Colorado Flood Threat Bulletin – 2016 Final Report

Project PDA - 1227

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2016 Colorado Flood Threat Bulletin

Final Report

1) INTRODUCTION

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, a southeast fetch of Gulf of Mexico moisture around the Atlantic subtropical high pressure ridge typically results in higher rainfall intensity than to the west. However, the hillier terrain to the west implies that less rainfall is required to generate problematic runoff, including mud flows and debris slides; surges of monsoon moisture are also an important factor in the west. The Colorado Flood Threat Bulletin (FTB) was developed in 2006 in order to provide the state with critical lead time in anticipating the threats described above. Additionally, a key goal of the FTB is to provide a consistent forecast across the state – one that takes into account the various hydrometeorological features and translates these into a single product.

In 2012, a competitive 5-year award of the Colorado Flood Threat Bulletin was made to Dewberry. Although we have upgraded several aspects of the program during our 5-year tenure, 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 issuance of a 15-day Flood Threat Outlook (FTO) to identify periods of rapid snowmelt, locally heavy rainfall, or conversely the development of drought conditions due to lack of precipitation and (iii) a daily Storm Total Precipitation (STP) product that recaps the past 24-hour hydrometeorological conditions across the state. In 2016, all forecasts were developed by Dewberry meteorologists Brad Workman (FTB, FTO, STP), Dmitry Smirnov (FTB, FTO, STP) and Jason Giovannettone (FTB, STP). Archived forecasts are available through the website www.coloradofloodthreat.com. Stuart Geiger was the program's project manager through August 2016, after which Dmitry Smirnov served in that role.

This objective of this report is to (i) provide a summary of weather conditions during the 2016 operational season, (ii) document all additional services provided, (iii) measure site viewership, including through social media, and most importantly, (iv) perform an objective analysis of FTB forecast performance.

Daily Flood Threat Bulletin (FTB)

The FTB is designed for daily issuance during the contract period by 11:00 AM. 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 of thunderstorm hourly rainfall rates and/or amounts. A four-tier category system is used to characterize the flood threat: Low, Moderate, High and High Impact.

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.

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 and a precipitation outlook by river basin. From 2012 to 2014, the FTO was presented as three 5-day increments (1-5, 5-10 and 10-15 day), but in 2015 the format was changed to be event-specific. This allowed for a better handling of events that could coincide with multiple 5-day periods.

Storm Total Precipitation (STP)

For 2016, Dewberry provided a continuation of the STP service through use of MapBox web mapping tools and a website based in Google Sites. The STP product was updated in 2014 to use gridded Stage 2 precipitation estimates obtained by merging NWS WSR-88D Storm Total Precipitation products from Boulder, Grand Junction, Pueblo, Cheyenne and Goodand sites so that point-by-point comparisons of the STP and observed data can be assessed. Additionally, Dewberry forecasters often used CoCoRaHS, COOP sites, Urban Drainage and Flood Control District's ALERT rain gages, SNOTEL data and NWS reports to supplement textual discussion with any notable weather events, such as extreme rainfall, flooding, debris slides, hail, wind and tornadoes.

FTB Performance metrics

Table 1 shows the final year to date number of all products provided, and the percent provided on time. In each case, **on-time products were delivered over 100% of the time**, meeting the CWCB-established metrics.

2) VERIFICATION METRICS

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 ultimately improve future forecasts. The data sources and methodology used to verify 2016 forecasts are described below.

TABLE 1: PRODUCT DELIVERY PERFORMANCE FOR 2016 FLOOD THREAT BULLETIN PRODUCTS.

Product	Total Products	Products on Time	Percent on Time
STP	153	153	100%
FTB	153	153	100%
FTO	43	43	100%
Total	**350**	**350**	**100%**

Observational Data Sources

1) Daily precipitation accumulation reports from about 850 CoCoRaHS observers across Colorado. This data is generally reported between 6AM-8AM and encompasses the previous 24-hours. We use only reports that are received from 6AM to 8AM to ensure that measurement is consistent with the forecast period.
2) Natural Resources Conservation Service (NRCS) SNOTEL daily precipitation accumulation (midnight-midnight) reports from about 100 sites across Colorado.
3) Radar-estimated, gage-adjusted gridded NOAA Stage IV precipitation data. This publically available product is prepared every hour by NOAA and uses many rain gages for post-processing first-guess radar reflectivity-precipitation algorithms. The horizontal resolution is about 4km (2.6 miles). There were four days when Stage IV data was not successfully retrieved: 5/9, 5/20, 9/20, 9/29. For these dates, we instead used River Forecast Center 24-hour precipitation estimates, which is very similar to Stage IV.
4) 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. If no magnitude is specified with a "Heavy Rain" report, it was dismissed unless the remark contained a specific reference to flooding.

5) NWS warning and advisory shapefiles, 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

A "flood-day" is hereby defined when any one of the following criteria is met:

1) Gridded or CoCoRaHS rainfall exceeds:
    a. 1.00 in. west of 104˚W
    b. 1.50 in. east of 104 ˚W
2) A qualifying NWS storm report described above is received that day. See description 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 CoCoRaHS reports, at least 2 reports satisfying the criterion (1) above must be received. This eliminates days with localized, marginal rainfall that is unlikely to cause flooding.
5) If a "flood-day" is based solely on the radar-estimated product, the areal coverage of rainfall exceeding flood-day thresholds must exceed 50 square-miles. Once again, this helps to eliminate days with localized, marginal rainfall that is unlikely to cause flooding.
6) Subjective analysis of a "flood-day" may overwrite the objective procedure above based on the following:
    a. A day with significant snowfall that results in "flood-day" precipitation totals, but is not an actual flood threat, or,
    b. A day where no rainfall occurs but flooding occurs due to strong snowpack melt or,
    c. High antecedent river levels that are causing flooding even in the absence of additional rainfall or,
    d. If "flood-day" identification is made solely using the radar estimated product, the rainfall estimates will be checked to ensure there is no overestimation due to radar beam scattering by hail.

Appendix A contains the daily forecast observations used for verification, while Appendix B shows all NWS storm reports along with ones that were forecasted and missed. In all, corrections listed in point (6) above are applied on 10 days (see right-most column in Appendix A).

Tables 2 (all months) and 3 (month by month) show contingency tables of overall forecast verification for the 2016 season. The four categories of each table are:

a) Flooding forecast and flooding observed (**Hit**)
b) No flood forecast but flooding observed (**Miss**)
c) Flooding forecast but no flooding observed (**False Alarm**)
d) No flood forecast and no flood observed (**Hit**)

TABLE 2: FORECAST METRICS BY TYPE OF FORECAST FOR THE 2016 FORECASTING PERIOD.

	Forecast Flood-day	Forecast No Flood-day	**Total**
Observed Flood-day	a) 80	b) 11	**91**
Observed No Flood-day	c) 13	d) 49	**62**
Total	**93**	**60**	**153**

The overall FTB accuracy can be calculated by adding the number of correct forecasts (refer to Table 2; a + d = 129) and dividing by number of forecasts (153) resulting in an 84.3% “hit rate”, noticeably higher than the 76-77% seen during 2014 and 2015. This year’s accuracy is on par with the 84-86% reported in 2012 and 2013, though it is important to note the substantially more rigorous validation that has been done since 2014. **Thus, it is quite likely that 2016 forecasts were the most accurate of our 5-year FTB history.** It is also likely that the boost in this year’s accuracy is partially the result of internal Numerical Weather Prediction guidance that we have been developing internally over the past 3 years. This is further discussed in section 4.

TABLE 3: FORECAST METRICS BY MONTH FOR THE 2016 FORECASTING PERIOD.

Forecast / Observed	May	June	July	August	September	Total
Flood / Flood (a)	12 (9)	21 (17)	21	21	5	**80 (73)**
No Flood / Flood (b)	1	2	5	2	1	**11**
Flood / No Flood (c)	2	1	2	5	3	**13**
No Flood / No Flood (d)	16	6	3	3	21	**49**
Total	**31**	**30**	**31**	**31**	**30**	**153**

In addition to the hit rates described above, there are other important measures of forecast accuracy. The probability that a flooding day was forecasted correctly, technically termed the Probability of Detection (POD), is determined by dividing the number of correct flood-days forecast (80) by the number of flood-days observed (91) or 88%, which is also a marked improvement over 2015’s 78%. The False Alarm rate of flood-day forecasts is found by dividing the number of incorrect flood-day forecasts (13) by the total number of non-flood-days (62), or 21%. This is lower than 2015’s 25% and below the program’s goal of 25%. Finally, the miss rate can be found by dividing the number of un-forecasted flood-days (11) by the total number of flood-days (91), or 12%. Note the sum of the miss rate and POD must add up to 100%. The sharp decrease in the miss rate from 2015’s 22% is partially a testament to the new guidance that was used during 2016 operations.

TABLE 4: COMPARISON OF PERFORMANCE SINCE 2012
more robust validation procedure incorporating radar-estimated rainfall data started in 2014
FA = False Alarm, POD = Probability of Detection

	Hit %	POD %	FA %	Miss %	Threats Issued	Flood-days
2012	86%	84%	18%	16%	65	64
2013	84%	85%	13%	15%	83	85
2014*	76%	73%	18%	27%	75	84
2015	77%	78%	25%	22%	85	88
2016	84%	88%	21%	12%	93	91

Table 4 summarizes the verification metrics described above for each year of our 5-year history preparing FTB forecasts. Note that the drop-off in overall forecast accuracy from 2013 to 2014 is at least partially attributed to the incorporation of gridded radar-based rainfall estimates that could identify flood-days in regions where there are no gages. It is encouraging to see that all metrics have rebounded since 2014 suggesting that forecast accuracy has improved despite the more robust validation techniques. In fact, **the high probability of detection and**

low miss rates during 2016 marked their best respective measures of any year in our 5-year tenure.

Table 5 shows the forecast performance as a function of threat level. A good forecast system should show higher skill as the threat level increases due to more confidence that flooding will be realized. Indeed, Table 5 shows this to be the case. Low threat forecasts verified about 77% of the time, up from 67% during 2015. Moderate, high and high impact threats verified 100% of the time they were issued. However, it should be noted that there were only 2 High and High Impact events during this season, which limits the conclusions that can be made about forecast accuracy for these levels.

TABLE 5: ACCURACY AS A FUNCTION OF THREAT LEVEL

	Observed Flood-day	Observed No Flood-day	Total
LOW	44 (77%)	13 (23%)	**57**
MODERATE	27 (100%)	0	**27**
HIGH	1 (100%)	0	**1**
HIGH IMPACT	1 (100%)	0	**1**
Total	**73 (85%)**	**13 (15%)**	**86**

One final metric of forecast performance is based on local storm reports. Appendix B shows all of the flood-related storm reports received by the National Weather Service. Of the 195 total reports during 2016, 170 (87%) were correctly forecasted (i.e. at least a low flood threat was issued for the location of the storm report) by the FTB. It is notable that this captures not only whether or not a flood threat verified anywhere across Colorado, but also that the report fell within a threat area. This represents an encouraging improvement from 2015's 79% and 2014's 73% accuracy. It is interesting to note that the 195 total reports received were lower during 2016 are significantly lower than last year's 300+ reports, signaling that this season was generally less severe than last year.

3) CHARACTERIZATION OF FORECAST PERIOD WEATHER

Overview

The 2016 operational season, spanning from May 1 to Sep 30, can be best characterized as warm and relatively dry. Heavy rainfall activity took a downturn compared to the abnormally wet 2013-2015 seasons. Nonetheless, from a statistical standpoint, this season still had its fair share of heavy rainfall. In fact, note from Table 4 that there were more flood threats issued during 2016 than any of the past 5 years, suggesting that this year had many marginal events but nonetheless those with flood-proned rainfall. Appendix C shows the number of flood threats issued for a given locale. The most active region was the Palmer Ridge, along with eastern Colorado in general; a secondary maximum was found over the San Juan mountains. These active regions are consistent with the climatology of summertime precipitation in Colorado.

Figure 1 shows the daily number of CoCoRaHS stations reporting over 1 and 2 inches of rainfall, along with the area exceeding "flood-day" standards as measured by the NOAA Stage IV gridded product. There were 81 days with at least one CoCoRaHS station observing over 1 inch of rainfall and 32 days where at least 1 station measured over 2 inches. These numbers are significantly lower than the 107 and 44, respectively, measured in 2015. Moreover, if we filter further to include only days when at least two gages measured qualifying rainfall, the numbers drop to 58 and 14, respectively, suggesting that heavy rainfall was quite isolated. Similar conclusions are reached when looking at "flood-day" area. Although at least some flood-day area was estimated on 93 days, only 59 days showed an area exceeding 100 sq. miles. Finally, the maximum flood-day area during the 2016 season was estimated at about 5,500 sq. miles on August 5th. This is only a fraction of the maximum flood-day area of over 15,000 sq. miles observed during multiple days in 2015.

Detailed Summary

This description can be best followed by looking at Figure 1 and Appendix A. The 2016 season started in generally tranquil fashion with light rainfall and snowfall observed during the first two weeks of May. The season's first flood threats were issued for an event on May 6th – 8th when more widespread chances of heavy rainfall emerged. Up to 2.91 inches fell on the 7th, prompting the season's first flood advisories from the National Weather Service.

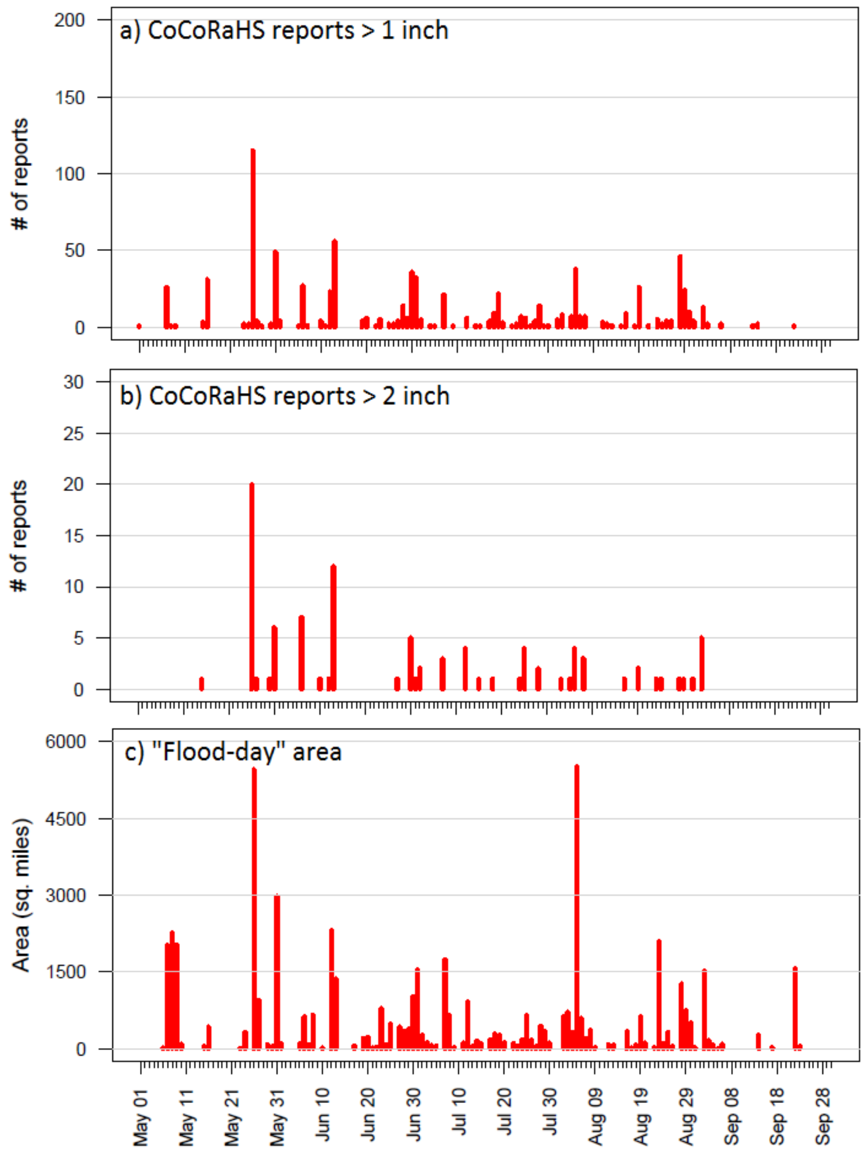


Figure 1: The number of daily CoCoRaHS reports exceeding (a) 1 and (b) 2 inches, and (c) the coverage of "flood-day" precipitation, in sq. miles, from the gridded precipitation product. For reference in (c), the total area of Colorado is about 104,000 sq. miles.

After the storm's passage, cooler conditions on the 9th allowed for persistent rain and snow showers to cover the state, especially west of the Continental Divide. After a few weeks of relatively quieter weather, the end of May began a ~3 week unsettled period, frequently accompanied by heavy rainfall. Particularly threatful days were May

25-26, May 31, June 6 and June 12-13. Each of those days saw at least 2 inches of rainfall, and multiple flash flood warnings issued. May 26th was notably severe, with large hail and a few tornadoes touching down in eastern Colorado. The June 12/13 event also featured large hail, up to 2 inches, and gusty winds. Isolated flash flooding was reported both days, with compounding concerns due to elevate river levels from snow melt. A Moderate flood threat was in place but widespread flooding was was fortunately avoided.

July was quite an active month, statistically speaking, but most events were of the marginal variety. Out of 23 flood threats issued that month, 16 were Low threats. The start of the southwest monsoon in early July meant that the western part of the state got in on some of the action. July 1, 7, 8, 12 and 24 were particularly active days. July 1 saw the highest precipitable water ever measured that day at Grand Junction and Denver. However, heavy rainfall was quite isolated. July 7 was a difficult forecast day with initially no threat identified, followed by the realization that a very moist outflow boundary would likely spark off thunderstorms in eastern Colorado in the evening hours. Very heavy rainfall occurred, resulting in flash flooding of I-25 in El Paso County, along with other rural areas of the eastern Plains. A case study of the event revealed opportunity for improving the forecast with an afternoon update. July 24 was noteworthy due the combination of very gusty winds (74mph at DIA), large hail (2.75 inches near Fort Morgan) and heavy rainfall. However, once again, flooding was very localized and wider-scale impacts were avoided during July.

During August, substantial rainfall finally arrived over the western slope with many locales picking up over 2 inches of rainfall during the first week of August. On August 4th, 0.57 inches of rainfall fell in 15-minutes in La Plata County, which is noteworthy for that part of the state (1 in 5 or 10 year event). Light to moderate rainfall amounts were frequently observed over the San Juans during August, leading to very wet conditions by the end of the month. The Dolores river basin received 430% of its average rainfall during the month of August (see Figure 5). However, intermittent and moderate-intensity nature of the rainfall meant slow and steady runoff and did not cause significant flooding issues.

September was a generally dry month for most of the state. However, there were two noteworthy rainfall events. An northwest-flow disturbance produced very heavy rainfall in eastern Colorado on 9/2 with nearly 4 inches falling in several hours (also see Figures 2-4). On 9/23, a fall-like Pacific disturbance combined with high moisture content to provide widespread moderate rainfall over the western slope. However, it was a close call, as just across the Moffat County border in Utah, very heavy slow-moving storms caused serious flash flooding. Despite these events, September ended abnormally dry for many areas, resulting in light to moderate drought conditions over the north-central region including the Denver metro. Fortunately, reservoir levels were in good shape and water supply was not threatened.

4) 2016 ADDITIONAL SERVICES

In additional to the FTB, FTO and STP products, Dewberry provided two additional services during the 2016 season.

a) Using encouraging feedback stemming from the 2013 Front Range flooding event, we continued to use social media to disseminate forecast information and other related products. Viewership continued to increase this season and statistics are presented in the section 5.
b) In 2014, Dewberry began a concerted effort to include more objective Quantitate Precipitation Forecast (QPF) guidance from weather models to (i) provide a benchmark for forecaster performance and (ii) assess instances when forecasts can be improved. In 2015, this data was first formally processed into internal guidance, providing us with summaries such as the Probability of Precipitation and Probability of Exceeding 1 inch of rainfall. Prior to the start of this season, we continued to improve internal guidance by culling poorer-performing lower resolution models and including additional high-resolution (<= 2.6 mile resolution) ones. A total of 23 models were used this season: 5 from the National Centers for Environmental Prediction (Silver Spring, MD), 10 from the National Corporation for Atmospheric Research (Boulder, CO) and 8 from the

National Severe Storms Lab (Norman, OK). Another key upgrade during 2016 was to make some of our internal guidance publicly available through a dedicated "QPF Viewer" page on the website. Three key fields were shown: the evolution of hourly maximum rainfall, the probability of exceeding 1 inch per hour and the probability of exceeding 1 inch in 24 hours. A snapshot of the QPF Viewer is shown in Figure 2.

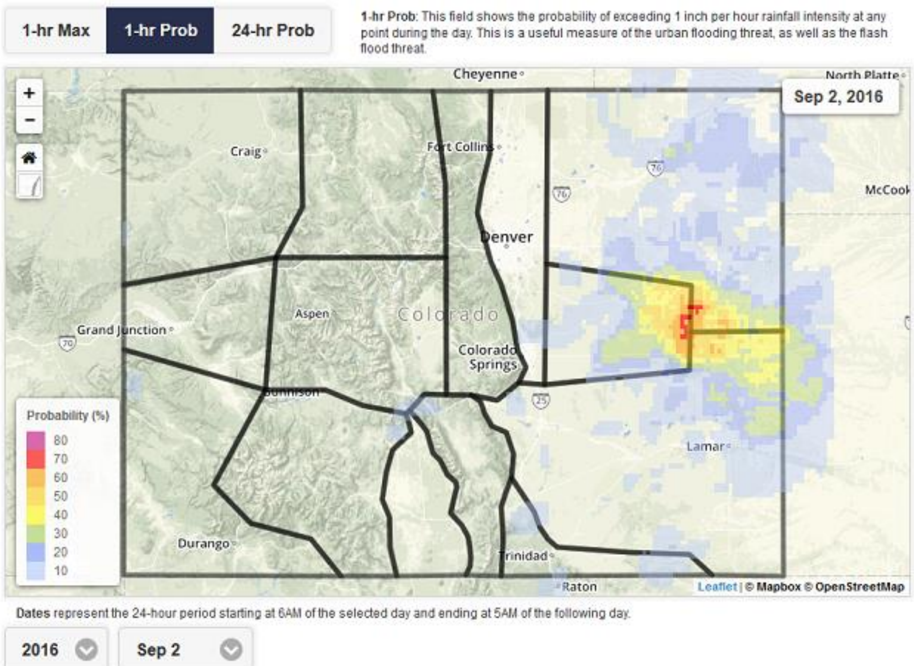


Figure 2: Example of the QPF Viewer showing the probability of hourly rainfall exceeding 1 inch across Colorado.

During 2016, the benefit of our upgraded internal guidance began to markedly show up in forecasts. An example of this is from September 2nd, when an upper-trough approached Colorado from the west. Our experience

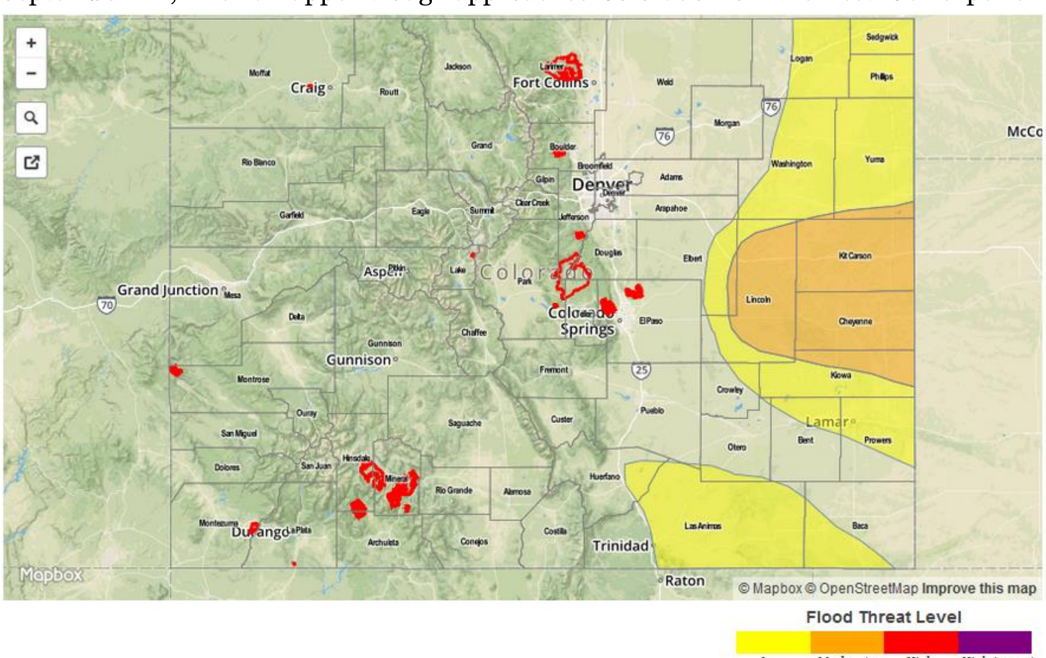


Figure 3: Flood threat map issued the morning of September 2nd, 2016.

suggested heavy rainfall was likely somewhere in eastern Colorado. However, as is often the case, it was difficult to pinpoint exactly where this may occur. Our internal guidance helped provide the answer: as shown in Figure 2, it suggested greater than 50% probability of exceeding 1 inch per hour in parts of Lincoln, Kit Carson and Cheyenne counties. Figure 3 shows that this translated as a moderate threat in the morning's flood threat map. As Figure 4 shows, very heavy rainfall, up to 3.74 inches, was indeed observed over the moderate flood threat region later in the afternoon and evening hours. A total of 23 flash flood warnings and advisories were posted that day, though the rural setting of the region prevented a much more serious situation. **We are not aware of any other products that provided as much lead time as our forecast**. It is likely that without our internal QPF guidance, we would not have been able to issue a Moderate flood threat (only a Low threat). This example shows a payoff of leveraging the supplemental research efforts during 2014 and 2015 in improving forecast guidance to ultimately benefit the state of Colorado.

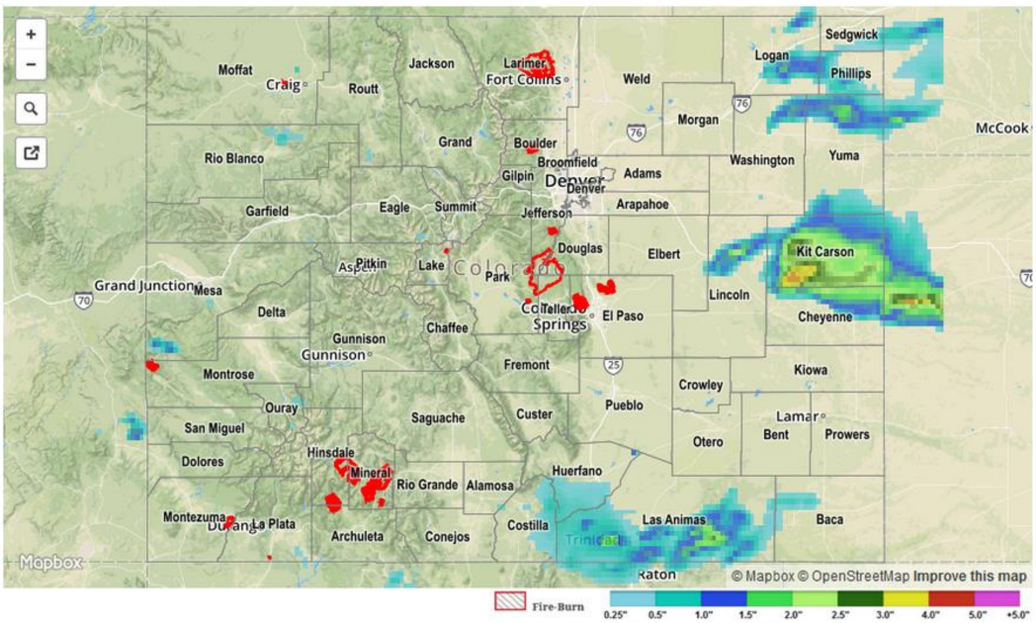


Figure 4: Storm Total Precipitation map showing 24-hour rainfall ending on the morning of September 3rd, 2016.

5) WEBSITE AND SOCIAL MEDIA VIEWERSHIP

During the historic floods of September 2013, we noted an opportunity to expand the outreach of the Colorado FTB 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, so it was expanded into a season-long tool for 2014, 2015, and 2016, 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, and (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 we collect through the FTB season, we expanded our social media strategy to maximize the way this data is leveraged. For example, Figure 5 shows a new monthly "product" that we have released since 2015: a tally of basin averaged total precipitation across Colorado. Such messages have shown their value by being well received by social media users with ample retweets and impressions.

In all, the FTB's Twitter account, @COFloodUpdates, has steadily gained usage since its inception, with the total number of followers up to 901 at the end of the 2016 season (+147 compared to the end of the 2015 season). This can be partially attributed to the amount of retweets a few of our tweets received, especially from accounts like

Colorado Emergency Management's Twitter feed, which has over 40,000 followers. This increase of viewership of our tweets continued to play a large role in expanding our outreach to those who may not have known about the @COFloodUpdates account and the FTB website otherwise. The use of specific hashtags also played a large role in expanding viewership; 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.

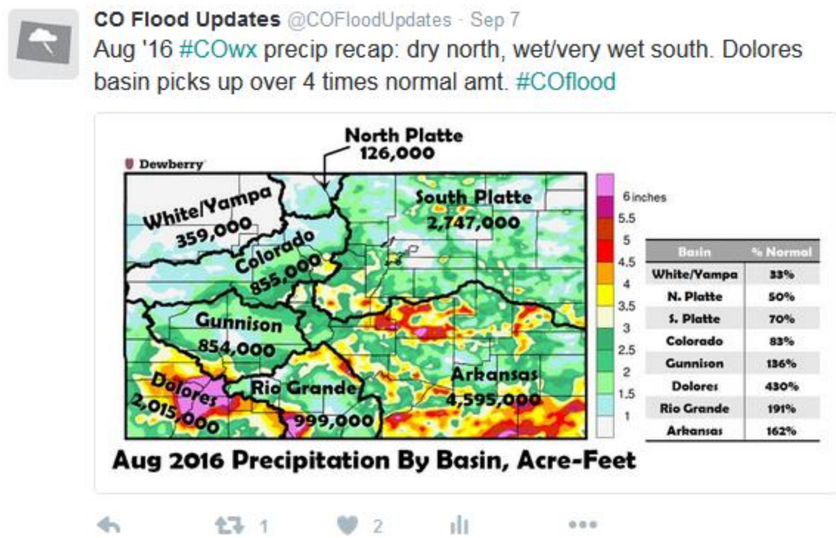


Figure 5: Example of tweet from September 7th showing total precipitation in acre-feet (and percent of normal) across major Colorado watersheds.

The following is a summary on how our season progressed in terms of followers:

- **May**: 815 followers (an increase of 148 followers over May 2015)
- **June**: 841 followers
- **July**: 857 followers
- **August**: 888 followers
- **September**: 901 followers

The graphical representation of site viewership in Figure 6 shows the continued success of driving users to the Flood Threat Bulletin website. Twitter remained the primary catalyst for increasing reach of our products, allowing the FTB site to continue attracting new/additional users (30% increase in users over 2015). The increase in the amount of users also led to a substantial increase in site visits (sessions) in 2016; a 30% increase over 2015. Average Session Duration, which measures the average amount of time a user stays on the website, increased by 10% over the 2015 season. This metric suggests that users found the information useful and worth their time. The Percent of New Sessions (percentage of first time visits) remained steady, with only a 0.42% decrease over 2015.

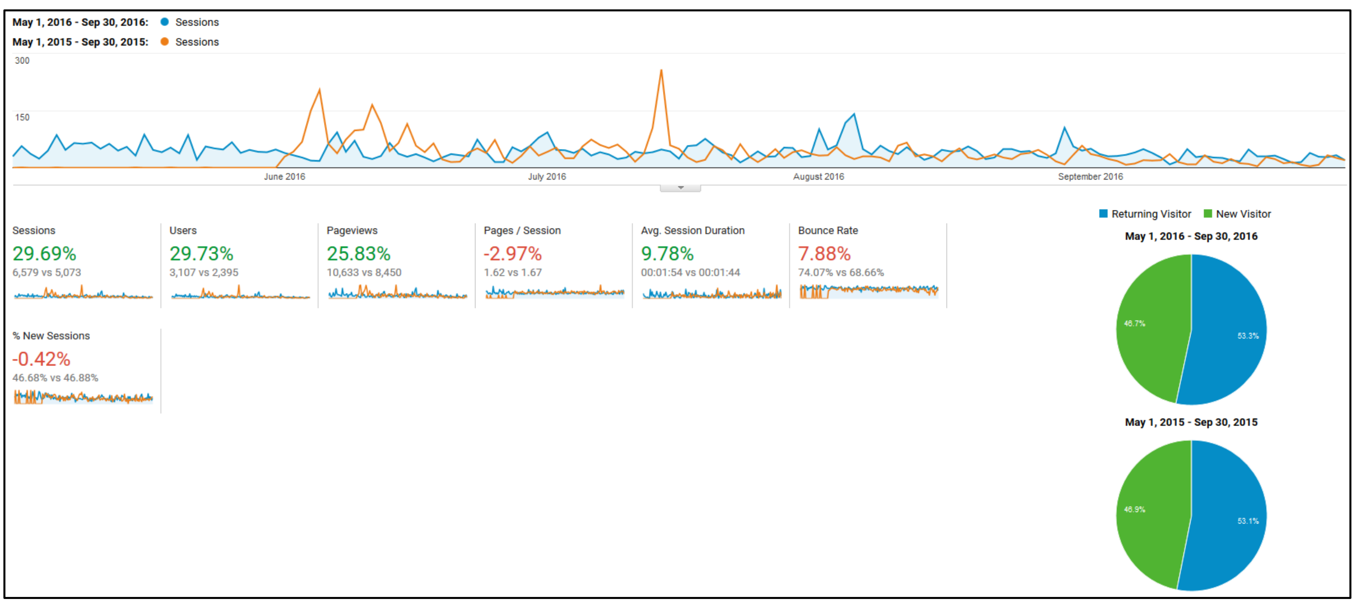


Figure 6: Visits to the ColoradoFloodThreat.com site in 2015 (orange line) vs. 2016 (blue line), including usage statistics.

New users (first time visits) continue to make up more than 46% of the total users on the website, which is evidence that the reach of the Flood Threat Bulletin continues to increase.

One final important note: After a large decrease in the number of pages per session between 2014 and 2015 (-25.35%), the metric leveled off in 2016 and remained fairly even to 2015 (1.67 pages/session in 2015, 1.62 pages/session in 2016). This confirms our conclusion that it was the result of the new website format, which streamlined information for users and reduced the number of total web pages on the website.

Mentioned previously, the use of hashtags played a large role in expanding the outreach of our Flood Threat Bulletin products. The following bullet points show a list of common tags that were used, as well as unique tags that were used to target specific events with large audiences that may be interested in the FTB.

- Common hashtags: #FTB, #FTO, #STP, #COwx, #COFlood
- Unique hashtags: #LaborDay, #Monsoon, #IndependenceDay, #Severe

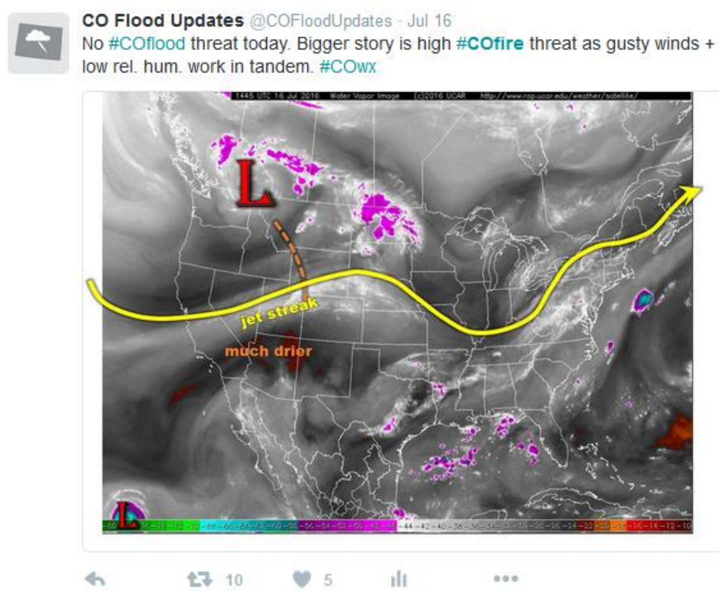


Figure 7: Tweet with greatest number of Twitter impressions (retweeted 10 times). July 16, 2016.

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. Average tweets received between 500-900 impressions, as this represents the base follower group of our account. The more engaging or important the content, the more impressions a tweet received as more people retweeted it. During the season, 34.3% of Tweets (80 out of 233 tweets) made over 1,000 impressions, with the best tweet making 7,932 impressions. Interestingly enough, that particular tweet (Figure 7) was for a "No Flood Threat" day, with the main story being high fire danger. It was retweeted 10 times, most notably by Colorado Flood DSS, Boulder OEM, Boulder County, and CO – Emergency Management.

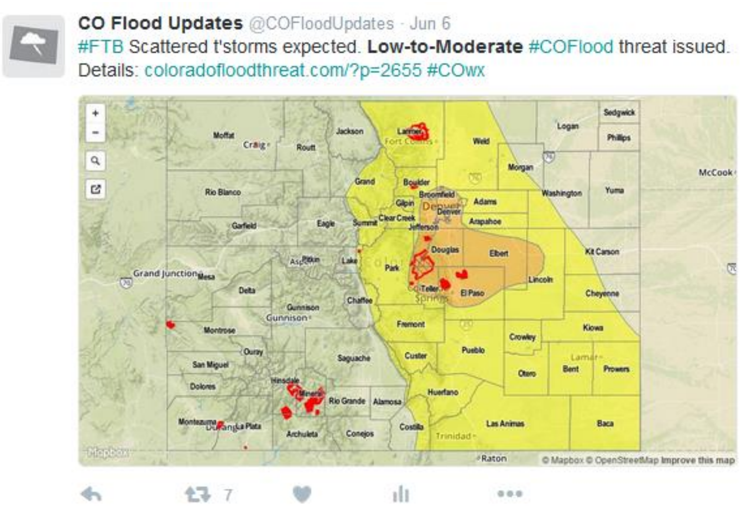


Figure 8: Tweet referencing a flood threat with the greatest number of Twitter impressions (retweeted 7 times). June 6, 2016.

The best performing tweet with a flood threat, with respect to impressions, was from June 6, 2016. This tweet included a reference to scattered thunderstorms, a low-to-moderate flood threat, an image of the day's flood threat, and a link to the Flood Threat Bulletin website (Figure 8). It was retweeted 7 times, most notably by CO – Emergency Management, KKTV 11 News, and Colorado Flood DSS.

In total, the FTB Twitter handle produced 276,065 impressions over the course of the 2016 season. The relationship between retweets and total impressions is illustrated in Figure 9.

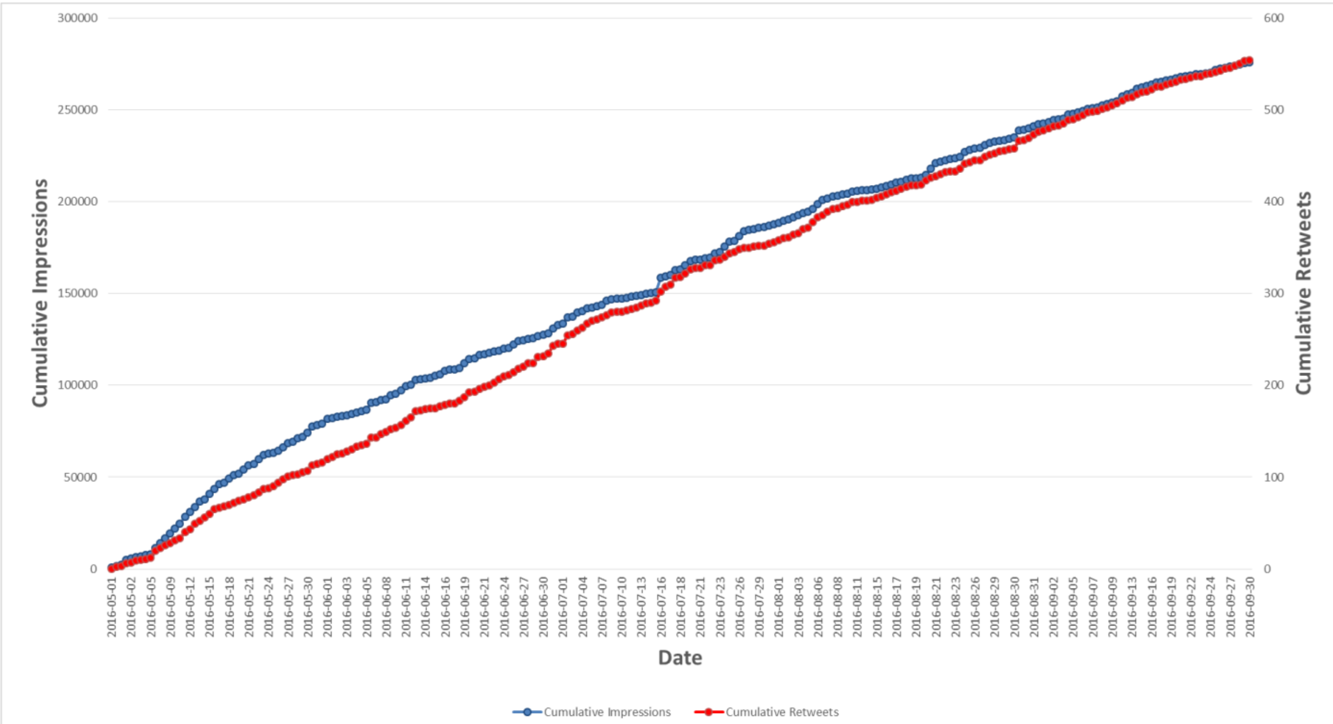


Figure 9: Relationship between cumulative retweets and impressions from Twitter Analytics. Note that in general, the pattern of impressions closely follows the pattern of retweets, showing the direct relationship between the two measures.

Currently, the most notable followers are the following: Colorado Emergency Management, Colorado Flood DSS, READY Colorado, 9News Denver, AAA Colorado, Red Cross Denver, Colorado State Patrol Troop 1E, Colorado.gov, NWS – Grand Junction, Forest Service, ARP, KDVR FOX31 Denver, FOX31/CW Pinpoint Weather, 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.

6) CONCLUSIONS

- After active seasons during the 2013-2015 seasons, the 2016 season saw overall drier conditions (see section 3). Nonetheless, 93 flood threats were issued, which was the highest during the entire 5-year period that we have been doing the FTB. However, most events were marginal and aside from a few very localized cases, no severe flooding was observed.

- Forecast accuracy improved markedly, compared to 2015 (see Table 4). Overall accuracy was 84% (up from 77% in 2015), with a false alarm rate of 21% (25% in 2015) and a miss rate of only 12% (22% in 2015). Of 195 flood-related storm reports, 170 (88%) fell within a region that had at least a Low flood threat issued. This is up from 79% in 2015. **Notably, 2016 saw the highest Probability of Detection (88%) and lowest Miss rate (12%) of our entire 5-year tenure of doing the FTB**. **This is at least in part a testament to the state-of-the-art internal precipitation guidance that has been updated yearly since 2014 using the supplemental FTB service funds. A clear example of this is the heavy rainfall of September 2nd, 2016 that we were able to pinpoint down to nearly the county level with our morning flood threat map (see Figures 2-4).**

- Website viewership continued to increased, with a 30% bump in page hits compared to 2015.

- The Twitter program continued to successfully expand, with the addition of almost 150 new followers to our Twitter handle and resulting in approximately 280,000 views of FTB flood threat information (Figures 6 and 9). We continued to see that interaction was most significant when we posted the threat map inside the Tweet, which overall expanded our view. This is consistent with online marketing trends that have clearly identified Twitter and other Social Media users as “content thirsty”. More people are drawn to images and are likely to review this information when it presented to them in their Twitter feed. As a result, it leads to more impressions and greater overall awareness. This program has provided immense value to the State of Colorado and we recommend that it is continued in the future FTB program.

Acknowledgment

We would like to acknowledge our former colleague, and now good friend, Mr. John Henz for passing the forecasting baton to us. His passion and enthusiasm for all things related to Colorado weather is relentless, and undoubtedly engrained in our forecast skills!

APPENDIX A – VERIFICATION WORKSHEET

Column descriptions:

GageE & GageW:

Maximum daily precipitation (in inches) from all available rainfall gages for areas east (E) and west (W) of 104^{o}W.

Nstats:

Number of rainfall gages exceeding 1.00 in. (west of 104˚W) and 1.50 in. (east of 104˚W)

GridE & GridW:

Same as GageE and GageW expect using gridded NOAA Stage IV radar-estimated rainfall.

Area:

Area of precipitation (in square miles) exceed 1.00 in. (west of 104˚W) and 1.50 in. (east of 104˚W) based on the NOAA Stage IV gridded precipitation analysis.

Warn & Adv:

Number of hydrologic-related warnings and advisories issued by the four NWS offices serving Colorado.

Obs:

Whether (1) or not (0) a “flood-day” was observed (see page XX for description of “flood-day”).

Threat:

Maximum threat in Flood Threat Bulletin (0=None, 1=Low, 2=Moderate, 3=High, 4=High Impact). False alarms are shaded in yellow; misses are shaded in light red.

Notes:

Indicates days where manual adjustment of observations was required, for one of the following reasons:
“LI”: Low-intensity precipitation (including snowfall) that exceeded “flood-day” standards, but no flooding was observed.
“RIV”: Riverine flooding from antecedent rainfall/snowfall, but no concurrent flood-day threshold precipitation.
“H”: An obvious 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, only the radar-estimated precipitation dataset indicated a flood threat.

Date	GageE	GageW	Nstats	GridE	GridW	Area	Warn	Adv	Obs	Threat	Notes
5/1	0.24	1.5	1	0.29	0.7	0	0	0	0	0	
5/2	0.05	0.32	0	0.06	0.79	0	0	0	0	0	
5/3	0.1	0.02	0	0.03	0.07	0	0	0	0	0	
5/4	0	0.1	0	0	0.07	0	0	0	0	0	
5/5	0	0.25	0	0	0.03	0	0	0	0	0	
5/6	0.49	0.84	0	0.64	1.25	18	0	0	0	1	
5/7	1.53	1.5	21	2.91	2.37	2023	0	4	1	1	
5/8	0.83	1.65	1	1.29	2.08	2265	0	0	1	1	
5/9	0.33	1	1	0.47	1.92	2029	0	2	0	0	LI
5/10	0.54	0.87	0	0.64	1.32	94	0	0	1	1	
5/11	0.65	0.34	0	0.58	0.5	0	0	2	1	1	RIV
5/12	0.01	0.02	0	0	0	0	0	0	0	0	
5/13	0	0.4	0	0.01	0.05	0	0	0	0	0	
5/14	0.25	0.36	0	0.08	0.55	0	0	0	0	0	

5/15	0.42	2.8	3	0.38	1.14	59	0	0	0	0	LI
5/16	0.73	1.37	31	1.99	1.33	425	0	0	1	2	
5/17	0.09	0.81	0	0.17	0.78	0	0	4	0	1	
5/18	0.02	0.62	0	0.04	0.94	0	0	0	1	1	RIV
5/19	0	0.45	0	0.16	0.73	0	0	0	0	0	
5/20	0.02	0.16	0	0	0.05	0	0	0	0	0	
5/21	0	0.02	0	0.38	0.31	0	0	0	0	0	
5/22	0.13	0.71	0	0.43	0.27	0	0	0	0	0	
5/23	0.6	0.3	0	1.57	0.58	6	0	2	0	0	
5/24	0.82	1.1	2	2.64	1.37	324	0	0	1	1	
5/25	1.35	1.01	1	0.93	0.46	0	0	0	0	0	
5/26	2.54	4.58	92	3.42	3.22	5450	4	2	1	2	
5/27	2.03	1.03	2	3.5	1.12	944	1	0	1	1	
5/28	0.56	1.47	1	0.55	0.44	0	0	0	1	1	RIV
5/29	0.38	0.42	0	2.71	0.79	83	0	0	1	0	
5/30	2.07	0.71	1	1.69	1.06	47	0	0	1	1	
5/31	3.85	1.83	39	4.12	2.59	2979	7	13	1	1	
6/1	1.98	1.02	2	1.43	2.67	106	0	2	1	1	
6/2	0	0.15	0	0.15	0.3	0	0	0	0	0	
6/3	0.04	0.02	0	0.06	0.11	0	0	0	0	0	
6/4	0	0.13	0	0.08	0.44	0	0	0	0	0	
6/5	0.27	1.84	1	0.7	1.36	100	0	0	1	1	
6/6	0.94	3.39	27	1.92	1.89	625	0	12	1	2	
6/7	0.43	1	1	1.21	1.41	83	5	0	1	1	
6/8	0.77	0.86	0	3.61	1.39	661	0	0	1	2	
6/9	0.02	0.76	0	0.08	0.96	0	0	6	1	1	RIV
6/10	0	2.08	4	1.27	1.3	12	0	4	1	1	
6/11	0.88	1.03	1	1.32	0.94	0	0	0	0	1	
6/12	1.54	3.7	14	3.05	2.85	2312	0	12	1	2	
6/13	2.57	2.86	41	1.96	2.52	1368	4	4	1	2	
6/14	0.02	0.68	0	0	0.01	0	0	4	1	1	RIV
6/15	0	0.01	0	0	0	0	0	2	1	1	RIV
6/16	0.05	0	0	0	0	0	0	0	1	1	RIV
6/17	0.64	0.19	0	1.43	1.52	53	0	3	1	1	
6/18	0	0.29	0	0	0	0	0	0	0	0	
6/19	0.12	1.28	4	0.52	1.62	201	0	3	1	0	
6/20	0.08	1.41	6	0.45	1.57	224	2	9	1	2	
6/21	0.05	0.65	0	0.52	1.02	12	0	0	0	0	
6/22	0.97	1.15	1	1.85	1.18	35	0	5	1	0	
6/23	1.34	1.18	1	2.6	2.18	784	0	5	1	2	
6/24	0.9	0.69	0	1.54	1.34	77	0	0	1	1	
6/25	1.56	0.75	1	1.56	2.44	478	0	0	1	1	
6/26	1.56	0.59	1	1.15	0.61	0	0	2	0	0	
6/27	2.8	0.51	1	2.06	1.36	425	0	0	1	1	

6/28	1.88	1.89	11	1.74	1.87	348	5	6	1	1	
6/29	1.7	1.27	2	2.47	2.97	378	2	2	1	1	
6/30	3.8	2.59	30	3.9	2	1015	3	10	1	2	
7/1	1.84	2.27	20	2.53	2.11	1545	7	21	1	3	
7/2	0.79	2.2	5	1.98	1.28	265	0	5	1	2	
7/3	0.51	0.77	0	1.97	1.14	118	8	0	1	1	
7/4	0.56	1.23	1	0.63	1.56	65	0	0	1	1	
7/5	1.38	0.82	0	0.94	1.47	59	0	0	1	0	
7/6	0.74	0.15	0	0.65	0.2	0	0	0	0	0	
7/7	1.45	2.55	17	3.44	3.29	1740	6	9	1	0	
7/8	0.49	0.45	0	2.34	2.82	643	2	14	1	1	
7/9	1.03	0	0	1.79	0	24	0	2	0	1	
7/10	0.15	0.02	0	0.01	0.01	0	0	0	0	0	
7/11	0.8	0.65	0	0.83	1.52	112	0	0	1	0	
7/12	2.81	0	6	3	0.36	914	4	2	1	0	
7/13	0.4	0.85	0	1.42	1.51	47	0	0	1	1	
7/14	0.6	1	1	2.06	1.25	147	0	0	1	1	
7/15	0.94	2.5	1	2.61	1.25	100	0	0	1	1	
7/16	0.2	0.24	0	0.39	0.92	0	0	0	0	0	
7/17	1.03	1.18	1	1.66	1.28	177	5	7	1	1	
7/18	2.35	1.43	4	2.49	1.83	283	0	10	1	2	
7/19	1.18	1.57	20	0.92	1.58	271	4	13	1	2	
7/20	1.09	1.45	1	1.27	1.48	124	8	4	1	2	
7/21	0.85	0.67	0	1.36	0.9	0	4	2	1	1	
7/22	1.09	0.78	0	1.83	1.08	106	10	8	1	1	
7/23	1.14	0.57	0	1.45	1.51	59	0	0	1	1	
7/24	2.18	1.13	5	1.88	1.58	171	0	2	1	2	
7/25	2.97	2.28	6	3.08	2.05	649	5	2	1	1	
7/26	1.42	0.55	0	2.08	0.89	165	0	2	1	2	
7/27	1.58	0.35	1	1.26	1.22	47	0	0	1	0	
7/28	2.25	2.06	12	1.94	1.75	442	5	0	1	1	
7/29	0.88	1.35	1	1.33	1.78	342	2	2	1	1	
7/30	1.24	0.71	0	2.2	1.51	112	0	6	1	1	
7/31	0.82	0.83	0	1.49	0.83	0	0	4	0	1	
8/1	0.11	1.42	5	0.83	0.63	0	0	0	1	1	
8/2	0.9	2.61	8	2.58	2.05	619	0	9	1	1	
8/3	0	0.95	0	0.48	1.26	714	2	6	1	2	
8/4	2.17	1.22	4	2.93	1	319	0	19	1	2	
8/5	2.42	2.67	34	3.57	2.56	5509	0	28	1	4	
8/6	1.54	1.23	4	2.5	1.59	596	2	2	1	2	
8/7	0.4	3.24	7	1.25	2	195	6	20	1	2	
8/8	0.95	0.75	0	1.84	1.48	360	4	10	1	1	
8/9	0.01	0.99	0	0.36	1.21	24	0	5	0	1	
8/10	0.17	0.48	0	1.09	0.63	0	0	0	0	0	

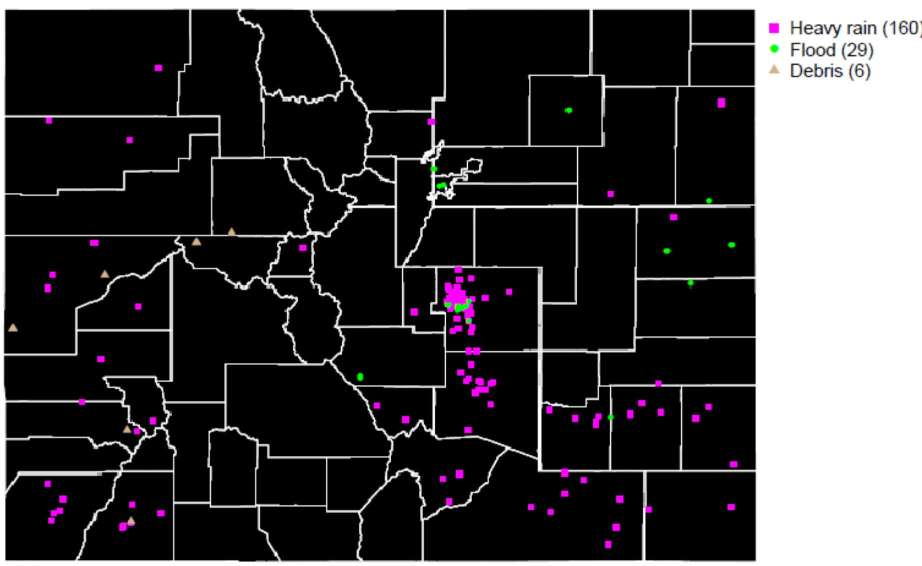
8/11	1.48	0.8	0	1.23	0.99	0	0	0	0	1	
8/12	0.44	1.02	2	0.66	1.99	83	4	4	1	1	
8/13	0.67	1.45	1	1.64	1.64	71	2	9	1	1	
8/14	0	0.11	0	0.1	0.53	0	0	0	0	0	
8/15	0.25	1.1	1	0.87	0.86	0	0	0	0	0	
8/16	0.54	2.02	9	2.24	2.35	342	10	18	1	0	
8/17	0.65	0.88	0	0.94	1.35	12	0	4	0	1	
8/18	0.34	1.02	1	2.14	1.43	77	0	4	1	1	
8/19	2.05	2.27	17	1.84	1.94	619	2	8	1	2	
8/20	0.14	0.4	0	1.06	1.6	112	4	7	1	0	
8/21	0.06	1.13	1	0.05	0.82	0	0	0	0	1	
8/22	0.07	0.9	0	1.12	1.48	24	4	8	1	2	
8/23	0.36	3.35	5	0.49	2.12	2094	6	5	1	1	
8/24	2.04	0.86	1	0.81	1.27	100	0	2	1	2	
8/25	0.6	1.23	4	1.7	1.88	324	0	4	1	1	
8/26	1.84	1.65	2	1.42	2.01	47	0	0	1	1	
8/27	0.6	0.53	0	1.2	0.55	0	0	0	0	1	
8/28	2.31	1.85	46	2.53	3.63	1268	2	14	1	1	
8/29	1	2.33	23	0.98	2.79	737	16	8	1	2	
8/30	1.57	1.53	5	2.08	2.49	501	6	13	1	2	
8/31	2.34	0.38	2	1.64	1.22	24	6	2	1	2	
9/1	0.34	0.91	0	0.08	0.92	0	0	0	0	1	
9/2	3.31	0.6	7	3.74	1.45	1516	23	0	1	2	
9/3	1.26	0.9	0	1.76	2.64	159	0	0	1	2	
9/4	0.47	0.48	0	2.21	1.31	77	0	0	0	0	H
9/5	0.51	0.08	0	1.58	0.27	6	0	0	0	0	
9/6	1.15	0.43	0	1.83	1	88	0	0	1	1	
9/7	0.04	0.03	0	0.56	0.16	0	0	0	0	0	
9/8	0.04	0	0	0.77	0.02	0	0	0	0	0	
9/9	0	0.01	0	0	0.06	0	0	0	0	0	
9/10	0	0	0	0	0	0	0	0	0	0	
9/11	0	0.12	0	0.09	0.15	0	0	0	0	0	
9/12	0.71	0.4	0	0.88	0.77	0	0	0	0	0	
9/13	0.11	1.05	1	1.04	0.97	0	0	0	0	0	
9/14	0.38	1.31	2	1.43	1.49	260	0	0	1	1	
9/15	0.98	0.35	0	1.03	0.62	0	0	0	0	0	
9/16	0.3	0.27	0	0.11	0.25	0	0	0	0	0	
9/17	0.65	0.01	0	2.16	0.42	24	0	0	0	1	
9/18	0.17	0.03	0	0	0	0	0	0	0	0	
9/19	0	0.06	0	0	0	0	0	0	0	0	
9/20	0.38	0.36	0	0.07	0.32	0	0	0	0	0	
9/21	0.58	0.73	0	0.81	0.73	0	0	0	0	0	
9/22	0.56	1.12	1	0.56	4.05	1569	0	5	1	1	
9/23	0.51	0.78	0	1.05	1.09	47	0	0	1	0	

9/24	0	0.5	0	0.02	0.59	0	0	0	0	0	
9/25	0	0.01	0	0	0.04	0	0	0	0	0	
9/26	0	0.03	0	0	0	0	0	0	0	0	
9/27	0	0.07	0	0	0	0	0	0	0	0	
9/28	0	0.15	0	0	0.26	0	0	0	0	0	
9/29	0	0.34	0	0	0.67	0	0	0	0	1	
9/30	0	0.48	0	0.44	0.95	0	0	0	0	0	

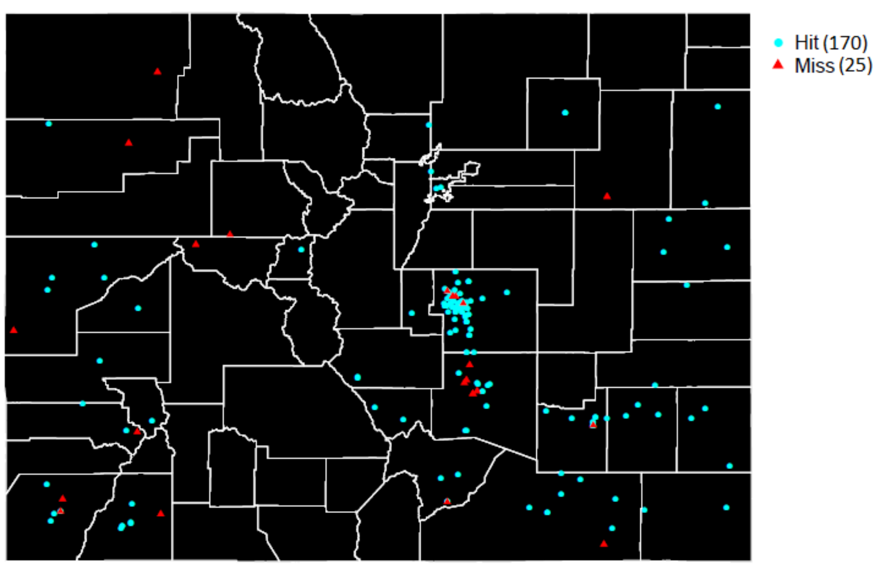
APPENDIX B – LOCAL STORM REPORT VERIFICATION

The maps below show (a) all NWS flood-related local storm reports received within Colorado from May 1 – September 30 and (b) an analysis of whether those reports fell within our threat area (b). Flood-related reports were categorized as those with the following "Event Type": Heavy Rain, Flood, Flash Flood and Debris Flow. For Heavy Rain reports, only those with a Magnitude exceeding 0.5 inches were retained. In all 195 reports were received during this operational season, down from over 300 reports last season. Out of the 195 reports, 170 (88%) fell within our flood threat area and were classified as hits, compared to 79% last season. **Notably, all 29 Flood and Flash Flood reports were observed in an area under at least a low flood threat**.

a) All flood-related reports



b) Verification



APPENDIX C – FLOOD THREATS ISSUED

The map below shows the total number of all flood threats (low, medium, etc) for a given location during the 2016 operational season.