Colorado Flood Threat Bulletin – 2022 Final Report

DECEMBER 30, 2022

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Contents

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ACRONYMS

CD .... Continental Divide

CoCoRaHS....................... Community Collaborative Rain, Hail, and Snow Network

COOP.............................. Cooperative Observer Program

CWCB.............................. Colorado Water Conservation Board

FAR................................. False Alarm Rate

FBF .... Fire Burn Forecast

FEMA............................... Federal Emergency Management Agency

FFG .... Flash Flood Guidance

FTB.................................. Flood Threat Bulletin

FTO.................................. Flood Threat Outlook

GIS................................... Geographic Information Systems

HMC................................ HydroMet Consulting, LLC

LSR .... Local Storm Reports

MRMS .... Multi-Radar Multi-Sensor

NAM .... North American Monsoon

NDMC .... National Drought Mitigation Center

NOAA .... National Oceanic and Atmospheric Administration

NRCS............................... Natural Resources Conservation Services

NSSL .... National Severe Storms Laboratory

NWS .... National Weather Service

POD................................. Probability of Detection

PWS.................................. Personal Weather Station

QPE .... Quantitative Precipitation Estimate

SPM................................. State Precipitation Map

TS .... Threat Score

USGS............................... United States Geological Survey

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2022 Colorado Flood Threat Bulletin

Final Report

1) INTRODUCTION

The 2022 forecast season (May 1st to September 30th) was the first year of a 5-year contract awarded to Dewberry and HydroMet Consulting, LLC (HMC) to produce the Colorado Flood Threat Bulletin (hereafter, Program) on behalf of the Colorado Water Conservation Board (CWCB). Since work began on the Program in 2006, it has maintained the double objective of 1) producing and disseminating reliable heavy rainfall and flood forecasts, and 2) incorporating the frontier of hydro-meteorological research into operations for more accurate forecasts, along with a transparent verification process. Numerous Program upgrades have been made since the Program's inception (see previous season's final reports, e.g. Dewberry and HMC, 2021) and the five main products of the Program in 2022 are:

1. the daily Flood Threat Bulletin (FTB) that both describes and visualizes the flood threat across the state of Colorado;
2. the bi-weekly (Monday/Thursday) 15-day Flood Threat Outlook (FTO) that highlights the upcoming possible flood threat from rapid snowmelt and local heavy rainfall, or conversely, the development of drought conditions;
3. the daily State Precipitation Map (SPM) that recaps the past 24- to 72-hours of hydrometeorological conditions and includes flood reports;
4. the daily Fire Burn Forecast (FBF) that is a standalone forecast system that assigns a daily flood threat to the most impactful wildfire burn areas, including yesterday's precipitation on burns areas and burn-specific flood/debris flow reports;
5. the monthly Streamflow Tracker that shows recent and Water Year to-date adjusted (i.e. naturalized) streamflow conditions across most of the largest river basins within Colorado.

For the 2022 operational season, Dewberry continued to operate as the Program's Project Manager with subconsultant HMC in charge of forecast operations (together, hereafter referred to as Team). Dewberry meteorologists Alyssa Hendricks Dietrich and Michael Ragauskis, and hydrologist Cara Williams produced the SPM and identified flood events for archiving within FBF. The Programs' forecasts (FTB/FTO/FBF), supplemental in-season FBF analyses and Streamflow Tracker tables were developed by HMC meteorologists Dmitry Smirnov, Dana McGlone, and Jessica Moore, who also contributed a handful of SPM posts. Archived forecasts continue to be available through the Program's website www.coloradofloodthreat.com. David Sutley served as the Project Manager for Dewberry, and Mat Mampara served as Principle-in-Charge.

This Final Report was created to provide verification metrics for the daily flood forecasts, summarize the hydro-meteorological weather conditions over the 2022 forecast season, evaluate Program viewership, and to document any upgrades made to the Program.

Daily Flood Threat Bulletin (FTB)

FTB daily issuance occurs by 11:00 AM within the forecast season. Often, FTB forecasts are issued earlier to provide increased lead time to end-users, which is especially important on days where there is an elevated flood threat issued. The FTB highlights the daily threat level of flooding across the state, describes the nature of the threat, and notes the time period in which the threat of flooding would be the greatest in a zone-specific manner (14 climate-defined Forecast Zones, see Figure 4). Additional information provided by the FTB includes the probability and maximum intensity of thunderstorm rainfall rates, expected storm totals and a characterization of the threat of severe weather (tornadoes, high winds, hail, etc.). Table 1 summarizes the six-tier category system that is used to characterize the daily flood threat. The first five-tiers indicate the day's flood threat: None, Low, Moderate, High, and High Impact. The last tier, NWS Warning, specifies if there are any active NWS Flood Warnings (riverine flood threat) at the time of the FTB post. During situations with a particularly threatening and/or rapidly evolving flood threat, the FTB is updated during the afternoon hours. There were two such forecast updates needed this season, and additional social media posts were also provided to notify end-users about the evolving flood threat.

Table 1: Description of the six-tier category threat system.

Threat	EXPECTED PROBABILITY OF FLOODING WITHIN A GIVEN COUNTY
NONE	Less than 10%
LOW	10-30%
MODERATE	30-60%
HIGH	Greater than 60%
HIGH IMPACT	Greater than 60% along with a particularly severe threat to life & property
NWS WARNING	Active NWS (riverine) Flood Warning(s)

The threat of daily flooding is conveyed to the end-user 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 flood threat to succinctly illustrate the probability of flooding (Figure 1). The more communicative graphical format enhances the visualization of threat area and probability of possible impacts. Additionally, a scroll over feature on the maps will pop up maximum rain rates and potential hazards by threat level. All forecasts continue to be archived in a blog-style manner and are available on the Program's website. The Program also allows anyone to report flooding through the "Report a Flood" tab located at the top of the website. This tool was created to fill the gray area between what the Program forecasts (i.e., flooding caused by rainfall) and what the Program does not forecast (i.e. riverine flooding caused by other factors such as snowmelt, ice jams, dam releases, etc.).

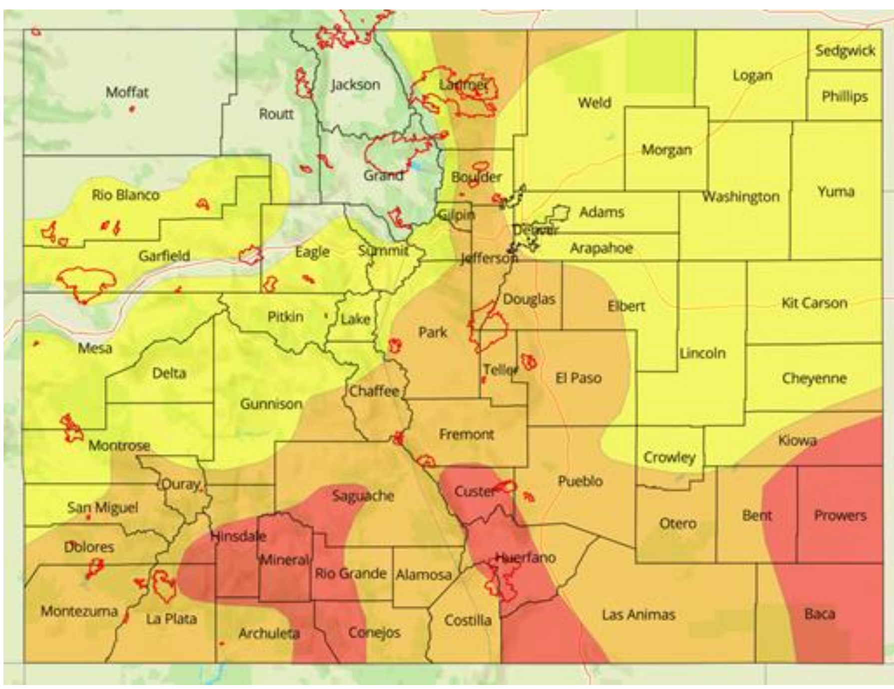


Figure 1: Example of the FTB map from July 28th, 2022. The Low, Moderate and High threats are highlighted in yellow, orange and red, respectively.

Flood Threat Outlook (FTO)

The FTO is a bi-weekly product issued on Mondays and Thursdays by 3PM to address the expected flood threat across the state over the next 15 days. This product addresses both the snowmelt and precipitation-driven flood threat, and it provides a precipitation forecast map for the entire state when meaningful precipitation is expected. The FTO continues to be structured in an event-based manner, where rainfall is partitioned by its forcing features and presented in a timeline at the beginning of each post.

An example of a threat "timeline" is shown below in Figure 2 from May 23rd. This FTO illustrates the addition of the snowmelt riverine flood threat, which peaks at the beginning of the warm season. Reservoir levels, and other metrics important to categorize drought conditions, were also tracked throughout the season in the FTOs, alongside our typical monthly departures from average temperature and precipitation. Upgrades to the FTO map, similar to the FTB map, now allow for more interaction by community users.

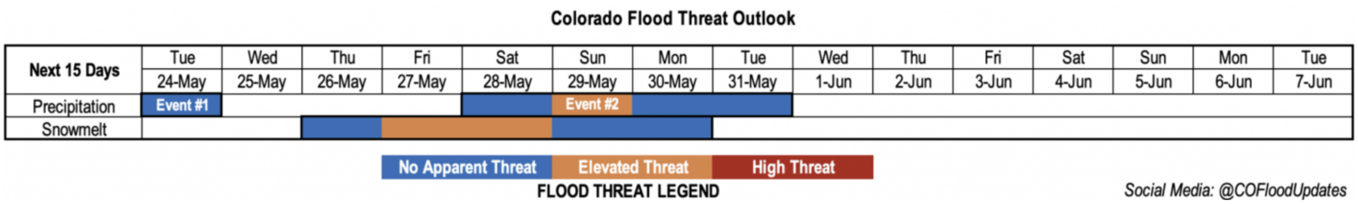


Figure 2: Example of an FTO "timeline" from May 23, 2022, illustrating the flood threat with the addition of a snowmelt outlook.

State Precipitation Map (SPM)

The State Precipitation Map (SPM) includes gridded Quantitative Precipitation Estimates (QPE) of 24-, 48- and 72-hour accumulations, as well as maximum 1-, 3- and 6-hour precipitation over the past 24-hour period at 250-meter resolution. The QPE product, MetStorm Live, was obtained from sub-consultant DTN, and data is visualized through a custom built, Dewberry-hosted webmap. Making sure the Program has the highest quality QPE is essential for post-storm assessment, tracking flood events, and assessing antecedent soil conditions that can influence the FTB forecast. During the 2022 season, MetStormLive was undergoing redevelopment by DTN and changes were made to the data transfer process. Dewberry received hourly QPE grids and computed accumulations and maximum durational precipitation, rather than receive the accumulated and maximum grids already. In previous seasons, gauge bias adjustment was also done by DTN; this service was ended in 2022 and was not included in any of the season's QPE. Development is underway by Dewberry to add back this functionality, as well as further grid quality control. MetStormLive redevelopment was completed in Fall 2022 and the next version, MetStorm Live version 2.0 will be used for the 2023 season. It should be noted, however, that the objective of the SPM is to provide a near real-time (i.e. very short lag time) look at precipitation accumulation. This comes at the cost of introducing a possible QPE bias, compared to rain gauge data, that is difficult to fully resolve by the SPM's noon issuance deadline (see Appendix E). To account for this complication, the data shown by the SPM was NOT used in the verification procedures outlined in Appendix A.

An example of the daily SPM is shown in Figure 3. In addition to the map-based visualization, meteorologists provided text-based summaries of recent hydrometeorological conditions including: contextualizing extreme rainfall totals, flooding, debris flows, hail, wind, tornadoes and wildfire activity. Discussions are also supplemented with gauge data from CoCoRaHS, COOP, Mile High Flood District's ALERT, SNOTEL and NWS Local Storm Reports. The "Report a Flood" tool on the website brought in only one report this season.

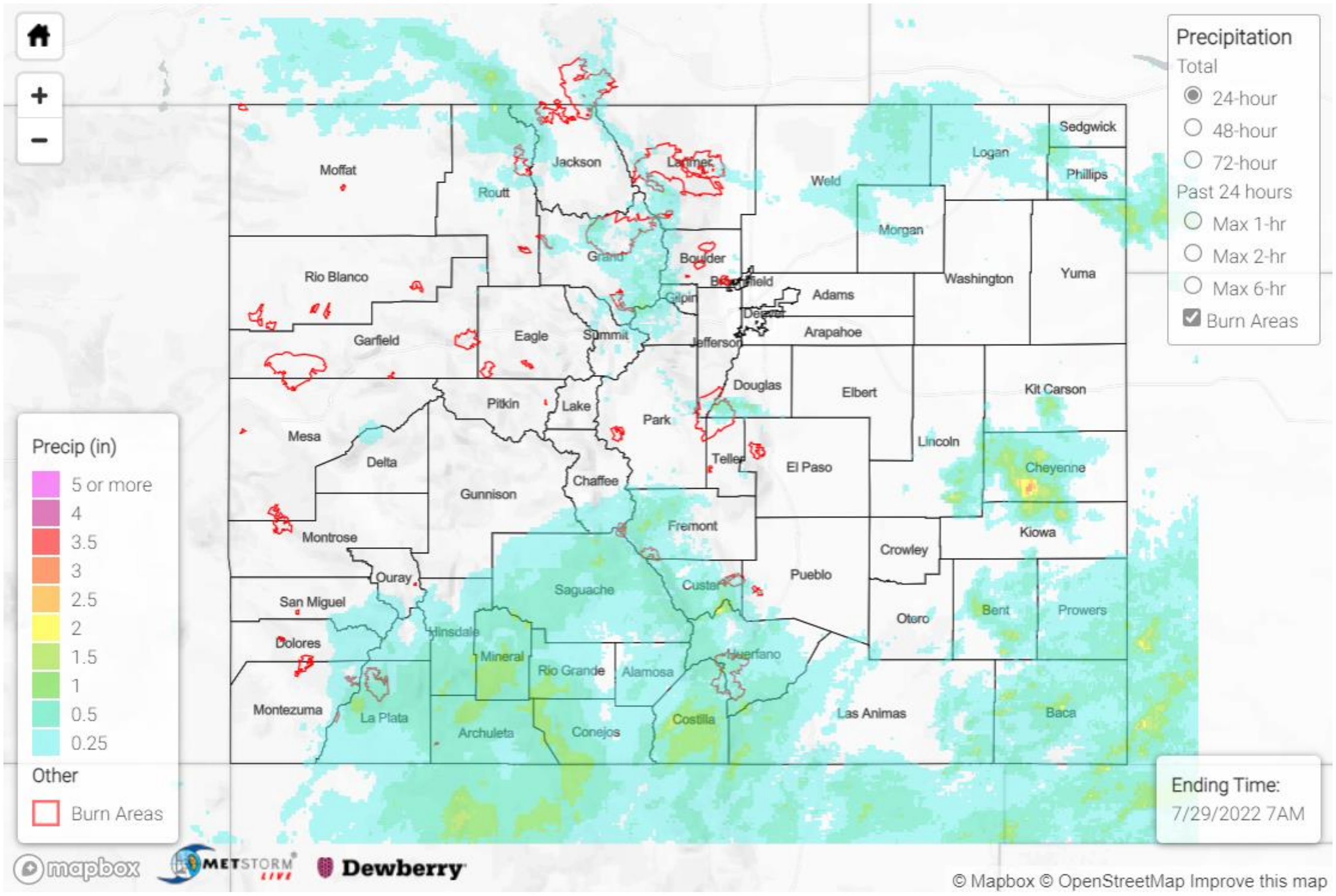


Figure 3: Example of SPM QPE from July 29th, 2022, showing the previous day's precipitation.

Fire Burn Forecast (FBF)

There is concern for extremely dangerous runoff, mud flows, and debris slides over recent wildfire burn areas located over steep terrain, especially those near population centers and highly traveled roads. During the 2020 wildfire season, Colorado experienced three of its largest fires on record with a total of seven fires exceeding 10,000 acres in size. Since roughly 1980, Colorado has experienced an increasing trend in wildfires exceeding 10,000 acres (HMC and Dewberry, 2022). Due to the stark difference between runoff sensitivity over burn areas compared to nearby unscarred areas, the Fire Burn Forecast (FBF) product was created in 2021. The FBF is a standalone wildfire forecast system meant to complement the overall goals of the Program and remove burn areas from the daily FTB discussions (as was done from 2017 to 2020). The main objective of the product is to create a concise, easily accessible tool that (i) helps assess and prepare for the flood threat specifically focusing on the most vulnerable burn areas, and (ii) archives recent conditions for an enhanced perspective of multi-day rainfall events. Similar to the FTB, the FBF provides an early outlook for threat awareness, and it is not to be used for real-time flood warning and monitoring.

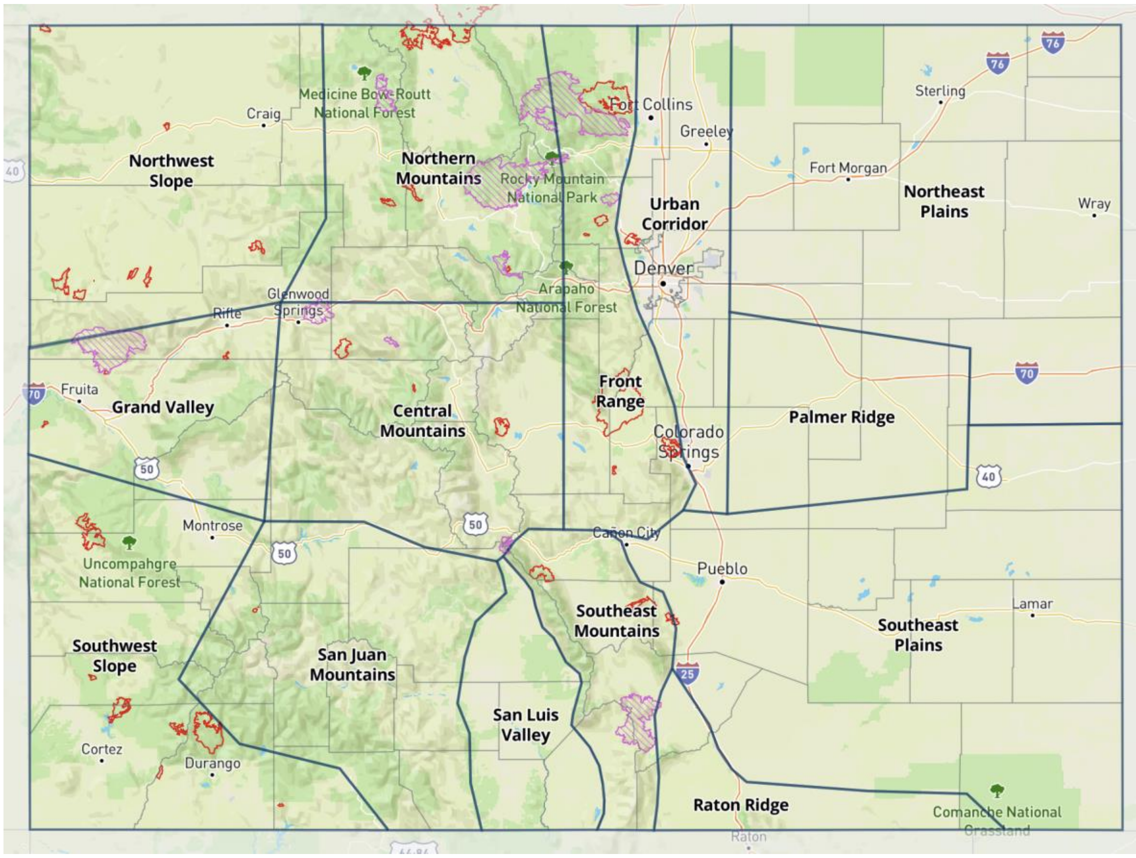


Figure 4: Wildfire burn areas that were featured on the daily FTB/FTO maps for 2022. The labeled burn areas (purple shade) were identified as the most hazardous and received daily dedicated flood threats in the FBF.
Source: National Interagency Fire Center

This forecast season, the Team identified and monitored 11 potentially dangerous burn areas in the FBF: Calwood (year of fire: 2020), Cameron Peak (2020), Decker (2019), East Troublesome (2020), Grizzly Creek (2020), Middle Fork (2020), Morgan Creek (2021), Pine Gulch (2020), Spring Creek (2018), Sylvan (2021) and Williams Fork (2020). Other burn areas over steep terrain that had occurred in the last 5 years and burned at least 700 acres were also included on the daily FTB/FTO maps (Figure 4). Ideally, every recent wildfire burn area would be the subject of a dedicated flood threat, but in practice limited resources imply the need to focus on the most impactful burn areas for the daily FTB: those which are relatively large in scale (corresponds to a higher runoff threat) and those that are near high population density and/or major roads. A couple of the larger and more complex historic wildfires (such as the Hayman Fire in 2002) will remain on the map until the Colorado State Forest Service informs the Program that burn areas have recovered enough to be removed. Similar to the FTB and FTO maps, the burn areas are interactive, and clicking on a burn area shows the fire's name, year of occurrence, and the number of acres burned.

An example of a daily FBF is shown in Figure 5. The daily forecast table shows three measures of antecedent rainfall for the prior 24 hours (blue columns) to assess the current soil conditions over the given burn area. The measures are: (1) maximum 3-hour and (2) average 24-hour rainfall over any portion of the burn area, and (3) the percentage of the burn area that received precipitation. These estimates are derived from gridded, gauge-adjusted radar rainfall products. A separate column shows an evaluation of whether flooding was reported in the past 24 hours. For "Today's Threat", the FBF uses the same five-tiered threat system as the FTB (None, Low, Moderate, High and High Impact) with the threat level representing the likelihood for excessive runoff, flash flooding, mud flows, and/or debris slides over the given burn area within the next 24 hours. Forecast thresholds for rainfall intensities estimated to cause flooding issues for each burn area were derived using methodology from Cannon et al. (2008) and observations from previous seasons. These rainfall thresholds are set at the beginning of each season, and then can be further adjusted prior to the start of the monsoon season as necessary. The Team has completed a high-level verification for burn area threats once again this season. More information and methodology can be found in Appendix B of this report.

Fire Name	Today's Threat	Max 3hr	Avg 24hr	Burn Area Coverage	Flooding Reported Yesterday?
Calwood	HIGH	1.5in.	0.5in.	>90%	NO
Cameron Peak	HIGH	1.3in.	0.4in.	65%	NO
Decker	HIGH	0.3in.	0.2in.	>90%	NO
East Troublesome	MODERATE	0.7in.	0.1in.	10%	NO
Grizzly Creek	MODERATE	0.7in.	0.1in.	35%	NO
Middle Fork	LOW	0.0in.	0.0in.	0%	NO
Morgan Creek	LOW	0.0in.	0.0in.	0%	NO
Pine Gulch	MODERATE	0.1in.	0.1in.	< 5%	NO
Spring Creek	HIGH	1.3in.	0.3in.	>90%	NO
Sylvan	MODERATE	0.0in.	0.0in.	0%	NO
Williams Fork	MODERATE	0.0in.	0.0in.	0%	NO

Figure 5: An example of a daily FBF forecast post from July 28th, 2022. The blue columns represent antecedent conditions from the past 24 hours.

Streamflow Tracker

To expand the Program's reach to a more diverse group of end-users, a streamflow table that tracks naturalized flow across 14 sites representative of Colorado's largest river basins was added this season. Historically, these sites produce large flows (combined average yearly flow close to 10 million acre-feet), have long periods of record, and represent key sites at their headwaters. The table is updated mid-month during the forecast season, and it uses "adjusted" observed streamflow from NRCS, which estimates the volume of streamflow that would occur without the influences of major upstream reservoirs or diversions. In addition to tracking monthly flow and Water Year to-date flows at each site, the table tracks the average and percentile values relative to normal. While average flow can be a useful metric, it does not do well at capturing the extremes of high and low flows at a site. For this reason, the percentile of normal flow was added, which better captures the potentially non-Gaussian distribution of flow relative to the site's history. This metric can be especially helpful when the site has a long period of record. Figure 6 below illustrates the tracker table from May 2022 (updated mid-June). Missing data presented a challenge for the product in its inaugural season, as sites are updated with a varying degree of latency or are sometimes backfilled only once a year. The Team will continue to work with NRCS and its partners (e.g. Northern Water) during the off season to work through such data complications.

COLORADO STREAMFLOW TRACKER [MAY 2022]								
Location	Latest Month Data (May)				Water Year To-Date Data (Oct-May)			
	Value	Normal	% of Average	Percentile	Value	Normal	% of Average	Percentile
SOUTH PLATTE RIVER basin								
South Platte	25.6	49.8	51%	17	74.5	123.5	60%	17
Cache la Poudre at Canyon Mouth		69.5				113.1		
ARKANSAS RIVER basin								
Arkansas River above Pueblo	70.8	67.9	104%	61		262.7		
RIO GRANDE basin								
Rio Grande River at Del Norte	134.3	156.2	86%	38	279.2	308.3	91%	42
NORTH PLATTE RIVER basin:								
North Platte near Northgate		64.4				155.3		
COLORADO RIVER basin (NORTH)								
Little Snake River near Lily	110.0	154.3	71%	31	186.6	271.6	69%	22
Yampa River near Maybell	308.8	379.3	81%	31	502.5	675.1	74%	18
White River near Meeker	72.7	94.2	77%	24	195.2	250.6	78%	9
COLORADO RIVER basin (CENTRAL)								
Colorado River near Cameo	676.1	663.2	102%	62		1469.2		
Gunnison River near Grand Junction	375.0	528.2	71%	28		1177.2		
COLORADO RIVER basin (SOUTH)								
Dolores River at Dolores	71.1	102.37	69%	27	129.4	176.6	73%	26
Animas River near Durango	111.7	137.94	81%	30	210.8	284.2	74%	19
Los Pinos River near Bayfield	53.0	65.8	80%	29	110.1	129.5	85%	31
San Juan River near Carracas	101.8	129.19	79%	33		298.7		
TOTAL	**2110.6**	**2528.4**	**83%**		**1688.4**	**2219.5**	**76%**	

All Units are x1000 acre-feet; Updated: June 13, 2022; Next Scheduled Update: July 14, 2022 HydroMet Consulting LLC

Figure 6. An example of the Streamflow Tracker from May 2022. The middle column shows monthly data, while the right column shows Water Year to-date data.

Performance Metrics

Table 2 shows the final year-to-date number of all products provided and the percent provided on time. Out of 503 total products delivered, 499 were delivered on-time or ahead of time. The four late products were 3 FBFs and 1 FTO. On September 22nd, there were issues with the interactive maps that delayed the FTO, but the mapping issue was resolved by the end of the day. So, all late products during 2022 were posted within an hour to a few hours after their deadline. Note that Table 2 also shows September performance, since there was no monthly Progress Report prepared. All necessary information for the September Progress Report is contained within this Final Report. Other 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.

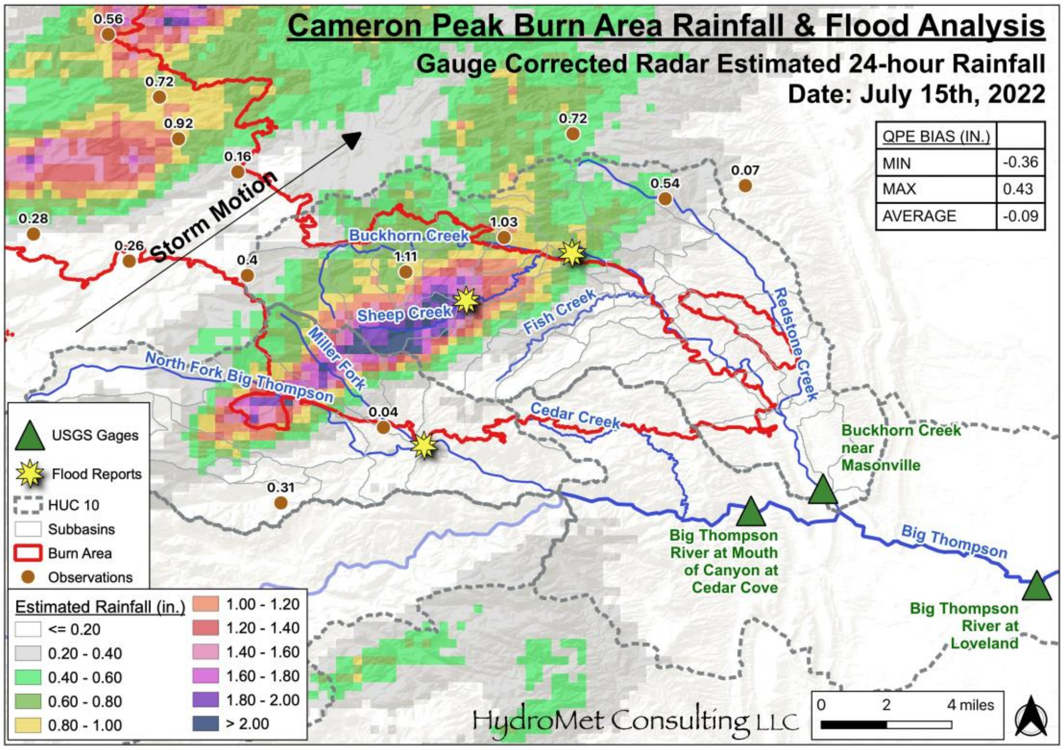
Table 2: On-Time performance metrics for all issued products in 2022 (SPM, FTB, FTO and FBF).

		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	153	0	100%
	FTO	8	7	1	88%		FTO	44	43	1	98%
	FBF	30	29	1	97%		FBF	153	150	3	98%
	TOTAL	**98**	**96**	**2**	**98%**		**TOTAL**	**503**	**499**	**4**	**99%**

In-Season Analysis of Flash Flood Events

In an effort to supply rainfall related data after a flash flood event, the Team has begun to produce in-season, event-based analyses. Near real-time reanalysis work, which can be helpful for end-users, particularly emergency management teams, has been lacking for flood events across Colorado. By providing information about the timing of rainfall, magnitude of rainfall, and corresponding peak flows on nearby rivers and creeks, responders can not only better assess a situation, but it may provide helpful insight about other potential flood events across an area. Also, by disseminating these analyses through social media, the Program can engage more end-users, boosting Program viewership and convey that the Program is not just about providing forecasts. For the 2022 season, an in-depth analysis was provided for an event on the Cameron Peak burn area. In addition to this analysis, the Team engaged the Middle Colorado Watershed Council Grizzly Creek post-fire technical advisory team about potential recovery over the burn area that caused several closures of I-70 in 2021 (see Outreach).

Just before 4PM on July 15, a strong thunderstorm developed and moved over the lower portion of the Cameron Peak burn area. This rainfall triggered a flood event that unfortunately caused both loss of life and property. The Team completed a rainfall reconstruction of the event (Figure 7, top), using nearby observations for calibration, and overlaid flood reports (yellow starbursts). The max point rainfall estimate (storm center) was estimated to have a 0.5 to 2% Annual Exceedance Probability (1 in 50-200 year event). With the limited spatial extent of the storm core, the sub-basin average rainfall totals yielded relatively unimpressive values (not shown). However, both the main stem Big Thompson and Buckhorn Creek basins developed significant and sudden peaks in streamflow later in the evening at 7:15PM and 10:30PM, respectively (Figure 7, bottom). This real-time experience, along with more theoretical modelling work by Enginuity Engineering Solutions (Gerald Blackler, personal communication) suggest that the burn area likely played a large role in increasing runoff from the storm. Despite the Cameron Peak burn occurring in 2020, this event indicates that the burn area still has quite a long way to a full recovery. As thunderstorms continue to track overhead next season, it is likely that there will continue to be a threat to life and property. The full analysis and images for this flood can be viewed on Twitter (@COFloodUpdates and @HydroMetLLC).



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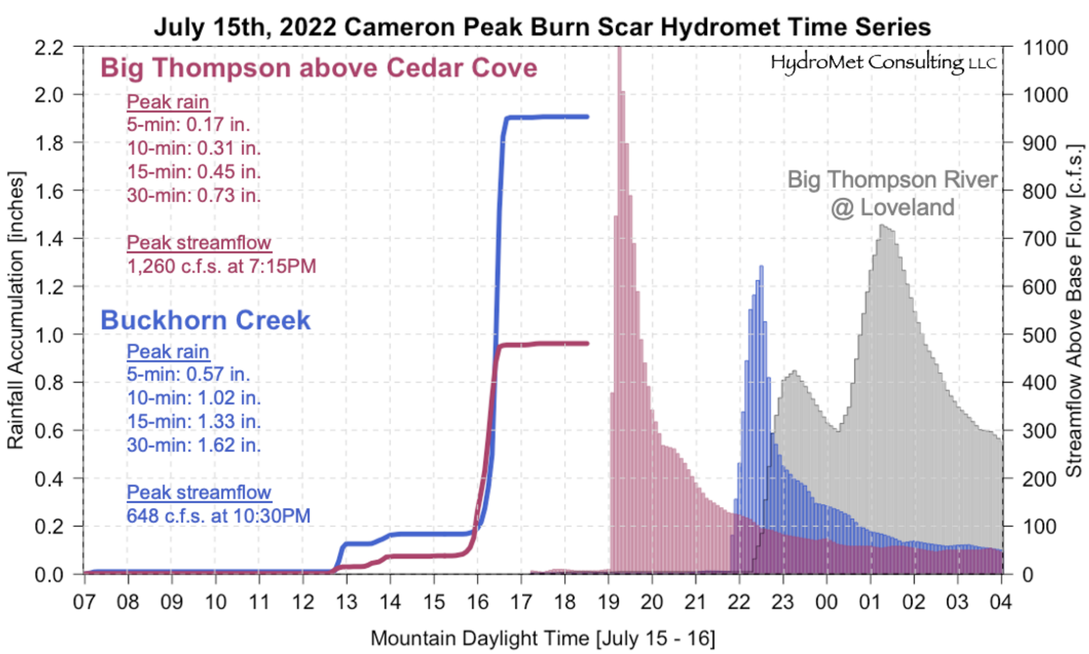

Figure 7. Top panel: Rainfall analysis of the fatal July 15, 2022, flood event in within the Cameron Peak burn area. In addtion to the loss of life, there was property and road damage over the areas marked by yellow starbursts. Bottom panel: Riverine response for the same rainfall event along the mainstem Big Thompson and Buckhorn Creek basins.

2) CHARACTERIZATION OF FORECAST PERIOD WEATHER

Overview

The 2022 operational season saw a wide spectrum of typical Colorado weather including: heavy rain, flooding, debris flows, wildfires, and severe weather. The season began with the entire state experiencing some drought conditions, ranging from abnormally dry in portions of the Northern and Central Mountains, to exceptional drought on the Southeast Plains (Figure 8). Late season snowfall in May, along with a generally northern favored precipitation pattern helped improve conditions in Northwestern Colorado and the Central Mountains, while the southern half of the state saw their drought conditions expand and worsen. A strong North American Monsoon (NAM) season began by mid-June and continued into August with additional moisture surges lasting well into September. The strong monsoon acted to reverse the late-springtime trend of northern favored precipitation for more southern and western portions of the state, especially the Southwest Slope and San Juan Mountains (Figure 9). By the end of the season in September, portions of the Northern, Central, and Southeast Mountains, along with the Front Range and Southeast Plains saw their drought conditions completely eliminated (Figure 8) along with slight improvement in the severity of drought classification for the Western Slopes; conversely the Northeast Plains saw conditions worsen from "Severe Drought" to "Exceptional Drought" in extreme Northeast Colorado. Consequences of the historic and devastating 2020 fire season were still in play as the Cameron Peak and East Troublesome scars remained vulnerable to flooding and debris flows following heavy rain (Table 3).

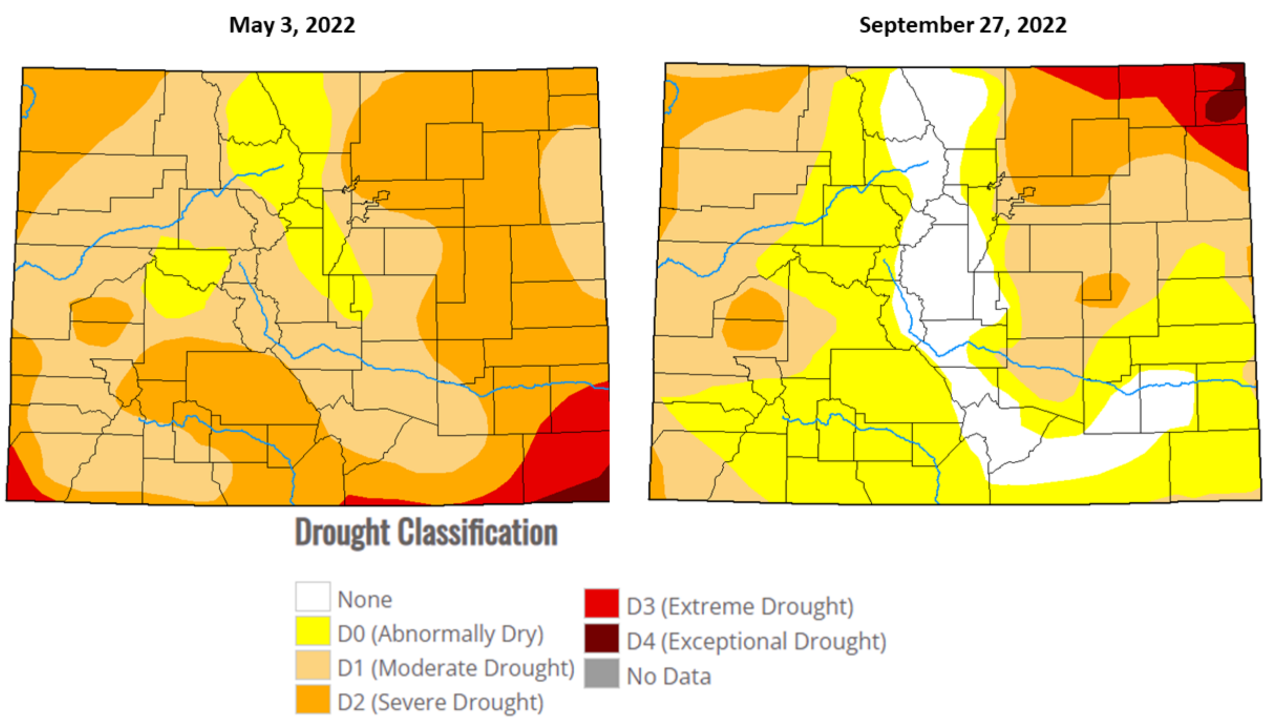

Figure 8. U.S. Drought Monitor update valid on May 3, 2022 (left) and September 27, 2022 (right), showing the drought conditions at roughly the start and end of the FTB season. Source: The U.S. Drought Monitor is jointly produced by the National Drought Mitigation Center (NDMC) and the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration. Maps courtesy of NDMC.

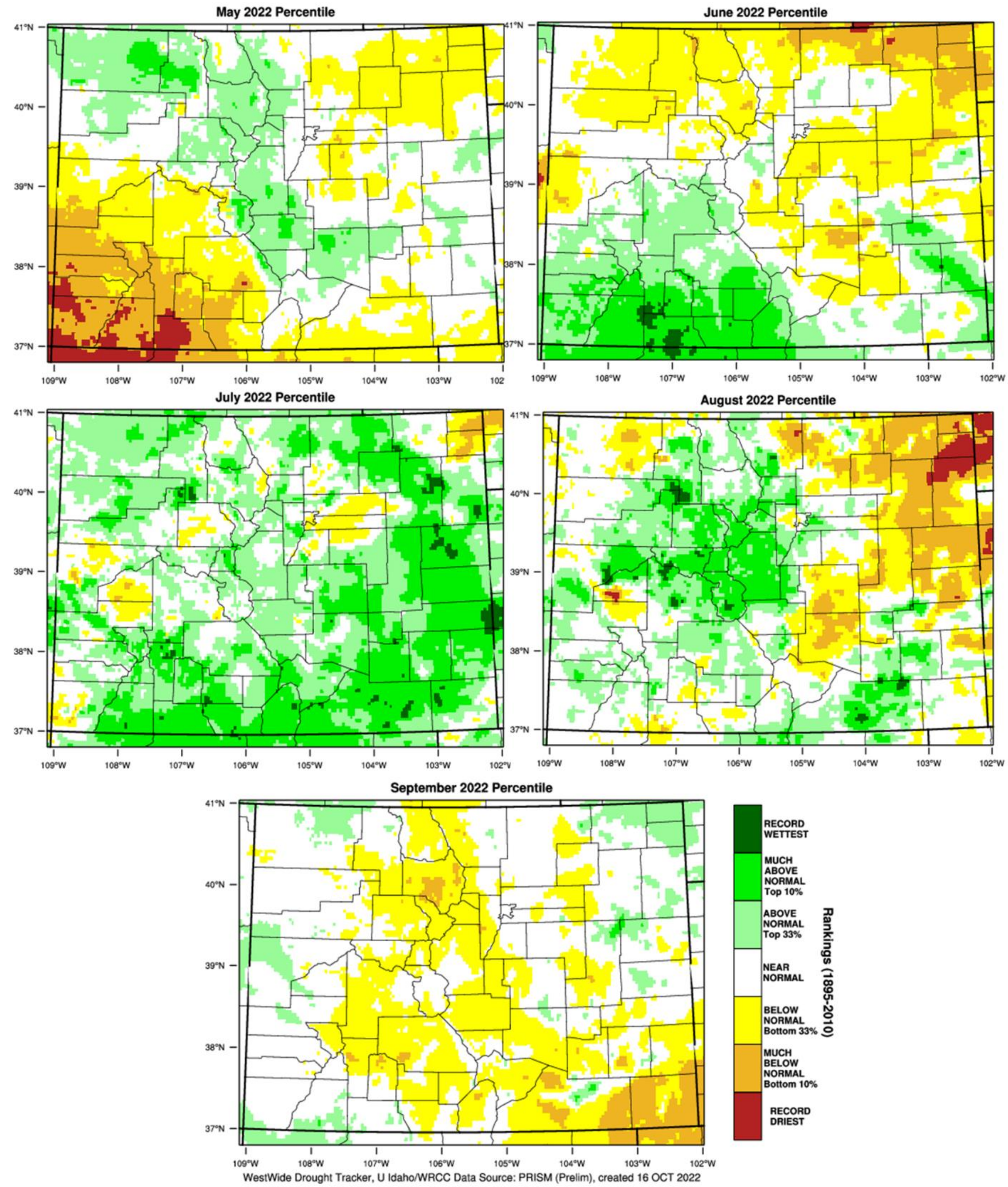

Figure 9. Monthly precipitation anomalies (PRISM) ranked by percentile for May-September 2022. Source: WestWide Drought Tracker.

Table 3. Number of days a flood was reported on each of the 2022 FBF burn areas. Due to the rural nature of many of the burn areas and closures following floods, it is possible that counts are underestimated.

Wildfire	Date of Fire	Burn Acreage	Number of Days With			
			Debris Flows	High QPE	Debris Flows + High QPE	Threats Issued
Calwood	Oct 2020	10,106	0	3	3	25
Cameron Peak	Aug 2020	208,913	7	58	65	51
Decker	Sep 2019	8,959	0	4	4	35
East Troublesome	Oct 2020	193,812	7	36	43	47
Grizzly Creek	Aug 2020	32,631	0	13	13	43
Middle Fork	Oct 2022	20,433	0	1	1	25
Morgan Creek	Jul 2021	7,586	0	2	2	38
Pine Gulch	July 2020	139,007	0	14	14	30
Spring Creek	Jun 2018	108,045	3	18	21	48
Sylvan	Jun 2021	3,792	0	10	10	32
Williams Fork	Aug 2020	14,577	0	19	19	46

Detailed Summary

Table 4. The Top 5 most impactful flood and rain events over the 2022 forecast season.

Flood Event	Date(s)	Intensity	Impacts
Cameron Peak Flash Flood	July 15	Radar estimated 1-2" rainfall over vulnerable burn scar	Loss of lives as camp trailer was swept in floodwaters near Buckhorn and Crystal Mountain; one of 7 debris flows on the burn area this season
Broomfield and Urban Corridor	August 16	Up to 3.5 inches in 3 hours in Broomfield Open Space	Rare, early morning event causing widespread flooding to parks, roadways, and residencies
Yuma and Eastern Colorado	June 3	3.0 inches in 2 hours in Yuma	Severe thunderstorms and tornadoes, high winds and heavy rain in southeast Colorado
Denver and Urban Corridor	July 26-27	Rainfall rates as high as 2" in 30 minutes in convective storms	Widespread flooding from monsoonal thunderstorms across Front Range and Urban Corridor
San Juan Monsoon Season	June-July	Over 200% of normal June and July precipitation from afternoon monsoonal thunderstorms	Improvement in drought conditions from D3 "Extreme Drought" at the beginning of June to D0 "Abnormally Dry" at the beginning of August

May

May kicked off the 2022 season with the state's median snowpack sitting at around 80%, though the northern basins were in much better shape, with 88-98% of snowpack, compared to southern basins with as little as 53-86% of median. Precipitation in May generally favored Northern Colorado (*Figure 9*), while seasonably warm and dry conditions in the south resulted in historically early snow melt-out. High winds were reported across Colorado in May, aiding in the ignition of some minor wildfires. Conditions remained hot and dry ahead of cold-front that entered the state on May 20th, drastically dropping temperatures and bringing up to a foot of snow to the high elevations. For portions of the Urban Corridor and Palmer Ridge, the frontal passage and associated snowfall resulted in record-setting daily snowfall totals, including over 17.5 inches in Colorado Springs. After the excitement of late-season snow, May wrapped up with a few days of warm, dry weather and returning high winds.

June

June started off strong with 1.22 inches of rain in Denver on the first day of the month, the biggest rainstorm in the area for over a year, and nearby rainfall totals ranging from 0.25-1.75 inches across the Metro Area and Front Range. June also saw the beginning of severe weather season for Eastern Colorado. On June 3, over 30 severe thunderstorm warnings were issued by Boulder and Pueblo WFOs for heavy rain, high winds, large hail, and even tornadoes. During this time, Yuma on the Eastern Plains saw up to 3.00 inches of rain in just 2-hours, correlating to a nearly 1:50-year average recurrence interval. Summer heat quickly approached by mid-June, with hot and dry conditions, on June 12th Denver tied its record high of 100 degrees. Record-breaking temperatures and Red Flag Warnings continued through the middle of the month, although the Urban Corridor and Eastern Plains saw some relief in the form convective afternoon thunderstorms. Initiation of the NAM in mid-June produced widespread storms and heavy rainfall for much of Colorado through the end of the month; the Southwest Slope and San Juan Mountains benefited most from plumes of monsoonal moisture (Figure 9). On June 26, a debris flow occurred on the East Troublesome burn scar, the first of seven this season (Table 3) after only 0.46 inches of rain fell on the sensitive burn area on. Highway 125 in Grand County was closed as burned trees, ash, and mud washed over the road.

July

Monsoonal thunderstorms continued through the first days of July, threatening burn areas as days of rainfall led to saturated soils. This was true outside of burn areas as well, and issuance of daily Red Flag Warnings was replaced by Flash Flood Warnings across Southern Colorado. Minor road and nuisance flooding was reported regularly, especially in the Urban Corridor where short-bursts of heavy rainfall met impermeable surfaces for quick runoff. Nearly all of the state saw above normal precipitation in July (Figure 9). A very active string of weather days produced another debris flow on the East Troublesome burn area, which closed Highway 125 again on July 5 as mud and debris, including burned trees, had to be removed from the road. On July 6, Eastern Colorado saw widespread heavy rain and severe weather. Highway 50 near La Junta was closed due to flash flooding under a railroad underpass and ditches were overflowing where over 2 inches of rain fell. With this same system, Rocky Ford received 3.36 inches of rain just one hour, amount to an over 350-year average recurrence interval.

High-elevation convection aided by monsoonal moisture was a recurring theme through the middle of the month, and weeks of additional moisture resulted in numerous flood reports on July 15. Street flooding was reported in Ouray and Grand Junction, a debris flow on Highway 145 near Sawpit, and flash flooding in Estes Park on the Cameron Peak scar – enough to sweep trailers into Buckhorn Creek and cause two fatalities.

The relentless monsoon caused yet another debris flow occurred on the East Troublesome burn area on July 23, again closing Highway 125 in Grand County for large, burned trees and rocks on the road. This was followed by the second debris flow on the Cameron Peak burn area on July 24. Widespread heavy rain and flooding was reported for the Front Range, Urban Corridor, and Eastern Plains including flash flooding in Northglenn, Fort Morgan, Brush, and Aroya, also on July 24. A few days later on July 26 and 27, widespread severe weather and heavy rain caused major flooding on Interstate-25 in Denver, flooded parking lots in Colorado Springs, pushed Fountain Creek to flood stage, and street flooding in Pueblo. Heavy rain continued through the end of the month, especially for Southern Colorado, with numerous flood reports across El Paso and Pueblo Counties.

August

August picked right up where July left off, with near daily high-elevation thunderstorms and flood risk. The Spring Creek and Hayden Pass burn areas saw debris flows and flooding on August 3, the first of three for the Spring Creek burn of the season (Table 3). The same day, flooded roadways were reported on Highway 50 in Texas Creek and

Highway 149 on the Mineral-Hinsdale county line. The next few days saw more road closures from flooding and debris at numerous locations in the Central Mountains. On August 5, yet another debris flow occurred on the Cameron Peak burn area.

A weak frontal boundary interacting with monsoonal moisture caused widespread rainfall on August 7 and associated flooding in the San Juans and Southeast Mountains, San Luis Valley, Palmer Ridge, and Urban Corridor. During this time, a newly constructed portion of Interstate-70 in Denver had to be closed due to floodwaters funneling into an underpass, stranding vehicles and prompting rescue from Denver Fire. There were a few calm days until mid-August, where heavy rain caused flash flooding for the Central Mountains. Despite the numerous debris flows in 2021, the Grizzly Creek burn area saw no noted flooding or debris flows in 2022. A rare early morning event with intense rainfall also occurred over the Front Range and Urban Corridor on August 16th. A NWS observation indicated 3.5 inches of rain fell over Broomfield in just three hours. This amounted to nearly 25% of their average annual rainfall, causing widespread flooding of parks, parking lots, and roadways. Yet another debris flow was reported on the East Troublesome burn area on August 22, and the following week continued to see heavy rain for the Central and San Juan Mountains to close out the month of August.

September

Occasional pulses of monsoonal moisture continued to enter the state through September, though with the pattern generally shifted to more frontal-passage and low-pressure system induced precipitation rather than convective thunderstorms, allowing for longer stretches of warm and dry days between incoming systems. High elevations also began to see their precipitation fall as snow during the month of September too. Some of the impactful systems include: September 10-11 where up to 0.94 inches of rain in Lakewood and the Urban Corridor after a cold frontal passage; widespread rainfall across nearly the entire state from low moving west to east September 14-17; and the high terrain of the San Juan Mountains and Central Mountains saw precipitation September 28-30. The 2022 season remained active until the very end, with heavy rain on the last day of the forecast season for Northwest Colorado, including up to 2.8 inches in Paonia State Park.

Monsoon Season

As previously mentioned, the 2022 season saw a widespread and active NAM, beginning in early June with events occurring well into September. To contextualize this season, a comparison of historical monsoon seasons was done at 10 long-term NRCS stations representing the major sub-basins in and around Colorado, seen in Table 5. For this analysis, all available data for June-September was collected for each station's entire period of record from the NRCS interactive map. Based on the results, all of the stations in Southern Colorado received above average precipitation, with the exception of Lone Cone representing the Upper Colorado – Dolores basins. Vallecito, located in the San Juan Mountains saw over 170% of average precipitation over this time period, behind only the 1999 season which saw over 220% of normal.

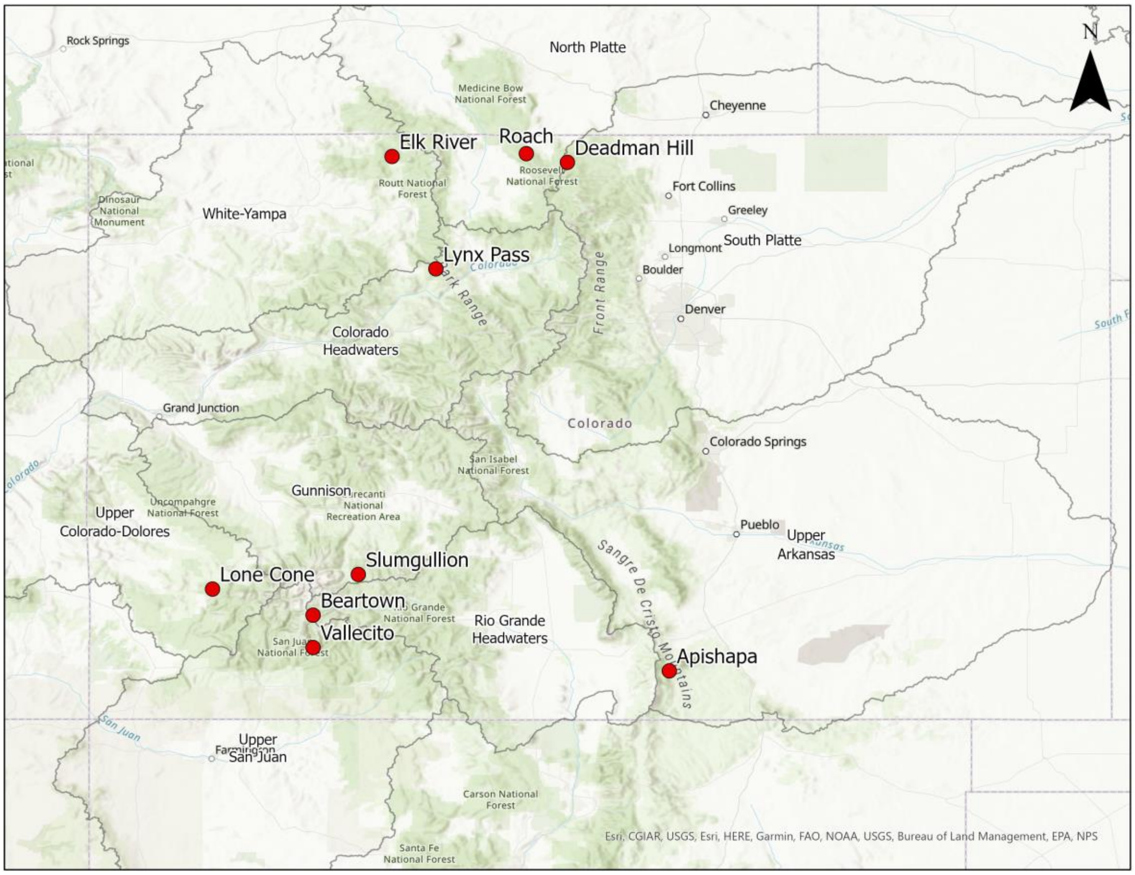

Figure 10. Map of long-term NRCS stations in each of the major sub-basins in Colorado.

Table 5. Monsoon extremes statistics at long-term NRCS stations for each of the major sub-basins in Colorado. Stations are sorted by highest percent of average precipitation for the 2022 season.

Station	Basin	Driest Year	Driest Year Total (in.)	Wettest Year	Wettest Year Total (in.)	2022 Precipitation (in.)	Period of Record	Average Precipitation (in.)	2022 % of Average
Vallecito	Upper San Juan	2019	2.30	1999	22.30	17.30	1987-2022	10.06	172%
Apishapa	Upper Arkansas	1987	3.20	1981	16.50	14.20	1981-2022	9.42	151%
Slumgullion	Gunnison	2011	3.40	1982	11.90	10.40	1981-2022	7.38	141%
Lynx Pass	Colorado Headwaters	2018	2.30	1984	10.40	6.50	1981-2022	6.09	107%
Beartown	Rio Grande Headwaters	2019	2.80	1999	17.40	11.90	1983-2022	10.1	118%
Elk River	White-Yampa	2020	2.60	1997	10.90	6.20	1979-2022	6.30	98%
Roach	North Platte	1994	1.90	2004	19.10	6.90	1981-2022	7.22	96%
Lone Cone	Upper Colorado-Dolores	2019	2.90	2006	14.7	7.90	1981-2022	9.28	85%
Deadman Hill	South Platte	2016	2.20	2004	10.50	5.00	1979-2022	6.50	77%

Seasonal Stats

There was a total of 52 Flood Days over the 2022 forecast season, which is notably below the 2012-2020 average of 69, but also higher than the recent quieter, drought-stricken years of 2018-2020. Figure 11 shows the daily number of rain gauge reports over one inch for each day of the season, separated by east and west gauge locations, as defined by the 5,250-foot elevation contour (see Figure 12). Also overlaid is the estimated areal extent of precipitation that exceeded one inch, measured by Stage IV gridded precipitation. There were 39 (10) days in total where at least one station measured over one (two) inch over eastern Colorado and 72 (24) days over western Colorado. Days with large areal extent and several gauges both east and west over 1 inch can be interpreted as large-scale rainfall events, such as July 6th as well as August 16th. More localized rainfall events tend cover smaller areas with fewer gauges such as July 20th and August 1st. The addition of areal coverage allows more rural Flood Day events to be captured, where rain gauges can be far and few between. One limitation of the figure for Flood Day identification is that rainfall intensity may have not occurred within an hour, so widespread events could be representative of a stratiform rainfall event which tend to not cause flooding issued Figure 11 also shows the ramp of the NAM with a very busy stretch of heavy rainfall events occurring from late July into mid-August. In fact, beginning on June 10th, Colorado saw a 99-day streak of at least 0.01 inches of rainfall falling somewhere over the state (not shown), which no doubt helped to temper the wildfire season. The late season monsoon events can also be seen in mid and late September.

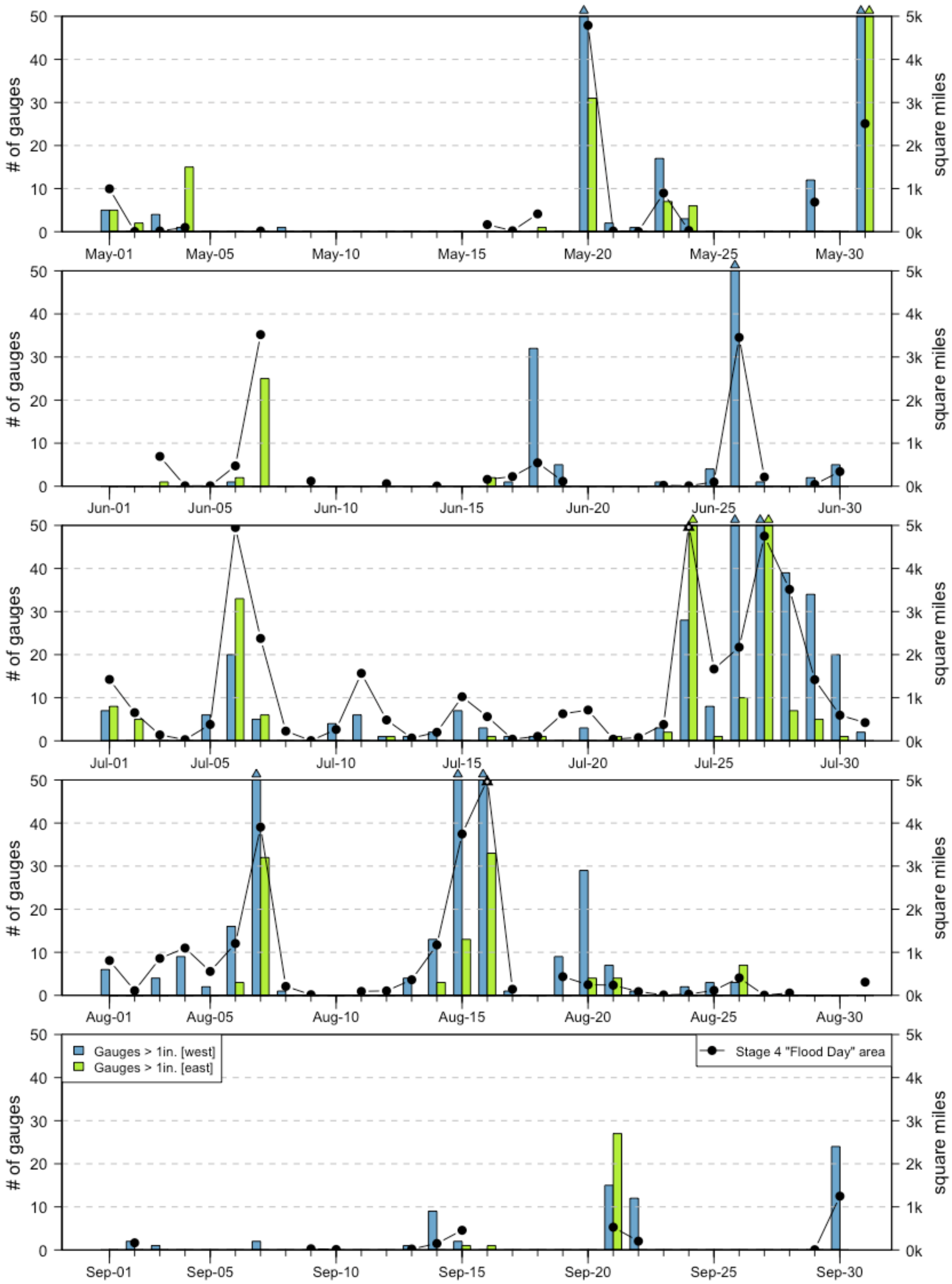

Figure 11. Daily summaries of number of gauges exceeding 1 inch of precipitation over "western" (blue) and "eastern" (green) areas. See Figure 12 for demarcation of these areas. An "X" indicates more than 50 gauges measured 1 inch. See Appendix A for more detailed daily gauge statistics. Also shown is the estimated areal coverage of precipitation, in square miles, exceeding 1 inch based on NOAA Stage IV gridded precipitation product (line with black dots). Upward point triangles indicate area in excess of 5,000 square miles. The total area of Colorado is 104,000 square miles.

3) VERIFICATION METRICS

Data Sources

Daily FTB forecasts were verified on several factors, most notably the ability to: (i) identify days when flood threats were realized, (ii) specify the approximate location of the potential flooding without grossly overestimating the flood threat area, and (iii) minimize False Alarm forecasts where flooding was forecast but not observed. The inclusion of the Multi-Radar Multi-Sensor (MRMS) QPE product from the National Severe Storms Laboratory (NSSL), and rigorous treatment of daily QPE product bias based on scatter plots between rain gauges and their QPE values has also helped create a more thorough analysis. The Team continually places substantial effort on verification to increase forecast utility and, in turn, help improve future forecasts. The data sources and methodology used to verify the 2022 forecasts can be found in Appendix C.

FTB Verification Methodology

To determine if a flood threat was realized on a given day, a "Flood Day" identification 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-type variable: it is either "Yes" when flooding and/or qualifying rainfall intensity is observed, or "No" otherwise. Note that, in practice, the latter condition is essential as flooding often goes undocumented or occurs in poorly gauged areas. Adding a measure based on rainfall intensity ensures a more comprehensive and consistent treatment of the issue. Given the large variance in the rainfall-runoff relationship across Colorado (see Appendix D), it would be difficult to describe a Flood Day with just a single intensity threshold. Thus, to provide some ability to cover relatively flatter eastern areas (higher threshold for flooding) compared with steeper central and western areas (lower threshold), a Flood Day is hereby defined when at least one of following three criteria is met in the issued flood threat area (e.g. Figure 13):

1. Gridded or observation based 1-, 2- and 24-hour rainfall exceeds (see Figure 12):
    a. 1.00 in. west of the 5,250-foot elevation contour over the eastern plains
    b. 1.50 in. east of the 5,250-foot elevation contour over the eastern plains
2. A qualifying NWS Local Storm Report (LSR) report is received. For more information, see Appendix C, data source "LSR" under "Storm Report".
3. If a Flood Day was based solely on the QPE data, additional conditions were checked. First, the areal coverage of qualifying rainfall must have exceeded ~50 square miles for each storm center. This helps to eliminate days with localized, marginal rainfall that is unlikely to cause flooding. Second, QPE bias plots were subjectively interpreted to ensure values were reasonable. See Appendix F for more information.

In year's past, the issuance of an NWS Flash Flood Warning would produce a Flood Day classification. However, due to varying topographic influences and uneven distribution of rainfall across the state (Appendix D), Flash Flood Warning issuance across Colorado NWS offices is not always consistent. Thus, NWS Flash Flood Warnings or Advisories alone will not cause a Flood Day classification. Both could contribute to a Flood Day if other factors are supportive. Note that this does NOT include Warnings and Advisories issued over fire burn areas, which have much lower rainfall intensity thresholds.

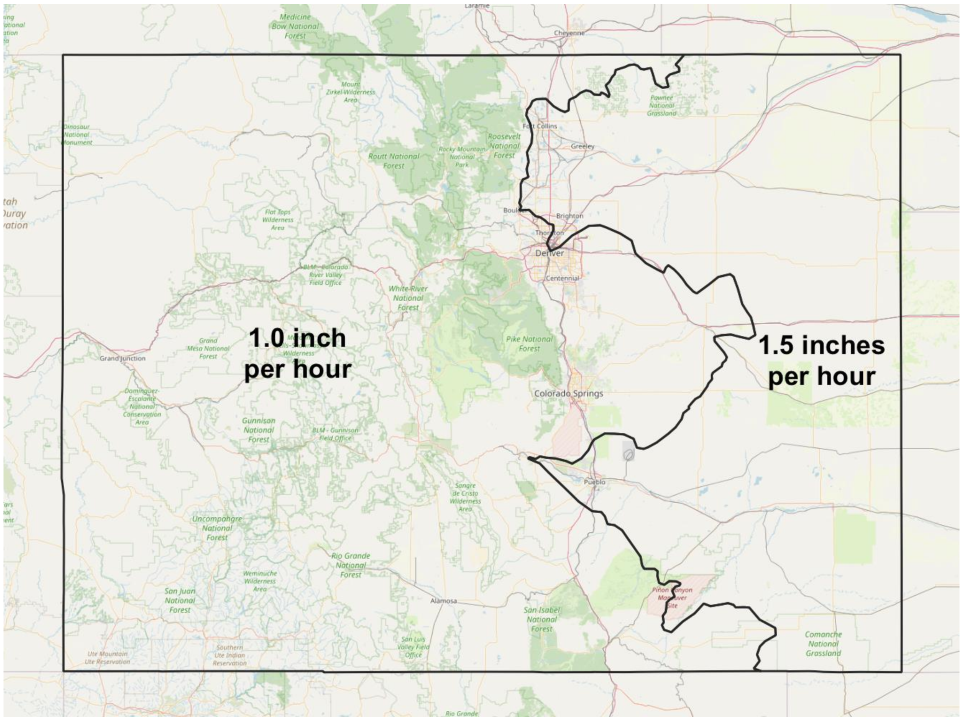

Figure 12: Colorado map with thick black line showing the 5,250-foot elevation contour line east of the Continental Divide, which acted as the demarcation in rainfall-runoff sensitivity. To the east, a rainfall threshold of 1.50 inches per day was used to denote a "Flood Day"; to the west, it was 1.00 inch.

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 an initial objective Flood Day calculation using the protocol above, a manual quality control procedure was completed to account for the overriding conditions shown in Table 6. As discussed previously, a significant addition to the manual procedure was the incorporation of a QPE bias assessment (BIAS in Table 6), which incorporates numerous factors and makes the previous years' HAIL and AREA conditions obsolete. Additionally, unlike in past years where the factors below generally resulted in a *removal* of an objectively defined Flood Day, the BIAS procedure is not one-way: it can either assign a Flood Day in a situation where QPE *underestimated* rain gauge data, OR remove a Flood Day assignment if QPE *overestimated* rain gauges. This also explains why the number of instances where BIAS was applied was much higher than the HAIL and AREA methods in previous years. Simply stated, there are many days when the highest rain rates occur between rain gauges, and BIAS deciphers which of those instances are suggestive of a Flood Day.

Table 6: 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	2
Long-duration low intensity precipitation causes qualifying 24-hour precipitation total, but runoff does not support flooding.	Low Intensity (LI)	Flood Day = 0	18
There is no rainfall, but antecedent conditions and/or snowmelt cause riverine flooding.	Riverine (RIV)	Flood Day = 0	0
A Flood Day was only triggered by QPE guidance, which was determined to overestimate rainfall intensity (see Appendix F).	BIAS	Flood Day = 0	37

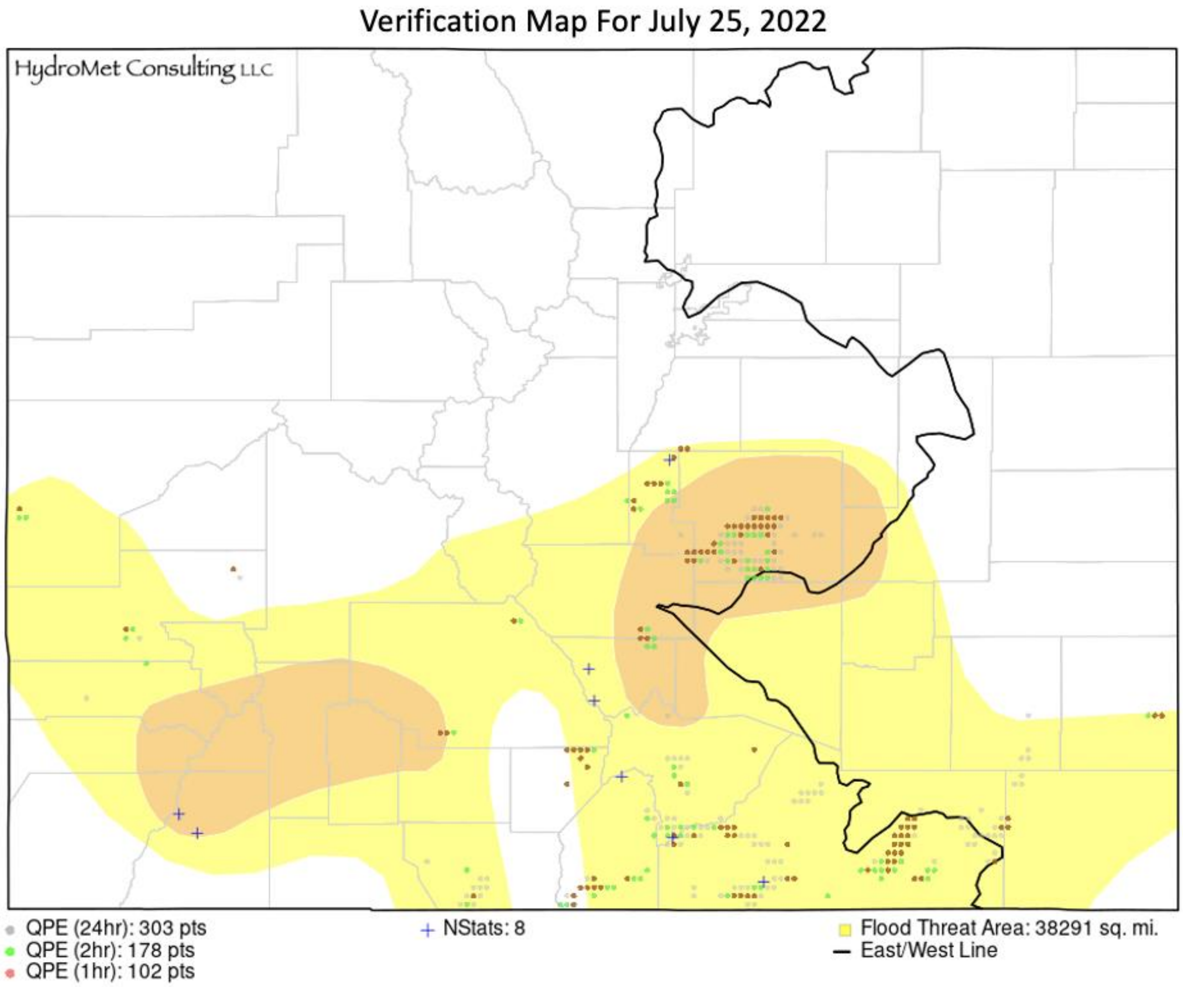

Figure 13: Example of daily verification map from July 25th, 2022, showing qualifying 1-hour (red), 2-hour (green), and 24-hour (gray) MRMS grid points, qualifying rain gauges (blue crosses) and Moderate/Low threat areas (orange and yellow color fill, respectively).

FTB Results

Appendix A contains the Verification Worksheet that was used to assess forecast performance. To be consistent with previous seasons, the analysis herein is based on the initial flood threat map only and does NOT include any afternoon updates to the flood threat. As there is no single number that can comprehensively measure forecast accuracy, Table 8 shows the seven metrics that are used in this report, all based on the contingency table approach shown in Table 7. There are two possible outcomes when a Flood Day forecast is issued: (i) a Flood Day is observed [case (a) in Table 7], a "Hit", or (ii) a Flood Day is not observed [case (c) in Table 7], 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 7]. Second, if a non-Flood Day is forecasted and a non-Flood Day is observed, this also results in a "Hit", although more specifically a "Dry Hit", which is often referred to as a correct negative [case (d) in Table 7]. Conventionally, real-time forecast operations generally strive to preferentially minimize the Miss Ratio, which, given the uncertainties with heavy rainfall forecasting, necessarily results in a higher False Alarm Ratio CWCB has also supported this methodology. As shown in Table 8, target percentages for each metric have been established based on values accepted as reasonable within the forecasting community.

Table 7: 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 8: Description of metrics used for validating forecast accuracy.

Metric	Abbreviation	Calculation (see *Table 7*)	Summary	Goal
Accuracy or "Hit" Ratio	Hit %	$\frac{a+d}{a+b+c+d}$	Measures probability that all Flood Days and non-Flood Days are accurately forecast. Perfect forecast value is 100%.	>75%
Threat Score	TS	$\frac{a}{a+b+c}$	Measures probability that Flood Days (Hit) and non-Flood Days are accurately forecast. Perfect forecast value is 100%.	>60%
False Alarm Ratio	FAR	$\frac{c}{c+a}$	Measures probability that a Flood Day (Hit) is forecast but a non-Flood Day is observed. Perfect forecast value is 0%.	<20%
Probability of Detection	POD	$\frac{a}{a+b}$	Measures probability of accurately forecasting Flood Days. Perfect forecast value is 100%.	>75%
Miss Ratio	Miss %	$\frac{b}{a+b}$	Measure probability that a non-Flood Day is forecast 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 forecast compared to those observed. Perfect forecast value is 1.0.	N/A

Table 9 shows the individual monthly and season-aggregated forecast verification. Forecast verification performance exceeded four of the five targets established in Table 8 for the season, while the remaining metric, (False Alarm Ratio) was only 5% above the targeted 20% goal. The overall Hit Ratio (Hit %) of 87% indicates that the forecast performance continues to remain high and well above the >75% targeted goal. Moreover, the Probability of Detection (POD) of 92% was the best performance since this stat has been aggregated. As mentioned, the False Alarm Ratio (FAR) at 25% was slightly over the targeted goal, but importantly the positive tradeoff was the lowest Miss Ratio (Miss %) in the Program's history at 8%. Moreover, all Miss days saw marginal rainfall in both area and intensity (not shown). As always, moving forward, the Program forecasters will try to find an optimal balance between the Miss % and FAR. It is important to stress that the Program errs on the side of caution in issuing threats, which necessarily results in a higher FAR, but lower Miss %. This is in stark contrast to the performance of National Weather Service's analogous Flash Flood Watch products, which have a very low FAR, but at the expense of a significant Miss %.

Looking into the month-to-month performance, it was a quiet year for May and September with a combined 3 Flood Days. This low number of Flood Days helped to skew some of the metrics, particularly the FAR, which was as high as 60%. As is typical with the ramp up of the North American Monsoon (NAM), July and August were both very active with 19 and 17 Flood Days recorded, respectively. This season had a long and robust monsoon season for many across the state, which helped alleviate drought conditions but also boost the number of Flood Days (also, see Section 2). For both July and August, 3 of the targeted 4 metrics verified with the Hit % in July only 1% below the targeted goal. August also had an impressive 100% POD with zero Misses and only 2 False Alarms recorded. All 6 of this seasons' High threats were issued during this active 2-month stretch, which also had a 16-day Flood Day streak starting on July 24th.

Table 9: 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	1	9	19	17	2	**48**
(b) No Flood / Flood	0	1	3	0	0	**4**
(c) Flood / No Flood	1	5	5	2	3	**16**
(d) No Flood / No Flood	29	15	4	12	25	**85**
Total Days	31	30	31	31	30	**153**
Hit %	97%	80%	74%	94%	90%	**87%**
POD	100%	90%	86%	100%	100%	**92%**
FAR	50%	36%	21%	11%	60%	**25%**
Miss %	0%	10%	14%	0%	0%	**8%**

Table 10 shows yearly performance summaries for the Program from 2012 to present. The number of Flood Days in 2022 was slightly less than last season but still somewhat in line with climatology. Forecast performance was also on par with 2021, arguably the best in Program history, with some metrics recording a Program best since the inception of forecast verification in 2012. The Team's preseason goal was to reduce the Miss %, which was accomplished. However, this objective was achieved at the expense of the higher FAR, which increased 5%. Improvements to the Colorado-specific forecast guidance has already been discussed, and these changes will be implemented into next season's forecasting practices to help improve the balance between the FAR and Miss %. Enhancements to this season's verification procedures, such as the threat's coverage of the heavy rainfall and an increase in the number of observation networks, continue to improve the verification process, and in turn will help improve the Team's guidance tools that are used heavily in the production of forecasts.

Table 10: Summary of yearly forecast performance since 2012. Note that the verification procedure was significantly enhanced in 2014, which makes it difficult to compare pre-2014 statistics to 2014-present. Additionally, the number of non-riverine threats issued in 2020 was actually 40, not 41. This has been adjusted in the table.

Year	Hit %	TS	FAR	POD	Miss %	Threats Issued	Flood Days	Bias
2012	86%	N/A	18%	84%	16%	65	64	1.02
2013	84%	N/A	13%	85%	15%	83	85	0.98
2014*	76%	N/A	18%	73%	27%	75	84	0.89
2015	77%	N/A	25%	78%	22%	85	88	0.97
2016	84%	N/A	21%	88%	12%	93	91	1.02
2017	86%	N/A	15%	86%	14%	76	74	1.03
2018	87%	N/A	21%	82%	18%	52	50	1.04
2019	86%	65%	13%	72%	28%	48	54	0.83
2020	89%	67%	13%	74%	26%	40	34	1.21
2021	88%	73%	20%	90%	10%	65	58	1.12
2022	**87%**	**71%**	**25%**	**92%**	**8%**	**64**	**52**	**1.25**

Table 11 shows the forecast performance as a function of threat level. Note that the threat level in the table represents the highest threat issued for a given day. A robust forecast system should show higher skill as the threat level increases due to more confidence that heavy rainfall and/or flooding will be realized. Similar to previous seasons, Table 11 shows this to be the case with a 59% Hit Ratio for Low threats, but a 95% Hit Ratio for Moderate threats and a continued 100% Hit Ratio for High threats. Fortunately, there were no days when a High Impact threat was issued this season (although several were issued for burn areas). The lower Hit % of Low threat forecasts suggests more marginal situations compared to years past. However, a look at the 16 False Alarm days (15 of which occurred during a Low threat), shows that 14 of the 16 had at least 1 inch of rainfall either estimated or observed. This suggests that moderate rainfall was present, but the intensity was just below Flood Day thresholds.

Table 11: Accuracy as a function of threat level, which corresponds to the (potential) impact. Note: threat levels categorization was reduced to the highest non-burn area threat level.

Threat Level	Observed Flood Day	Observed Non-Flood Day	Total Days
Low	21 (59%)	15 (41%)	36
Moderate	21 (95%)	1 (5%)	22
High	6 (100%)	0	6
High Impact	0	0	0
Total	49 (75%)	16 (25%)	64

4) USER ENGAGEMENT

An online presence through the Program's website and social media accounts continues to be of importance for increasing the Program's audience and reputation. Even a perfect forecast can have little to no value if it is not properly disseminated, which is why the Program continues to participate in forecast communication through a diverse set of mediums. Like prior seasons, the Team provided end-users with four outlets to receive forecast updates and other flood threat information (Table 12). Most significant is the Program website, which has been the main form of communication since the Program began. Beginning in 2017, Dewberry began providing an email alert option that sent the Flood Threat Bulletin's headline to end-user's inbox each morning with a link to the full post. The Team also continues to utilize the Twitter social media platform to provide forecast updates, interesting hydrometeorological observations, and other informational messages. In 2018, a Facebook page was created to reach a separate demographic from Twitter. All four forms of communication continue to be utilized with encouraging results on the social media front. Nonetheless, in the future, direct outreach to Office of Emergency Mangers (OEM), Police, Fire, or government entities that do not follow one or more of the Programs' accounts would be beneficial to expand the Program's utility.

Table 12: Website and social media accounts used by the Flood Threat Bulletin.

Platform	Account	Engagement
Website	www.coloradofloodthreat.com	277 Subscribers
Twitter	@COFloodUpdates	1,591 Followers
Facebook	@COFloodUpdates	585 Followers

Due to the always changing popularity of the various social media outlets and platform layout updates, it is recommended that the Program always monitor the effectiveness of its online presence and the popularity of the content that is shared by the Program. It is also important to note that, to some extent, all of the communication methods described herein compete with one another (i.e. if an end-user uses Twitter to view Program content, they may not use another method). Thus, providing end-users with options, but without excessive bombardment, is a logical strategy. *Table 13* summarizes the most important social media and website usage metrics over the 2016-present period. As anticipated, it illustrates an increase in popularity across all methods of forecast communication. The high number of Impressions, especially when compared to Facebook Reaches, implies that Twitter continues to be the best method to reach end-users. Overall, the popularity of the Program continues to rise across all its platforms when compared to prior seasons.

Table 13: The Program's website and social media usage metrics from 2016 to 2022.

Social Media Metric	2016	2017	2018	2019	2020	2021	2022
Email Subscribers (end of season)	--	19	35	128	131	142	165
Median Daily Website Viewership on No-Threat Days	24	18	22.5	51	27	46	42.5
Median Daily Website Viewership on Low Threat Days	32	22	44	66.5	44	48	70
Median Daily Website Viewership on Moderate Threat Days	41.5	34	58	98	56	86	98.5
Median Daily Website Viewership on High/Very High Threat Days	90.5	42	117	106	212	191.5	185
Twitter Followers	901	1,036	1,183	1,331	1,404	1,528	1,591
Avg Daily Twitter Impressions	1,874	1,973	2,059	1,597	1,590	3,299	1,782
Facebook Followers	--	--	155	272	323	421	585
Avg Daily Facebook Reaches	--	--	--	--	440	456	953

Website

Figure 14 shows daily website usage during 2022 (black) overlaid with the previous four seasons. Website usage reached a record number of users (1,130) on July 15, 2022, a day with widespread low to moderate flood threat issued across Western Colorado. Usage generally remained high from mid-July to mid-August, with several days of triple-digit usage. This period aligned with the prolonged monsoon season, where low to high threats were issued regularly. From July 15 to August 15, a total of 11 days saw a Low flood threat issued, 11 days with a Moderate flood threat issued, and 2 days with a High flood threat issued; and average daily usage during this period was 165 users. This indicates that the more threatening (potential) flooding messages are being better received by end-users, which is important for the Programs' goal of early detection and enhanced awareness. For the second year in a row the peak usage date fell on a Friday, which is typically when Colorado mountain activity ramps up for the weekend.

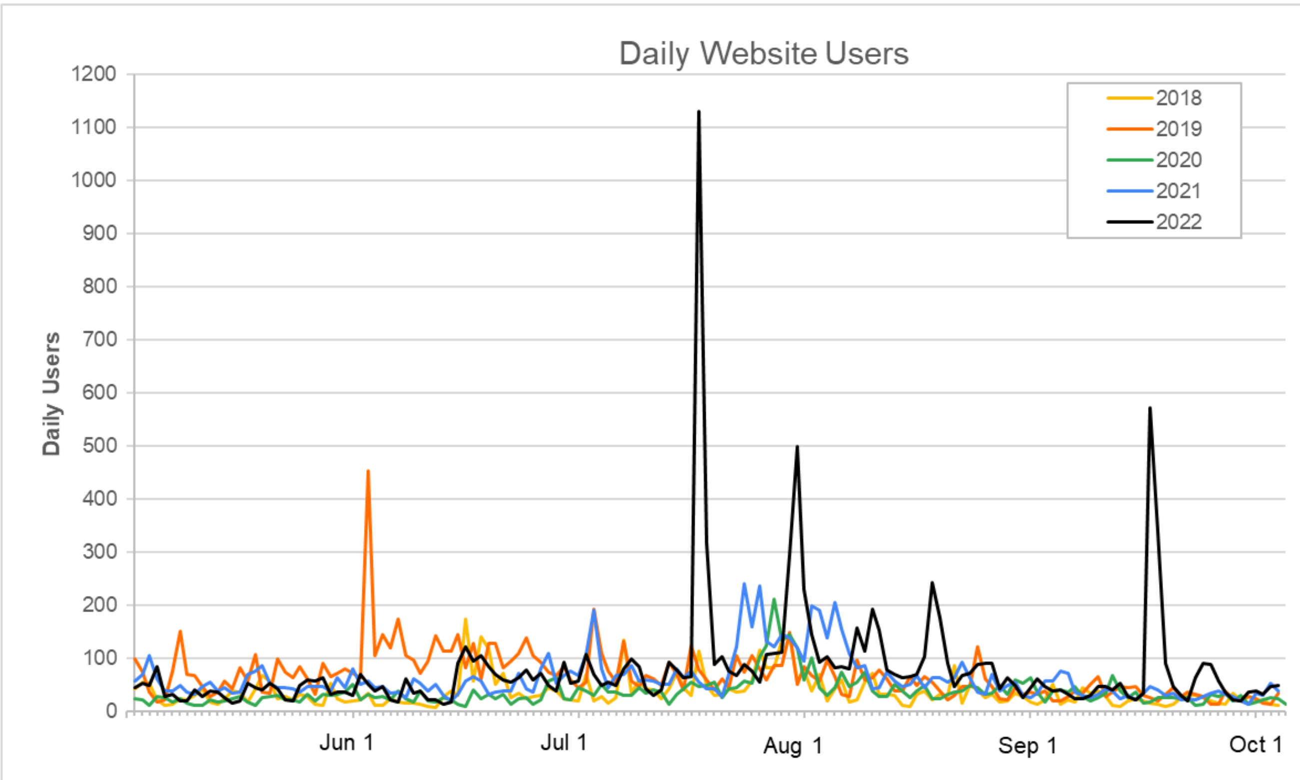

Figure 14. Daily Website users during 2018 (yellow), 2019 (orange), 2020 (green), 2021 (blue), and 2022 (black).

Social Media

During the historic floods of September 2013, the Program 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 that was selected was the Twitter social media platform, with the goal being to provide updates on any impending flood-related threat across Colorado in a concise, headline-style matter. The Twitter account was an immediate success during the September floods, and it was assimilated 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 or observations, (iii) life threatening National Weather Service Flash Flood Warnings, and (iv) 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 the daily FTB and bi-weekly FTO posts, the Program's social media strategy attempts to maximize the way this data is leveraged by creating unique posts. For example, *Figure 15* is a pair of tweets sent on August 7th indicating the potential for heavy rainfall along the Front Range, Urban Corridor, and Palmer Ridge. These tweets combined saw over 15,000 Impressions and 15 retweets. Twitter continues to be a tested and effective social media strategy for the Program's product dissemination.

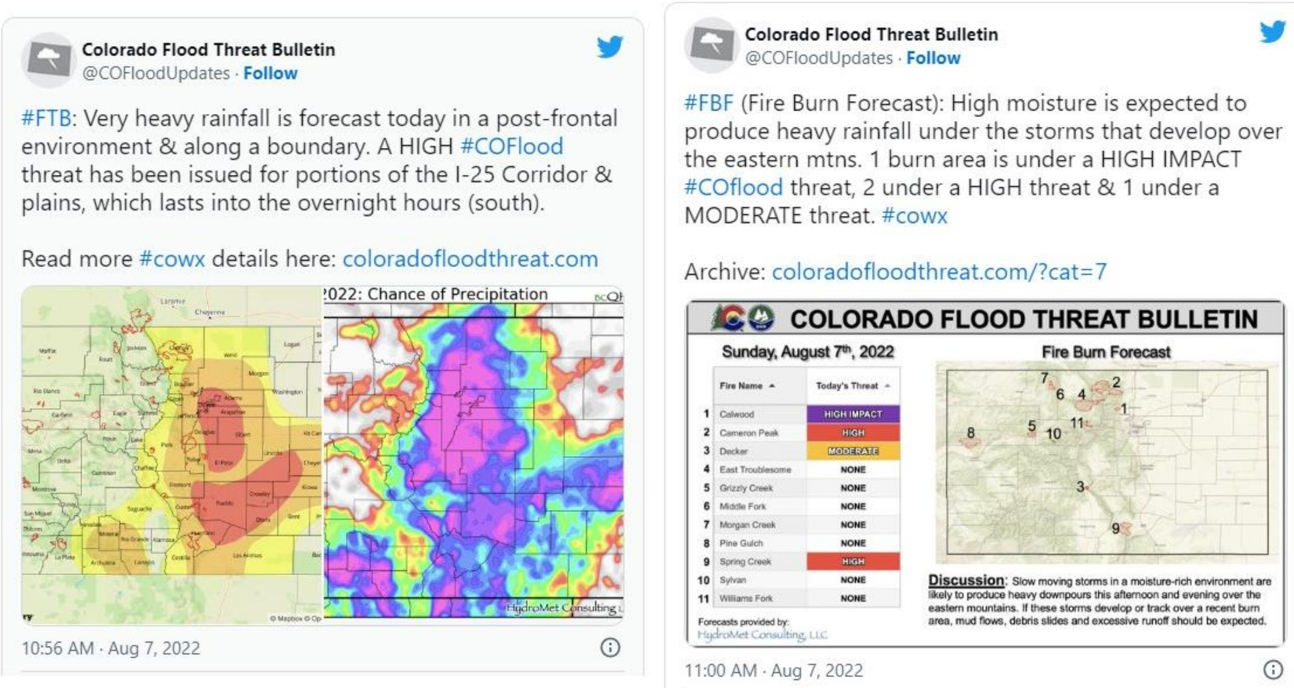

Figure 15: A pair of tweets from August 7, 2022 for a particularly high threat day to the Front Range, Urban Corridor, and Palmer Ridge, including the Calwood, Cameron Peak, and Spring Creek burn areas. These tweets saw the highest total twitter impacts with a combined 15,660 impressions (times seen) and 566 engagements (times interacted with a tweet which includes any clicks, likes, retweets, replies, and follows).

The Program's Twitter account, @COFloodUpdates, continues to increase viewership since its inception with the total number of followers up to 1,591 by the end of 2022 season. This is a modest increase in followers of 63 from the end of the 2021 season. A good portion of the Program's ongoing success can be attributed to the number of retweets from well-followed and respected accounts such as the Colorado Emergency Management (68K+ followers) and the Colorado Climate Center (4K followers), and FEMA Region 8 (44K+ followers). As always, retweets by popular media accounts can add new Twitter followers, and at the same time expose the Program to a more diverse group end-users. Over the 2022 season, the Program created 316 unique Tweets (36 more than 2021).

However, in 2022, Twitter removed several millions spam bot accounts from the platform. Though bot accounts likely made up only a small number of Program Followers, it is very likely this could have impacted the daily average Impressions across the two seasons. For this reason, the Impression numbers shown below should be interpreted with caution. Off season work is recommended to maximize viewership of the Programs' Tweets, and this is particularly true with the current volatility in overall Twitter usage following the major corporate changes within the company in 2022.

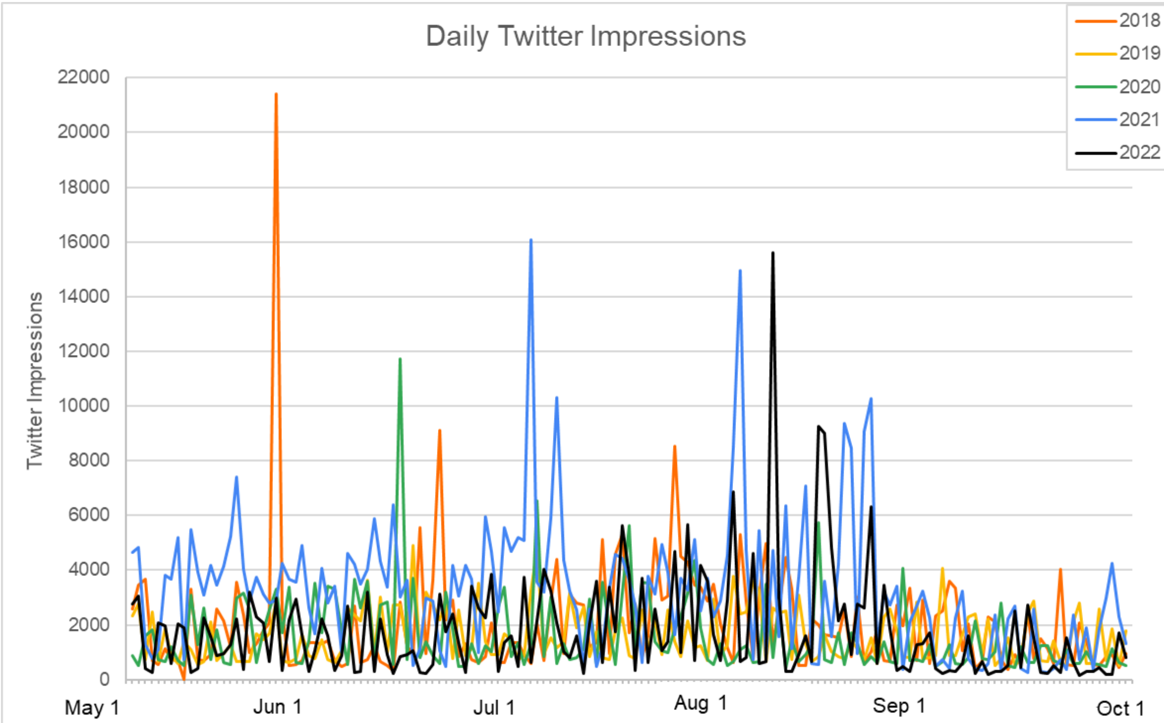

Figure 16: Daily Twitter impressions during 2022 (black), 2021 (blue), 2020 (green), 2019 (yellow), 2018 (orange).

Our most notable followers of our Twitter account remain steady: Colorado Emergency Management, FEMA Region 8, Colorado Flood DSS, READY Colorado, 9News Denver, CoCoRaHS, ESRI, AAA Colorado, Red Cross Denver, Colorado State Patrol Troop 1E, Denver Sheriff, Colorado.gov, NWS – Grand Junction, NWS – Pueblo, NWS – Goodland, NWS – Boulder, Colorado Climate Center, CU Boulder, Durango Herald, 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, CASFM, Denver Water, The Disaster Channel, Weather West, Colorado Wildfire Info, GMUG National Forests, and Colorado Springs Gazette. Although not mentioned by name, various police precincts, city/county government offices, TV and newspaper reporters and meteorologists from across the state, radio stations, academia meteorologists, individual citizens of Colorado, private meteorologists, fire and rescue units also follow the Program's Twitter account. We will continue to engage local media as new accounts continue to be created each season.

Since the Twitter account has been successful at circulating the FTB forecast products, a Facebook account for the Program was created at the beginning of the 2018 season. The main push behind the idea was that the Facebook page would likely reach a different demographic of potential end-users. The @COFloodUpdates handle was reused for the Facebook page to keep uniformity across the social media accounts. All posts on Facebook were also updated simultaneously with the Twitter account, so information exchange would be consistent. One drawback to Facebook is that posts do not show up on the News Feed chronically, so end-users must visit the page directly for up-to-date flood information. The Facebook platform can be best utilized for upcoming events laid out in the FTO, since these are not as time sensitive as ongoing forecasts. During the 2022 season, FTO had an average of ** impressions, (add impact statement).

Facebook, like Twitter, has its own set of analytics called Insights, which can be used to evaluate the success of the additional social media account. By the end of its fifth season, the Facebook account gained several new Followers putting the total at 585. While this number continues to be quite a bit lower than the Twitter account, the number of Followers increased approximately 40% from the end of the 2021 season (following a similar increase between 2020 and 2021), which shows the media platform still has utility. The most similar analytic to Twitter Impressions are post "Reaches". Reaches are defined as the number of people who had any posts from our page enter their screen, and they can also assess the effectiveness of each post.

The use of specific hashtags also plays a large role in expanding viewership on all social media platforms and helps grab attention on specific holidays when outdoor recreation can be increased. 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 the Program consistently uses and has become almost completely dedicated to our products. Hashtags are searchable through Twitter and Facebook and using these relevant and popular hashtags such as #COwx or #COFlood allows people looking for specific information to be directed to our products. The following is a list of common tags that were used in 2022: #FTB, #FTO, #SPM, #COwx, #COFlood, #COFire, and #CODrought.

Email Alerts

A subscription for receiving the daily FTB headline to an end-user's email began on April 28th, 2017. As of November 1st, there are 165 active subscribers, which is up an additional 23 end-users from the end of the 2021 season. Likewise, content and quality of the information provided in the emails should be discussed. Continuing to increase the number of subscribers should continue to be a key objective for the Program, which could be achieved by another preseason campaign. It is also recommended to consider other methods on how to better advertise the email subscription option, such as prior idea of reaching out to local OEMs that do not follow the Program. Finally, a reminder email should be sent out to subscribers in mid-April alerting them of the return of the FTB May 1st, 2022 and inform end-users of any additional upgrades to the products.

Outreach

The addition of the dedicated Outreach budget has allowed the program to increase user engagement through two highly attended User Trainings. A training webinar was provided by the consultants to end-users of the Program on June 30, 2022. The timing of the webinar was scheduled to occur before the onset of the monsoon season to maximize viewership and understanding of the products before an active monsoon season. The webinar was also recorded and uploaded to YouTube for users that could not attend the live webinar. Topics of the training webinar included a brief history of the program, detailed discussions of each product (FTB, FBF, FTO, SPM, and streamflow tracker) and how they are produced by forecasters, followed by a question and answer session. The webinar was well-attended, with 47 total attendees from various organizations including the Colorado Water Conservation Board, FEMA Region 8, NRCS, Bureau of Reclamation, Colorado Department of Transportation, Colorado River District, the Red Cross, and several local community jurisdictions.

A follow up webinar focused on the FBF process and specific case studies was held on September 30, 2022, for the Middle Colorado Watershed Council. Their stakeholders requested a deep dive session to better understand the data going into the FBF products and re-cap specific debris flow events on the Grizzly Creek Burn Scar over the last two forecast seasons. The meeting was attended by 11 total attendees including the NRCS, USGS, Colorado River District, and several western slope jurisdictions. A summary of presentation results will be provided with the Fire Burn Forecast end of season technical memo, accompanying this final report.

5) CONCLUSIONS

1. The 2022 forecast season saw above average rainfall across large parts of Colorado, but especially over the higher terrain. It was a near-record monsoon season for parts of San Juan Mountains and Southeast Mountains (see Table 4). Isolated locations in the southern San Juan Mountains likely received over 20 inches, which is close to twice their normal value. Fortunately, the rainfall activity in this region was spread out across many multi-day events, precluding serious flooding. The only region to experience much below normal rainfall activity was parts of the Northeast Plains towards the Kansas border, leading to portions of the area being placed under "Moderate" and "Severe" drought by summer's end.

   In terms of maximum rainfall intensity, July 6th saw widespread heavy rainfall over the Northeast and Southeast Plains with many locations receiving over 3 inches of rain in only 1-2 hours. For example, Rocky Ford measured 3.36 inches in an hour. However, flooding was relatively minor and limited to more urban areas with higher impervious area. A morning storm on August 16th over Broomfield produced about 2.5 inches in 60 minutes, 3.3 inches in 2 hours and a storm total of 3.70 inches in less than 3 hours leading to some urban flooding.

   In all, the 2022 forecast season experienced 52 Flood Days, which is notably below the 2012-2020 average of 69 Flood Days, but also higher than the recent quieter, drought-stricken years of 2018-2020 (see Table 9).

2. There were 65 days with flood threats issued, 37 of which were Low threats, 22 Moderate and 6 with High threats. In terms of total flood threat issued, parts of the eastern San Juan Mountains were the "hot spot" with over 40 threat days (see Figure 21, Appendix E). However, the vast majority of the threats were of the Low category, a fortuitous outcome given the aforementioned very high seasonal rain totals in the region.

3. The FBF product's expansion from 6 to 11 burns was done successfully and received significant viewership through the use of dedicated Twitter posts. The Cameron Peak burn area experienced seven flooding events, including one fatal event, along with an incredible additional 58 days where moderate or heavy rainfall was estimated (see Table 3). Preliminary data suggests the burn has yet to recover to its pre-burn hydrologic conditions (see Figure 7). Meanwhile, the dangerous Grizzly Creek burn area received well above normal rainfall for a second straight season but did not experience a single (observed) flooding event suggesting recovery is well underway.

4. Forecast verification metrics continued to show encouraging performance with an overall Hit Ratio of 87%. Notably, the Probability of Detecting a Flood Day (92%) metric was the best in the Program's history since at least 2012. Of particular importance, the Miss Ratio was only 8%, also the best since at least 2012 and the first time this metric dropped below 10% (see Table 9). However, the False Alarm Rate moved from 20% in 2021 to 25% this year, which is slightly above the Program's goal of 20%. Research during the off-season will be directed at attempting to reduce the False Alarm ratio, with a particular emphasis on improvement during marginal setups that prompted many Low threats this year.

5. New to the Program this season is the inclusion of a monthly Streamflow Tracker, which shows recent and Water Year streamflow conditions across a handful of Colorado's largest basins. The Tracker was posted on Twitter and received some interest from the community. Interestingly, it proved surprisingly difficult to attain some streamflow data in near real-time, prompting some correspondence with NRCS, Northern Water and others about the various complications. The Team expects to communicate with the State Engineer's Office to further improve understanding of streamflow volume estimates in time for the 2023 forecast season.

6. The Team began supplying rainfall and flooding related analyses after noteworthy flash flood events to provide near real-time insight about the event. The posts, disseminated via Twitter, received significant attention from a variety of end-users including media outlets.

7. Website viewership and email subscriptions have increased since last season and have shown drastic increases since their inception in 2016 and 2017, respectively. Twitter and Facebook remain important tools for disseminating forecasts and other Program information, with similar increases in followers and viewers. The exception to this is a decrease in average daily Twitter impressions compared to 2021, though this may be due to changes within the Twitter platform itself as the number of Twitter followers continued to increase.

6) REFERENCES

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APPENDIX A – FORECAST VERIFICATION WORKSHEET

Table 14 shows the daily verification worksheet documenting the intensity and coverage of heavy precipitation, along with whether a Flood Threat was issued. An asterisk (*) next to the date indicates that an afternoon updated was issued. To be consistent with previous seasons, the analysis herein is based on the initial flood threat map only and does NOT include any afternoon updates to the flood threat. Two asterisks (**) indicates that a threat was issued, but that it did not encompass the heavy rainfall event, so it was counted as a "Miss" (this is a new upgrade beginning in 2022). Finally, dates where an NWS Flood or Flash Flood Watch was issued are shaded in green. The columns of Table 14 are described below.

NSSL MRMS Quantitative Precipitation Estimate: Contains the sub-categories below.

Max1hr-E (inches): Maximum 1-hour precipitation east of the 5,250 ft. elevation contour.

Max2hr-E (inches): Maximum 2-hour precipitation east of the 5,250 ft. elevation contour.

Max1hr-W (inches): Maximum 1-hour precipitation west of the 5,250 ft. elevation contour.

Max2hr-W (inches): Maximum 2-hour precipitation west of the 5,250 ft. elevation contour.

Max24hr-E (inches): Maximum 24-hour precipitation east of the 5,250 ft. elevation contour.

Max24hr-W (inches): Maximum 24-hour precipitation west of the 5,250 ft. elevation contour.

NOAA Stage IV (ST4) Quantitative Precipitation Estimate: Contains the sub-categories below.

Max24hr-E (inches): Maximum 24-hour precipitation east of the 5,250 ft. elevation contour.

Max24hr-W (inches): Maximum 24-hour precipitation west of the 5,250 ft. elevation contour.

QPE: Contains the highest total number of 24-hour points exceeding Flood Day threshold between the MRMS and Stage IV data. Note that 1 point is equivalent to about 5.5 square miles of areal coverage.

Rain Gauges: Contains the sub-categories below. See Appendix C for more information about gauge networks considered in this analysis.

NStats (number): Total number of rainfall gauges exceeding Flood Day thresholds statewide.

Max-E (inches): Maximum observed rainfall from all gauges, east of the 1600m contour.

Max-W (inches): Maximum observed rainfall from all gauges, west of the 1600m contour.

Flood 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.

Total Threat Area: Areal coverage (square miles) the issued Flood Threat covered that day.

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

SNOW*:* Snowfall results in a qualifying Flood Day 24-hour precipitation total but did not result in flooding.

LI: Low-intensity, long-duration precipitation that exceeds the Flood Day threshold but did not result in flooding.

RIV: Riverine flooding from antecedent rainfall/snowfall, but no concurrent Flood Day threshold precipitation was observed.

BIAS: Indicates significant discrepancy, both overestimates and underestimates, between gridded QPE and rain gauge estimates that required a manual adjustment of the Flood Day assignment (see Appendix F).

Outcome: Classification of Flood Threat into the following three categories. Note that a blank implies a correct forecast though no Flood Day occurred (dry case).

False Alarm: A Flood Day was forecasted, but a non-Flood Day was observed,

Miss: A Flood Day was observed but not forecasted,

Hit: A Flood Day was observed and forecasted correctly.

Table 14: Daily FTB Verification Worksheet

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 QPE		QPE	Rain Gauges			Flood Reports							
Date	Max 1hr E	Max 2hr E	Max 1hr W	Max 2hr W	Max 24hr E	Max 24hr W	Max 24hr E	Max 24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat	Total Threat Area	Flags	FD Category	Outcome
Units	inches	inches	inches	inches	inches	inches	inches	inches	points	number	inches	inches	number				Miles			
1-May	1.74	1.93	1.24	1.4	2.31	2.39	1.79	1.78	181	6	1.17	1.34						BIAS		
2-May	0.75	0.93	0.35	0.46	1.49	1	1.15	0.59	1	1	1.57	0.9	1					BIAS		
3-May	0.23	0.34	0.32	0.4	0.57	0.72	0.55	1.25	3	4	0.72	1.01						SNOW		
4-May	1.15	1.36	1.17	1.31	2.14	1.77	1.85	1.33	18	1	1.37	1.26	1			Low	2	BIAS		FA
5-May	0.26	0.29	0.04	0.05	0.31	0.09	0.29	0.05	0	0	0.3	0.43								
6-May	0	0	0.02	0.02	0	0.02	0	0.01	0	0	0.26	0.4								
7-May	0.27	0.29	0.69	1.01	0.33	1.49	0.33	1.03	3	0	0.25	0.7						BIAS		
8-May	0.08	0.13	0.2	0.25	0.17	0.7	0.19	0.97	0	1	0.31	0.9								
9-May	0	0	0.11	0.17	0	0.28	0	0.36	0	0	0	0								
10-May	0	0	0	0	0	0	0	0.05	0	0	0	0								
11-May	0.31	0.43	0.01	0.01	0.43	0.06	0.38	0.02	0	0	0.04	0.35								
12-May	0.16	0.16	0.2	0.21	0.16	0.23	0.23	0.21	0	0	0.14	0.46								
13-May	0	0	0	0	0	0	0	0.04	0	0	0.29	0.3								
14-May	0	0	0.02	0.02	0	0.02	0	0.02	0	0	0	0								
15-May	0	0	0.06	0.06	0	0.09	0	0.05	0	0	0	0								
16-May	1.1	1.6	1.3	1.62	1.79	3.55	1.9	0.75	30	0	0.37	0.47						BIAS		
17-May	1.69	1.72	1.26	1.27	1.87	1.45	1.53	0.97	4	0	0.55	0.33						BIAS		
18-May	1.87	3.02	1.95	2.71	3.47	2.98	2.62	1.56	75	0	1.15	0.93			Yes	Low	4		GRIDDED	Hit
19-May	0.07	0.12	0.17	0.25	0.26	0.53	0.33	0.67	0	0	0.51	0.74								
20-May	0.31	0.5	0.34	0.5	1.21	1.77	1.17	1.7	871	273	1.47	3.5						SNOW		
21-May	0.2	0.24	0.24	0.32	0.95	1.11	0.69	1.01	3	2	0.95	1.67						LI		
22-May	0.65	0.68	0.38	0.54	0.89	1.02	0.81	0.83	1	1	0.87	1.89						LI		

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 QPE		QPE	Rain Gauges			Flood Reports							
Date	Max 1hr E	Max 2hr E	Max 1hr W	Max 2hr W	Max 24hr E	Max 24hr W	Max 24hr E	Max 24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat	Total Threat Area	Flags	FD Category	Outcome
23-May	0.63	0.84	0.72	0.91	1.35	1.55	1	0.99	163	17	1.44	1.73						LI		
24-May	0.56	0.68	0.56	0.78	1.36	1.27	1.27	0.96	5	3	1.4	2	2					LI		
25-May	0	0	0.01	0.01	0.02	0.01	0	0.04	0	0	0.16	0.49								
26-May	0	0	0.01	0.01	0	0.01	0	0.09	0	0	0.13	0.5								
27-May	0.46	0.46	0.23	0.27	0.51	0.27	0.31	0.18	0	0	0.09	0.3								
28-May	0.14	0.14	0.71	0.84	0.21	1.03	0.19	0.59	0	0	0.05	1						LI		
29-May	0.86	0.96	0.98	1.53	1.07	5.27	0.85	1.44	125	12	0.61	1.72	2					LI		
30-May	0.65	0.65	0.5	0.61	0.67	0.67	0.5	0.7	0	0	0.3	1								
31-May	0.43	0.54	0.87	1.37	2.12	2.93	1.53	1.44	456	198	2.07	2.36						LI		
1-Jun	0.3	0.41	0.16	0.23	0.5	0.36	0.39	0.26	0	0	0.54	1								
2-Jun	0.15	0.22	0.67	0.72	0.25	0.93	0.22	0.79	0	0	0.49	0.4				Low	3			FA
3-Jun	3.09	4.19	1.49	1.68	6.41	2.17	5.73	1.52	126	1	1.9	0.77	1		Yes	Low	20		GRIDDED	Hit
4-Jun	1.27	1.36	0.28	0.33	1.7	0.33	1.35	0.4	2	0	0.31	0.3				Low	12	BIAS		FA
5-Jun	1.41	1.55	0.35	0.49	1.8	0.57	1.33	0.49	2	0	0.61	0.42						BIAS		
6-Jun	1.44	1.44	1.17	1.48	2.65	1.66	2.5	1.26	86	2	1.71	1.14		YES	Yes	Low	19		GAUGE	Hit
7-Jun	2.17	3.06	1.37	1.67	4.42	3.19	3.62	1.77	640	15	3	1	1	YES	Yes	Low	15		LSR	Hit
8-Jun	0.54	0.54	0.68	0.71	0.54	0.76	0.4	0.64	0	0	0.16	0.3				Low	3			FA
9-Jun	1.13	1.43	1.43	1.55	1.65	1.58	0.79	1.39	22	0	0.27	0.5						BIAS		
10-Jun	0.02	0.02	0.07	0.08	0.03	0.09	0.01	0.04	0	0	0.15	0.36								
11-Jun	0.96	1	0.43	0.65	1.12	0.66	1.04	0.4	0	0	0.55	0.47								
12-Jun	1.83	1.86	0.56	0.56	2.16	0.63	2.02	0.45	11	0	0.41	0.43						BIAS		
13-Jun	0.05	0.06	0.15	0.2	0.06	0.44	0.06	0.52	0	0	0.22	0.43								
14-Jun	1.55	1.56	0.18	0.22	1.57	0.38	1.24	0.35	1	0	0.35	0.4						BIAS		
15-Jun	0	0	0.02	0.04	0	0.09	0	0.07	0	0	0.14	0.43								
16-Jun	2.48	2.75	2.01	2.7	3.08	3.22	2.82	2.3	29	1	2.22	0.43		YES	Yes	Low	8		GAUGE	Hit

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 QPE		QPE	Rain Gauges			Flood Reports							
Date	Max 1hr E	Max 2hr E	Max 1hr W	Max 2hr W	Max 24hr E	Max 24hr W	Max 24hr E	Max 24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat	Total Threat Area	Flags	FD Category	Outcome
17-Jun*	0.21	0.21	1.76	2.79	0.26	3.74	0.09	2.82	41	1	0.29	1.2			Yes	Mod	32		GAUGE	Hit
18-Jun	0.56	0.56	1.21	1.72	0.67	2.34	0.62	1.39	99	32	0.55	2				Mod	37	LI		FA
19-Jun	0.39	0.43	0.86	0.94	0.46	1.65	0.31	1.02	21	5	0.59	2.07			Yes	Low	24		GAUGE	Hit
20-Jun	0.59	0.65	0.07	0.07	0.8	0.07	0.67	0.14	0	0	0.42	0.5								
21-Jun	0.83	0.93	0.05	0.07	1.42	0.34	0.85	0.24	0	0	0.46	0.44								
22-Jun	0.28	0.35	0.2	0.33	0.55	0.66	0.38	0.61	0	0	0.27	0.8				Low	12			FA
23-Jun	1.23	1.35	1.38	1.39	1.45	1.55	1.3	0.9	4	1	0.4	2	1	YES				BIAS		
24-Jun	1.06	1.27	0.61	0.65	1.94	0.96	1.19	0.6	2	0	0.95	0.61						LI		
25-Jun	0.27	0.33	0.79	1.04	0.56	1.34	0.42	1.44	18	4	0.45	1.32		YES	Yes	Low	11		GAUGE	Hit
26-Jun	0.22	0.32	1	1.05	0.68	2.26	0.46	2.38	628	54	0.38	2.53	10	YES	Yes				GAUGE	Miss
27-Jun	0.85	0.97	1.81	2.2	1.11	2.64	1.02	1.54	39	1	0.56	1.19	3		Yes	Low	9		GAUGE	Hit
28-Jun	0.06	0.06	0.8	0.87	0.06	1.15	0.04	0.68	0	0	0.24	0.84						BIAS		
29-Jun	0.57	0.6	0.73	0.79	0.72	1.35	0.47	0.93	8	2	0.36	1.02						LI		
30-Jun	2.56	3.95	1.63	1.66	4.39	2.11	2.98	1.3	62	5	1	1.42		YES	Yes	Mod	43		GAUGE	Hit
1-Jul	1.74	1.81	3.02	4.61	1.99	5.86	2.1	3.96	259	8	1.7	2.9	2	YES	Yes	Mod	37		GAUGE	Hit
2-Jul	2.09	2.24	2.18	2.33	2.41	2.5	2.13	2.21	119	1	1.65	0.97	7	YES	Yes	Low	13		GRIDDED	Hit
3-Jul**	1.13	1.31	2.02	2.24	1.33	2.47	0.9	1.96	25	0	0.38	0.91		YES	Yes	Low	33		GRIDDED	Miss
4-Jul	1.05	1.14	0.75	1.01	1.41	1.41	1.16	1.27	5	0	0.41	1		YES				BIAS		
5-Jul	1.81	1.95	1.52	1.72	1.96	2.41	1.2	2.33	69	6	0.67	1.8	1	YES	Yes	Low	31		GRIDDED	Hit
6-Jul	2.91	3.81	2.97	3.51	4.53	3.74	3.61	2.64	900	39	3.25	3.36	9	YES	Yes	High	61		GAUGE	Hit
7-Jul	2.91	3.33	2.07	2.9	3.43	3.04	2.77	2.63	432	9	2.9	2.5	4	YES	Yes	Low	14		GAUGE	Hit
8-Jul	2.55	3.03	1.44	1.82	3.4	1.87	3.03	1.4	41	0	0.89	0.91				Low	13	BIAS		FA
9-Jul	1.14	1.31	0.73	1.03	1.62	1.11	1.33	0.71	1	0	0.11	0.39						BIAS		
10-Jul	1.96	2.08	2.07	2.52	2.25	2.97	1.81	1.44	48	4	0.81	1.75	1	YES	Yes				GAUGE	Miss
11-Jul	2.04	3.54	2.44	2.93	3.77	3.13	1.72	1.55	285	6	0.29	1.65	3	YES	Yes	Mod	20		GAUGE	Hit

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 QPE		QPE	Rain Gauges			Flood Reports							
Date	Max 1hr E	Max 2hr E	Max 1hr W	Max 2hr W	Max 24hr E	Max 24hr W	Max 24hr E	Max 24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat	Total Threat Area	Flags	FD Category	Outcome
12-Jul	2.13	2.51	1.78	1.92	2.51	2.06	2.39	1.64	88	1	1.45	1.07		YES	Yes	Low	19		GAUGE	Hit
13-Jul	0.28	0.33	1.26	1.33	0.47	1.88	0.26	1.83	12	1	0.16	1.08				Low	19	BIAS		FA
14-Jul	1.09	1.14	1.4	1.82	1.29	2.13	0.94	1.45	36	2	0.2	2.06				Low	13	BIAS		FA
15-Jul	1.74	2.13	1.6	1.8	2.56	2.52	2.03	2.11	186	7	0.51	2.18	2	YES	Yes	Mod	47		GAUGE	Hit
16-Jul	1.65	1.76	1.89	2.27	2.08	2.58	1.68	2.14	102	3	1.04	1.37	2	YES	Yes	Mod	50		GAUGE	Hit
17-Jul	0.01	0.01	1.25	1.25	0.01	1.44	0	1.14	7	1	0.45	1.4				Low	2	BIAS		FA
18-Jul	2.12	2.51	1.33	1.55	2.51	1.87	1.2	0.87	19	1	1.03	1.57			Yes				GAUGE	Miss
19-Jul	0.72	0.72	1.82	2.27	1.11	3.42	0.86	2.99	114	0	0.69	0.96			Yes	Low	23		GRIDDED	Hit
20-Jul	1.81	2.13	2.31	2.54	2.15	2.7	1.8	2.18	130	3	0.88	1.5	1	YES	Yes	Mod	37		GRIDDED	Hit
21-Jul	2.44	2.7	0.88	0.94	2.7	1.17	1.88	0.72	7	0	1.4	0.72	1					BIAS		
22-Jul	0.82	1.12	2.35	2.59	1.12	2.71	0.71	1.7	14	0	0.12	0.5						BIAS		
23-Jul	1.59	1.8	1.47	1.63	1.94	2.68	1.06	1.49	69	4	1.56	1.22		YES		Low	17	BIAS		FA
24-Jul	2.45	3.51	2.33	3.15	4.19	3.7	3.41	2.33	1105	57	2.9	2.4	13	YES	Yes	High	64		LSR	Hit
25-Jul	1.89	2.13	2.71	3.9	3.31	4.2	2.01	2.73	303	8	1.2	1.9	9	YES	Yes	Mod	38		LSR	Hit
26-Jul	2.21	2.44	2.06	2.88	2.99	3.38	2.08	2.93	395	119	1.58	3.02	12	YES	Yes	Low	31		LSR	Hit
27-Jul	2.75	3.62	2.16	2.45	4.44	3.11	4.45	2.69	864	143	3.68	2.99	9	YES	Yes	Mod	48		LSR	Hit
28-Jul	2.21	4	1.36	1.62	4.39	2.93	3.12	2.31	639	43	1.94	2.16	1	YES	Yes	High	90		GRIDDED	Hit
29-Jul	2.14	2.62	1.9	2.48	3.24	2.81	5.01	4.47	258	37	2.15	2.4	13	YES	Yes	Mod	62		LSR	Hit
30-Jul	1.83	2	2.11	2.54	2.07	3.33	1.61	2.45	108	20	1.31	1.64	2	YES	Yes	Mod	35		LSR	Hit
31-Jul	2.27	2.71	1.56	1.86	3.09	2.19	2.28	1.68	77	2	0.83	1.33	2	YES	Yes	Low	31	LI	GRIDDED	Hit
1-Aug	0.53	0.53	2.43	2.5	1.23	3.28	0.88	2.25	147	6	0.11	1.82	1	YES	Yes	Mod	31		LSR	Hit
2-Aug	1.2	1.22	1.28	2.03	1.37	2.33	1.01	1.39	20	0	0.31	0.8		YES	Yes	Low	21		LSR	Hit
3-Aug	0.22	0.33	2.7	3.18	0.33	3.23	0.16	2.9	156	4	0.57	1.51		YES	Yes	Mod	31		LSR	Hit
4-Aug	2.15	2.68	2.79	3.73	2.89	3.93	1.4	2.74	200	9	0.61	2.6	2	YES	Yes	Mod	29		LSR	Hit
5-Aug	1.21	1.25	2.29	2.5	1.29	3	0.78	2.07	101	2	0.15	1.05		YES	Yes	Mod	43		GRIDDED	Hit

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 QPE		QPE	Rain Gauges			Flood Reports							
Date	Max 1hr E	Max 2hr E	Max 1hr W	Max 2hr W	Max 24hr E	Max 24hr W	Max 24hr E	Max 24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat	Total Threat Area	Flags	FD Category	Outcome
6-Aug	1.98	2.29	2.51	2.94	2.32	4.07	1.99	3.12	219	16	1.15	3.14	2	YES	Yes	Mod	36		LSR	Hit
7-Aug	2.65	2.94	2.62	3.48	3.95	4.86	2.99	4.21	710	72	2.72	2.5	15	YES	Yes	High	53		LSR	Hit
8-Aug	2.37	2.78	1.93	2.32	2.78	2.32	1.85	1.33	38	1	0.47	1.6	13	YES	Yes	Low	15		GRIDDED	Hit
9-Aug	0.83	0.98	1.17	1.38	0.98	1.63	0.78	0.96	3	0	0.14	0.51						BIAS		
10-Aug	0	0	0.78	0.85	0	1	0	0.85	0	0	0.14	0.4								
11-Aug	0	0	1.18	1.37	0	1.85	0	1.33	17	0	0.1	0.97						BIAS		
12-Aug	0	0	1.52	1.64	0	2.45	0	1.09	19	0	0.13	1		YES				BIAS		
13-Aug	0.94	1.2	1.33	1.66	1.2	2.71	0.83	2.15	66	4	0.68	1.2		YES		Low	18	LI		FA
14-Aug	3.15	3.26	2.5	2.57	3.31	2.69	3	2.27	213	13	1.1	2.04	1	YES	Yes	Mod	29		GAUGE	Hit
15-Aug*	2.01	2.52	2.3	3.1	2.72	3.82	2.23	3.04	681	208	1.9	3.44	46	YES	Yes	High	57		LSR	Hit
16-Aug	2.58	2.97	1.76	2.33	3.69	3.26	4.01	2.76	1174	132	2.85	3.9	12	YES	Yes	High	76		LSR	Hit
17-Aug	0.85	0.85	1.06	1.54	1.05	2.18	0.57	2.68	26	1	0.25	1.37	1	YES	Yes	Mod	14		LSR	Hit
18-Aug	0	0	0	0	0	0	0	0	0	0	0.16	0.38		YES						
19-Aug	1.13	1.19	1.55	1.63	1.36	2.47	1.39	1.64	79	9	0.65	1.97	5	YES	Yes	Mod	33		LSR	Hit
20-Aug	1.2	1.53	1.55	2.4	1.67	2.74	1.26	1.38	45	31	1.81	2.55	8	YES	Yes	Mod	34		GAUGE	Hit
21-Aug	2.01	2.24	1.3	1.91	2.81	2.5	2	1.7	43	7	1.39	1.4		YES	Yes	Mod	36		GAUGE	Hit
22-Aug	0.96	1.13	1.07	1.31	1.51	1.33	0.97	1.05	16	1	0.47	1.18	1			Low	19	BIAS		FA
23-Aug	0	0	1.02	1.07	0	1.07	0	1.09	2	0	0.16	1	1					BIAS		
24-Aug	0	0	1.17	1.17	0	1.4	0	0.99	5	2	0.23	1.67	1	YES				BIAS		
25-Aug	0.17	0.21	1.55	1.81	0.34	3.13	0.28	1.88	21	3	0.71	1.32			Yes	Low	27		GAUGE	Hit
26-Aug	1.81	2.74	2.33	2.43	3.35	2.63	2.33	2.4	74	3	1.32	1.18	2	YES	Yes	Low	25		GRIDDED	Hit
27-Aug	0.13	0.13	1	1.1	0.13	1.39	0.08	0.83	1	0	0.17	0.82	1	YES				BIAS		
28-Aug	0.5	0.54	1.25	1.38	0.54	1.55	0.47	1.71	10	0	0.28	0.81	1	YES				BIAS		
29-Aug	0.15	0.16	0.22	0.25	0.18	0.43	0.1	0.31	0	0	0.17	0.4								
30-Aug	0.02	0.02	0.12	0.13	0.02	0.15	0.01	0.4	0	0	0.36	0.58								

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 QPE		QPE	Rain Gauges			Flood Reports							
Date	Max 1hr E	Max 2hr E	Max 1hr W	Max 2hr W	Max 24hr E	Max 24hr W	Max 24hr E	Max 24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat	Total Threat Area	Flags	FD Category	Outcome
31-Aug	1.76	2.57	1.5	1.81	2.64	1.89	2.06	1.3	56	0	0.86	0.75	1					BIAS		
1-Sep	0.04	0.04	0.15	0.15	0.05	0.18	0.02	0.17	0	0	0.2	0.39								
2-Sep	1.16	1.3	0.96	1.15	1.66	1.69	1.23	1.39	30	2	0.73	1.65						BIAS		
3-Sep	0.01	0.01	0.94	0.96	0.01	1.06	0.01	0.78	0	1	0.25	1.34						BIAS		
4-Sep	0	0	0.02	0.02	0	0.03	0	0.03	0	0	0.18	0.35								
5-Sep	0	0	0.56	0.62	0	1.05	0	0.35	0	0	0.13	0.31						LI		
6-Sep	0	0	0.55	0.65	0	1	0	0.14	0	0	0.15	0.42								
7-Sep	0	0	0.23	0.26	0	0.39	0	1.56	0	2	0.17	1.77						BIAS		
8-Sep	0.13	0.15	0.34	0.47	0.2	0.55	0.7	0.78	0	0	0.2	0.52	1							
9-Sep	0.33	0.33	1.35	2.19	0.39	2.69	0.27	1.87	5	0	0.82	0.94						BIAS		
10-Sep	0.43	0.44	1.01	1.05	0.5	1.11	0.34	0.61	2	0	0.26	0.86						BIAS		
11-Sep	0	0	0.54	0.6	0.01	0.74	0	0.82	0	0	0.3	0.87								
12-Sep	0	0	0.17	0.18	0	0.17	0	0.25	0	0	0.26	0.4								
13-Sep	0.07	0.07	0.32	0.5	0.09	1.16	0.06	1.23	4	1	0.23	1.2				Low	24	BIAS		FA
14-Sep	0.98	1.12	0.94	0.98	2.01	1.56	2.09	1.61	27	9	0.83	1.72	3		Yes	Low	15		GAUGE	Hit
15-Sep	3.07	3.86	1.86	2.03	4.14	2.38	2.57	1.6	83	2	1.14	1.15		YES	Yes	Low	2		GAUGE	Hit
16-Sep	1.06	1.36	0.64	0.64	1.47	0.71	1.43	0.76	0	1	1.67	0.85	1					LI		
17-Sep	0.42	0.46	0.57	0.62	0.63	0.67	0.46	0.55	0	0	0.18	0.6								
18-Sep	0.23	0.23	0.01	0.01	0.23	0.02	0	0.02	0	0	0.15	0.3								
19-Sep	0.94	1.2	0.41	0.41	1.2	0.57	1.14	0.45	0	0	0.33	0.28								
20-Sep	0.96	0.96	0.39	0.39	0.96	0.41	0.85	0.4	0	0	0.33	0.55								
21-Sep	0.65	0.89	0.78	0.84	2.83	1.57	2.03	1.16	96	22	1.93	2.2	19			Low	13	LI		FA
22-Sep	0.29	0.48	0.65	0.78	0.63	1.2	0.45	1.3	37	12	0.47	1.9	8			Low	2	LI		FA
23-Sep	0	0	0	0	0	0.01	0	0.08	0	0	0.19	0.4								
24-Sep	0	0	0	0	0	0	0	0.03	0	0	0.25	0.13								

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 QPE		QPE	Rain Gauges			Flood Reports							
Date	Max 1hr E	Max 2hr E	Max 1hr W	Max 2hr W	Max 24hr E	Max 24hr W	Max 24hr E	Max 24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat	Total Threat Area	Flags	FD Category	Outcome
25-Sep	0	0	0.05	0.05	0	0.06	0	0.22	0	0	0.19	0.48								
26-Sep	0	0	0.09	0.15	0	0.17	0	0.45	0	0	0.16	0.6								
27-Sep	0.15	0.17	0.59	0.66	0.28	0.85	0.19	0.73	0	0	0.19	0.43								
28-Sep	0.31	0.31	0.56	0.56	0.5	0.8	0.36	0.4	0	0	0.2	0.4								
29-Sep	0.55	0.55	0.87	1.09	0.76	1.2	0.41	0.73	1	0	0.47	0.45						LI		
30-Sep	0.96	1.24	1.06	1.16	1.5	1.86	1.14	2.24	227	24	0.97	2.44	12	YES				LI		

APPENDIX B – BURN AREA VERIFICATION WORKSHEET

Table 15 is a daily verification worksheet documenting heavy precipitation and debris flow/flash flooding reports over burn areas featured in the FBF. Shading within a cell indicates that a flood threat was issued with the color corresponding to the Program's four-tier threat system. The color yellow corresponds to a "Low" threat, orange to a "Moderate" threat, red to a "High" threat and purple to a "High Impact" threat. A blank cell indicates that no specific burn area threat was issued for that day. The text provided in Table 15 are described below.

Burn Area: The names of the 11 burn areas that were forecast this season. More information can be found in Table 3.

FLOOD: Indicates that a debris flow report was recorded from a LSR (see Appendix C) or social media reports (Twitter and Facebook).

QPE: Marks days that the QPE threshold was exceeded. These thresholds are set at the beginning of the season using historical data from the previous season. If the burn area is new, the threshold is set to 0.25 inches per hour. Thresholds used for this worksheet are:

Cameron Peak, East Troublesome, Morgan Creek, Sylvan, and Williams Fork: **0.25 inches per hour**

Girzzly Creek, Middle Fork, and Pine Gulch: **0.50 inches per hour**

Calwood, Decker, and Spring Creek: **0.75 inches per hour**

Table 15: Daily Burn Area Verification Worksheet

Date	Cameron Peak	East Troublesome	Morgan Creek	Sylvan	Williams Fork	Grizzly Creek	Middle Fork	Pine Gulch	Calwood	Decker	Spring Creek
1-May	QPE										
2-May											
3-May	QPE										
4-May	QPE	QPE									
5-May											
6-May											
7-May	QPE	QPE									
8-May											
9-May											
10-May											
11-May											
12-May											

Date	Cameron Peak	East Troublesome	Morgan Creek	Sylvan	Williams Fork	Grizzly Creek	Middle Fork	Pine Gulch	Calwood	Decker	Spring Creek
13-May											
14-May											
15-May											
16-May											
17-May	QPE										
18-May											
19-May											
20-May	QPE	QPE			QPE						
21-May											
22-May	QPE										
23-May											
24-May	QPE	QPE									
25-May											
26-May											
27-May											
28-May											
29-May	QPE	QPE	QPE	QPE	QPE		QPE				
30-May											
31-May	QPE	QPE									
1-Jun											
2-Jun											
3-Jun	QPE										
4-Jun											
5-Jun	QPE										
6-Jun	QPE	QPE			QPE						
7-Jun											

Date	Cameron Peak	East Troublesome	Morgan Creek	Sylvan	Williams Fork	Grizzly Creek	Middle Fork	Pine Gulch	Calwood	Decker	Spring Creek
8-Jun											
9-Jun											
10-Jun											
11-Jun											
12-Jun											
13-Jun											
14-Jun											
15-Jun											
16-Jun											
17-Jun	QPE	QPE									QPE
18-Jun											
19-Jun	QPE										
20-Jun											
21-Jun											
22-Jun											
23-Jun					QPE						
24-Jun	QPE										
25-Jun											
26-Jun	QPE	FLOOD									
27-Jun	QPE										
28-Jun											
29-Jun	QPE	QPE				QPE					
30-Jun	QPE	QPE				QPE		QPE			
1-Jul	QPE	QPE		QPE						QPE	QPE
2-Jul	QPE										QPE
3-Jul	QPE	QPE									

Date	Cameron Peak	East Troublesome	Morgan Creek	Sylvan	Williams Fork	Grizzly Creek	Middle Fork	Pine Gulch	Calwood	Decker	Spring Creek
4-Jul	QPE										
5-Jul	QPE	FLOOD			QPE	QPE					QPE
6-Jul	FLOOD										
7-Jul	FLOOD	QPE									
8-Jul	QPE										QPE
9-Jul											
10-Jul											
11-Jul											FLOOD
12-Jul	QPE										QPE
13-Jul	QPE	QPE		QPE							
14-Jul	QPE	QPE		QPE	QPE			QPE			
15-Jul	FLOOD	QPE		QPE		QPE					
16-Jul	QPE	QPE				QPE					QPE
17-Jul											
18-Jul		QPE			QPE						
19-Jul				QPE				QPE			
20-Jul	QPE					QPE					QPE
21-Jul	QPE										
22-Jul											
23-Jul	FLOOD	FLOOD									QPE
24-Jul	QPE	QPE			QPE			QPE			
25-Jul											FLOOD
26-Jul											
27-Jul	QPE								QPE		QPE
28-Jul	QPE	QPE			QPE						
29-Jul	FLOOD	QPE									

Date	Cameron Peak	East Troublesome	Morgan Creek	Sylvan	Williams Fork	Grizzly Creek	Middle Fork	Pine Gulch	Calwood	Decker	Spring Creek
30-Jul	QPE	FLOOD			QPE						QPE
31-Jul	QPE	QPE			QPE						
1-Aug	QPE	QPE		QPE						QPE	QPE
2-Aug	QPE	QPE						QPE			
3-Aug	QPE									QPE	FLOOD
4-Aug										QPE	QPE
5-Aug	FLOOD	QPE			QPE						
6-Aug											QPE
7-Aug									QPE		QPE
8-Aug											QPE
9-Aug											
10-Aug				QPE							
11-Aug	QPE	QPE		QPE	QPE			QPE			
12-Aug	QPE										
13-Aug	QPE	QPE									
14-Aug	QPE	QPE				QPE		QPE			
15-Aug	FLOOD	QPE		QPE	QPE	QPE		QPE			
16-Aug		QPE			QPE	QPE		QPE	QPE		QPE
17-Aug											
18-Aug											
19-Aug	QPE	QPE									
20-Aug	QPE	FLOOD				QPE		QPE			
21-Aug	QPE	FLOOD			QPE			QPE			
22-Aug		FLOOD			QPE						
23-Aug	QPE										
24-Aug	QPE	QPE									

Date	Cameron Peak	East Troublesome	Morgan Creek	Sylvan	Williams Fork	Grizzly Creek	Middle Fork	Pine Gulch	Calwood	Decker	Spring Creek
25-Aug	QPE										
26-Aug	QPE	QPE			QPE	QPE		QPE			
27-Aug											
28-Aug	QPE	QPE									
29-Aug											
30-Aug											
31-Aug											QPE
1-Sep											
2-Sep	QPE										
3-Sep											
4-Sep											
5-Sep											
6-Sep											
7-Sep											
8-Sep											
9-Sep											
10-Sep											
11-Sep											
12-Sep											
13-Sep											
14-Sep	QPE					QPE		QPE			
15-Sep		QPE									
16-Sep											
17-Sep											
18-Sep											
19-Sep											

Date	Cameron Peak	East Troublesome	Morgan Creek	Sylvan	Williams Fork	Grizzly Creek	Middle Fork	Pine Gulch	Calwood	Decker	Spring Creek
20-Sep											
21-Sep	**QPE**										
22-Sep											
23-Sep											
24-Sep											
25-Sep											
26-Sep											
27-Sep	**QPE**										
28-Sep											
29-Sep	**QPE**										
30-Sep	**QPE**	**QPE**	**QPE**		**QPE**	**QPE**		**QPE**			

APPENDIX C – DATA SOURCES

Below are the data sources used for verification in this final report. Questionable observations within each data source were noted and discarded based on comparison with other data.

Data Source	Additional Information	Access
Rain Gauges		
CoCoRaHS	Community Collaborative Rain, Hail and Snow Network. Daily precipitation accumulations from up to 1,300 observers across Colorado. This data is generally reported in the morning and encompasses the previous 24-hours of precipitation accumulation. Only reports received from 6AM to 9AM are used to ensure that measurements are consistent with the forecast period.	https://www.cocorahs.org
NRCS	Natural Resources Conservation Service. SNOTEL hourly precipitation data was used and also aggregated into daily accumulations at approximately 65 high-elevation sites across Colorado.	https://www.nrcs.usda.gov/wps/portal/wcc/home
MesoWest	University of Utah's hourly precipitation data, which has many contributing networks. The major networks include: 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). Secondary networks (i.e. lower quality) also include the Citizen Weather Observer Program (CWOP). Hourly precipitation data was used along with aggregated 24-hour totals.	https://mesowest.utah.edu
USGS	United States Geological Survey. Sub-hourly precipitation data was aggregated into a rolling 1-hour totals and daily accumulations. This data source is particularly helpful over the high terrain fire burn areas and the more populated areas of Teller and El Paso Counties.	https://co.water.usgs.gov/infodata/COPrecip/index.html
Personal Weather Stations (PWS)	In addition to using CWOP station data via MesoWest (see above), other personal weather station network data was accessed via the Ambient Weather network, Weather Underground and Aeris Weather. At this time, PWS data is only used subjectively to inform on heavy rainfall that occurs in poorly gauged areas. However, subject matter expert judgment could have affected the BIAS flag in Appendix A.	http://www.ambientweather.net https://www.weatherunderground.com https://www.pwsweather.com
Gridded Quantitative Precipitation Estimate (QPE)		
MRMS	NSSL Multi-Radar Multi-Sensor. This is a near real-time hourly gridded product based on an initial best-guess of radar, satellite and weather model rainfall estimates that is corrected with gauge data. The resolution of the product is roughly 1km; however, due to Colorado's large spatial extent (~100,000 square miles, or roughly 300,000 MRMS grid points), the native grid was re-sampled to roughly 4 km (2.6 mile) resolution to be directly comparable to Stage IV QPE (see below). MRMS 24-hour, maximum 1-hour, and maximum 2-hour QPE were used for verification.	https://mrms.nssl.noaa.gov
Stage IV	NOAA Stage IV. This is an hourly product based on a radar-estimated, gauge-adjusted technique using all NWS NEXRAD radars and many quality-controlled rain gauges. The horizontal resolution is about 4 km (2.6 mile). Due to the availability of more consistent MRMS data at the 1-hour and 2-hour interval, only 24-hour Stage IV QPE was used.	https://data.eol.ucar.edu/dataset/21.093

Data Source	Additional Information	Access
	Storm Reports	
LSR	Local Storm Report. Obtained from the four NWS offices that are responsible for Colorado: Boulder, Pueblo, Grand Junction, and Goodland (KS) using the Iowa Environmental Mesonet. 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. Like CoCoRaHS data, reports of 24-hour accumulation were only retained if the report ending time was between 6AM and 9AM. If a "Heavy Rain" report did not specify a magnitude, it was dismissed unless the observer's note contained a specific reference to flooding.	https://mesonet.agron.iastate.edu/lsr/
Flood Reports	Flood reports obtained from the Program's web-based report submission system, subject to quality control by the Team.	No Public Access
	NWS Warning and Advisory Products	
NWS	National Weather Service warning and advisory GIS data. Obtained from the Iowa Environmental Mesonet, this data source includes metadata such as the location and when the product was issued. Flash Flood Warning, Riverine Flood Warning and Areal Flood Advisory products were included for verification.	https://mesonet.agron.iastate.edu/request/gis/watchwarn.phtml

APPENDIX D - 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 and debris flows, in addition to the usual flash flooding concerns that are experienced statewide. The following section summarizes key aspects of Colorado's physiographic features 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 17 (Atlas 14, 2017) 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 Western counterpart (also see Appendix E).

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 17: 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 18, early in the operational season (May), the highest potential for heavy rainfall is almost exclusively east of the Continental Divide, and in particular the northeast quadrant of the state (PRISM, 2017). During early June (not shown), snow is significant factor in the Front Range and Gore Mountains. Meanwhile, by August (Figure 18 bottom), 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.

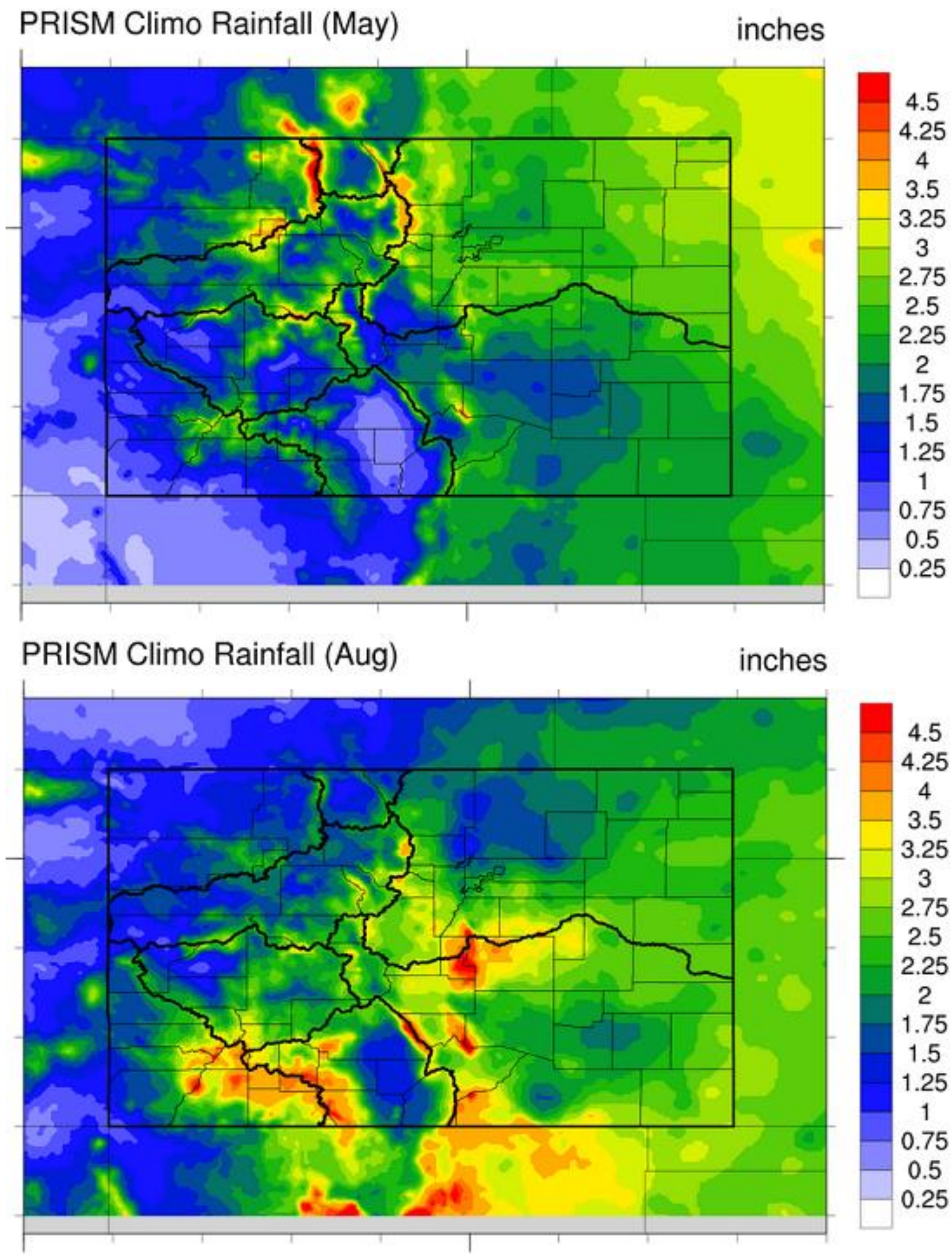


Figure 18: Monthly average precipitation for (top) May and (bottom) August. Source: Oregon State University PRISM group.

c) Surface characteristics

While a significant focus of the Flood Threat Bulletin is 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 19 shows the 1-hour Flash

Flood Guidance (FFG) for central and eastern Colorado from their respective River Forecast Centers. These products are updated daily by the 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 just under 6 inches, while over the northern Front Range, it is between 1 and 2 inches. An even starker example of the importance of surface characteristics is over a fresh fire burn area, where the burnt, and now resultant hydrophobic soil mass, can cause significant flooding concerns for even 0.25 inches of rainfall per hour. This can be seen over Huerfano and Fremont County where the Spring Creek and Decker burn areas reside, respectively (pink in the top figure). Surface characteristics play an integral role in the translating the heavy rainfall threat to a flooding potential.

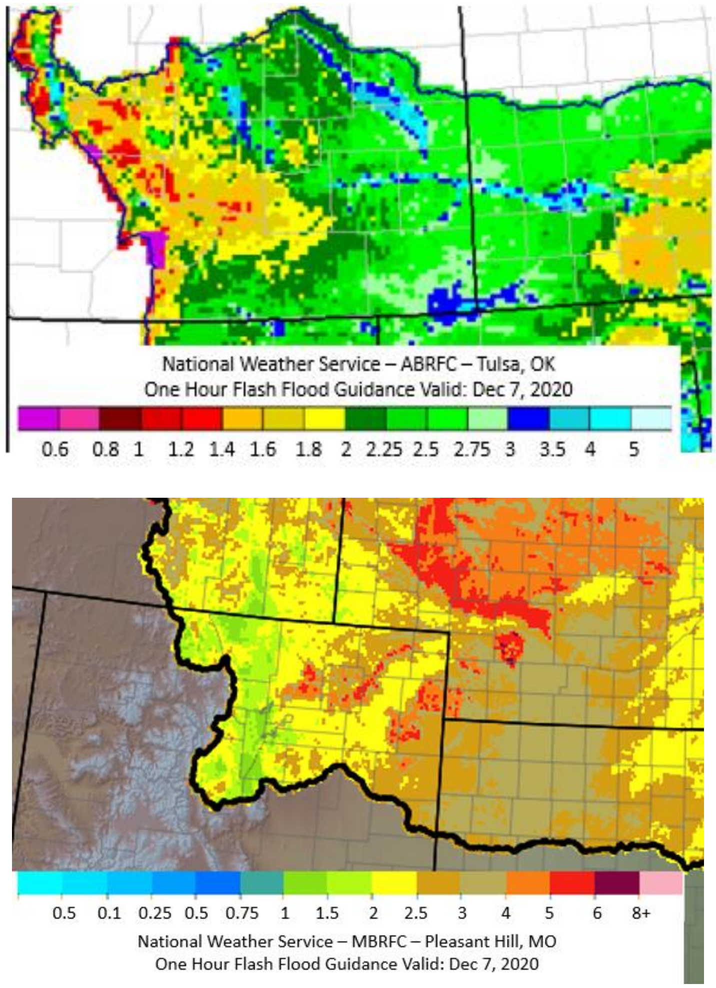


Figure 19: 1-hour Flash Flood Guidance for central and eastern Colorado, valid December 7th, 2020. Source: National Weather Service River Forecast Centers.

APPENDIX E – FLOOD THREATS ISSUED

Figure 20 shows the total number of days when a given location was under a flood threat during the 2016 to 2022 operational seasons. Note that this does not distinguish the type of flood threat (e.g. Low versus Moderate). For reference, there are normally 153 days during the forecast season with 154 days during 2018.

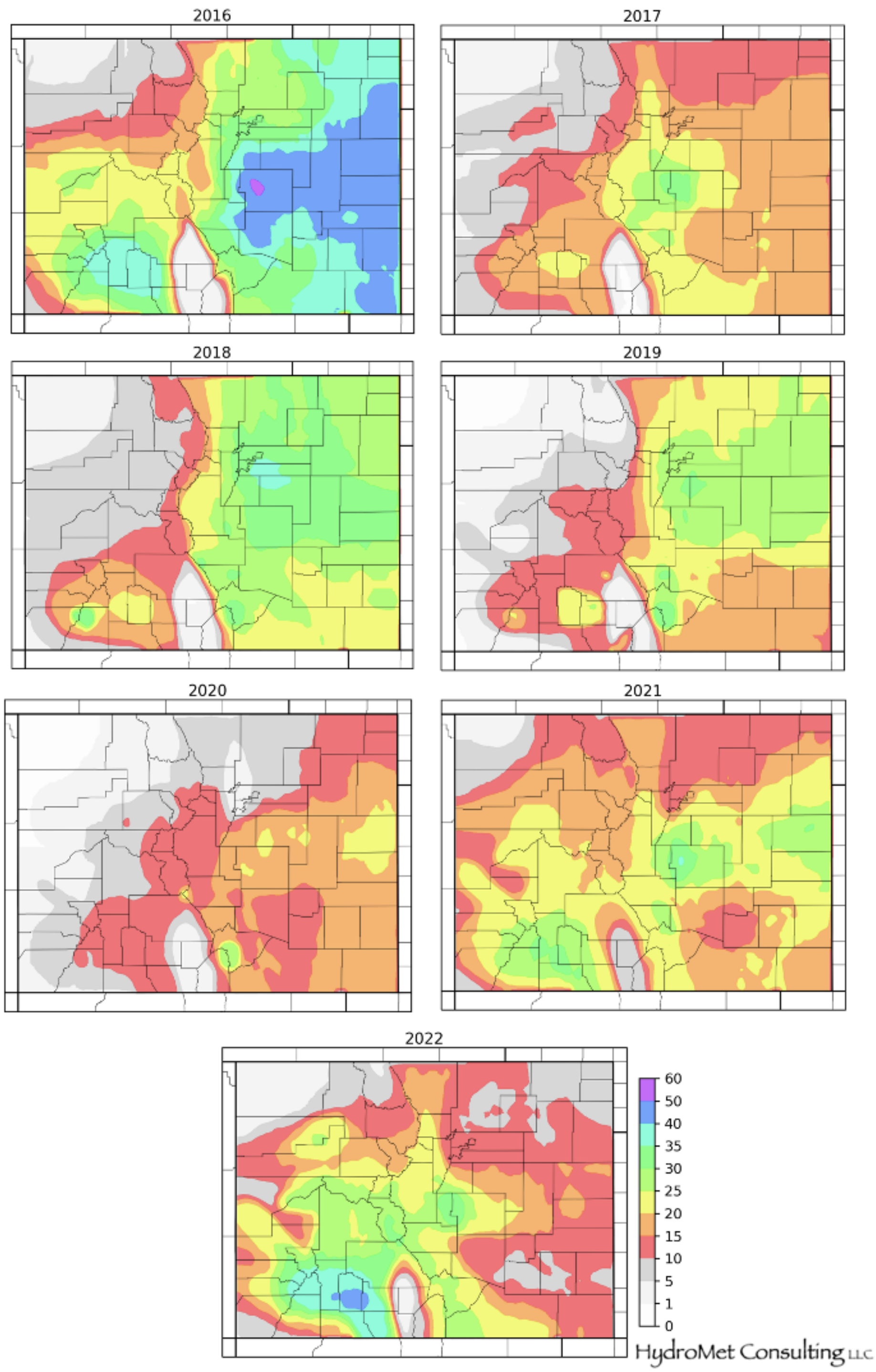


Figure 20: Number with days with a flood threat issued from 2016 to 2022. Note that until 2021, burn areas were considered within the FTB. After 2020, they were covered by the FBF.

APPENDIX F – QPE BIAS ASSESSMENT

An assessment of QPE product bias over the 2022 forecast season showed a systematic tendency for both the MRMS and Stage IV to slightly *overestimate* precipitation when compared directly to gauges, in situations where over 0.25 inches of precipitation were estimated OR observed. For example, as shown in Figure 21, over the course of the season, the MRMS product overestimated precipitation about 6% more often as it underestimated it. The MRMS bias was lower than Stage IV, indicating an overall better performance of MRMS compared to Stage IV (not shown).

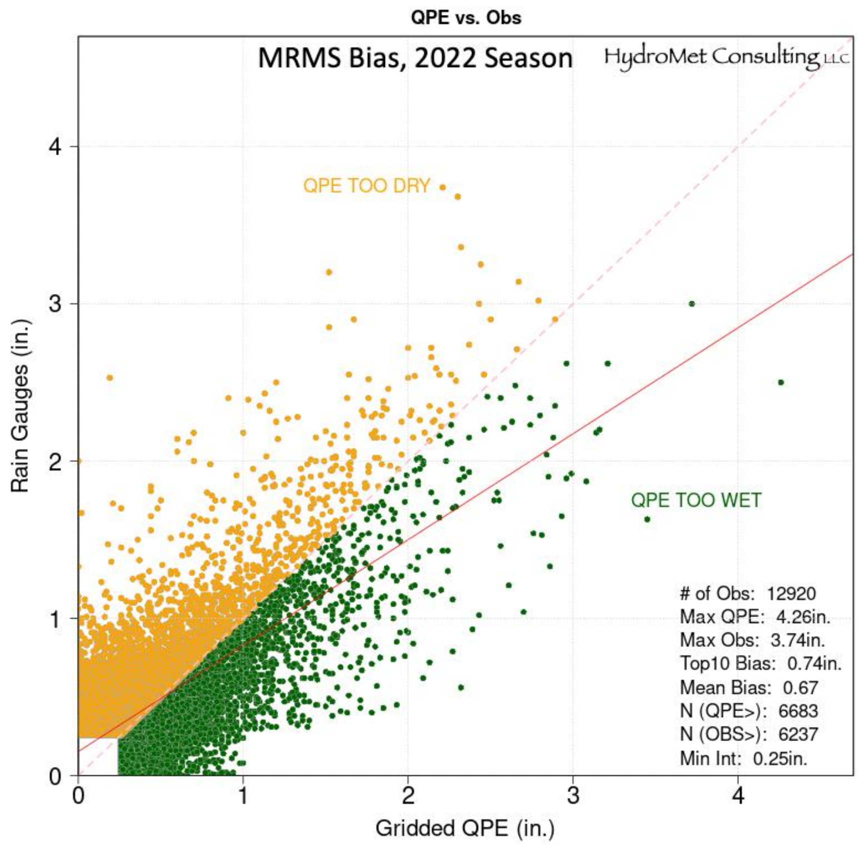
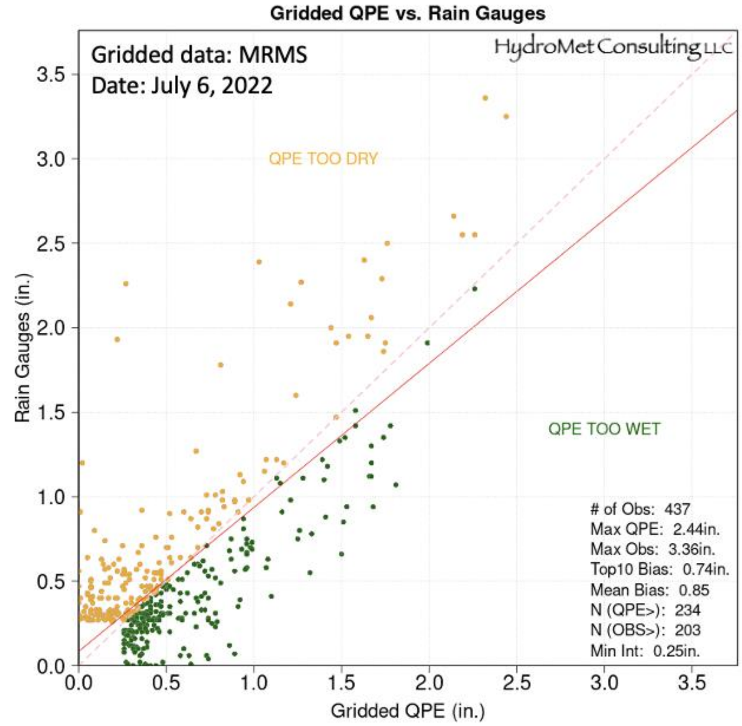


Figure 21: An example of a daily MRMS QPE vs Rain Gauge plot that shows overestimation of the gridded QPE product.

However, despite the overall bias shown above, there were significant variations on an event-by-event basis. These likely arose from numerous factors known to affect QPE, including but not limited to variations in the atmospheric moisture profile, sub-cloud layer depth, slow versus fast moving storms, distance from radar sites, the presence or absence of hail, as well as cloud temperature. To gain some perspective on the implications of these, Figure 22 shows the MRMS bias (representative of the QPE bias, in general) from two events with different atmospheric setups. On July 6th (top), widespread heavy rainfall fell across eastern Colorado and the MRMS performed well. Of 840 stations with meaningful rainfall, QPE overestimated rainfall at 488, while underestimating at 352. Meanwhile, on July 13th (bottom), isolated storms occurred over western Colorado within a relatively dry boundary layer. These factors resulted in an overestimate of rainfall: of 143 stations with meaningful rainfall, MRMS overestimated 97 of these while underestimating 46 stations. The average overestimate was roughly 50%. An important implication from the July 13th event is that on days where heavy rainfall largely skirts between reliable and widely spaced precipitation gauges, there is general potential to overestimate rainfall severity. To account for this, MRMS and Stage IV biases were subjectively assessed for each event, to determine if a Flood Day classification was warranted.



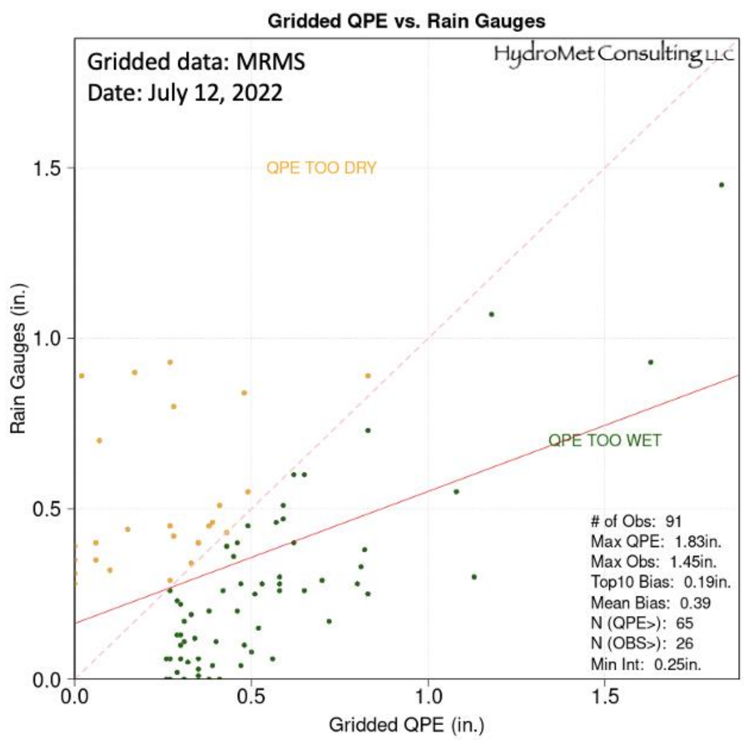


Figure 22: An example of MRMS gridded QPE versus rain gauge scatter plots from July 6th (top) and July 12th (bottom). The images show that the QPE bias is not constant and must be assessed on a daily level to help assign the Flood Day classification.

Finally, Figure 23 looks at the MRMS mean daily bias across each county for the course of the 2022 forecast season. The blue over eastern Colorado indicates a slight overestimation of precipitation for select counties. The darker red values over northwest and southwest Colorado indicates a 0.25 to 0.50 inch underestimation of daily precipitation. Stage IV indicates a similar underestimation over southwest Colorado, although of lesser magnitude. The underestimation of precipitation has been noted in past seasons, and it is likely directly related to lack of radar coverage due to beam blockage from the complex topography over the area. A new radar was installed at Alamosa airport in late 2019, and it helped alleviate underestimations previously seen over the San Luis Valley. Additionally, the number of observations within a given county can vary quite drastically from 1,522 in Larimer County to 12 in Hinsdale County. Therefore, the number of observations can sway the results of the analysis and should be interpreted with caution. For example, the 0.25 to 0.50 inch underestimation of precipitation is largely dependent on the limited number of observations in Moffat County (31), an area of ~4,700 sq mi. Therefore, this mean daily bias may not accurately representative the entire county. However, generally speaking, the lowest bias tends to occur in areas of high population (more gauges available for QPE calibration) and/or areas with better radar coverage.

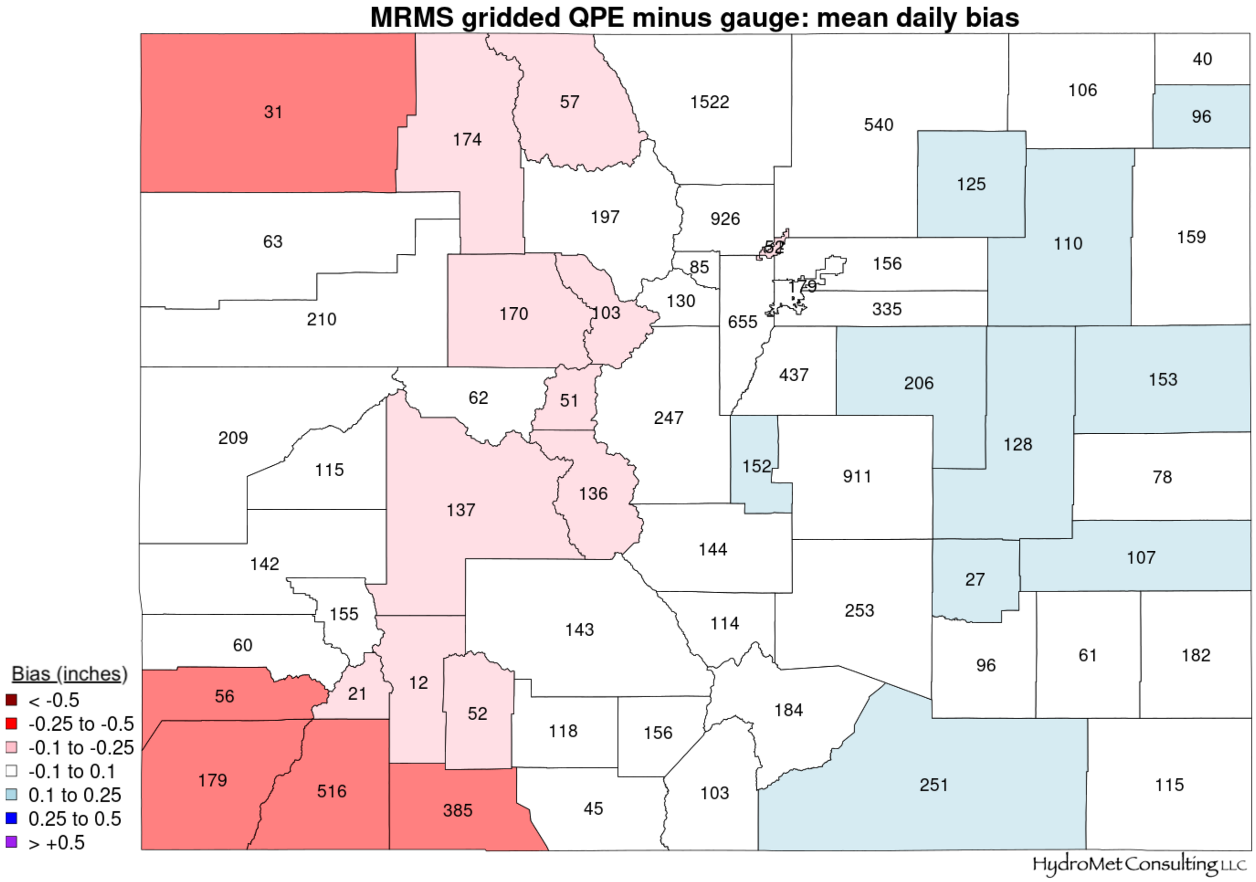


Figure 23: MRMS mean daily bias within each county from June to September of 2022. May was excluded due to several snowfall events, during which the bias is not as meaningful for the Program. Blue (red) represents an overestimation (underestimation) of precipitation and the numbers in each county represent the number of observations OR estimates over 0.25 inches going into the calculation.