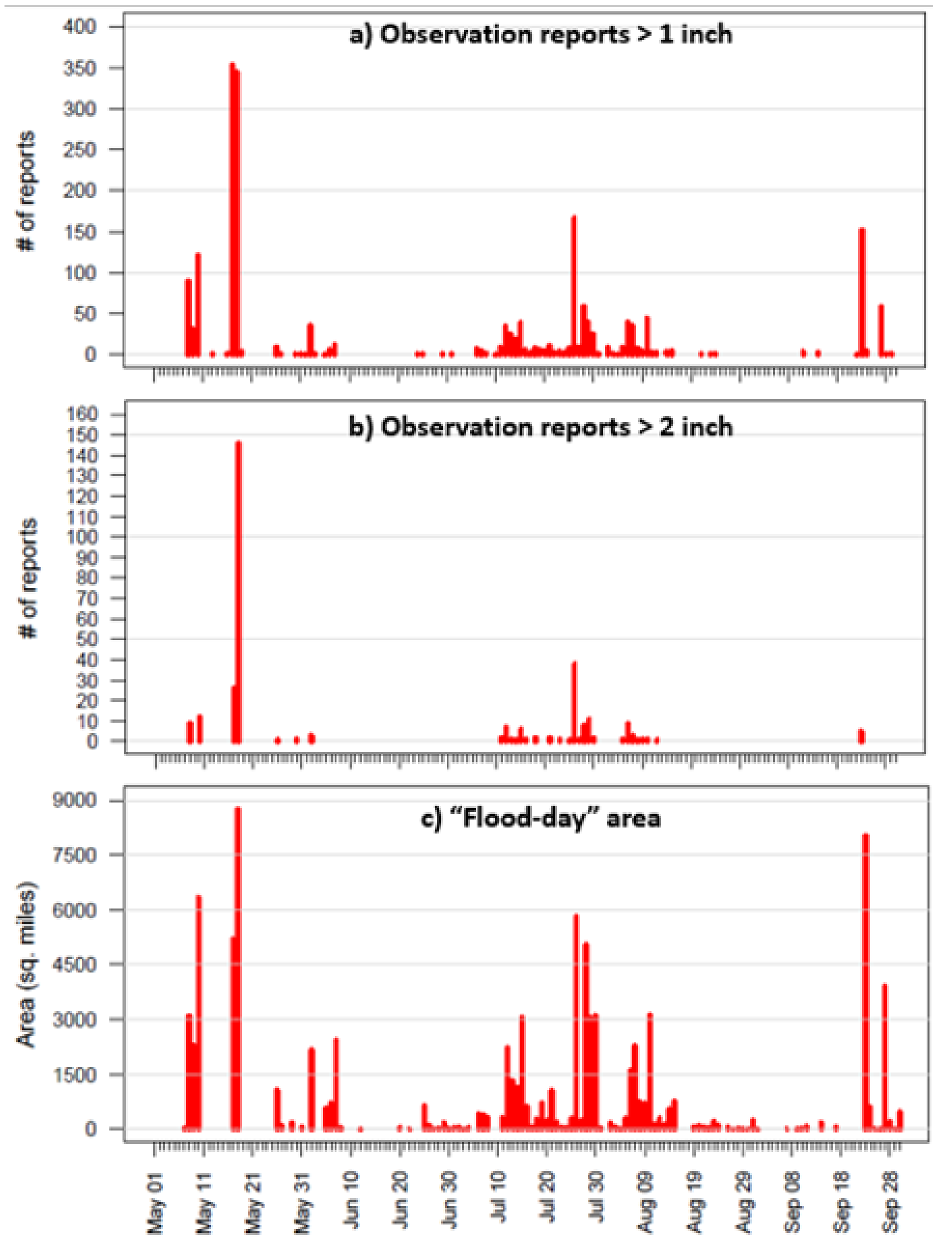

Figure 7: The number of daily observation reports exceeding (a) 1 and (b) 2 inches, and (c) the coverage of Flood Day precipitation, in sq. miles, from the gridded precipitation product. For reference in (c), the total area of Colorado is about 104,000 sq. miles.

Detailed Summary

This description can be best followed by looking at Figure 7 and Appendix A. The 2017 season started in generally tranquil fashion with only light precipitation recorded during the first week of May. The first flood threat was issued on May 8, part of a 10-day stretch featuring heavy precipitation and riverine flooding conditions. A slow-moving cut-off low approached Colorado from the southwest on May 7 – 10 resulting in significant moisture advection into Colorado from the southeast. Flash flooding was reported May 8 - 10 as widespread areas received at least 2 inches of rainfall. The most severe flood threat was likely on May 10, when over 4 inches of precipitation was observed in parts of the Southeast Plains. The town of Beulah received a disaster declaration on May 11 as heavy rainfall washed out roads (see Figure 8). Further aggravating the situation was significant runoff, including mud flows, from the nearby Junkins and Beulah Hill fire burn areas.

Much quieter weather was observed over the May 11 – May 16 time period as a weak upper-level ridged moved into Colorado. However, the antecedent rainfall combined with increasing snow melt to cause the Arkansas River to run high downstream of the Pueblo Dam. Interestingly, this was a harbinger of the extremely active period that the area would experience all the way through July.

Figure 8: Twitter post from May 11 by the Pueblo County Sheriff regarding the Beulah flood.

After a low-end heavy rainfall event on May 16, a significant snow storm affected mainly the Front Range and Urban Corridor on May 17-18. This storm was impressive, even by May standards (note that May is the wettest month for many areas in the Front Range and Urban Corridor). Widespread 48-hour totals above 4 inches were observed along the I-25 corridor from the Wyoming border through the Denver metro area. This represents over a month worth of rainfall from the climatological standpoint. Heavy snowfall was mainly limited to elevations above 6,500 feet, coincident with the freezing level. Convective rain and snow occurred along the I-25 corridor causing enough runoff to send the South Platte River and its tributaries into Action or Minor flood stage levels.

Relatively quiet weather followed the May 18 snow storm, followed by a prolonged active stretch from May 26 through June 8. During this stretch, nine of 13 days qualified as Flood Days. However, aside from June 2 and June 7, most of the Flood Days were low-end events. On June 2, over 2,000 sq. mi. of Flood Day area was recorded along with numerous Flash Flood Warnings and Advisories issued. On June 7, the Northeast Plains received a round of heavy rainfall accompanied by large hail and tornadoes. In typical Colorado fashion, June 10 marked a sudden reversal to very dry and hot weather as dry air was imported into the state from the southwest. Snow-melt intensified from June 10-12 causing elevated streamflow across the High Country, interestingly in concert with an elevated wildfire risk.

The next wave of heavy rainfall activity was over the June 20 through July 8 period. However, generally low-end events were observed during this time. For example, on June 25, an observer noted 1.5 inches of rainfall in 10 minutes in Baca County (a 1 in 100-year event) prompting a brief spike in the Purgatoire River. On June 29, slow moving storms amounted to 3 inches of rainfall over isolated parts of the Palmer Ridge and Otero County.

The period of July 11 through August 13 marked a 33 day stretch of incredibly active weather across eastern Colorado. This is likely the most active stretch that we have encountered since 2012. Flood threats were issued on 30 out of those 33 days, with five High threats and 15 Moderate threats amongst them. Even more impressive was how focused the activity was on the Southeast Plains. Figure 10 shows a Twitter post from the program's account highlighting the rarity of 60-day rainfall totals over parts of southeast Colorado. Several areas notched over 12 inches of rain in a 30-day period with isolated locations receiving over 20 inches over the 60-day period ending on

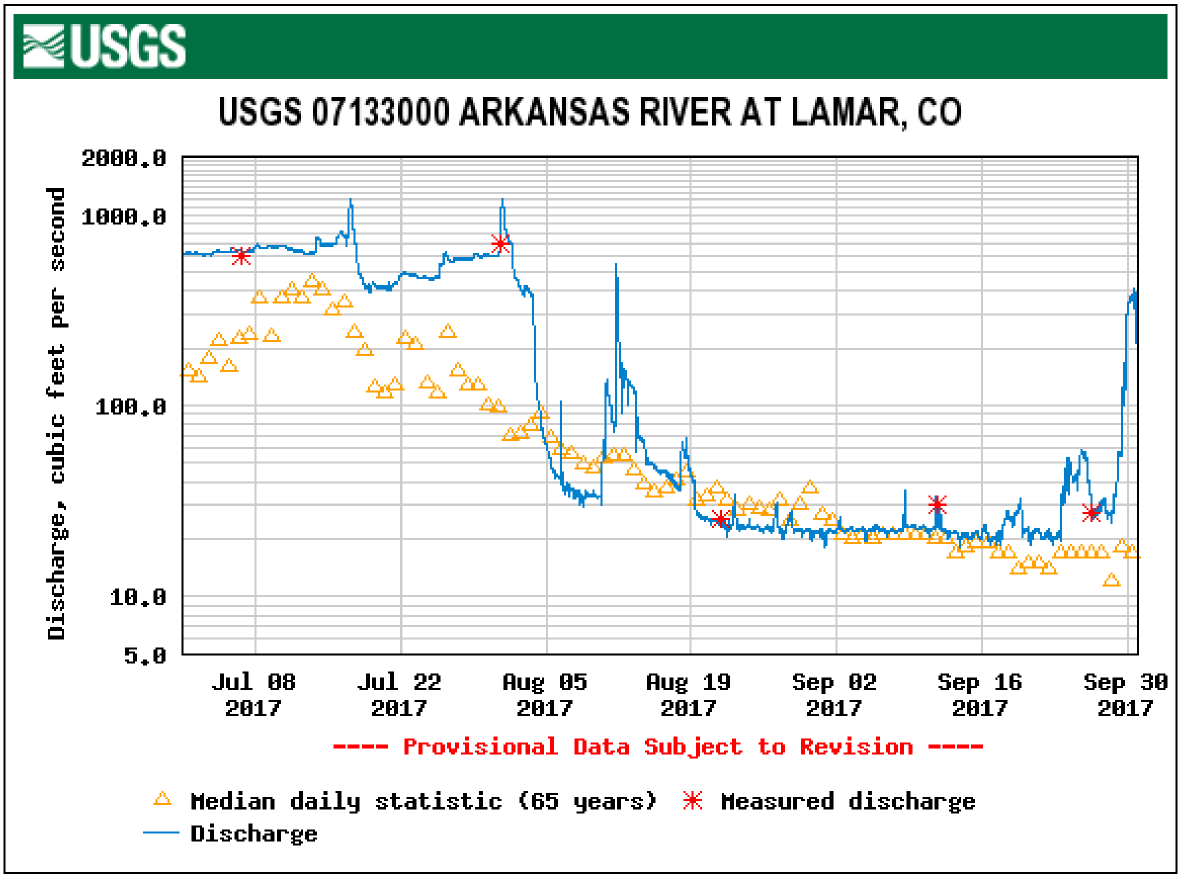

Figure 9: Flow of the Arkansas River at Lamar from July 1 through September 30. Source: USGS.

August 14. On a day-to-day level, flash flooding was reported on more than 10 days during this stretch. Particularly notable 24-hour precipitation amounts include an observed 4.35 inches on July 11, 4.21 inches on July 15, an estimated 4.62 inches on July 26, and an observed (but localized) 6.2 inches on August 6.

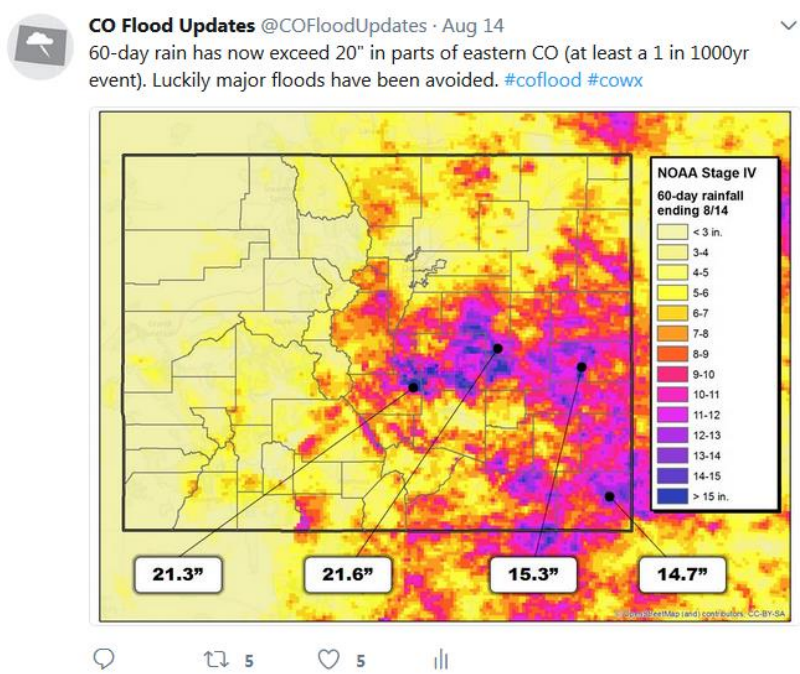

Figure 10: Our Twitter post on August 14, highlighting impressive 60-day rainfall totals across southeast Colorado.

Fortuitously, Figure 9 shows that while the Arkansas River flowed at levels well above normal for at least a 5-week period beginning in late June, significant flooding was avoided. For example, Minor flood stage at this gage is approximately 1,900 cfs, while “Action” level is about 1,000 cfs implying that only twice did the river approach or briefly exceed Minor flood stage.

Conditions gradually turned quieter in mid-August, though not without a few exceptions. A monsoon surge brought above normal moisture into the western part of the state beginning August 19, spilling eastward over the Continental Divide by August 23. However, rainfall totals were generally limited to 2 inches for isolated locations. August closed out with very hot and dry weather west of the Continental Divide and seasonal temperatures along with scattered showers and thunderstorms east of the Continental Divide. The main areas of concern at this time were the fire scars in the Southeast Plains, though fortunately flooding was not reported.

Moving into September, the first 20 days of the month were featured seasonable temperatures and mostly dry weather. Only four flood threats were issued from September 1 through 21 with heavy rainfall being observed on the 11th, 14th and 17th in association with a slow-moving cut-off low pressure system. All heavy rainfall was very isolated spatially with intensities limited to 1.5 inches per hour or less. Interestingly, the cooler air aloft brought in by the upper-level trough caused 10 straight days with hail reported somewhere in Colorado. Only on two of the days, the 14th and 17th, did hail reach 1 inch in diameter. The operational season closed out with a prolonged active stretch from the 23rd through the 30th with at least 1 inch of precipitation being reported somewhere over Colorado every day. The most severe day was September 23, when the Flood Day area exceeded 8,000 sq. mi. and 109 stations reporting over 1 inch of precipitation. Most of the action was across the southeast quadrant of the state. No flooding was reported although a majority of the heavy rainfall fell across rural parts of the Arkansas River basin, implying that some flooding may have note been reported. Cooler temperatures moved into the state on the 27th, eliminating atmospheric instability and transitioning the dominant precipitation type from convective to stratiform. Slow and steady rainfall, and higher elevation snowfall amounted to generous amounts of beneficial precipitation as the state headed into its dry season.

Although the end of September typically marks the end of thunderstorm activity in Colorado, this is not always the case as we noted in 2017. A favorable juxtaposition of atmospheric systems provided a surge of anomalously moist air into southeast Colorado from the Gulf of Mexico. As shown in Figure 11, we posted a Twitter message on September 30 highlighting the possibility of heavy rainfall through October 7. This was warranted given the near-record moisture, by October standards that made its way into eastern Colorado. Despite Precipitable Water values well over 1 inch (early October average is about 0.55 inches), only isolated moderate rainfall was observed over the eastern Plains on the 6th and 7th, putting an end to the 2017 flood threat season.

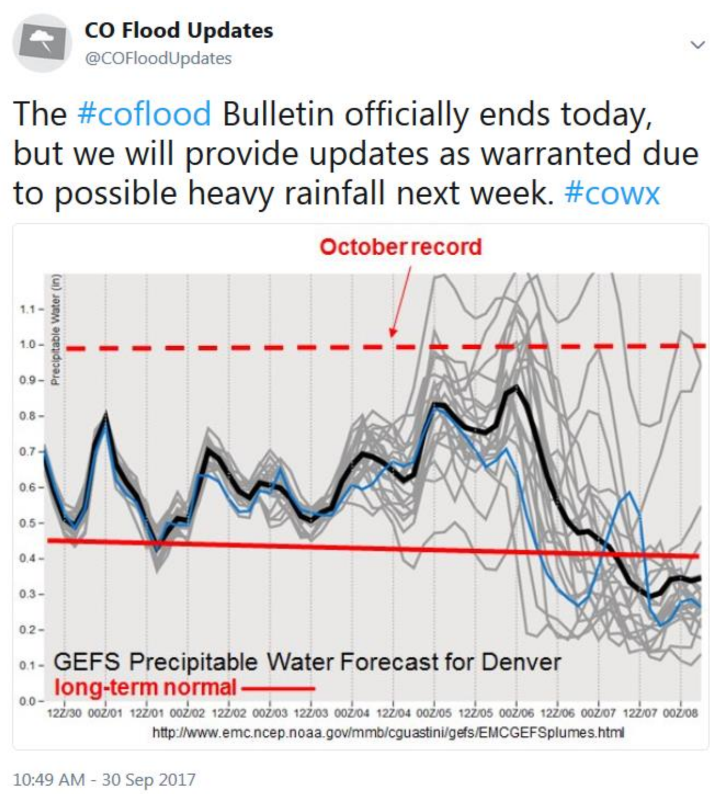

Figure 11: Our Twitter post issued on September 30 highlighting the possibility of heavy rainfall during the first week of October.

4) 2017 ADDITIONAL SERVICES

Halfway through the 2017, a significant service upgrade was completed when the existing State Total Precipitation product was upgraded and renamed to the State Precipitation Map product. The new product used the Quantitative Precipitation Estimates from sub-consultant MetStat Inc.'s MetStormLive product that is based on a similar radar-estimated, gage adjusted precipitation estimation technique as the legacy product with two major improvements. First, the spatial resolution is now 500-m versus the 4-km of the legacy product. Second, about 400 more rain gages are used the gage adjustment process.

A good example of how the newer product improved upon the previous method is shown in Figure 12 for August 10, 2017. On this day, a broad Moderate/Low flood threat was issued for parts of eastern Colorado. Numerous rounds of thunderstorm activity developed during the afternoon, with many storms producing very heavy rainfall. Widespread amounts above 1 inch were reported. However, the new MetStormLive product was able to resolve smaller scale areas that received particularly heavy rainfall. For example, parts of Bent County received close to 4 inches of rain, which caused significant runoff and Flash Flood warnings from the National Weather Service.

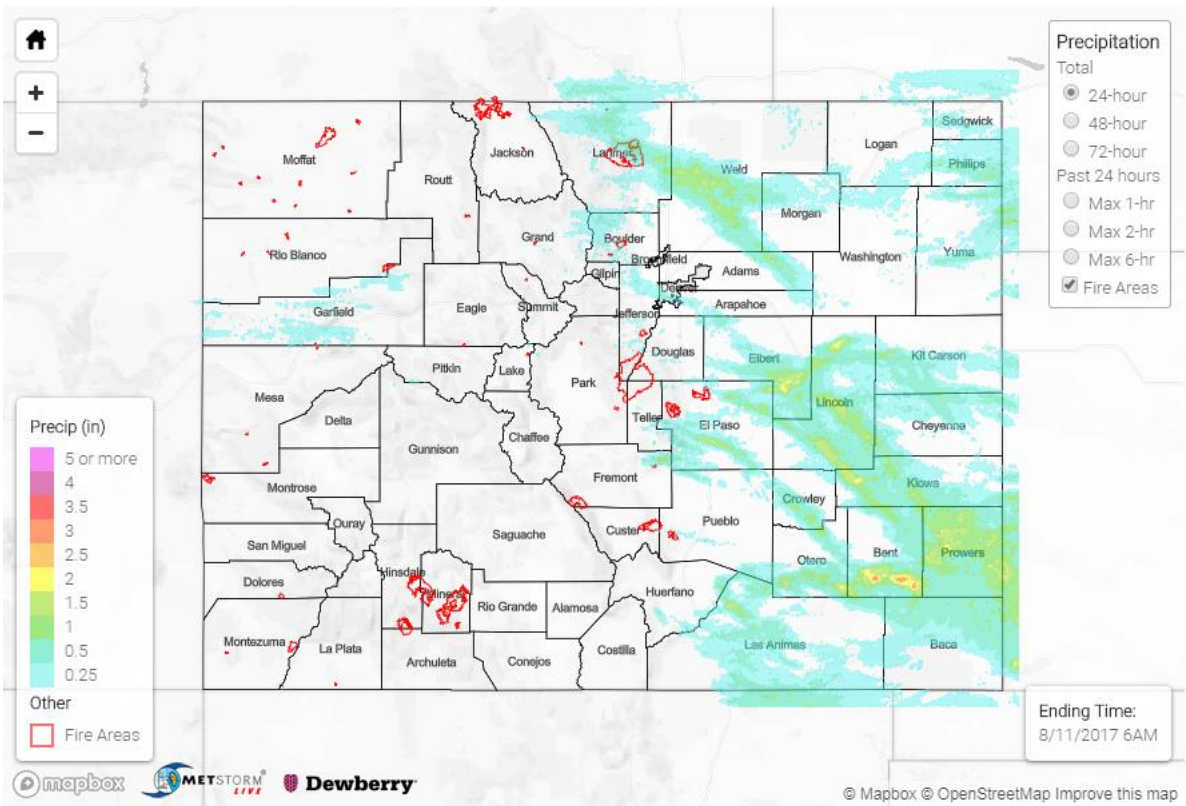

Figure 12: State Precipitation Map estimates of 24-hour rainfall ending August 11, 2017 at 6AM.

Daily monitoring of the new SPM performance suggested that the product underestimated rainfall to the west of the Continental Divide during several monsoonal events. Dewberry immediately notified our sub-consultant MetStat, Inc. of the issue and collaborative efforts are underway to reduce these errors in time for the 2018 season.

5) USER ENGAGEMENT

As even a perfect forecast can have little to no value if it is not properly disseminated, communication is a critical piece of the Flood Threat Bulletin. During 2017, we provided users with three options of how to receive forecast updates and other information. First, and foremost is the program website (www.coloradofloodthreat.com), which has been the main communication form since the program began. Second, we continued to embrace the Twitter social media platform to provide forecast updates and other informational message. Third, in 2017, we began providing an email alert option where users could receive a daily notification of the Flood Threat Bulletin headline in the email inbox. Fortunately, all three forms of communication continue to evolve with encouraging results, as described further below.

Website

Figure 13 shows daily website usage during 2017 (blue line). Average daily website usage continued to stay at a relatively robust 25.4 users per day, which depended strongly on whether or not a flood threat was issued. On days when a threat was issued, the average daily user count was 31.1. On the five days when a high threat was issued, the average daily user count was over 50. Interestingly, website usage was down from 2016, when the average daily user count was 33. There are several reasons that likely account for this decrease:

a) There were fewer days with a flood threat (74 in 2017 versus 91 in 2016; about a 20% drop);
b) From Appendix C, it is apparent that 2017 was much less spatially active than 2016 with notable decreases in the number of flood threats issued for the San Juan Mountains, I-25 corridor north of Denver and farther east that likely counteracted the slight increase in the Southeast Mountains and Southeast Plains;
c) The position of the flood threat has a significant impact on website usage. Stated simply, if a Moderate or High flood threat was issued for a populated area such as Colorado Springs or Denver, website usage tended to be very high. For example, on August 5, 2016, a spatially confined High Impact flood threat was issued for the Denver-Colorado Springs corridor, and 115 users visited the site that day. In contrast, when a large-scale Moderate/High flood threat was issued for relatively rural parts of the Arkansas River basin on August 7, 70 users visited the site. From the standpoint of the service, it is essential that there be no location bias in forecasting and dissemination, which are the only variables within our control;
d) The creation of an email alert feed (discussed later) could reduce the number of users that visit the site since they see the headline in their email and may not want to read further;
e) Gradual long-term trends towards increased Social Media usage could reduce website traffic if a user sees the headline and does not want to read further.

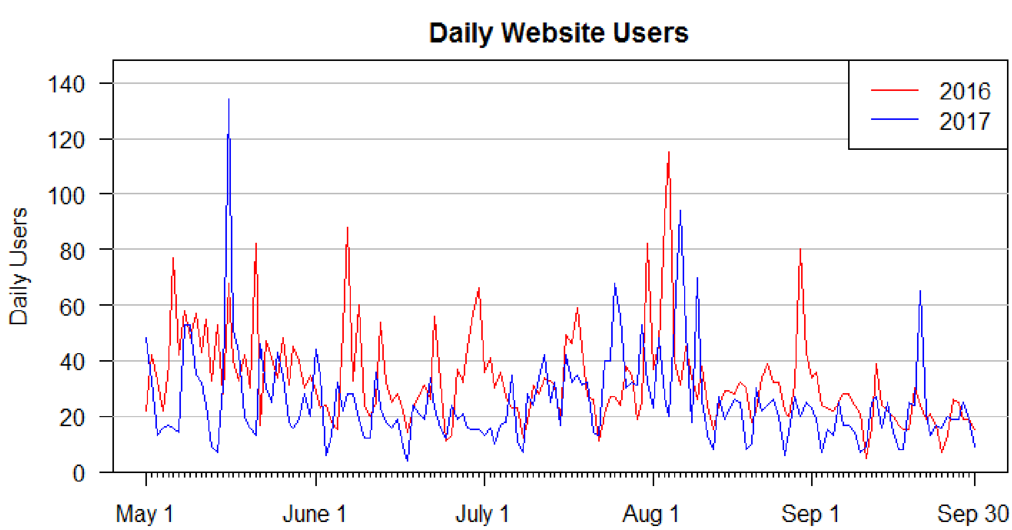

Figure 13: Daily website users during 2016 (red) and 2017 (blue).

Twitter Account

During the historic floods of September 2013, we noted an opportunity to expand the outreach of the Flood Threat Bulletin to better inform the public of the current and forecasted flood situation. The method we selected was the Twitter social media platform, with the top-level goal being to provide updates on any impending flood-related threat across Colorado. The Twitter account was a great success during the September floods, and was expanded into daily operations starting in 2014 to provide (i) meteorological information in the form of links to our forecast products (FTB and FTO), (ii) "nowcasts," of interesting flood-related weather conditions, (iii) the most current heavy rain/flooding reports from the public and National Weather Service offices. Additionally, due to the wealth of hydrometeorological data that is collected in support of daily FTB operations, we expanded our social media strategy to maximize the way this data is leveraged. For example, Figure 10 shows a Tweet that highlights the impressive amount of rainfall over the southeast part of the state. Such messages have shown their value by being well received by social media users through ample retweets and impressions.

The FTB's Twitter account, **@COFloodUpdates**, continued to gain usage since its inception with the total number of followers up to 1036 at the end of the 2017 season (an increase of 135 compared to the end of the 2016 season). This can be partially attributed to the number of retweets a few of our tweets received, especially from accounts like Colorado Emergency Management, which has over 40,000 Twitter followers. @COFloodUpdates was also featured in the 9NEWS Local Market science section and mentioned by their associated twitter account June-September (12,200 followers). The continued increase of viewership of our tweets expand our outreach to those who may not have known about the @COFloodUpdates account and the FTB website otherwise. Figure 14 shows two example tweets that received significant user interaction, both in terms of impressions and retweets.

The use of specific hashtags also played a large role in expanding viewership. A hashtag is a method of organizing messages into categories that the hashtag is supposed to succinctly summarize. For example, the #COFlood hashtag is one that we commonly use, and has become an almost dedicated area for our products. Hashtags are searchable through Twitter, and using relevant popular hashtags such as #COwx or #COFlood allows people looking for specific information to be directed to our tweets. The following is a list of common tags that were used, as well as unique tags that were used to target specific events where flooding could be a relevant concern.

- Common hashtags: #FTB, #FTO, #STP, #COwx, #COFlood, #COfire
- Unique hashtags: #4thOfJulyWeekend, #Monsoon, #Eclipse2017, #Solstice, #drought, #swampcoolerintrouble, #LaborDay, #MemorialDay

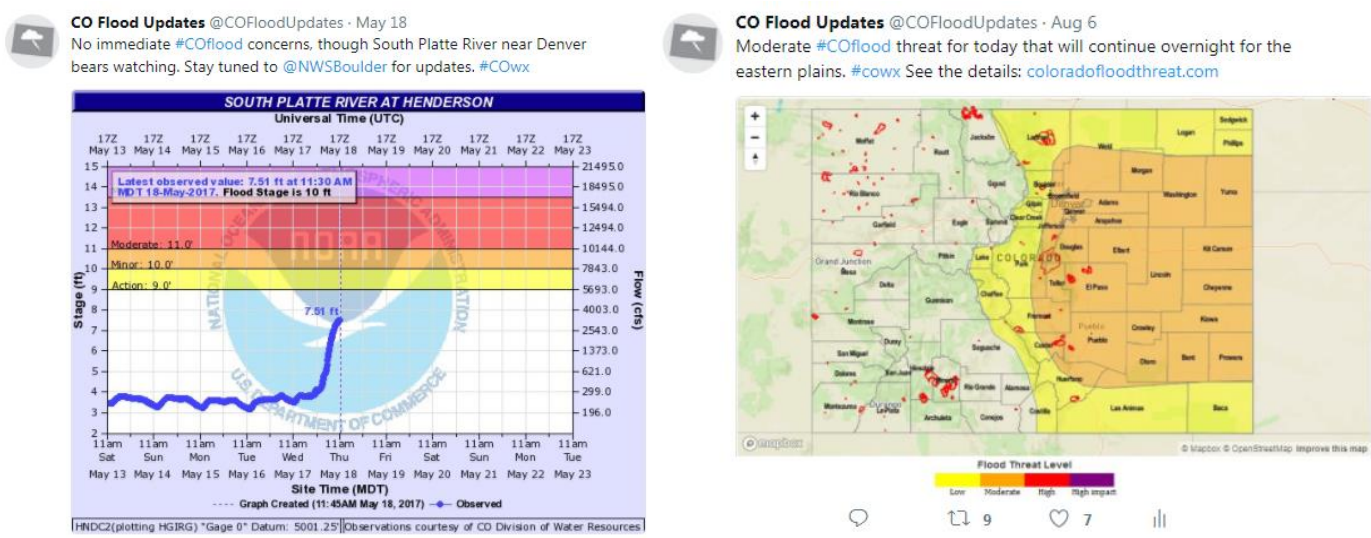

Figure 14: Example of tweets that received significant user interaction: (left) South Platte River spikes after the May 17-18 snow event, and (right) widespread Moderate flood threat issued on August 6, that notably continued into the overnight hours.

Twitter provides an Analytics website for all public Twitter accounts. Arguably the most useful data variable is "impressions." Impressions are defined as the number of times Twitter users saw a particular tweet and demonstrates the effectiveness of the use of specific hashtags and interactions (retweets) from other accounts that may have more followers. Tweets can receive anywhere from a few hundred to tens of thousands of impressions. The more engaging the content, the more impressions a tweet received as more people retweeted it. Graphics and maps are an excellent way to convey complex information, and almost all of our Tweets contain one or the other. Figure 15 shows the daily impressions received during 2017 (blue line).

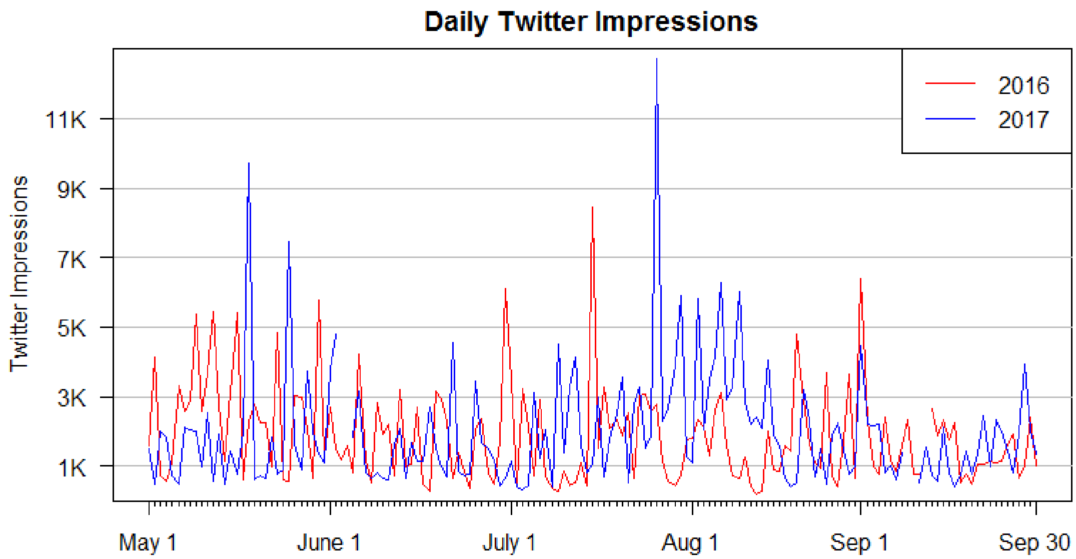

Figure 15: Daily Twitter impressions during (blue) 2017 and (red) 2016.

During the 2017 season, we disseminated 310 Tweets (about 2 per day compared to about 1.5 per day in 2016) and received a total of about 293K impressions. Of the 153 operational days, during 98 of them, our Tweets received over 1,000 impressions. The best performing flood threat relate Tweet, in terms of total impressions, was from August 6 (see Figure 14, right panel). This tweet included a reference to overnight, heavy rainfall, a low-to-moderate flood threat, an image of the day's flood threat, and a link to the Flood Threat Bulletin website. It was retweeted 9 times, most notably by CO – Emergency Management, Reporter-Herald, and the CWCB's Colorado Flood DSS account.

Compared to 2016 (285K), 2017 (294K) received more cumulative impressions despite a substantially quieter season (93 flood threats issued in 2016 versus 76 in 2017). This suggests that the @COFloodUpdates is gaining popularity amongst Twitter users. However, social media trends are very fluid and we will continue to monitor and reassess whether Twitter is the most effective social media platform for the FTB service.

Currently, the most notable followers of our Twitter account are the following: Colorado Emergency Management, Colorado Flood DSS, READY Colorado, 9News Denver, ESRI, AAA Colorado, Red Cross Denver, Colorado State Patrol Troop 1E, Colorado.gov, NWS – Grand Junction, NWS – Pueblo, NWS – Goodland, NWS – Boulder, Colorado Climate Center, CU Boulder, Forest Service, ARP, KDVR FOX31 Denver, FOX31/CW Pinpoint Weather, CBS Denver, KKTV 11 News, CASFM, Pikes Peak Red Cross, Northern Colorado Red Cross, Colorado National Guard and Colorado Springs Gazette.

Various police precincts, city/county government offices, TV and newspaper reporters and meteorologists from across the state, academia meteorologists, individual citizens of Colorado, private meteorologists, fire and rescue units also follow the FTB Twitter account.

Email Alerts

A subscription for receiving daily email notification of the Flood Threat Bulletin was begun on April 28. As of September 30, there were 10 subscribers (not including the CWCB project manager!) with an eleventh added in late October. Interestingly, there was only one case where a subscriber asked to be removed from the service, suggesting that the users are content with the quality, amount and frequency of information provided. As noted earlier, if more users choose to receive the Bulletin through email alerts, it is very likely to decrease website traffic. However, the key objective from the program's standpoint is to provide as many communication options as reasonable and continue to learn and adapt to user preferences. Dewberry is currently considering methods on how to better advertise the email subscription option, such as a pre-season notification to Emergency Manager groups that this option exists.

6) CONCLUSIONS

- On a statewide level, 2017 was a relatively quiet year with only 76 days with a Flood Threat. This is about 10% below the 2012-2016 average of 82 days, and sharply lower than 2016's 91 days. Despite the lower than average statistic, the southeast quadrant of the state experienced an incredibly active year with over 20 inches of rainfall falling over a 60-day period in parts of the Arkansas River basin. Fortunately, major riverine flooding was avoided. Perhaps the most notable flood of 2017 was the Beulah flood that occurred on May 11, causing a disaster declaration and requiring evacuations. A Moderate flood threat was posted that day. Another impactful day was July 29 when Hardscrabble Creek flows quickly rose and caused flash flooding in Wetmore and Greenwood, requiring evacuations. A Moderate flood threat was also posted for that event.

- The former Storm Total Precipitation product was improved to use MetStat Inc.'s MetStormLive Quantitative Precipitation Estimate product. The new product is called the State Precipitation Map and features a zoom-enabled web map showing the 24, 48 and 72-hour precipitation estimates at 500-m resolution. Additionally, users can see the maximum 1, 2 and 6-hour precipitation over the past 24-hour period to note areas where flash flooding may have occurred.

- Forecast accuracy during 2017 was on par with or higher than any year since 2012. The overall "Hit" rate was 86%, as was the Probability of Detection (i.e. of detecting a Flood Day). These are above the Program targets of 75%. The False Alarm rate was a relatively low 15%, while the Miss Rate was 14%. The rigor of the validation was improved further this year due to the incorporation of about 500 additional rain gages, and creation of daily validation maps to enable efficient manual inspection.

- Website viewership averaged 25 users per day over the course of the season. However, on days with a High flood threat, more than 50 users accessed the Program website. Website usage was down from about 33 users per day in 2016 due to several factors including fewer total flood threats issued and fewer flood threats issued for relatively populated areas.

- The Program's Twitter account (@COFloodUpdates) continued to expand, and exceeded 1,000 followers for the first time (since the beginning of 2017, 135 followers were added. Total "impressions" from the Program's Tweets were just under 300,000, which is about 5% higher than 2016 despite a generally quieter season. Social media is likely driving a significant amount of day-to-day website usage, making it an integral piece of the Program's communication strategy moving forward.

- An Email Alert subscription was implemented for the first time; as of September 30, ten users have subscribed to receive daily notifications when the Flood Threat Bulletin is released. This communication option will be better advertised in the weeks before the 2018 season start.

APPENDIX A – VERIFICATION WORKSHEET

Table 9 is a daily verification worksheet documenting the intensity and coverage of heavy precipitation, along with whether a Flood Threat was issued. The columns of Table 9 are described below. The double asterisk next to the date denotes an afternoon update was issued.

NOAA Stage IV Quantitative Precipitation Estimate: Contains the sub-categories below.

- **Max1hr-E (inches)**: Maximum 1-hour precipitation east of the 5,250 feet elevation contour.
- **Max2hr-E (inches)**: Maximum 2-hour precipitation east of the 5,250 feet elevation contour.
- **Max1hr-W (inches)**: Maximum 1-hour precipitation west of the 5,250 feet elevation contour.
- **Max2hr-W (inches)**: Maximum 2-hour precipitation west of the 5,250 feet elevation contour.
- **Max24hr-E (inches)**: Maximum 24-hour precipitation east of the 5,250 feet elevation contour.
- **Max24hr-W (inches)**: Maximum 24-hour precipitation west of the 5,250 feet elevation contour.
- **Flood Area (square miles)**: Total area of precipitation exceeding Flood Day thresholds.

Rain Gages: Contains the sub-categories below.

- **Max East (inches)**: Number of rainfall gages exceeding Flood Day thresholds east of the 5,250 foot contour.
- **Max West (inches)**: Number of rainfall gages exceeding Flood Day thresholds west of the 5,250 foot contour.
- **NStats (number)**: Total number of rainfall gages exceeding Flood Day thresholds statewide.

NWS Issues: Contains the sub-categories below.

- **FA_FF**: Total number of Flash Flood Warnings and Areal Flood Advisories issued that day.
- **FL_HY**: Total number of Flood Warnings and/or other hydrological warnings issued that day.

Reports: Whether or not a flooding or qualifying heavy rainfall report was received that day.

Flood Day: Denotes whether or not the day qualified as a Flood Day.

Threat: Highest category of the Flood Threat.

Flags: An overriding factor to the objective Flood Day classification due to the following.

- *SNOW*: Frozen precipitation that exceeded "flood-day" standards and did not result in flooding.
- *LI*: Low-intensity precipitation that exceeded "flood-day" standards and did not result in flooding.
- *RIV*: Riverine flooding from antecedent rainfall/snowfall, but no concurrent Flood Day threshold precipitation was observed.
- *H*: An overestimate of rainfall totals in the NOAA Stage IV precipitation estimates due to excessive hail scattering of the radar beam. On this type of day, typically only the Stage IV product triggered a Flood Day.
- *AREA*: Flood Day area threshold exceeded, but was spatially scattered and was unlikely to cause flooding.

Outcome: Classification of Flood Threat into the following two categories. Note that a blank implies a correct forecast.

- *False Alarm:* A Flood Day was forecasted, but a non-Flood Day was observed,
- *Miss*: A Flood Day was observed but not forecasted.

Table 9: Daily Verification Worksheet

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	Inches	Inches	Inches	Inches	Inches	Inches	square miles	inches	inches	number	number	number					
1-May	0.07	0.13	0.06	0.12	0.14	0.32	0	0.04	0.3	0	0	0					
2-May	0.22	0.45	0.26	0.51	0.35	0.51	0	0.25	0.62	0	0	0					
3-May	0.32	0.61	0.24	0.44	0.52	0.49	0	0.3	0.37	0	0	0					
4-May	0	0.04	0.02	0.04	0	0.04	0	0.13	0.2	0	0	0					
5-May	0	0.04	0.01	0.04	0	0	0	0.01	0.29	0	0	0					
6-May	0.26	0.45	0.6	1.15	0.26	0.6	0	0.04	0.34	0	0	0					
7-May	1.31	2	0.94	1.61	1.64	1.09	24	0.17	0.68	0	0	0					
8-May	1.39	2.76	1.23	2.42	3.06	2.96	3103	3.75	1.77	53	25	0	Yes	Yes	Mod		
9-May	1.55	2.93	0.79	1.24	2.61	1.86	2294	1.52	1.41	17	18	2	Yes	Yes	Mod		
10-May	2.38	4.52	2.4	4.29	4.68	5.74	6347	3.5	3.21	95	54	0	Yes	Yes	Mod		
11-May	0.21	0.4	0.21	0.35	0.66	0.56	0	0.44	0.77	0	5	8		Yes	Mod	RIV	
12-May	0	0.04	0.14	0.28	0	0.24	0	0.65	0.2	0	0	2		Yes	Mod	RIV	
13-May	0.05	0.1	0.03	0.05	0.05	0.03	0	1.31	0.18	0	0	2		Yes	Mod	RIV	
14-May	0.07	0.13	0.03	0.07	0.07	0.04	0	0.29	0.15	0	0	0		Yes	Mod	RIV	
15-May	1.08	2	0.74	1.41	1.35	0.74	0	0.06	0.78	0	0	0		Yes	Mod	RIV	
16-May	0.92	1.83	0.55	0.97	1.45	0.91	0	1.3	0.4	0	0	0			Low		False Alarm
17-May	1.01	1.97	0.59	1.11	2.36	1.72	5197	3.25	3.1	276	2	0		Yes	Low		
18-May	0.83	1.63	0.78	1.52	2.92	3.41	8753	4.25	3.8	321	2	2		Yes			Miss
19-May	0.26	0.49	0.25	0.46	0.94	0.78	0	1.15	0.74	0	0	8					
20-May	0.07	0.14	0.05	0.09	0.16	0.17	0	0.15	0.58	0	0	4					
21-May	1.06	2.03	0.52	1	1.42	0.8	0	0.67	0.6	0	0	0					
22-May	0.38	0.71	0.31	0.59	0.77	0.77	0	0.25	0.5	0	0	0					
23-May	0.03	0.04	0.05	0.1	0.03	0.02	0	0.59	0.4	0	0	0					
24-May	0.02	0.05	0.05	0.1	0.03	0.12	0	0.19	0.97	0	0	4					
25-May	1.07	2.02	0.69	1.36	1.43	0.97	0	0.14	0.9	0	0	0			Low		False Alarm
26-May	1.44	2.71	1.11	2.12	3.12	1.48	1068	2.55	1.91	5	8	2	Yes	Yes	Mod		
27-May	1.12	2.14	0.81	1.59	2.42	0.96	88	1.25	0.6	0	0	0		Yes	Low		
28-May	0.57	0.93	0.22	0.43	0.6	0.43	0	0.28	0.38	0	0	0					
29-May	1.25	2.42	1.71	3.19	1.3	2.75	177	0.8	0.32	0	0	0		Yes			Miss
30-May	1.14	2.04	0.9	1.79	1.17	0.91	0	2.4	1.21	2	0	0		Yes	Low		

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	Inches	Inches	Inches	Inches	Inches	Inches	square miles	inches	inches	number	number	number					
31-May	1.35	2.69	0.98	1.73	1.74	1.03	59	1.26	0.47	0	0	0		Yes	Low		
1-Jun	0.54	0.79	0.5	0.98	0.54	0.67	0	1.24	0.64	0	0	0			Low		False Alarm
2-Jun	1.96	3.85	1.21	1.84	3.14	1.57	2177	2.1	1.01	15	32	0		Yes	Mod		
3-Jun	1	1.84	0.43	0.66	1.11	0.43	0	1.1	0.2	0	2	0			Low		False Alarm
4-Jun	0	0.04	0.3	0.56	0	0.42	0	0.01	0.33	0	0	0					
5-Jun	1.86	3.62	1.47	2.92	2.89	1.94	578	0.13	1.11	1	3	0		Yes	Low		
6-Jun	1.83	3.56	1.65	2.16	2.94	2.51	720	1.8	1.84	5	27	0	Yes	Yes	Mod		
7-Jun	1.74	3.05	1.37	2.71	3.21	1.87	2436	1.91	1.74	4	12	2	Yes	Yes	Mod		
8-Jun	0.09	0.17	1.05	1.83	0.18	1.68	53	0.02	0.33	0	4	4				AREA	
9-Jun	0	0.04	0	0.04	0	0.05	0	0	0.3	0	0	0		Yes	Low	RIV	
10-Jun	0.02	0.04	0.13	0.17	0.02	0.13	0	0	0.4	0	0	0		Yes	Low	RIV	
11-Jun	0.77	1.47	0.32	0.56	0.83	0.32	0	0	0.2	0	0	0			Low		False Alarm
12-Jun	0.56	1.05	0.81	1.47	0.69	1	6	0	0.27	0	2	0					
13-Jun	0	0.04	0.01	0.04	0	0.04	0	0	0.2	0	0	0					
14-Jun	0.19	0.34	0.22	0.42	0.19	0.22	0	0	0.3	0	0	0					
15-Jun	0.02	0.04	0	0.04	0.02	0	0	0	0.2	0	0	0					
16-Jun	0.01	0.04	0.02	0.04	0.01	0.17	0	0	0.3	0	0	0					
17-Jun	0.17	0.31	0.26	0.49	0.18	0.28	0	0	0.2	0	0	0					
18-Jun	0.04	0.06	0.19	0.36	0	0.33	0	0	0.6	0	0	0					
19-Jun	0	0.04	0	0.04	0	0	0	0	0.24	0	0	2					
20-Jun	1.39	2.48	1.5	2.91	1.93	1.61	53	0.25	0.5	0	2	0		Yes			Miss
21-Jun	0.77	1.32	0.76	1.35	0.89	0.8	0	0.26	0.11	0	0	2			Low		False Alarm
22-Jun	1.05	2.05	0.8	1.53	1.5	1.01	6	0.33	0.4	0	0	3			Low		False Alarm
23-Jun	0.79	1.47	0.2	0.28	0.68	0.23	0	0.04	0.31	0	0	1					
24-Jun	0.34	0.65	0.3	0.6	0.95	0.4	0	1.08	0.2	0	0	0					
25-Jun	1.78	3.43	1.35	2.37	2.08	1.56	643	0.2	1.07	1	0	0	Yes	Yes	Low		
26-Jun	1.04	1.93	1.2	2.16	1.53	1.92	106	0.31	0.3	0	12	0		Yes	Low		
27-Jun	1.17	2.23	0.63	1.2	1.6	0.69	6	0.02	0.7	0	0	0					
28-Jun	0.92	1.82	0.9	1.72	1.39	1.1	24	0.1	0.4	0	0	0					
29-Jun	1.65	3.26	0.8	1.58	4.39	1.37	189	0.51	1.4	1	0	0		Yes			Miss

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	Inches	Inches	Inches	Inches	Inches	Inches	square miles	inches	inches	number	number	number					
30-Jun	0.29	0.56	0.84	1.64	0.45	1.22	29	0.04	0.66	0	0	0			Low		False Alarm
1-Jul	0.76	1.38	1.34	2.33	1.14	1.48	47	1.35	0.2	0	2	0	Yes				
2-Jul	1.11	2.1	1.19	2.31	1.22	1.35	59	0.33	0.13	0	0	0					
3-Jul	1.34	2.4	0.89	1.61	1.57	0.9	6	0.09	0.15	0	0	0					
4-Jul	1.01	1.91	1.14	2.15	1.18	1.24	47	0.06	0.1	0	0	0					
5-Jul	0	0.04	0.38	0.75	0	0.4	0	0	0.2	0	0	0					
6-Jul	1.94	3.67	1.12	2.19	2.36	1.41	425	1.38	0.6	0	0	0		Yes			Miss
7-Jul**	1.67	3.29	1.19	2.36	2.24	1.8	407	0.71	1.55	5	10	0	Yes	Yes	Low		
8-Jul	1.42	2.78	1.66	2.69	1.48	1.91	324	0.14	1.3	2	3	0		Yes	Mod		
9-Jul	0.28	0.55	0.41	0.81	0.32	0.71	0	0.01	0.45	0	0	0					
10-Jul	0.64	1.16	0.59	1.05	0.7	0.69	0	0.25	1	1	4	0					
11-Jul	1.94	3.82	1.08	2.05	2.04	1.48	319	4.35	1.7	8	7	0	Yes	Yes	Low		
12-Jul**	1.94	3.66	1.33	2.62	3.7	2.31	2212	2.83	1.39	27	23	0	Yes	Yes	High		
13-Jul	2.52	4.55	2.32	4.16	2.8	2.72	1339	2.12	1.87	21	24	0	Yes	Yes	High		
14-Jul	2.31	4.12	1.9	3.56	2.5	2.32	1156	1.54	2.41	17	22	0	Yes	Yes	High		
15-Jul	3.02	6.02	1.97	3.94	4.03	2.55	3061	4.21	2.2	24	35	0	Yes	Yes	Mod		
16-Jul	1.88	3.54	1.63	2.89	2.61	2.53	625	2.21	1.1	3	18	0		Yes	Low		
17-Jul	1.14	2.1	1.19	2.06	1.45	1.71	77	0.23	1.36	3	2	0		Yes	Mod		
18-Jul	1.28	2.29	1.7	3.39	2.05	2.12	283	1.54	2.42	9	8	0	Yes	Yes	Mod		
19-Jul	1.08	2.11	1.41	2.64	1.63	2.41	720	1.4	1.4	2	31	0	Yes	Yes	Low		
20-Jul	0.74	1.02	1.39	2.38	0.81	2.24	248	0.01	1.8	5	20	0		Yes	Mod		
21-Jul	1.29	2.3	2.45	4.27	2.76	2.61	1056	2.09	2.3	10	20	0	Yes	Yes	Mod		
22-Jul	1.33	2.35	1.6	2.99	1.48	2.39	195	0.02	1.4	3	9	0		Yes	Mod		
23-Jul	0.04	0.06	1.02	1.94	0.06	1.15	71	0	2.52	4	0	0		Yes	Low		
24-Jul	0.78	1.52	0.7	1.25	0.85	1.43	53	0.06	1.1	3	0	0		Yes	Mod		
25-Jul	2.28	4.02	1.17	2.29	2.81	1.95	307	2.07	1.82	9	22	0	Yes	Yes	Mod		
26-Jul**	3.44	6.1	2.54	4.66	4.62	3.53	5839	3.5	3.6	156	70	2	Yes	Yes	High		
27-Jul**	1.35	2.67	1.36	2.7	2.35	1.74	236	2.35	1.2	5	19	0	Yes	Yes	Mod		
28-Jul	2.29	4.56	1.58	2.98	3.42	2.07	5055	3.25	1.75	33	34	0	Yes	Yes	Mod		
29-Jul	2.06	3.55	1.62	2.96	3.69	4.09	3044	3.02	2.09	32	36	0	Yes	Yes	Mod		
30-Jul	2.01	3.97	1.84	3.61	3.58	2.59	3108	2.15	2.33	17	71	0	Yes	Yes	Mod		

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	Inches	Inches	Inches	Inches	Inches	Inches	square miles	inches	inches	number	number	number					
31-Jul	1.06	2.04	1	1.79	1.17	1.34	41	0.27	1.32	2	16	2	Yes	Yes	Low		
1-Aug	0.89	1.66	0.61	1.03	1.14	0.89	0	0.17	0.49	0	0	0					
2-Aug	2.45	4.85	0.91	1.75	2.55	1.19	177	1.24	1.1	1	14	0	Yes	Yes			Miss
3-Aug	0.58	1.14	1.64	2.95	0.67	1.84	77	0.13	1.1	2	8	0	Yes	Yes	Mod		
4-Aug	1.17	2.23	0.91	1.74	1.33	1.22	24	0.2	1	1	13	0	Yes	Yes			Miss
5-Aug	1.3	2.52	1.63	3.13	1.66	1.76	301	2.15	1.17	5	11	0	Yes	Yes	Low		
6-Aug	1.88	3.71	1.32	2.37	3.96	1.56	1622	6.2	2.17	22	30	0		Yes	Mod		
7-Aug	1.78	3.45	1.88	3.56	3.23	3.77	2283	2.15	2.63	33	4	0	Yes	Yes	High		
8-Aug	1.85	3.58	1.63	2.55	2.04	2.17	749	0.6	2.8	8	9	0	Yes	Yes	Low		
9-Aug	1.17	2.26	1.71	3.39	2.43	2.27	726	0.68	2.37	5	4	0	Yes	Yes	Low		
10-Aug	2.01	3.85	2.03	3.88	3.58	2.49	3126	2.3	1.34	11	14	0	Yes	Yes	Mod		
11-Aug	1.71	3.31	1.06	2.06	2.04	1.34	153	1.34	0.84	0	6	0	Yes	Yes	Low		
12-Aug	1.53	2.91	1.58	3.07	1.63	2.67	301	0.76	3.17	3	17	0		Yes	Low		
13-Aug	1.08	2.16	1.36	2.42	1.9	1.44	136	0.34	0.3	0	5	0	Yes	Yes	Low		
14-Aug	1.73	3.1	1.32	2.51	2.5	1.81	554	1.49	0.4	0	14	0	Yes	Yes			Miss
15-Aug	1.97	3.58	1.56	2.65	2.78	2.79	779	1.05	1.77	4	11	0		Yes	Low		
16-Aug	0.38	0.67	0.48	0.86	0.48	0.49	0	0.01	0.12	0	0	0					
17-Aug	0.69	1.34	0.71	1.31	1.14	0.74	0	0.44	0.3	0	0	0					
18-Aug	0	0.04	0.06	0.12	0	0.1	0	0	0.4	0	0	0					
19-Aug	1.38	2.71	1.06	1.78	2.04	1.58	83	0.01	0.1	0	0	0		Yes			Miss
20-Aug	0.59	1.15	0.98	1.8	0.8	1.57	88	0	0.37	0	2	0		Yes			Miss
21-Aug	0.64	1.14	0.82	1.55	0.93	1.31	77	0.19	1.4	1	9	0	Yes	Yes	Low		
22-Aug	0.01	0.04	0.94	1.84	0.02	1.43	53	0	0.8	0	0	0		Yes	Mod		
23-Aug	1.43	2.76	1.54	2.75	2.39	1.67	224	0.36	1.21	1	0	0		Yes	Low		
24-Aug	0.99	1.9	1.15	2.08	1.68	1.45	124	1.25	1.18	1	8	0		Yes	Low		
25-Aug	0.76	1.5	0.69	1.35	1.24	0.69	0	0.13	0.3	0	0	0					
26-Aug	1.36	2.44	1.53	2.74	2.12	1.63	71	0.11	0.2	0	0	0				AREA	
27-Aug	0.5	0.96	0.91	1.7	0.73	1.03	6	0	0.34	0	2	0					
28-Aug	0	0.04	0.75	1.46	0	1.55	35	0.04	0.41	0	2	0					
29-Aug	0.94	1.61	0.94	1.75	1.15	1.25	18	0.45	0.6	0	4	0					
30-Aug	1.28	2.27	0.69	1.36	1.59	0.9	6	0.02	0.33	0	3	0					
31-Aug	1.27	2.12	1.14	2.17	1.87	2.12	254	0.35	0.5	0	3	0		Yes	Mod	BURN	

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	Inches	Inches	Inches	Inches	Inches	Inches	square miles	inches	inches	number	number	number					
1-Sep	1.3	2.25	1.26	2.04	1.36	1.28	6	0.03	0.38	0	0	0			Low		False Alarm
2-Sep	0	0.04	0.34	0.57	0	0.66	0	0	0.2	0	0	0					
3-Sep	0	0.04	0.31	0.59	0	0.51	0	0	0.4	0	0	0					
4-Sep	0.38	0.68	0.61	1.21	0.38	0.65	0	0	0.2	0	0	0					
5-Sep	0	0.04	0.04	0.06	0	0.04	0	0	0.1	0	0	0					
6-Sep	0.01	0.04	0.54	1.04	0.01	0.77	0	0	0.24	0	0	0					
7-Sep	0.18	0.28	0.63	1.21	0.24	1.05	12	0	0.4	0	3	0					
8-Sep	0.68	1.2	0.66	1.3	0.69	0.72	0	0.14	0.3	0	0	0					
9-Sep	1.14	1.73	1.05	2.01	1.17	1.07	12	0.13	0.4	0	0	0					
10-Sep	1.16	2.32	0.88	1.62	1.45	1.32	24	0.19	0.64	0	6	0					
11-Sep	0.91	1.7	1.19	2.08	1.23	1.58	88	0.77	1.2	4	0	0		Yes	Low		
12-Sep	0.29	0.56	0.52	0.95	0.35	0.52	0	0	0.52	0	4	0			Low	BURN	False Alarm
13-Sep	0.99	1.95	0.58	0.87	1.2	0.61	0	0.1	0.79	0	0	0					
14-Sep	0.98	1.89	0.64	1.27	1.31	1.54	189	0.06	1.36	3	0	0		Yes	Low		
15-Sep	0.58	1.11	0.41	0.76	0.79	0.77	0	0.38	0.5	0	0	0					
16-Sep	0.25	0.41	0.26	0.5	0.29	0.26	0	0.01	0.3	0	0	0					
17-Sep	1.33	2.62	0.96	1.84	1.7	1.61	71	0.73	0.56	0	0	0				H	
18-Sep	0.01	0.04	0.02	0.04	0	0.05	0	0.01	0.4	0	0	0					
19-Sep	0	0.04	0.11	0.21	0	0.56	0	0.08	0.5	0	0	0					
20-Sep	0	0.04	0.01	0.04	0	0.15	0	0	0.3	0	0	0					
21-Sep	0	0.04	0.07	0.12	0	0.11	0	0	0.3	0	0	0					
22-Sep	0.6	1.02	0.21	0.41	0.61	0.8	0	1.43	0.8	0	0	0			Low	BURN	False Alarm
23-Sep	0.87	1.67	1.29	2.45	2.48	1.89	8034	2.41	1.83	109	5	0	Yes	Yes	Mod		
24-Sep	1.25	2.42	0.41	0.74	3.38	0.8	608	1.5	0.6	1	3	0	Yes	Yes	Low		
25-Sep	1.13	2.09	0.53	0.82	0.65	1.49	12	0.38	0.31	0	0	0					
26-Sep	0.09	0.13	0.46	0.91	0.12	1.02	18	0.12	0.98	0	0	0					
27-Sep	0.42	0.84	0.42	0.83	1.41	2.08	3917	1.22	1.48	53	0	0			Low	BURN; LI	False Alarm
28-Sep	0.31	0.6	0.32	0.58	0.71	1.23	206	0.43	1.45	1	0	0				LI	
29-Sep	0.24	0.46	0.38	0.75	0.38	1.14	6	0.16	1.47	2	0	0				LI	
30-Sep	0.63	1.25	0.71	1.42	0.86	1.43	484	0	0	0	0	0				H; LI	

APPENDIX B - COLORADO CLIMATE

Colorado's geographic position and over 10,000 feet of topographic contrast can be conducive to both short-term flash flooding from single thunderstorms and prolonged heavy rainfall and flooding as most recently occurred over the Front Range during September of 2013. Moreover, the placement of the Continental Divide separates the state into contrasting climates. To the east, the relatively close proximity of Gulf of Mexico moisture supports higher rainfall intensity, especially over shorter durations, compared to areas west of the Continental Divide. However, the hillier terrain to the west implies that less rainfall is required to generate problematic runoff. For example, over the eastern Plains, hourly rainfall rates of 1.5 inches or more are typically required to cause excessive runoff. For western areas, hourly rainfall rates of less than 1 inch could cause issues. Furthermore, hillier terrain can play host to mud flows and debris slides, in addition to the usual flash flooding concerns that are experienced statewide. The following section summarizes key aspects of Colorado's that play an essential role in daily flood forecasting.

a) Importance of Continental Divide

The most important control of heavy rainfall potential in Colorado (even more important than elevation, by itself) is arguably the position relative to the Continental Divide (hereafter, CD). Figure 16 shows the stark differences in rainfall recurrence statistics at Denver (east of the CD) compared to Silt (west of the CD). While both locations have a similar elevation of about 5,300 feet, the 30-minute 10-year rainfall at Denver (1.09 inches) is 81% higher than the analogous value for Silt (0.60 inches). Similarly, the 30-minute 100-year rainfall at Denver (1.91 inches) is 80% higher than the analogous value at Silt (1.06 inches). In short, despite other possibly counteracting factors, this contrast consistently results in more flood threats east of the CD compared to its west (also see Figure 19 in Appendix C).

Denver, CO

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.217** (0.174-0.270)	**0.267** (0.214-0.334)	**0.358** (0.286-0.448)	**0.439** (0.349-0.552)	**0.562** (0.435-0.737)	**0.665** (0.500-0.877)	**0.774** (0.561-1.04)	**0.892** (0.619-1.22)	**1.06** (0.704-1.48)	**1.19** (0.770-1.68)
10-min	**0.317** (0.255-0.396)	**0.392** (0.314-0.489)	**0.524** (0.418-0.656)	**0.644** (0.511-0.808)	**0.823** (0.637-1.08)	**0.973** (0.732-1.28)	**1.13** (0.821-1.52)	**1.31** (0.906-1.79)	**1.55** (1.03-2.17)	**1.75** (1.13-2.46)
15-min	**0.387** (0.310-0.483)	**0.478** (0.383-0.597)	**0.639** (0.510-0.800)	**0.785** (0.623-0.986)	**1.00** (0.776-1.32)	**1.19** (0.892-1.57)	**1.38** (1.00-1.86)	**1.59** (1.11-2.19)	**1.89** (1.26-2.65)	**2.13** (1.37-3.00)
30-min	**0.545** (0.437-0.680)	**0.670** (0.537-0.837)	**0.892** (0.713-1.12)	**1.09** (0.868-1.37)	**1.39** (1.08-1.82)	**1.64** (1.23-2.17)	**1.91** (1.38-2.56)	**2.19** (1.52-3.01)	**2.60** (1.73-3.64)	**2.93** (1.89-4.11)
60-min	**0.683** (0.548-0.853)	**0.834** (0.669-1.04)	**1.10** (0.881-1.38)	**1.35** (1.07-1.69)	**1.71** (1.33-2.25)	**2.02** (1.52-2.67)	**2.35** (1.70-3.16)	**2.71** (1.88-3.72)	**3.21** (2.14-4.50)	**3.62** (2.33-5.09)
2-hr	**0.822** (0.666-1.02)	**0.998** (0.807-1.23)	**1.31** (1.06-1.63)	**1.60** (1.28-1.99)	**2.04** (1.59-2.65)	**2.40** (1.83-3.14)	**2.80** (2.05-3.72)	**3.22** (2.26-4.38)	**3.83** (2.57-5.31)	**4.32** (2.81-6.02)

Silt, CO (near Glenwood Springs)

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.116** (0.091-0.147)	**0.148** (0.116-0.188)	**0.205** (0.159-0.261)	**0.255** (0.198-0.327)	**0.329** (0.248-0.447)	**0.391** (0.287-0.537)	**0.456** (0.323-0.645)	**0.525** (0.356-0.768)	**0.623** (0.406-0.941)	**0.701** (0.443-1.07)
10-min	**0.170** (0.133-0.215)	**0.217** (0.170-0.276)	**0.299** (0.233-0.382)	**0.373** (0.289-0.479)	**0.482** (0.364-0.654)	**0.572** (0.420-0.787)	**0.667** (0.473-0.945)	**0.769** (0.522-1.13)	**0.912** (0.594-1.38)	**1.03** (0.649-1.57)
15-min	**0.207** (0.162-0.263)	**0.264** (0.207-0.336)	**0.365** (0.285-0.466)	**0.455** (0.353-0.584)	**0.588** (0.443-0.798)	**0.698** (0.512-0.960)	**0.814** (0.576-1.15)	**0.938** (0.637-1.37)	**1.11** (0.725-1.68)	**1.25** (0.792-1.91)
30-min	**0.264** (0.207-0.336)	**0.346** (0.270-0.440)	**0.484** (0.377-0.617)	**0.604** (0.468-0.775)	**0.776** (0.583-1.05)	**0.915** (0.670-1.25)	**1.06** (0.748-1.49)	**1.21** (0.819-1.76)	**1.42** (0.923-2.14)	**1.58** (1.00-2.42)
60-min	**0.343** (0.269-0.436)	**0.431** (0.337-0.548)	**0.580** (0.452-0.741)	**0.710** (0.550-0.911)	**0.897** (0.674-1.21)	**1.05** (0.768-1.44)	**1.21** (0.852-1.70)	**1.37** (0.928-2.00)	**1.60** (1.04-2.41)	**1.78** (1.12-2.72)
2-hr	**0.422** (0.334-0.532)	**0.516** (0.407-0.651)	**0.677** (0.532-0.856)	**0.817** (0.638-1.04)	**1.02** (0.772-1.36)	**1.18** (0.874-1.60)	**1.35** (0.965-1.88)	**1.53** (1.05-2.20)	**1.78** (1.17-2.64)	**1.97** (1.26-2.97)

Figure 16: Subset of NOAA Atlas 14 rainfall recurrence statistics for (top) Denver and (bottom) Silt. Note that the elevation of both locations is about 5,300 feet above sea level.

b) *Seasonality*

Seasonality is likely the second most important factor in controlling heavy rainfall potential in Colorado. As shown in Figure 17, early in the operational season (May, June), the highest potential for heavy rainfall is almost exclusively east of the Continental Divide, and in particular the northeast quadrant of the state. Snow is significant factor in the Front Range and Gore Mountains through early June. Meanwhile, by August, average rainfall decreases sharply north of the Palmer Ridge and increases significantly over the southeast quadrant of the state as well as in the San Juan Mountains (due to moisture transport into the region by the North American monsoon). The flood threat largely evolves in a similar fashion.

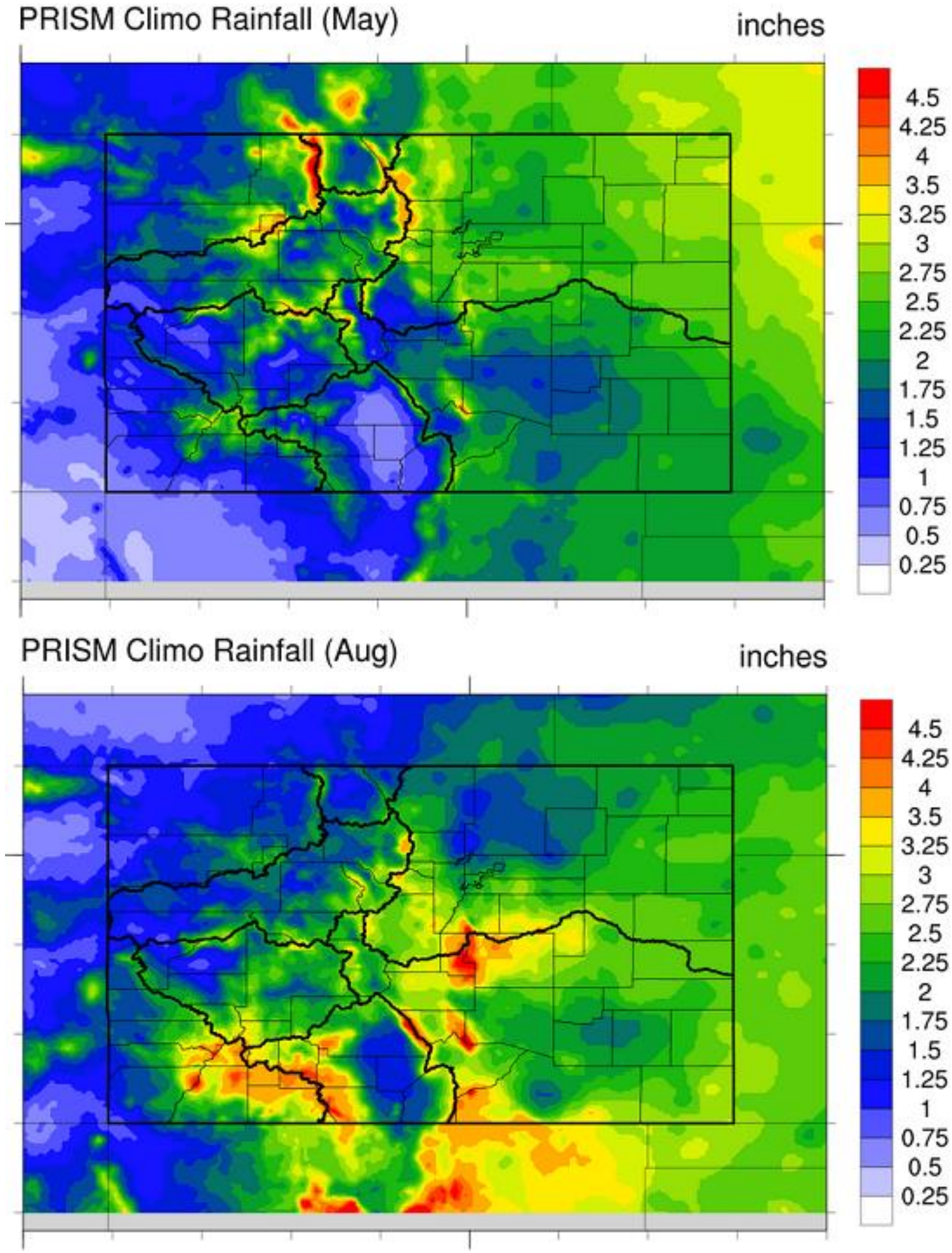

Figure 17: Monthly average precipitation for (top) May and (bottom) August. Source: Oregon State University PRISM group.

c) Surface characteristics

While a significant focus of the Flood Threat Bulletin is only heavy rainfall potential, an equally important factor is surface characteristics such as slope, ground cover type, soil type, antecedent rainfall, etc. Collectively, these factors can cause significant sensitivity when translating between rainfall and runoff. Figure 18 shows the 1-hour Flash Flood Guidance (FFG) for central and eastern Colorado. This product is updated daily by National Weather Service River Forecast Centers. Note that, in general, FFG is significantly higher over the eastern Plains compared to the higher terrain. For example, along the Kansas border, the 1-hour FFG could be as high as 2.75 inches, while over the San Juan Mountains, it can be below 0.75 inches. An even starker example of the importance of surface characteristics is over a fresh fire burn area, where the burnt now hydrophobic soil mass can cause significant flooding concerns for even 0.25 inches of rainfall per hour. Surface characteristics play an integral role in the translating the heavy rainfall threat to a flooding potential.

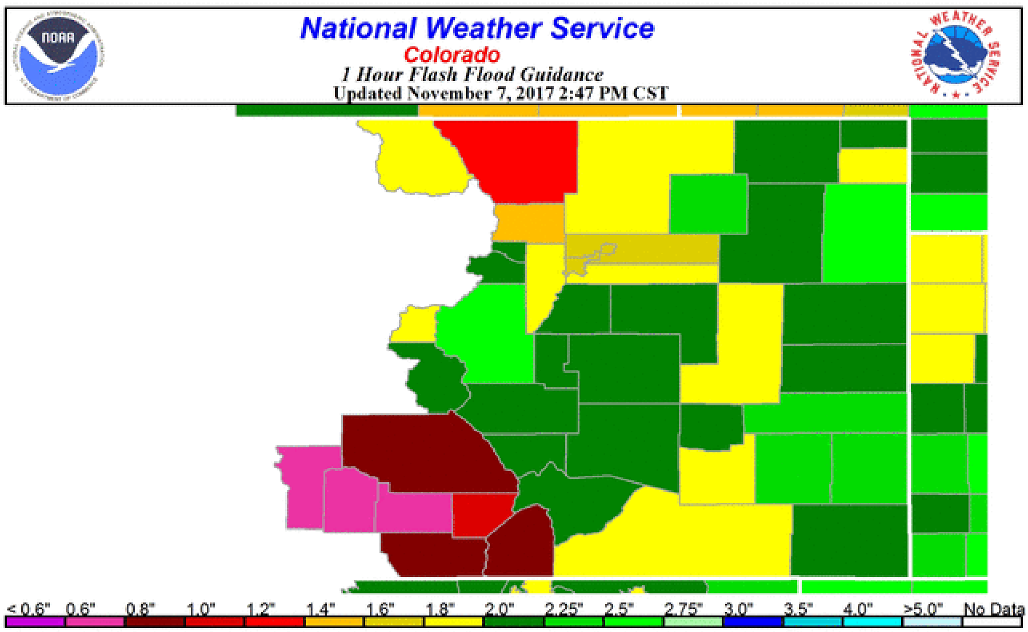

Figure 18: 1-hour Flash Flood Guidance for central and eastern Colorado, valid November 7, 2017. Source: National Weather Service River Forecast Centers.

APPENDIX C – FLOOD THREATS ISSUED

Figure 19 shows the total number of days when a given location was under a flood threat during the 2016 (top; for reference) and 2017 (bottom) operational seasons. Note that this does not distinguish the type of flood threat (e.g. low versus moderate). For reference, there are 153 days during the forecast season.

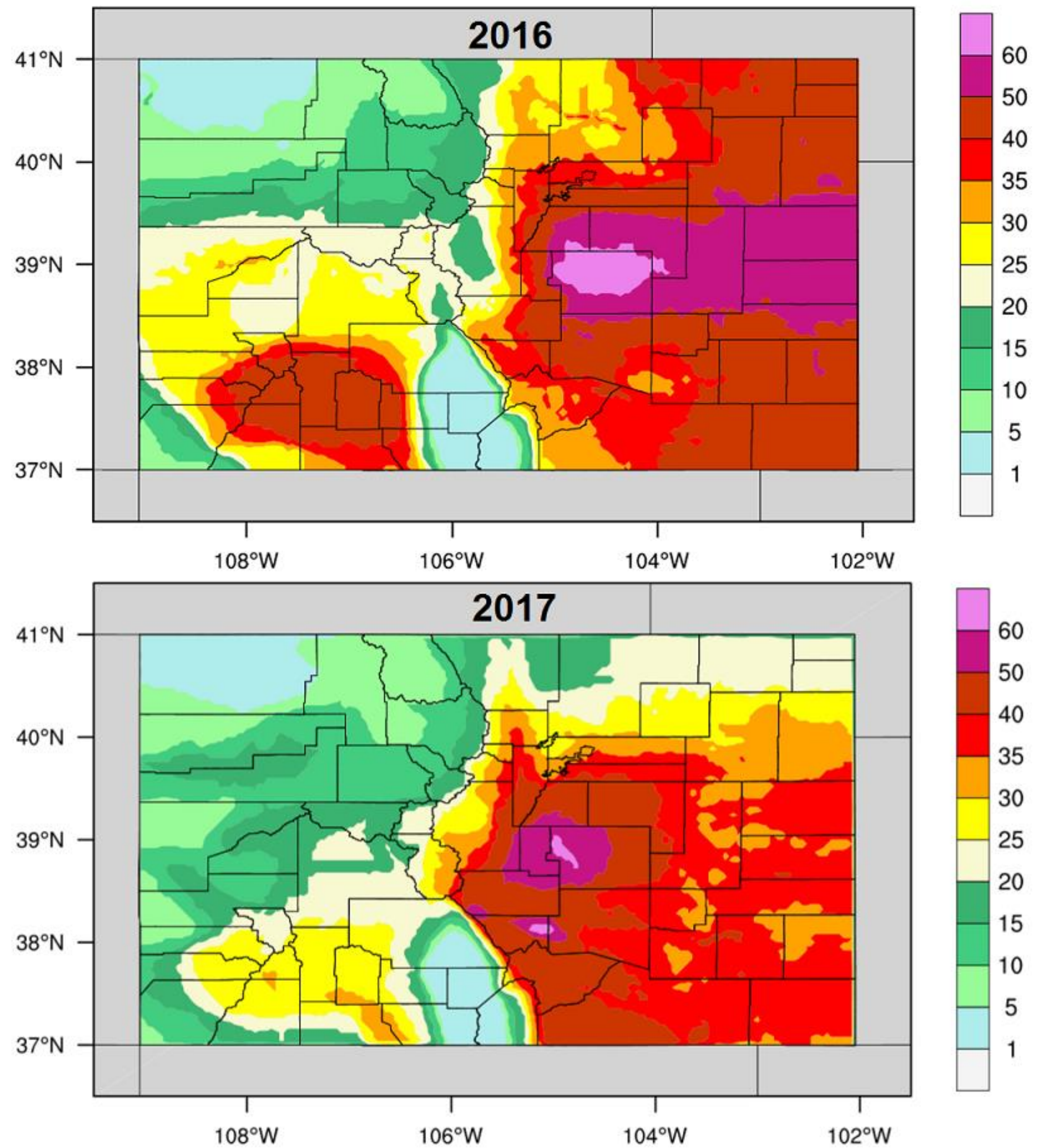

Figure 19: Number with days with a flood threat during (top) 2016 and (bottom) 2017.