Colorado Flood Threat Bulletin – 2024 Final Report

DECEMBER 31, 2024

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Contents

ACRONYMS

CDOT..... Colorado Department of Transportation

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

CO-NM REPS.....Colorado-New Mexico Regional Extreme Precipitation Study

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

HMC..... HydroMet Consulting, LLC

IEM..... Iowa Environmental Mesonet

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

PM Update ..... Update to FTB product during the afternoon hours

POD..... Probability of Detection

QPE ..... Quantitative Precipitation Estimate

SNOTEL..... Snow Telemetry

SPM..... State Precipitation Map

SQL ..... Standard Query Language

SWE..... Snow Water Equivalence

USGS..... United States Geological Survey

2024 Colorado Flood Threat Bulletin

Final Report

1) INTRODUCTION

The 2024 forecast season (May 1st to September 30th) was the third year of a five-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 effectively disseminating reliable heavy rainfall and flood forecasts, and 2) incorporating the frontier of hydro-meteorological research into operations for more accurate heavy rainfall forecasts. To build confidence in the forecast accuracy, a transparent and robust verification process was added in 2014. Numerous Program upgrades have been made since the Program's inception (see previous season's final reports, Dewberry and HMC, 2022 & Dewberry and HMC, 2023). For the Program's 2024 season, the five main products remained unchanged:

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 2024 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 Stevenray Janke, 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 Dana McGlone, Dmitry Smirnov and Julie Gaddy. 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 2024 forecast season, evaluate Program viewership, and to document any upgrades made to the Program.

Website Upgrades

Following the major website redesign in 2023, 2024 upgrades were focused on backend functionality and continued usability. This included working with CWCB and the state to ensure the site is accessible to all and in line with the Web Content Accessibility Guidelines (WCAG) version 2.2, levels A and AA criteria. These guidelines not only help make web content accessible to users with sensory, cognitive, and mobility disabilities but ultimately to all users, regardless of ability. Changes were made to improve color contrast of headers, tables, and maps, and to add text-alternatives to icons and images.

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 when there is an elevated flood threat. The FTB highlights the daily threat level of flooding across the state, describes the nature of the threat, and notes the time in which the threat of flooding would be the greatest in a zone-specific manner (14 climate-defined Forecast Zones, see Figure 4). The beginning of each FTB discussion also highlights any threats issued for the FBF and provides a direct link to that forecast page for more information. 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, National Weather Service (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 and associated map can be updated during the afternoon hours (PM Update). This will occur when there is (1) initially "no threat", but at least an upgrade to Low threat is warranted, or (2) when a threat needs to be upgraded to a High threat, regardless of the initial threat issued in the morning. Updates to social media posts are also provided to notify end-users about the evolving flood threat. It is essential to note that the FTB was originally designed, and is still intended to be, a *forecast* product analogous to an NWS Flash Flood Watch, in contrast to shorter-lead *nowcast*-type NWS products such as Flash Flood Warnings or Areal Flood Advisories. In short, the FTB is not meant to be a substitute for the latter.

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 using graphics and text. The graphical component of 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). Scroll over features on the maps will pop up relevant maximum rain rates and potential hazards by threat level for each of the threat areas drawn (not shown). All FTB forecasts issued for the season are available at the bottom of the product's page using a calendar search, and past forecasts (prior to 2023) are available through Dewberry.

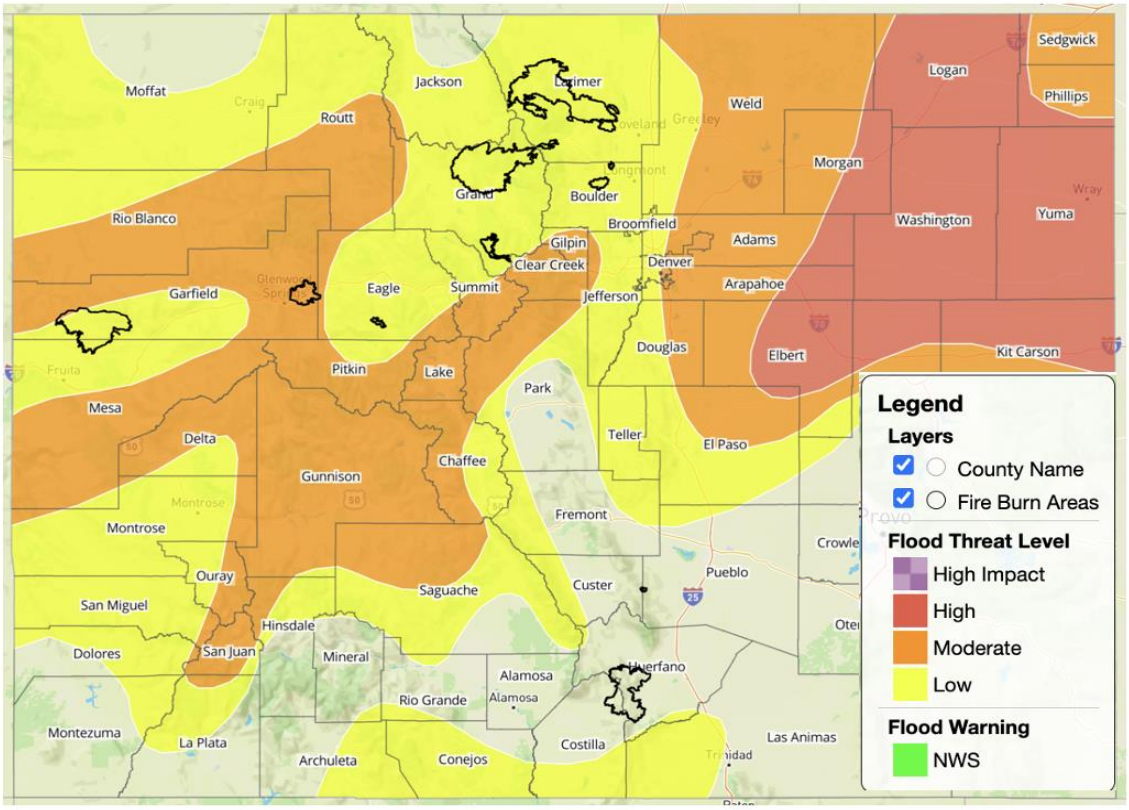

Figure 1: Example of the FTB map from August 13, 2024. The Low, Moderate and High threats are highlighted in yellow, orange, and red, respectively. Verification for this day can be found on Figure 15.

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 (May/June) and precipitation-driven flood threat, and it provides a precipitation forecast map, by event, for the entire state when meaningful precipitation is expected. Each event's precipitation map is available via a drop-down menu as a visual aid to the forecast discussion. The FTO continues to be structured in an event-based manner, where rainfall is partitioned by its meteorological forcing features and presented in a timeline at the top of the product's page.

An example of a threat "timeline" is shown below in Figure 2 from June 6th. This FTO includes a snowmelt riverine flood threat forecast, which peaked at the statewide scale in the beginning of June this season. On the first Thursday of each month, an additional climate-related analysis describing the previous month's precipitation is provided within the FTO. The focus is on the precipitation anomaly and sometimes includes graphics such as Snow Water Equivalent (SWE), percent of normal, changing drought conditions, and reservoir storage. Similar to FTB, past forecasts are available at the bottom of the page by use of a calendar, and past forecasts (prior to 2023) are available through Dewberry.

Next 15 Days	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
	07-Jun	08-Jun	09-Jun	10-Jun	11-Jun	12-Jun	13-Jun	14-Jun	15-Jun	16-Jun	17-Jun	18-Jun	19-Jun	20-Jun	21-Jun
Precipitation	Event 1	Event 1	Event 1	Event 1			Event 2	Event 2	Event 2			Event 3	Event 3	Event 3	Event 3
Snowmelt															

No Apparent Threat | Elevated Threat | High Threat

Figure 2: Example of an FTO "timeline" from June 6, 2024, illustrating the flood threat and 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 begins with Multi-Radar, Multi-Sensor (MRMS) Pass II QPE available from the National Severe Storms Laboratory (NSSL) and is gauge-adjusted with 24-hour accumulations from the Community Collaborative Rain Hail and Snow (CoCoRaHS) network.

Making sure the Program has the highest quality QPE and gauge-based precipitation observations is essential for post-storm assessment, tracking flood events, and assessing antecedent soil conditions that can influence the FTB forecast. It should be noted that the objective of the SPM is to provide a near real-time (i.e., very short lag time) look at precipitation accumulation across Colorado. This comes at the cost of introducing a possible QPE bias 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.

In addition to QPE, automated data pipelines pull and store daily flood and heavy rainfall reports from the NWS using Iowa Environmental Mesonet (IEM). The NWS does not generally provide durational context to these heavy rain reports, so reports less than 0.5 inches are manually removed from display. The Team also manually identifies flood reports, for example those from Colorado Department of Transportation (CDOT) or social media, which are also stored in the Team's database. Additionally, heavy rain reports are also computed from any 24-hour CoCoRaHs gauge accumulation that exceeded that 10-year 24-hour average recurrence interval precipitation from CO-NM REPS. This helps provide greater context on heavy rain days as NWS heavy rain reports are infrequent and irregular, but is limited by the 24-hour duration, though accumulations are likely less than 24-hours. All heavy rain and flood reports can then be displayed on the web map as shown by the blue and green dots in Figure 3.

Lastly, meteorologists and hydrologists provided text-based summaries of recent hydrometeorological conditions including contextualizing extreme rainfall totals, severe weather, and wildfire activity. Discussions are also supplemented with gauge data from CoCoRaHS, Cooperative Observer Program (COOP), Mile High Flood District's ALERT, and Snow Telemetry (SNOTEL) networks, which are not always supplied from the data pipelines. The Program continues to allow anyone to report flooding through the "Report a Flood" tab located at the top of the website, however it was only utilized once during the 2024 season.

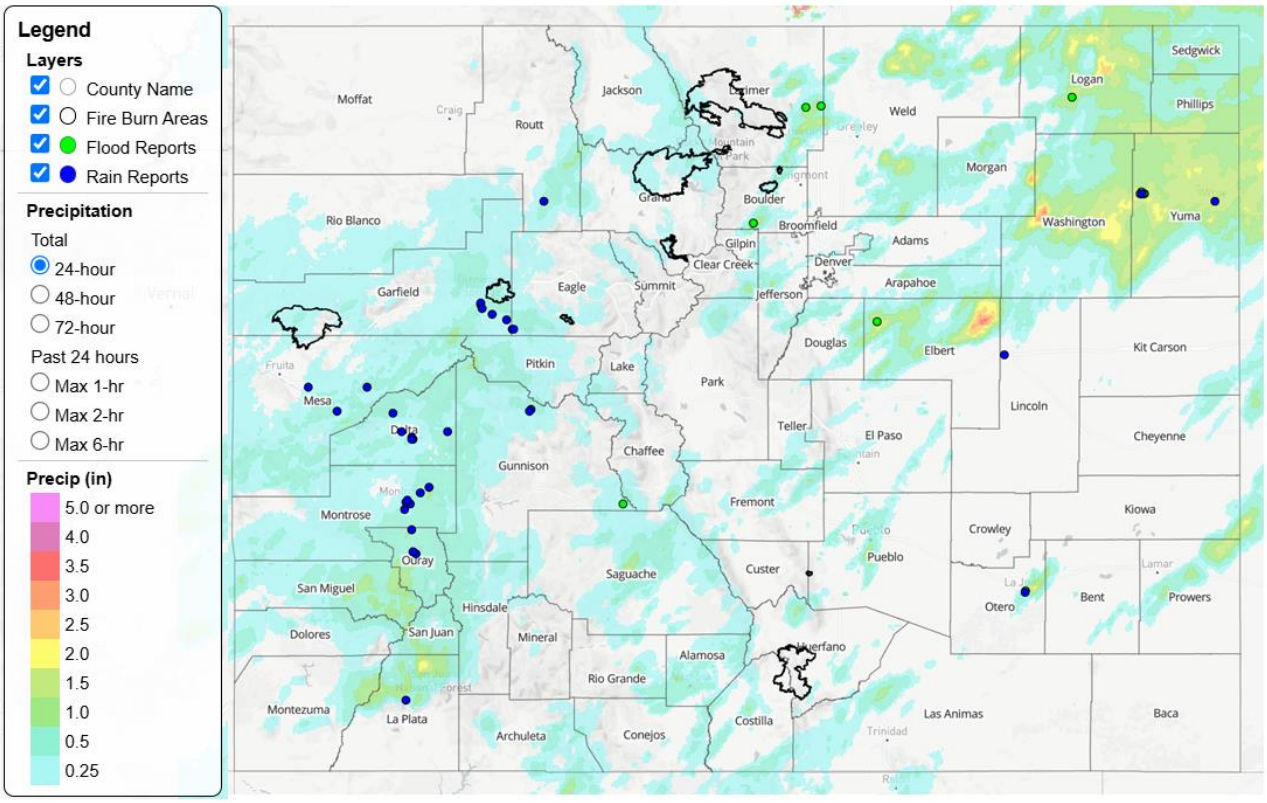

Figure 3: Example of SPM from August 14th, 2024, showing the previous day's precipitation, flood reports (green) and heavy rainfall reports (blue).

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. Since roughly 1980, Colorado has experienced an increasing trend in wildfires exceeding 10,000 acres (HMC and Dewberry, 2022). During the 2020 wildfire season alone, Colorado experienced three of its largest fires on record with a total of seven fires exceeding 10,000 acres in size. While burn areas continue to recover each season, they still produce enhanced flooding hazards, frequently with much lower rain intensity, during heavy rainfall events. Due to the stark difference between runoff sensitivity over burn areas compared to nearby unscarred areas, the 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.

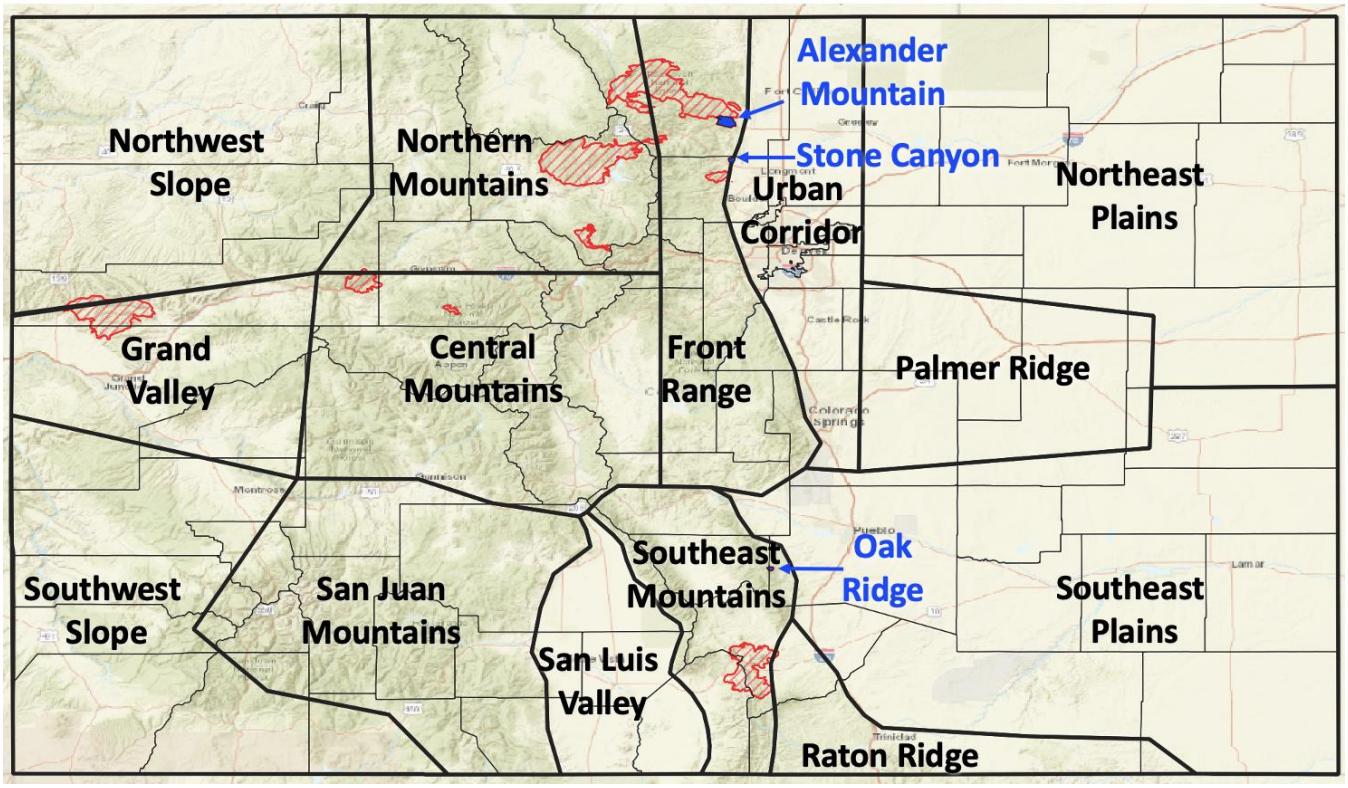

Figure 4: Forecast zones and wildfire burn areas (red hatch) that were featured on the daily FTB and FBF maps for 2024. In solid blue are three new burn areas that were added to the FBF on August 10, 2024. Source: National Interagency Fire Center

This forecast season, the Team and CWCB Program Manager initially identified and monitored the 9 potentially dangerous burn areas in the FBF (Figure 4): Calwood (year of fire: 2020), Cameron Peak (2020), East Troublesome (2020), Grizzly Creek (2020), Pine Gulch (2020), Spring Creek (2018), Sylvan (2021) and Williams Fork (2020). With a drought worsening along the Front Range and a very early season melt out for the San Juan Mountains, the fire season this summer picked up by June/July. In early August, there were three new burn areas that were deemed a safety hazard to the public. So, on August 10th, the Alexander Mountain, Stone Canyon and Oak Ridge burn areas were added to the FBF table for the remainder of the season. Fortunately, there was only one (minor) debris flow this season. It was associated with the Alexander burn area prior to adding the burn area to FBF.

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 FBF: 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. Similar to the FTB and FTO maps, the burn areas are interactive on every Program map, and clicking on a burn area shows the fire's name, year of occurrence, and the number of acres burned.

An example of data displayed in the daily FBF is shown in Figure 5. The product contains both the daily forecast as well as rainfall statistics over each burn area from the prior day. The "Fire Burn Forecast" threat level (Figure 5, left) 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. Burn area rainfall thresholds are set at the beginning of each season and are adjusted prior to the start of the monsoon season, as necessary. There were no adjustments this season due to the lack of rainfall events over the burn areas prior to the monsoon. If the FTB threat overlaps a burn area, the burn area will have at least a 1 tier higher threat issued to show extra sensitivity over the burn area to flood events. More information about the "Post-Season Fire Burn Forecast Threshold Assessment" can be found below.

The “Fire Burn Info” (Figure 5, right) shows three measures of antecedent rainfall for the prior 24 hours 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. The estimates in 2024 are derived from the same MRMS and CoCoRaHS gauge adjustments in the SPM and if there is an over or underestimation by the gridded QPE, values are manually adjusted to gauge measurements in the area. The last column shows an evaluation of whether flooding was reported in the past 24 hours, which is determined from news reports, social media reports, storm reports and personal contacts. The Team still maintains specific contacts for burn area known to have flooding issues, such as Cameron Peak and Spring Creek. The Team added new contacts for the Alexander Mountain and Oak Ridge burn areas this season. To get an idea of forecast performance, the Team 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 Burn Forecast 8-13-2024 | **Fire Burn Info 8-12-2024**

Fire Name	Today’s Threat	Max 3hr (in)	Avg 24 hr (in)	Burn Area Coverage	Flooding Reported
Alexander Mountain	High	0.8	0.3	> 90 %	NO
Calwood	Moderate	0.3	0.1	65 %	NO
Cameron Peak	Moderate	1.1	0.3	> 90 %	NO
East Troublesome	Moderate	0.4	0.1	75 %	NO
Grizzly Creek	High	0.1	0.1	60 %	NO
Oak Ridge	None	0.1	0.1	75 %	NO
Pine Gulch	Moderate	0.4	0.2	> 90 %	NO
Spring Creek	None	0.2	0.1	80 %	NO
Stone Canyon	High	0.1	0.1	40 %	NO
Sylvan	Moderate	0.0	0.0	0 %	NO
Williams Fork	Moderate	0.0	0.0	0 %	NO

Figure 5: An example of data shown in the daily FBF post from August 13, 2024.

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 continued to be provided this season after implementation in 2022. 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 National Resources Conservation Services (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 2024 (updated mid-June). Blue shades indicate values above normal whereas orange shades indicate values below normal. Missing data continues to present a challenge for the product as sites are updated with a varying degree of latency or are sometimes backfilled only once a year. For example, monthly statistics available by mid-month at each site ranged from 86% (May) to 57% (August). The Team reached out to Northern Water to see if the Cache la Poudre could be available during the season (real-time vs. backfilled once a year), but they did not think this was possible due to the complicated nature of the diversion system.

COLORADO STREAMFLOW TRACKER [MAY 2024]

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	49.1	49.8	98%	65	119.0	123.5	96%	62
Cache la Poudre at Canyon Mouth		69.5				113.1		
ARKANSAS RIVER basin								
Arkansas River above Pueblo	53.7	67.9	79%	38	207.3	262.7	79%	23
RIO GRANDE basin								
Rio Grande River at Del Norte	132.9	156.2	85%	35	273.4	308.3	89%	39
NORTH PLATTE RIVER basin								
North Platte near Northgate		64.4				155.3		
COLORADO RIVER basin (NORTH)								
Little Snake River near Lily	122.0	154.3	79%	34		271.6		
Yampa River near Maybell	327.1	379.3	86%	40		675.1		
White River near Meeker	72.0	94.2	76%	23		250.6		
COLORADO RIVER basin (CENTRAL)								
Colorado River near Cameo	524.2	663.2	79%	30	1361.1	1469.2	93%	47
Gunnison River near Grand Junction	280.6	528.2	53%	15	906.1	1177.2	77%	25
COLORADO RIVER basin (SOUTH)								
Dolores River at Dolores	46.4	102.4	45%	8	84.0	176.6	48%	9
Animas River near Durango	77.6	137.9	56%	10	167.8	284.2	59%	7
Los Pinos River near Bayfield	58.7	65.8	89%	40	112.3	129.5	87%	33
San Juan River near Carracas	85.5	129.2	66%	16	189.8	298.7	64%	18
TOTAL		**2528.4**				**5695.7**		

All Units are x1000 acre-feet; Updated: June 13, 2024; Next Scheduled Update: July 15, 2024

HydroMet Consulting LLC

Figure 6: An example of the Streamflow Tracker from May 2024. 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 504 total products delivered, the Team delivered 498 on time or ahead of time. **All 153 FTB products were delivered on time**. Of the five late products, one was FBF and the other 4 were FTOs. Four of the five late products this season were posted within 30 minutes of their deadline with the final late product being posted with 1.5 hours of the deadline. While the lateness of an FTO is not ideal, this product is not as urgent to get out on time as FTB since the forecast period is not over the next 24-hour period. Below, Table 2 shows September performance, since there was no monthly Progress Report prepared, and all other 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 3 weeks after the end of the month. The SPM has one additional product day (154), summarizing conditions for the last day of the season on October 1.

Table 2: On-Time performance metrics for all issued products in 2024 (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	9	9	0	100%		FTO	44	40	4	91%
	FBF	30	30	0	100%		FBF	153	152	0	99%
	TOTAL	**99**	**99**	**0**	**100%**		**TOTAL**	**503**	**498**	**5**	**99%**

In-Season Analysis of Flash Flood Events

To supply rainfall related data after a noteworthy flash flood event, the Team produces in-season, event-based analyses at the request of the Program Manager. The near real-time reanalysis work can be helpful for end-users, particularly emergency management teams. The analyses provide information about the timing of rainfall, magnitude of rainfall, and corresponding peak flows on nearby rivers and creeks, which allows responders better assess similar, future situations and gain insight about other potential flood events across an area. The analyses are disseminated through social media, which allows the Program to engage more end-users, boosts Program viewership, and conveys that the Program is not just about providing forecasts for heavy rainfall.

Since the only debris flow that occurred was insignificant this season, Alexander Mountain on August 7th, there was no specific post-storm analysis requested by the Program Manager. To keep the Program moving forward, the Team took on daily forecasts for three new burn areas from August 10th to September 30thFigure 4. This included Alexander Mountain (near Loveland), Stone Ridge (Lyons), and Oak Ridge (Beulah Valley) (Figure 4). The forecasting threshold used was 0.25 inches in 15 to 30 minutes per accepted United States Geological Survey (USGS) literature on very recent burn scars. To the Team's knowledge, neither of the other burn areas experienced any flooding issues despite the burn areas seeing multiple events within this threshold.

Post-Season Fire Burn Forecast Threshold Assessment

As an effort to keep track of the recovery over each burn area and adjust rainfall intensity thresholds prior to the start of the season, the Team produces a yearly Technical Memo during the off season addressing the FBF thresholds (HMC, 2022 & HMC, 2023). The procedure for the Post-Season Fire Burn Forecast Threshold Assessment uses the same general methodology for post-wildfire burn debris flow forecasting from the latest peer-reviewed literature (e.g., Hoch et al., 2021). The methodology follows that burn areas have high initial sensitivity (<= 1 year after the burn occurred) and over a 3–5-year period after, this threshold begins to recover to the "normal" value of the surrounding terrain.

For each burn area, a two-part analysis is completed. The first part of the analysis is to inform of the long-term net precipitation deficit/surplus over the burn, which serves as a proxy for the vegetative recovery process. For this analysis, a time series of net warm season precipitation accumulation (from the year of the burn) is compared to climatology. An example of this for Cameron Peak is shown in Figure 7. Cumulative anomaly, percent of normal and maximum 24-hour totals over the period are also collected (top left). The second part of the analysis (not shown) informs on the number of hours during the warm season (since the year *after* the burn occurred) where greater than 0.25 inches of rain was estimated using Multi-Radar Multi-Sensor (MRMS) data. This also helps inform on the vegetation's recovery, but this analysis includes a spatial component.

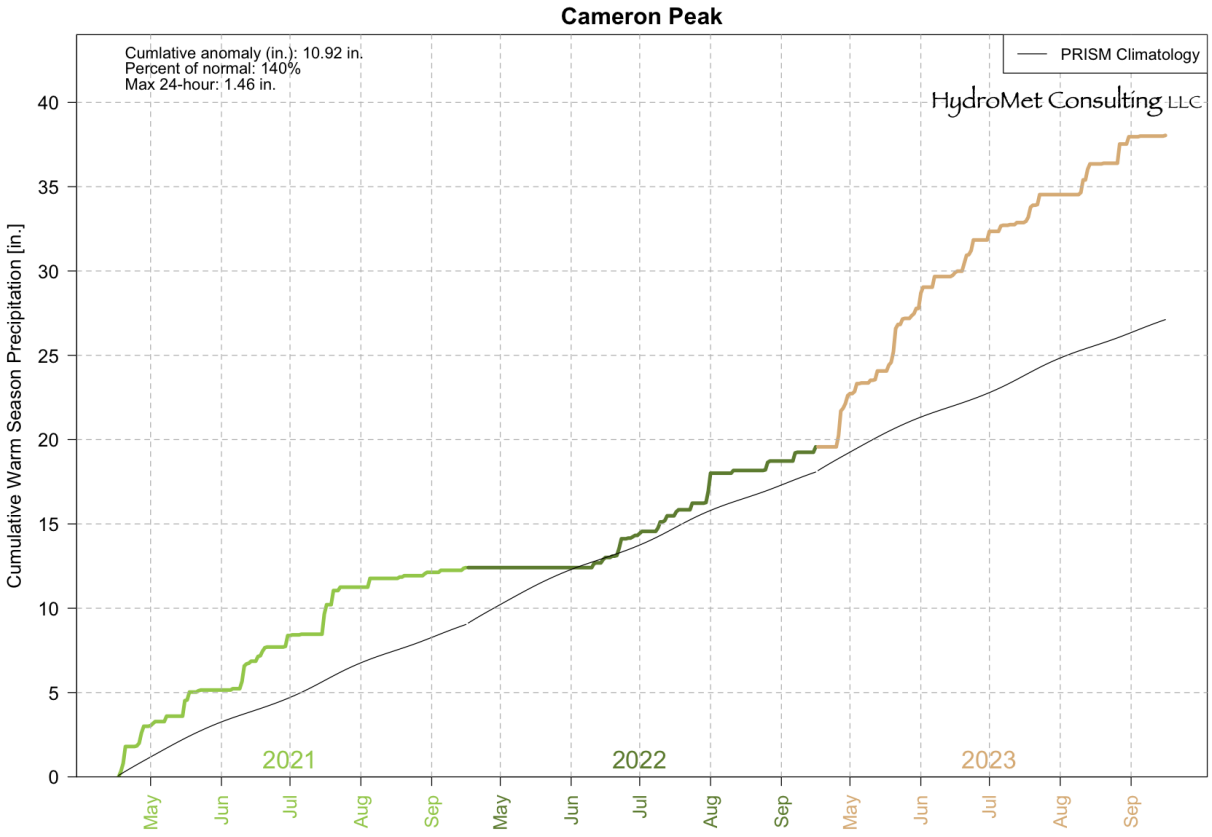

Figure 7. Example of a cumulative warm-season rainfall graphic (2021 green, 2022 dark green, 2023 tan) over the Cameron Peak Burn area as compared to normal (black line).

Assessments and recommendations are then presented in the preseason to the CWCB Program Manager. Adjustments to thresholds are finalized with input also received from Emergency Managers prior to the start of next season. As expected, the rainfall intensity thresholds utilized in the FBF product either stay the same or increase each season. Table 3 shows the 2024 forecast thresholds for each of the burn areas. While the thresholds listed are in inches per hour (to match the Team's internal guidance as well as gridded rainfall estimates), the assumption is that most rainfall accumulation occurs in a 15 to 45-minute period. For the thresholds given below, the bottom four burn areas (green) match the Program's 1.0 inch per hour threshold over mountainous terrain. However, unlike FTB, there is no areal coverage of rainfall rates that need to be met to issue a FBF threat. Additionally, if one of these four burn areas is included in the FTB threat map, the FBF forecast threat level is raised one category (e.g., Low up to Moderate). As previously mentioned, forecast thresholds may be adjusted prior to the onset of the monsoon, but only with CWCB Program Manager approval and after being tested by a variety of intense rainfall events. No thresholds were changed mid-season in 2024.

Table 3: Fire burn area thresholds used for 2024 forecast operations.

Burn Area Name	Year of Fire	Acres Burned	Forecast threshold (inches/hour)
Alexander Mountain	2024	9,969	0.25
Oak Ridge	2024	1,557	0.25
Stone Canyon	2024	1,309	0.25
Cameron Peak	2020	208.912	0.75
East Troublesome	2020	193,811	0.75
Grizzly Creek	2020	32,431	0.75
Calwood	2020	10,114	1.00
Pine Gulch	2020	138,803	1.00
Spring Creek	2018	108,131	1.00
Sylvan	2021	3,792	1.00
Williams Fork	2020	14,833	1.00

2) CHARACTERIZATION OF FORECAST PERIOD WEATHER

Overview

The northern half of the state began the season on May 1st with around median snowpack, 93-104% of normal median (Figure 8), and largely drought free across the majority of the Northwest Slope, Northern and Central Mountains, Front Range, Urban Corridor, and Northeast Plains (Figure 9). The southern half of the state began the season with below median snowpack – only 71-77% of normal median and as low as 57% of normal median in the Upper Rio Grande (Figure 8). However, it is important to note that this is the result of rapid snowmelt which took place before the season began in April. Small portions of the Southeast Plains, Northwest and Southwest Slopes, Grand Valley, San Juan and Southeast Mountains, and San Luis Valley entered the season with D1-Moderate Drought conditions, with widespread D0-Abnormally Dry conditions extending through the Grand Valley, Southwest Slope, San Juan Mountains, San Luis Valley, as well as portions of the Southeast and Central Mountains, Palmer and Raton Ridges, and Northeast and Southeast Plains (Figure 9).

The 2024 operational season saw multiple significant rainfall events across the state but was noticeably less active than the previous year. A list of five significant events reported this season is shown in Table 4. These events are chronologically ordered and were selected for having both widespread impacts and various locations across the entire state, providing a snapshot of headlines throughout the season.

The North American Monsoon (NAM) showed a pattern of ups and downs throughout this season. The NAM became active in late June, and although August was quite significant, many typical areas of monsoon rain (mountains and adjacent ridges) saw drier than normal conditions throughout July and September (Figure 10) Figure 5 shows this season's monsoon statistics for Colorado's major basins and illustrates the spatial difference in NAM's precipitation across the state; for example, the Upper San Juan basin received up to 171% of average monsoon season precipitation while the South Platte saw only 76% of average.

As the season ended, the Southwest Slope, San Juan Mountains, and San Luis Valley were completely drought free, as well as large portions of the Grand Valley and Central mountains, all thanks to the wetter than average months of June and August. On the other hand, portions of the Northwest Slope, Northern Mountains, Front Range, Urban Corridor, Palmer Ridge, and Southeast Plains experienced mostly below average precipitation this season, causing D1-Moderate drought conditions for some of these areas. D2-Severe drought conditions also existed around along the Urban Corridor and Front Range, especially the Denver metro area, as well as parts of the Southeast Plains at the end the season.

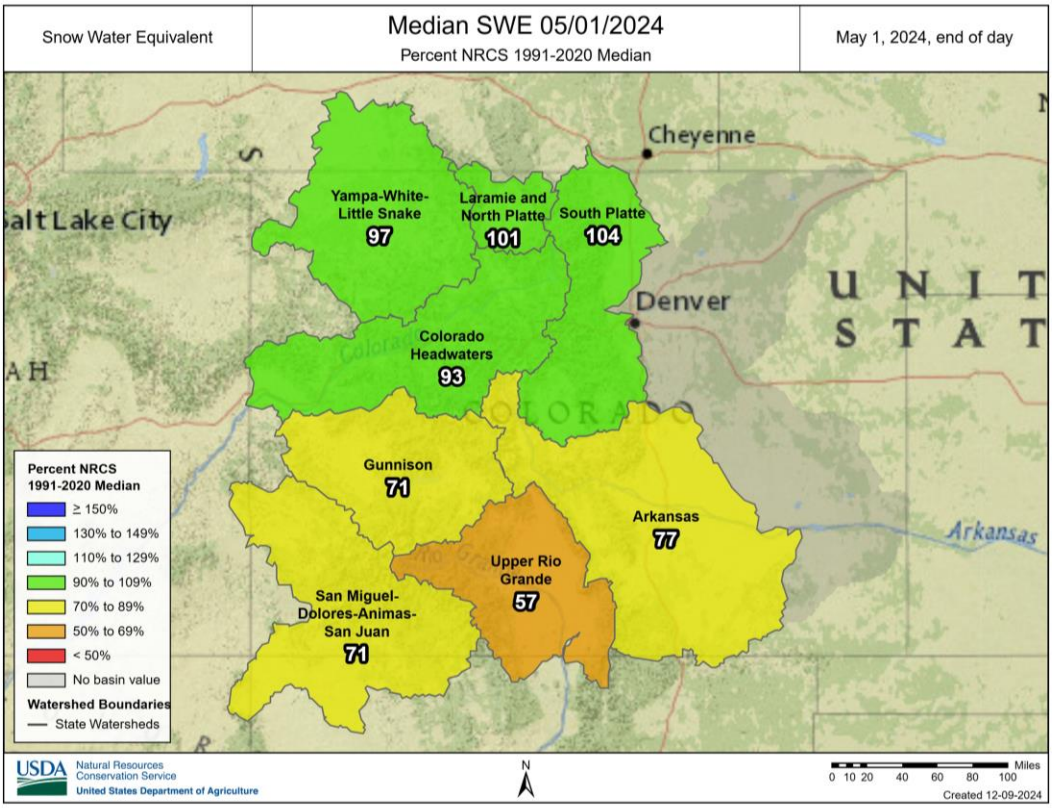

Figure 8: Percent of Median Snow Water Equivalent on May 1, 2024. Source: NRCS

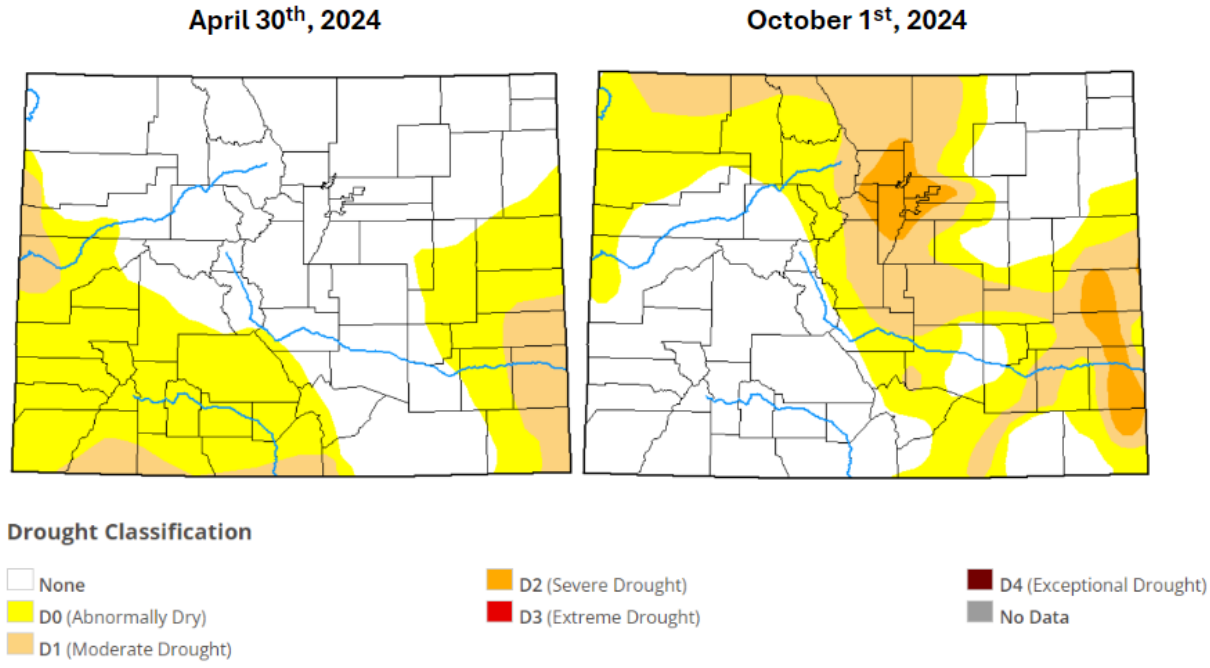

Figure 9: US Drought Monitor update valid on April 30, 2024 (left) and October 1, 2024 (right), showing the drought conditions at roughly the start and end of the 2024 season. Source: The U.S. Drought Monitor.

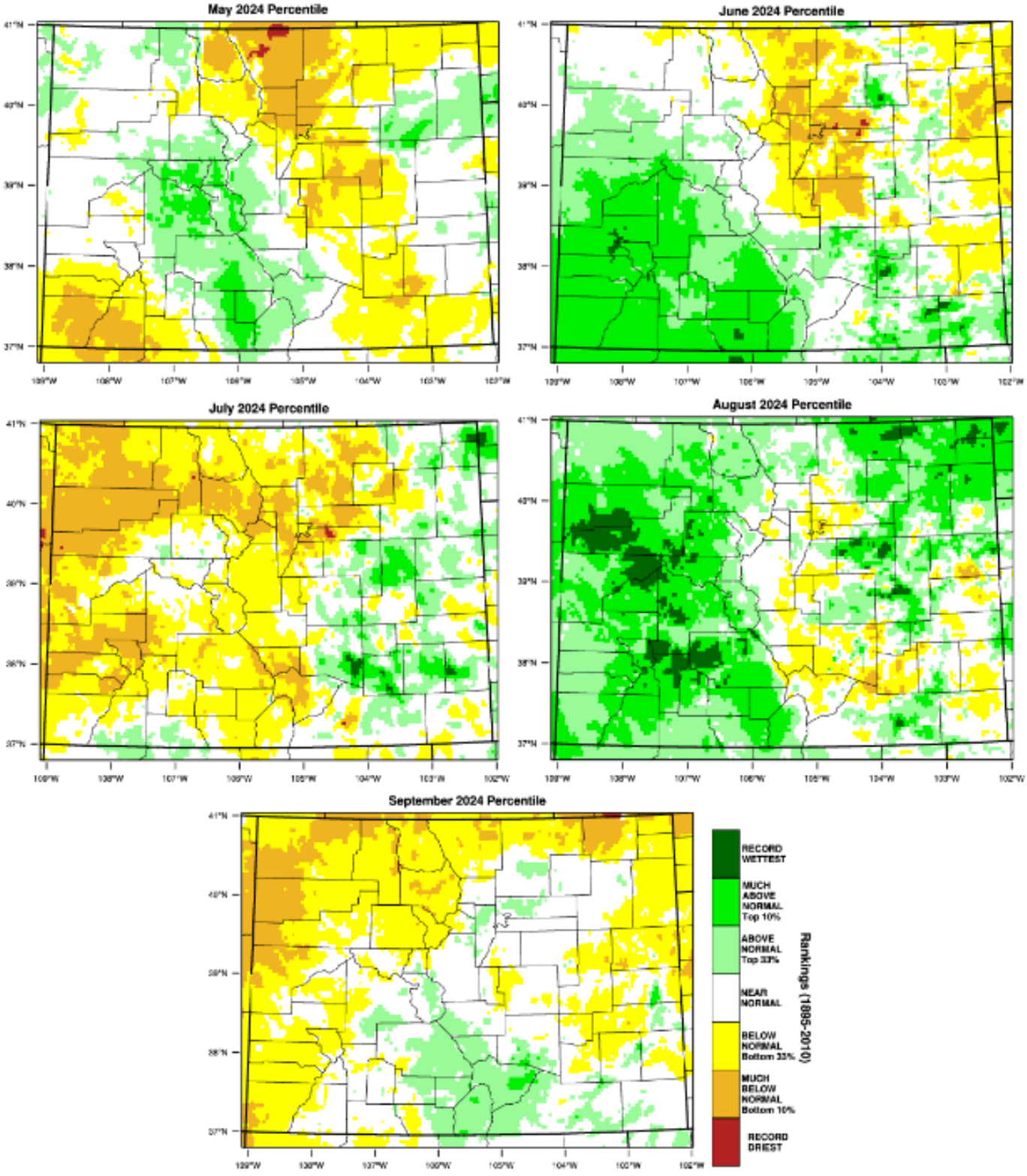

Figure 10: Monthly precipitation anomalies (PRISM) ranked by percentile for May-September 2024. Source: WestWide Drought Tracker.

Table 4: Five impactful flood and rain events over the 2024 forecast season, in chronological order.

EVENT	DATE (S)	INTENSITY	IMPACTS
Northeast Plains flooding and hail	May 20th, 2024	2.5-3 inches near Yuma within 2 hours, up to 3-inch hail	Flash flooding and hail caused severe damage to homes and cars. Several water rescues were made.
Greeley flooding	May 28th, 2024	3.96 inches reported in the Greeley area in roughly 2 hours	Severe flooding of homes and roads. Several water rescues were made. 1 death was reported along with multiple injuries.
Logan County heavy rainfall and flooding	June 1st, 2024	4.27 inches of precipitation in a 24-hour period	Several reports of street flooding and several feet of water over roads
Heavy widespread rainfall on Eastern Plains	August 12-13th	20 flood reports over 2 days, 4 inches of precipitation in under 3 hours in Brush and south of Limon	Widespread flash flooding, closure of CO 71, widespread flash flooding in Brush, Highway 59 reported to have over 3 ft of water covering it.
Ouray heavy rainfall and debris flow	August 5th-15th, 2024	Isolated areas of up to 5 inches in this 10-day period, with up to 4" over the heaviest 72-hr period	Multiple debris flows on August 11th at the end of the heaviest 72 hours of rainfall. Ouray County state of emergency declared on August 14th for extensive damage within the county and towns of Ouray and Ridgeway.

Table 5. Monsoon extremes statistics at long-term NRCS stations for each of the major sub-basins in Colorado. Stations are sorted alphabetically.

Station	Basin	Driest Year	Driest Year Total (in.)	Wettest Year (in.)	Wettest Year Total (in.)	2024 Precipitation (in.)	Period of Record	Average Precipitation (in.)	2024 % of Average
Apishapa	Upper Arkansas	1987	3.2	1981	16.5	14.2	1981-2024	9.37	152%
Beartown	Rio Grande Headwaters	2019	2.8	1999	18.7	11.9	1983-2024	10.99	108%
Deadman Hill	South Platte	2016	2.2	2004	10.5	5	1979-2024	6.55	76%
Elk River	White-Yampa	2020	2.6	1997	10.9	6.2	1979-2024	6.35	98%
Lone Cone	Upper Colorado-Dolores	2019	2.9	2006	14.7	9.4	1981-2024	9.28	101%
Lynx Pass	Colorado Headwaters	2018	2.3	1984	10.4	6.5	1981-2024	6.15	106%
Roach	North Platte	1994	1.9	2004	19.1	6.9	1981-2024	7.24	95%
Slumgullion	Gunnison	2011	3.4	1982	11.9	10.4	1981-2024	7.44	140%
Vallecito	Upper San Juan	2019	2.3	1999	22.3	17.3	1987-2024	10.12	171%

Detailed Summary

May

The flood threat was minimal the first half of the month of May thanks to limited and low-intensity precipitation. On May 15th, a shortwave and an associated cold front moved through the state, bringing strong thunderstorms and the first flood reports of the season. The strongest storms were focused along the Urban Corridor and Southeast Plains, bringing up to 1.79 inches of precipitation to Rye, most of that falling in just a few hours. Street flooding was reported in nearby Colorado Springs and in Crowley after the intense storms moved through.

Active weather continued May 18th-21st as a trough, along with increased instability and moisture, brought days of intense storms to the Northeast and Southeast Plains. On the 18th, storms over the Southeast Plains flooded US287 near Eads, causing it to close. The worst impacts came on the 20th after intense supercell storms moved through Washington and Yuma counties, with the town of Yuma receiving the brunt of impact. Hailstones as large as 3 inches were recorded with the severe storms and 2.78 inches of rain fell near Yuma, again most of that within a couple hours. The storms left several feet of water in the roads of Yuma, causing water rescues and leaving some vehicles floating. While the rainfall itself wasn't overly impressive, several inches to feet of hail accumulated on the ground, causing severe street flooding.

At the end of the month, another mid-level trough and accompanied cold front brought intense storms and significant flooding. On the 28th, an extremely intense storm developed over Greeley during the late evening hours. The nearly stationary storm dumped an immense amount of rain over the area. Precipitation observations in the area were as high as 3.96 inches, most of that falling in just a few hours. 3.96 inches in 6 hours or less has just a 0.11% annual chance of occurrence in Greeley, according to precipitation frequency estimates from CO-NM REPS. As expected, significant flooding was reported including several flooded buildings downtown and road closures. Tragically, one person was found dead, and another was seriously injured from storm-related injuries in Greeley. Hail stones greater than 2 inches were also reported with the storm. The next day, more severe storms moved across the Northeast and Southeast Plains, causing a stream of mud and hail to flow across County Road 3z in northern Lincoln County. QPE suggested up to 2.5 inches in the area fell in just 2 hours.

June

A mid-level trough over the western U.S. set up an active start for June, with intense rainfall and flooding on the Eastern Plains for the first 2 days of the month. On the 1st, in Logan County, a severe storm quickly dumped several inches of rainfall, with a CoCoRaHS observer in Sterling reporting 4.27 inches of precipitation in a 24-hour period. That amount has just a 0.3% annual chance of occurrence – and most of that precipitation fell in an even shorter duration, around 3 hours. Several reports of street flooding were reported in Sterling, including photos posted to social media showing several feet of water covering roads in town. On the 2nd, more severe storms were scattered across the Eastern Plains, including in southern Yuma County, where 1.30 inches of precipitation fell in just 40 minutes. Minor field flooding was reported nearby with several inches of water running alongside a county road in the area.

A cut-off low combined with a shortwave began to funnel ample moisture into the state, once again elevating the flood threat from the 8th-10th. The 8th saw the worst flooding of the 3-day stretch, with severe storms on the Northeast Plains causing 10 flood reports from Wiggins to Burlington. Most of the flood reports involved road flooding and closures, including US 24 near Burlington. Extreme flooding of fields was also noted in Washington County, where 2.25 inches of precipitation was recorded in just a few hours. On the 9th, the flood threat shifted west, where the more intense storms and flooding occurred for the Urban Corridor this season. Near Parker, a severe storm dumped over 3 inches of rain, causing flash flooding which swept cars down streets in the area. Nearby Cherry Creek and Plum Creek both quickly rose into minor flood stage caused by the short, intense burst of rainfall. To the South, portions of I-25 were flooded in Pueblo after an intense storm. After passage of the low, a building ridge brought several days of elevated temperatures which accelerated snowmelt and pushed streams and rivers to flood stage, particularly the Arkansas River. A search and rescue occurred along the river near La Junta due to the dangerously high-water levels on June 12th.

For the second half of June, the heaviest rainfall largely occurred in the western half of the state. On the 20th, an upper-level trough to the west fed moisture into the state, bringing storms and flooding from the Western Slope to the Urban Corridor. West of Salida, a debris flow occurred on US 50 after storms in the area. In Grand Junction, a strong storm dumped over an inch of rainfall, causing 6-8 inches of water to run along streets and parking lots in town. To the east, strong storms also impacted the Urban Corridor, with minor street flooding reported in Broomfield and several inches of water flowing across County Road 29 near Eaton. Just a couple days later, Highway 64 west of Meeker was forced to close due to a debris flow after a storm quickly dumped 1 inch of precipitation.

As the month wrapped up, monsoon-like conditions brought heavy rainfall to widespread areas west of the Continental Divide. In the afternoon on the 27th, a cluster of strong storms entered the state and caused a swath of Flood and Flash Flood Warnings in its wake. One CoCoRaHS observer impacted by the storms in southwest San Miguel County noted "major flooding" and that water covered the ground at their location. Glenwood Springs experienced flooding on the 29th, with street flooding noted in downtown. The heaviest rain from the day was located on the Southeast Plains, where over 4 inches of precipitation fell near Walsh, though no flood reports were found in the area. On the last day of the month, Glenwood Springs experienced more heavy rain, including minor flooding in the town and debris flows just north of town; the Grizzley Creek burn area was not impacted.

July

Picking right up where June left off, July began with a trough and daytime heating leading to heavy rain and flooding. On the 1st, showers and storms west of the Continental Divide caused a debris flow along Highway 133 near Redstone. On the 2nd, La Junta experienced 1.5 inches of precipitation in just 2-hours, which pushed the Arkansas River back into minor flood stage in the area. Continuing east, the same storms brought down powerlines and caused flooding along US 50 in Manzanola. Hail accompanied the heavy rainfall threat on the 3rd, with storms producing 3-inch diameter hail northwest of Limon and 1.75-inch hail in Lincoln County. Storms continued to cause issues again for the Eastern Plains a few days later on the 6th and 7th. An intense storm tracked through rural Bent and Prowers Counties on the 6th, with rainfall estimates of 4-5 inches in 24-hours based on QPE. No flood reports were recorded on the 6th, likely due to the rural nature in the storm's path. On the 7th, US 50 in Manzanola was flooded once again after severe storms moved through.

Conditions calmed down until mid-month, when another trough and associated cold front brought another stretch of active weather. Strong storms impacted the Front Range and Urban Corridor on the 15th, with one CoCoRaHS observer in Westminster observing 0.77 inches of precipitation in a 15-minute period. Minor street flooding was also reported in the area. On the 16th, the Northwest and Southwest Slopes experienced strong storms which caused flash flooding in Moffat County and a debris flow west of Telluride, which closed CO 145. On the 18th, the same area along CO 145 was impacted by 4 separate debris flows, closing several miles of the road. Also on the 18th, minor flooding was observed in Colorado Spring and Estes Park with heavy rain causing hillside soil erosion, leading to soil/stone debris on a road.

Another round of elevated moisture and a trough caused consecutive flood days from the 20th through the 22nd. The flood threat on the 20th was focused along the Urban Corridor with several reports of flooded roads in Denver and Colorado Springs. The flood threat was more widespread on the 21st, with flood reports from the Southwest Slope to Southeast Plains. Durango received up to 1.20 inches of rain after an afternoon storm, causing a debris flow on Highway 550 which reduced traffic to one lane. Near Avondale, farm fields were flooded with 1-2 feet of water after 1.94 inches of precipitation fell in around an hour. The 22nd saw another debris flow on the Southwest Slope, this time on CO 151 between Pagosa Springs and Arboles. A few days later on the 26th, strong overnight storms caused yet another debris flow on Highway 133 south of Carbondale, closing it in both directions. After the 26th, high pressure built in to close out the month bringing record high temperatures and dry conditions. Several fires took advantage of this environment, especially along the Front Range, which led to evacuations and smoky skies for much of the state.

August

Fires along the Front Range were the main weather story to start the month as hot and dry weather continued into August, though the flood threat persisted. On the 4th, subtropical moisture brought heavy rain to western portions of the state which caused debris flows in Georgetown and Carbondale. A few days later on the 7th, the NWS issued a rare Flash Flood Emergency for the still burning Alexander Mountain fire after strong afternoon storms brought brief but heavy rain. A minor debris flow was reported along Highway 34 on the southern edge of the burn area; the only debris flow reported on a burn area this season. Thankfully, this was the only reported debris flow over a burn area this season.

From the beginning to the middle of the month, the NAM began to cause a very active weather pattern. There were several days of heavy rainfall and significant flooding from the 9th to the 13th. The flood threat stayed mostly west of the Continental Divide on the 9th through 11th, with 8 debris flows recorded in that 3-day period. Ouray County experienced the worst impacts and experienced multiple debris flows, resulting in County Emergency declaration, text from the declaration is below.

"Ouray County has received significant moisture due to monsoonal events commencing August 5, 2024 that have caused and have continued to cause flooding, debris flow and mudflow activities. Such activities include but are not limited to County Road 17 washout and closure affecting access and loss of an important emergency evacuation route northbound from Ouray towards Ridgway; mudslides and rockslides across County Road 23; debris removal from Amphitheater and County Road 361. Other areas of the county are experiencing saturation of agricultural fields and pastures, flooding and mudflow into homes and other structures. The City of Ouray has experienced damage at Bridal Veil Bridge, Fedel Court, Skyrocket and Oak Creek; and the Town of Ridgway has suffered damage at their headgates which feed into the reservoir." – Ouray County Emergency Disaster Declaration, August 14, 2024

The flood threat shifted eastward on the 12th and 13th, with severe storms causing numerous flood reports across the Eastern Plains. On the 12th, two separate intense storms dropped 4" of precipitation in under 3 hours in Brush and south of Limon, based on QPE. Widespread flash flooding was reported in Brush and CO71 was forced to close south of Limon. On the 13th, Yuma experienced extremely intense rainfall with an estimated 3ft of water reported on roads in the town and nearby Highway 59 was described as a river due to the large amount of rushing water on the road. An additional 3 more debris flows to the west were also tallied during this stretch.

August ended with another stretch of active heavy rain days from the 19th to 26th; widespread flooding was reported in Colorado Springs, as well as closure of Highway 36 in Adams County on the 19th. On August 22nd, 4.75 inches of rain fell in Burlington, the highest CoCoRaHS observation of the season, and rural Raton Ridge/Southeast Plains saw up to 4.5 inches of rain on the 26th. In total, 60 flood reports were recorded during August, including 17 debris flows – the highest month of the 2024 season.

September

The season calmed down drastically in September with only three flood reports during the entire month. The first flood report occurred on the 11th, where a CoCoRaHS observer reported minor flooding in Steamboat Springs following an afternoon thunderstorm. The other two flood reports occurred on the 17th after a line of showers and storms brought widespread rainfall and gusty winds to the state; both reports involved minor flooding on US160 north of Pagosa Springs. While most days with precipitation in September saw only isolated/scattered diurnal showers with limited intensity, there were a few exceptions, including on the 16th and 21st, which both saw widespread long-duration rainfall across south-central portions of the state. Several observations from those days exceeded 1", but intensity was generally lighter, which limited the flood potential. September ended with a stretch of hot, but quiet weather.

Seasonal Stats

There was a total of 57 Flood Days over the 2024 forecast season, which is below the 2012-2023 average of 67 Flood Days. 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 14). Also overlaid is the estimated areal extent of precipitation that exceeded one inch, measured by Stage IV gridded precipitation. There were 44 (12) days in total where at least one station measured at least one (two) inch over eastern Colorado and 69 (20) days over western Colorado. These numbers are down compared to last season, especially east. Typically, when there is a large areal extent and several gauges either east and west (or both) over 1 inch, one can interpret this as large-scale rainfall event. An example of this is on June 20th, where central and southwest portions of western Colorado saw heavy rainfall. The graphic can also distinguish events that are more rural in nature. That is when the Flood Day area is a higher end value, but the gauge count is low, such as May 9th. This was a flood event confined to the San Luis Valley and Southeast Mountains. One limitation 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 issues. Finally, it's worth pointing out in Figure 10 that the NAM this season was nearly nonexistent in July, which is atypical for the state, especially for the eastern half of the state. The NAM began to get very active in early August with traces of the NAM into late August, which is later than typical. Thankfully much above average June rainfall over western Colorado helped to temper the wildfire season after an early melt out of the snowpack over the central and southwest portions of the high terrain.

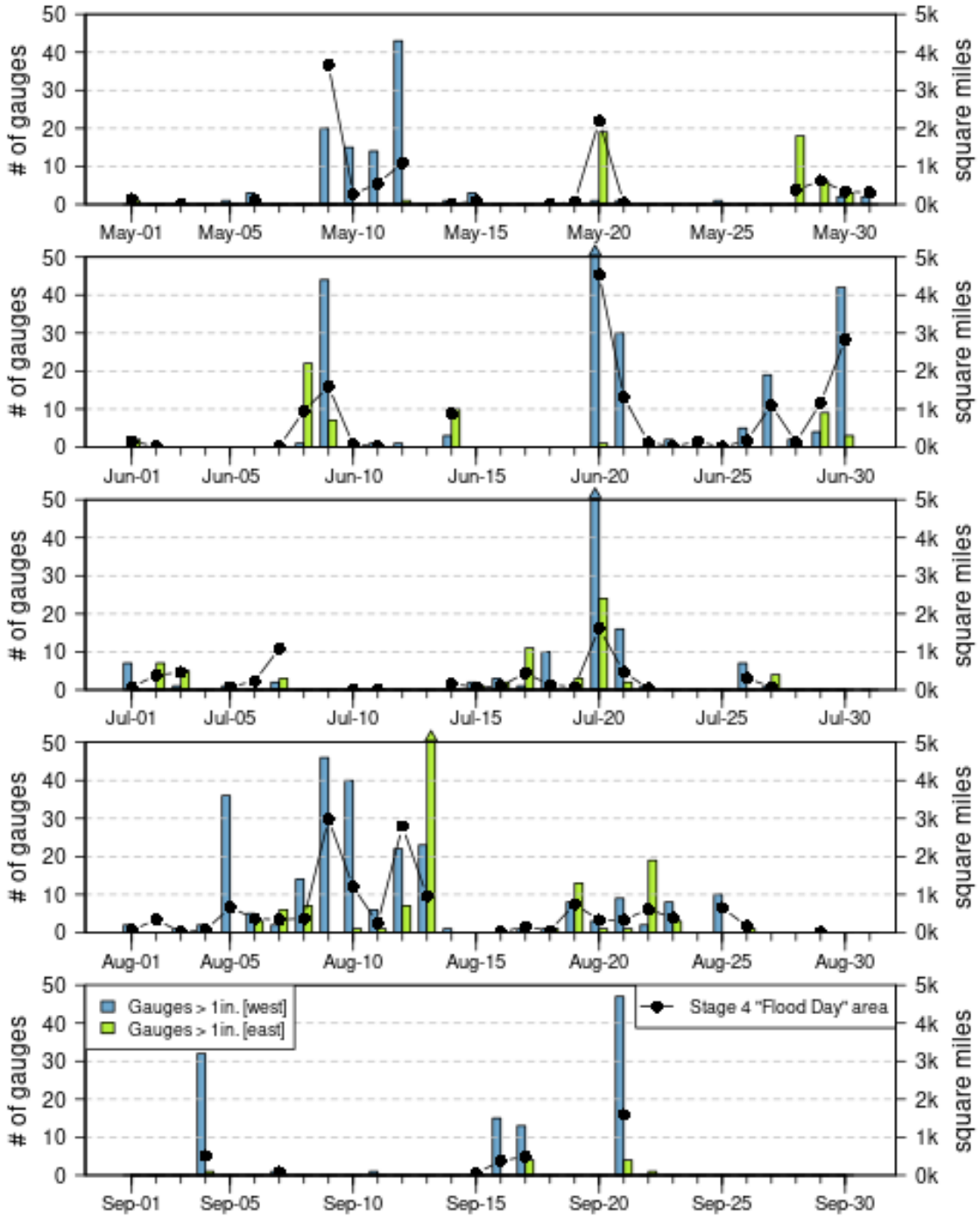

Figure 11: Daily summaries of number of gauges exceeding 1 inch of precipitation over "western" (blue) and "eastern" (green) areas. See Figure 14 for demarcation of these areas. A blue or green triangle indicates more than 50 gauges measuring 1 inch. See Appendix A for more detailed daily gauge statistics. 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 an area in excess of 5,000 square miles. The total area of Colorado is 104,000 square miles.

There was a total of 130 individual flood reports this season, down significantly from 2023. This is not surprising due to the fact widespread flooding events were far and few between, and July experience below to much below normal precipitation of most of the state. Flood reports this season came from various sources including NWS Local Storm Reports, CoCoRaHS observation remarks and significant weather reports, social media, and CDOT. August saw the greatest number of flood reports this season, coinciding with the most active period of the NAM, and was the only month this season that had more flood reports than 2023 (Figure 12). Flood reports spanned across nearly all forecast zones, excluding the Raton Ridge, Southeast Mountains, and San Luis Valley did not record any reports despite seeing several flood days.

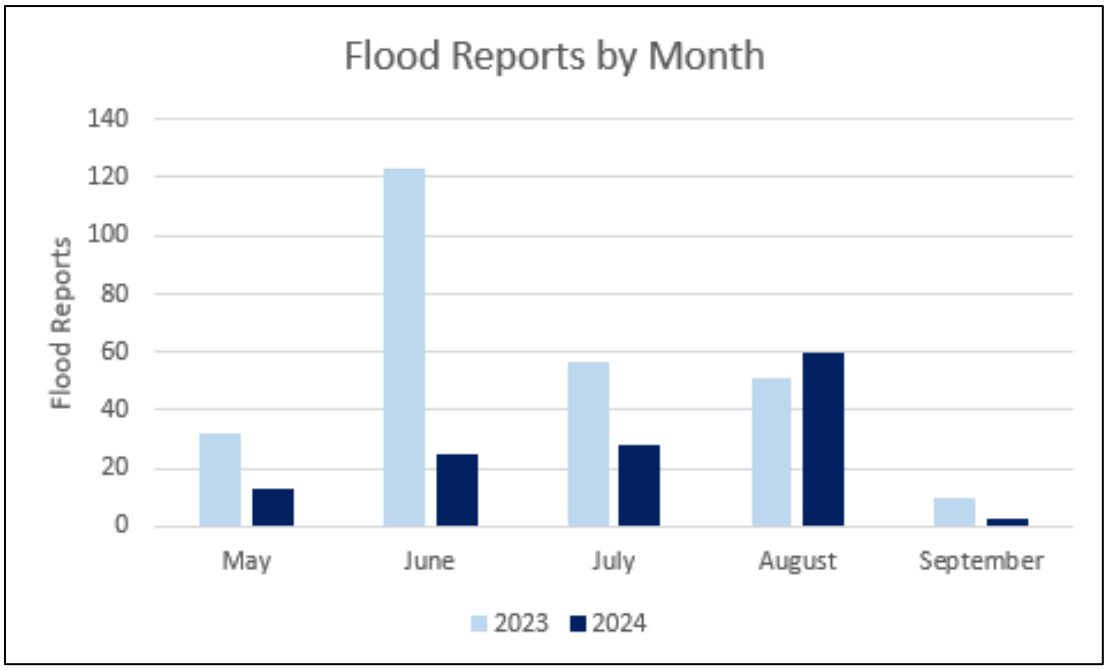

Figure 12:Total number of reports for each month in the 2024 season are as follows: May- 13, June- 25, July- 28, August- 60, and September- 3. August saw the greatest number of flood reports this season, at 60 total reports. With the ongoing flood database, this

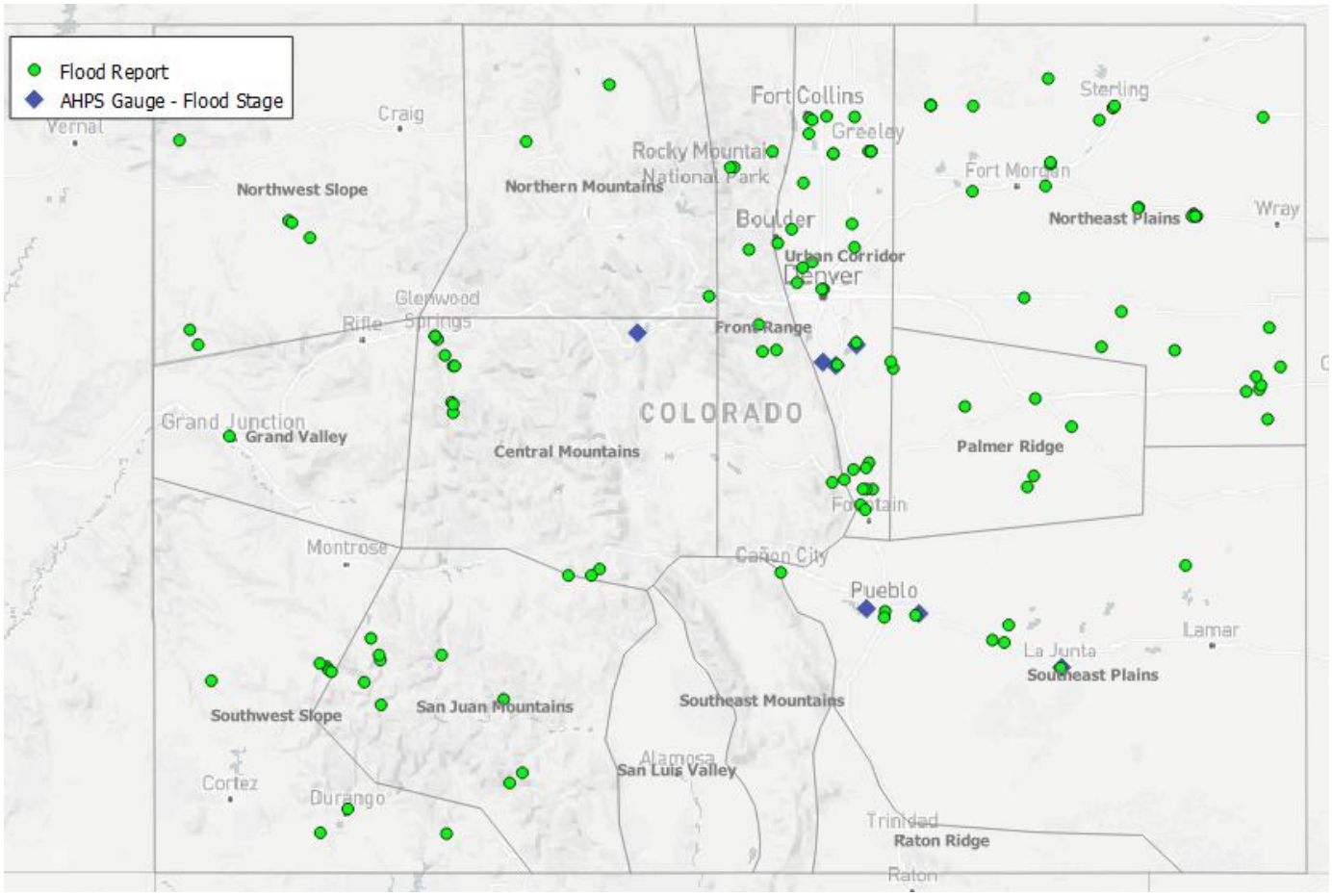

Figure 13: Map of all flood reports within the state from May 1 – September 30, 2024.

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 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 2024 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 relating to rainfall intensity 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 preliminarily defined when at least one of following three criteria is met in or in close proximity to the issued flood threat area (e.g., Figure 15):

1. Gridded or observation-based 1-hour and 2-hour rainfall exceeds (see Figure 14):
    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. Gridded or observation-based 24-hour rainfall exceeds (see Figure 14):
    a. 2.75 in. west of the 5,250-foot elevation contour over the eastern plains
    b. 5.00 in. east of the 5,250-foot elevation contour over the eastern plains
3. A qualifying NWS or manually added Local Storm Report (LSR) report is received. For more information, see Appendix C, data source "LSR" under "Storm Report".
4. 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 (i.e. a single grid point), 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 verification reports from 2016 to 2021, 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 protocol across Colorado NWS offices varies significantly. Thus, NWS Flash Flood Warnings alone no longer cause a Flood Day classification. They could however contribute to a Flood Day if other factors are supportive. Note that this does NOT include Warnings issued over fire burn areas which have much lower rainfall intensity thresholds.

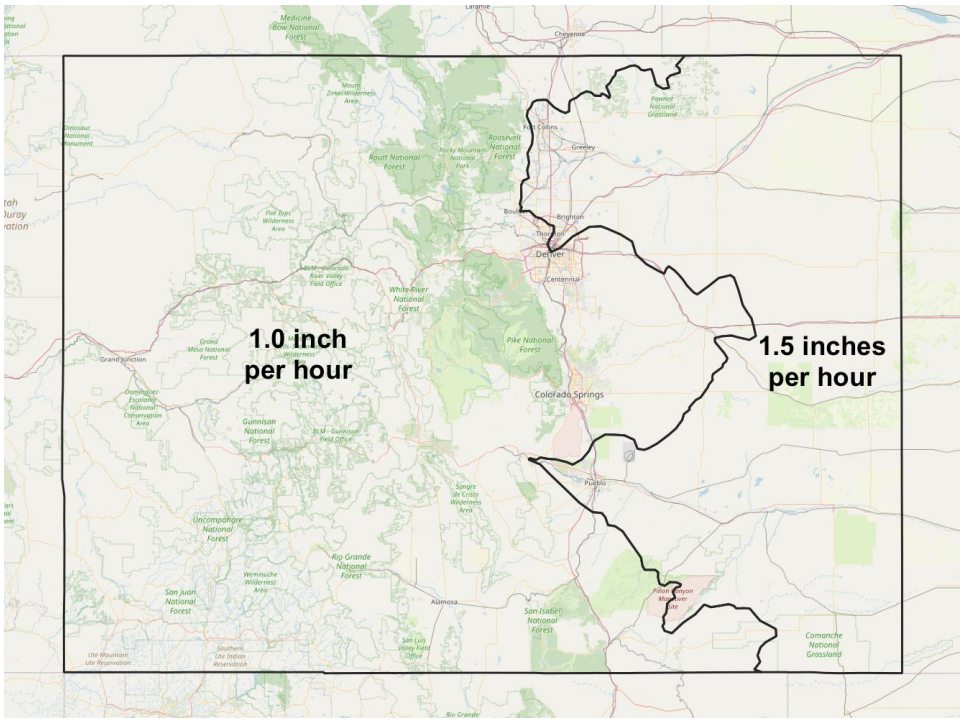

Figure 14: Colorado map with thick black line showing the 5,250-foot elevation contour line east of the Continental Divide, which acted as the demarcation in rainfall-runoff sensitivity. To the east, 1.50 inches in 1-hour is used to denote a "Flood Day"; to the west, 1 inch in 1-hour is used.

After an initial objective, preliminary Flood Day classification 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 no longer 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. Nonetheless, the predominant bias in QPE is to overestimate rainfall, and of the 26 BIAS adjustments, 25 were to remove the Flood Day classification. Lastly, since 1-hour and 2-hour gridded QPE and sub-hourly rainfall gauges are reliably available and the Program has new 24-hour thresholds for flooding set this season (2.75 inches west and 5 inches east), the Low Intensity (LI) flag used in past reports for long duration events has become obsolete and been removed as an overriding condition. New to 2024 verification is a Manual Miss (MAN MISS) flag. This occurs when a flood threat was issued, but it did not overlap the area that experienced heavy rainfall or underwent a flash flood event (LSR).

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	Flood Day = 0	0
There is no rainfall over an area, but antecedent conditions and/or snowmelt cause riverine flooding.	RIVERINE	Flood Day = 0	5
QPE alone was required to identify a Flood Day, as no gauge observations were available. QPE was determined to be either too wet requiring a preliminary Flood Day classification to be removed, or too dry requiring a Flood Day to be assigned (see Appendix F).	BIAS	Flood Day = 0	26
A Flood Day occurred, but the threat issued did not overlap the area that experienced the flood event.	MAN MISS	Flood Day = 0	3

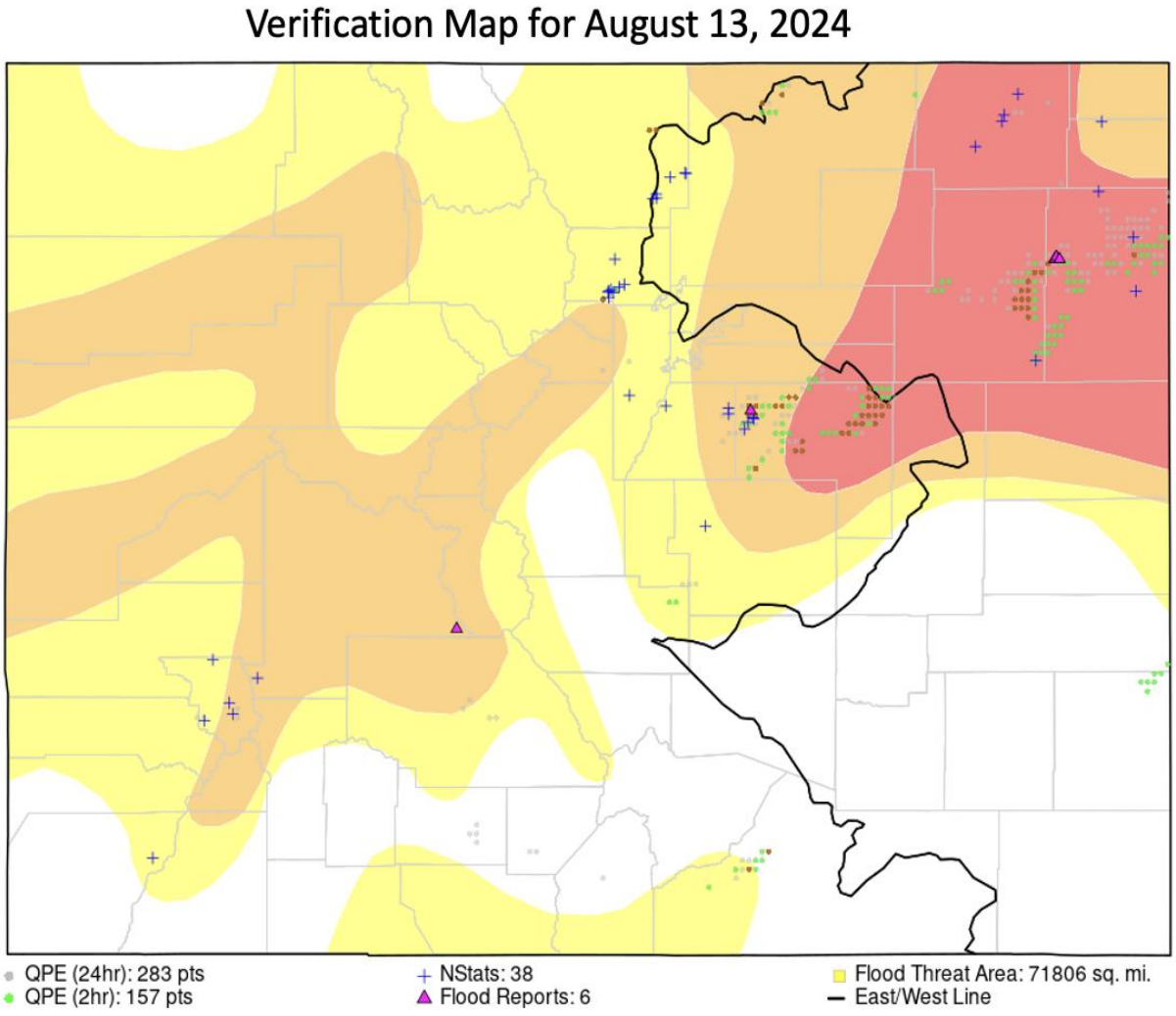

Figure 15: Example of daily verification map from August 13, 2024, showing qualifying 1-hour (red), 2-hour (green), and 24-hour (gray) MRMS grid points, qualifying rain gauges (blue crosses) and High/Moderate/Low threat areas (red, orange and yellow color fill, respectively).

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 (PM Update) to the flood threat. Although, PM Update will be discussed in more detail below. 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 forecast, but is observed, this results in a "Miss" [case (b) in Table 7]. Second, if a non-Flood Day is forecast 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	Calculations (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 all targets established in Table 8 for the season**. The overall **Hit Ratio (Hit %) of 91%** indicates that forecast performance remains high and well above the >75% targeted goal. More importantly, the **Probability of Detection (POD) was 89%,** which is consistent from last season. This metric specifically singles out Hits vs. Dry Hits, which indicate the accuracy of the flood threat forecasts issued. The **False Alarm Ratio (FAR) was 14%,** which is important because a lower FAR helps increase confidence in the forecasts that

are issued by the Program. The **11% Miss % was slightly lower than last season and meets Program goals**. The Program continues to err on the side of caution in issuance of flood threats, which often and necessarily results in a higher FAR, but lower Miss %. With the Miss % and FAR values nearly equal, this suggest Program forecasters were able to find close to the optimal balance between the two this season. Balancing this ratio is in stark contrast to the performance of the NWS analogous Flash Flood Watch product, which tends to have a very low FAR at the expense of a significant Miss %.

Looking into the month-to-month performance (Table 9), July was significantly less active on the heavy rainfall front when compared to climatology (only 13 days), and the busiest month was August (20 days). While August was the most active month for heavy rainfall, the 20 Flood Days experienced is right around average. However, it's not often the combination of June and August account for 60% of the Flood Days in a season. May was much less active than last season with only 7 Flood Days occurring, and September only had 2 Flood Days. Another noteworthy statistic is zero False Alarms in the month of June with a low Miss %. Program forecast metrics were best in June with a secondary peak in forecast skill during August. The FAR during July was right at the cutoff, but overall, it's always nice to see the verification stats peaking over the monsoon season. Metrics are skewed in September because there were only 2 Flood Days recorded, so interpret this portion of the table with caution.

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	6	13	11	18	1	49
(b) No Flood / Flood	1	1	2	2	1	6
(c) Flood / No Flood	2	0	3	2	1	8
(d) No Flood / No Flood	22	16	16	9	27	90
Total Days	31	30	31	31	30	153
Hit %	90%	97%	87%	87%	93%	91%
POD	86%	93%	92%	90%	50%	78%
FAR	25%	0%	21%	10%	50%	14%
Miss %	14%	7%	8%	10%	50%	11%

Taking a more in-depth look at Misses, 2 of the 6 Misses (see Appendix A) occurred on days where a Flood Threat was issued and a Flood Day was observed, but the threat area did not overlap with the qualifying rainfall intensity. An example of this is shown in Figure 16 from August 7, 2024. A Moderate/Low threat was drawn along the Southeast and Central Mountains, but the qualifying rates for a Flood Day and flood report (Alexander Mountain) occurred over the Front Range and Palmer Ridge. In this case, the total flood area determined by QPE was about 600 square miles, with some BIAS likely (Table 10). The other event had a flood area just over 150 square miles, and it had no flood reports. While a marginal Miss can be somewhat understandable even with forecast advancements, how to deal with larger areal Misses and Misses outside areas with elevated threat levels will continue to be addressed in the off-season. Forecasts will also continue to be monitored throughout the day, so if a forecast drastically changes, a PM Update can be issued.

Table 10: Days where a flood threat was drawn but did not overlap the Forecast Zone(s) where flooding occurred.

Date	Threat Level	Flood Area (sq mi)	Pluvial Flood Reports
July 27	Low	150	
August 7	Moderate	600	Flooded road curb to curb near Cañon City. Washed chairs and tables from outdoor event down the street.

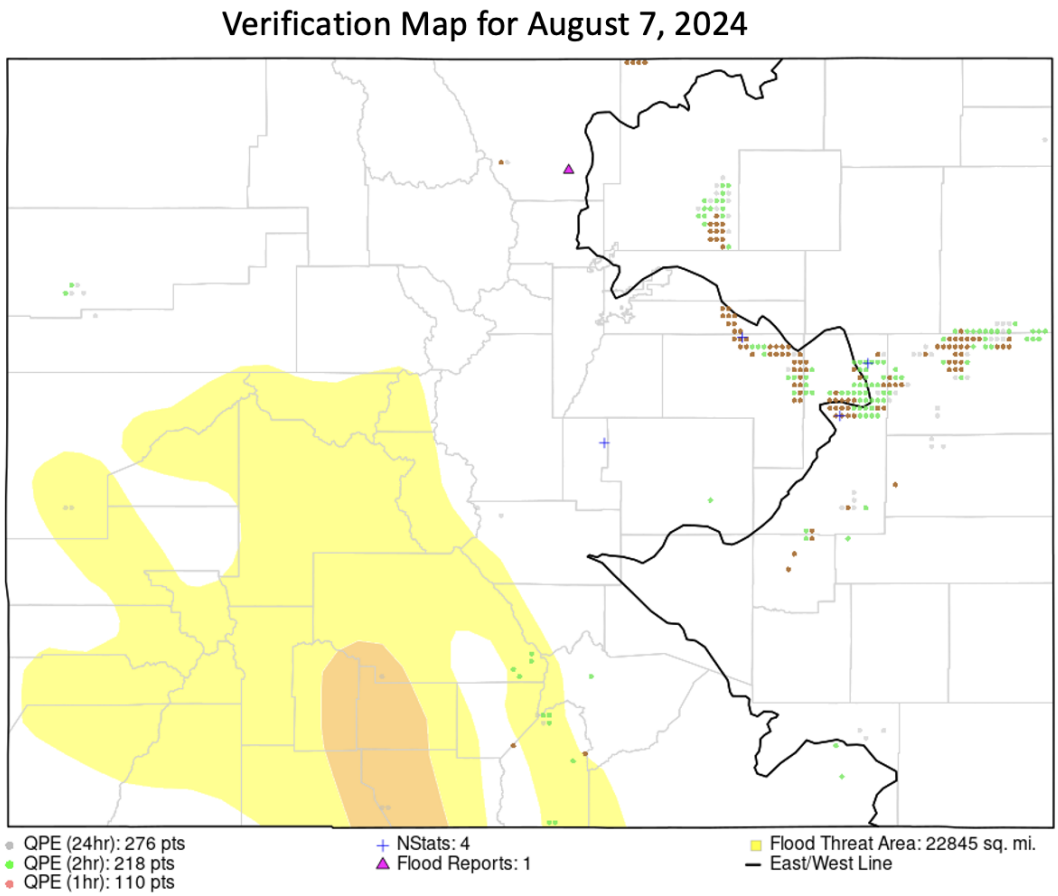

Figure 16: Daily verification map for August 7, 2024, showing qualifying 1-hour (red), 2-hour (green), and 24-hour (gray) MRMS grid points, qualifying rain gauges (blue crosses) and Low threat area (yellow color fill). There is also a riverine flood warning along the Purgatoire River near Las Animas (green color fill).

Table 11 shows yearly performance summaries for the Program from 2012 to present. T**he total number of Flood Days was 55 this season. This is ~20% below the 2012 to 2023 average of 67 Flood Days, and down sharply from last year's 73 Flood Days. As far as hitting all the forecast metrics presented in Table 8, this is the fourth time in Program history that this has been achieved since the overhaul of the verification procedure in 2014. It is also the first time this has been achieved in back-to-back seasons.** Although the FAR was slightly up from the last season, it remains well above the target goal. The Miss % of 11% is down from last season, with the POD and Hit % slightly up. Interestingly, the Bias is back above 1, which reiterates the slight preference towards False Alarms as desired by CWCB. The Team aimed at reducing the Miss % this season, which was accomplished; and not at the expense of the FAR, which only slightly increased. With two years of excellent metrics in a row, the latest improvements to the Team's internal forecast guidance appears to be effective. Off-season research and development will continue to go into forecast guidance, which should set the Team in a favorable position for another successful 2025 forecast season.

Table 11: 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.

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%	41	34	1.21
2021	88%	73%	20%	90%	10%	65	58	1.12
2022	87%	71%	25%	92%	8%	64	52	1.25
2023	90%	80%	9%	86%	14%	72	73	0.95
2024	**91%**	**78%**	**14%**	**89%**	**11%**	**57**	**55**	**1.04**

Table 12 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 Hit % as the threat level increases due to more confidence that heavy rainfall and/or flooding will be realized. This continues to be the case again for 2024 with an **76% Hit % for Low threats, 96% for Moderate threats and 100% for High threats.** Metrics are slightly lower for Low and Moderate threats when compared to last season, but still very good. This is mostly driven by a handful more observed non-Flood Day (False Alarm) for Low threats issued, but there is also one for the Moderate threats issued, which had a 100% Hit % last season. Like last season, the 2024 season had no days when a High Impact threat was issued. Interestingly, the ratio between Low, Moderate and High threats was unusual this season with many Moderate threats, but only 3 High threats. Typically, due to the nature of heavy rainfall in Colorado, there is often a steady decrease in the number of threats as the threat level increases. Thus, Table 12 indicates that perhaps forecasts were a bit *underconfident* this season, and some of the Moderate threats should have elevated to a High or High Impact threat. We will continue to work in the off-season to discuss when and where High threats should be issued, especially if flooding is expected to significantly impact urban areas.

Table 12: 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	22 (76%)	7 (24%)	29
Moderate	24 (96%)	1 (4%)	25
High	3 (100%)	0	3
High Impact	0	0	0
Total	49 (86%)	8 (14%)	57

PM Updates

Occasionally, there are forecast uncertainties that make the morning flood threat assessment challenging. For example, cloud cover may be present causing uncertainty in afternoon instability, which would directly impact the chance for stronger thunderstorm development and resulting heavy rainfall. Or a forecast can change from what is predicted. For example, if dew points trend several degrees higher than the original forecast, rainfall rates are likely going to be higher than initially forecast. There may also be some uncertainty in the impact from rainfall. Often confidence for a flood event increases over the course of the day as ingredients come together. So, what is initially forecast as a Moderate flood threat may become a High flood threat by the early afternoon. All these scenarios are reasons why a PM Update may be issued by the Team. For the 2024 season, to be in line with the Project's scope, the Team tried to limit the issuance of a PM Updates to only two scenarios. The first scenario is when there was No threat and at least a Low threat was needed. The second was when an upgrade to a High threat was necessary. By limiting the number of PM Updates issued, the Team's goal was to better grab the attention of the end-user when it was most needed. This can give the PM Updates more value when they are issued.

The PM Update includes an update to the flood threat map, more accurate maximum rainfall intensities, and the specific locations that are most likely to see flood impacts. When possible, the Team also tries to mention the possibility of a PM Update and where forecast uncertainty lies in the morning discussion. This will allow the end-user to tune back in by early afternoon (before rainfall begins) for any updates to the forecast. In addition to a short discussion explaining the PM Update issuance at the top of the day's FTB discussion, new social media posts are also disseminated to the Program's accounts. This is the most effective way to quickly get information to end-users because the social media platforms best deal with "real-time" information.

Over the course of the 2024 season, there were four PM updates issued, which is four less than last season (Table 13). Of these updates, three featured upgrades of the morning threat level due to higher confidence in the chance of flooding later in the day. For example, the two Moderate threats on June 29th and August 12th were upgraded to High threats once there was better confidence in the magnitude/placement of heavy rainfall. Both days "Hit" in the High threat area and flooding was reported. However, the PM Update issued on June 18th ended up being a False Alarm. In the morning post, only NWS Warnings (riverine) were issued for portions of the Arkansas River, but there was an increasing threat for longer duration overnight rainfall over the southwest corner. Thus, the Low threat issued for Baca and Prowers County. There was uncertainty in the location of where the front will stall, which is why only a Low threat was issued. The cold front ended up sliding just south of the border by about 30 miles, but a CoCoRaHS station outside Goodwell, OK reported 10.50 inches! There were also several other stations in the area reporting over 5 inches that next morning. Thus, the threat was warranted even though it slightly dinged the metrics. Both above examples illustrate the value of PM Updates and demonstrate the importance of monitoring storm ingredients throughout the day for the best available flood forecast. Though it is ideal to provide FTB forecasts with maximum lead time, the PM Updates are often still able to provide at least 1 to 2 hours of lead time.

Table 13: Dates when a PM Update was issued. Asterisks indicate an increase or decrease in metric improvement from the morning forecast.

Dates	AM Threat	PM Threat	AM Outcome	PM Outcome
June 18*	None	Low	Hit (Dry)	False Alarm
June 29	Moderate	High	Hit	Hit
August 1	Low	Low	Hit	Hit
August 12	Moderate	High	Hit	Hit

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. Most significant is the Program website (Table 14), which has been the main form of communication since the Program began. Beginning in 2017, the Team 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 X (formerly 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 X. All four forms of communication were continued in 2024.

It is important to note that, to some extent, all the communication methods described herein compete with one another (i.e., if an end-user uses X 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 15 summarizes the most important social media and website usage metrics over the 2016- present period. This season ended up having some positive and negatives in terms of the typical end of season metrics. Starting with areas of decline, website viewership was down on all flood threat days except High compared to last year. On X, the average number of Impressions per day was 1,026, which is also down from previous seasons. On the flip side, the daily Facebook reaches at 493, implies growth on that platform. Despite diminishing reach to X, it continues to be the best method to reach the maximum number of end-users.

Table 14: Website and social media accounts used by the Flood Threat Bulletin.

SOURCE	ACCOUNT	ENGAGEMENT
Email Subscription	coloradofloodthreat@gmail.com	286 Subscribers (+9)
X (formerly Twitter)	@COFloodUpdates	1735 Followers (+15)
Facebook	@COFloodUpdates	673 Followers (+35)

Table 15: The Program's website and social media usage metrics from 2016 to 2024

SOCIAL MEDIA METRIC	2016	2017	2018	2019	2020	2021	2022	2023	2024
Email Subscribers (end of season)	--	19	35	128	131	142	165	278	**286**
Median Daily Website Viewership on **No-Threat Days**	24	18	22.5	51	27	46	42.5	38	**23.5**
Median Daily Website Viewership on **Low Threat Days**	32	22	44	66.5	44	48	70	45	**41**
Median Daily Website Viewership on **Moderate Threat Days**	41.5	34	58	98	56	86	98.5	79	**68**
Median Daily Website Viewership on **High/Very High Threat Days**	90.5	42	117	106	212	191.5	185	73	**87**
X Followers	901	1,036	1,183	1,331	1,404	1,528	1,591	1,720	**1735**
Avg. Daily X Impressions	1,874	1,973	2,059	1,597	1,590	3,299	1,782	2,171	**1,026**
Facebook Followers	--	--	155	272	323	421	585	638	**673**
Avg. Daily Facebook Reaches	--	--	--	--	440	456	953	386	**493**

Website

The website continues to utilize the latest Google Analytics (GA4) to track website usage. Figure 17 shows daily website usage during 2024 (black) overlaid with the previous four seasons. Website usage this year peaked on August 9th, when 176 end-users accessed the website where a Moderate flood threat was issued for a large area of Southern Colorado. This was in the middle of a stretch of severe storms and flooding towards the beginning of the month of August where the monsoon became more active and widespread rainfall affected populated areas. Usage remained relatively high throughout August, a month where a total of 10 Moderate and 2 High flood threats were issued.

Website usage for the remainder of the season decreased after September 1st, averaging 20 daily users for the last month of the season. This decrease can likely be attributed to the decrease in daily flood threats issued and heavy rainfall events that occurred. Overall median website usage was down this season from 2023, although viewership on Moderate Threat days remained around the same and increased on High Threat days. It is difficult to pinpoint exact reasons that website viewership may be down, particularly on High threat days, but improved bot filtering in GA4 in 2023 may indicate artificially high viewership in seasons prior to 2023.

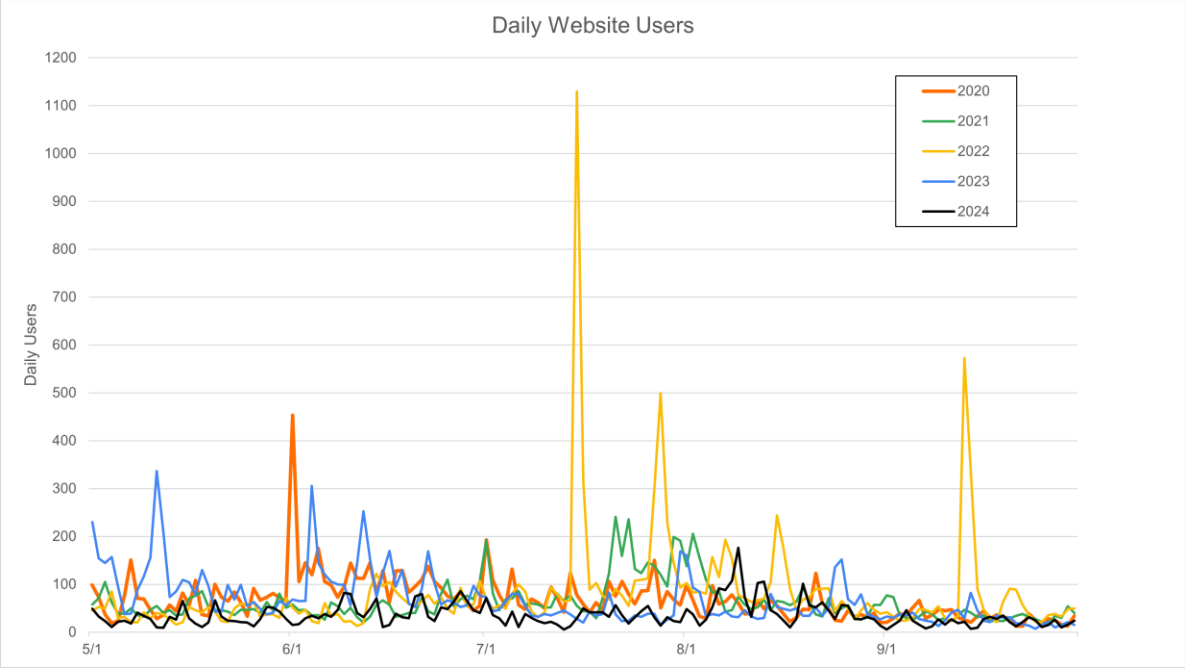

Figure 17: Daily Website users during 2020 (orange), 2021 (green), 2022 (yellow), 2023 (blue), and 2024 (black).

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 X 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 X 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, SPM, and biweekly FTO posts, the Program's social media strategy attempts to maximize the way this data is leveraged by creating unique posts. For example, Figure 18 is a tweet that received the most views for the 2024 season, with 2,967 Impressions and 5 retweets including a quote from @COEmergency (Colorado Emergency Management).

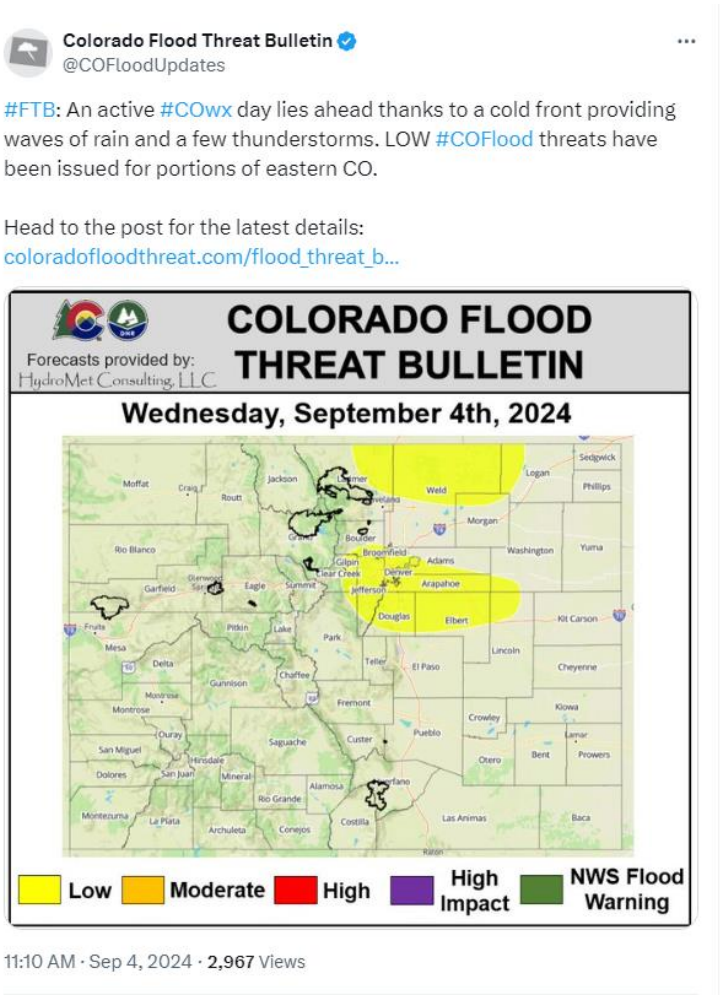

Figure 18: The highest-viewed X post issued during the 2024 season, with 2,967 impressions.

The Program's X account, @COFloodUpdates, continues to see an increase in followers since its inception with the total number of followers up to 1,735 as of October 1, 2024. However, this is only a small increase in followers (+ 15) from the end of the 2023 season, and this number has actually decreased to 1,648 as of December 2024 (-72 Followers). Daily X impressions are presented in Figure 19 and similarly indicate a decrease in viewership compared to previous seasons. This season there were 526 Retweets, which is down from 633 last season. As always, Retweets by popular media accounts can add new X followers, and at the same time expose the Program to a more diverse group of end-users. Over the 2024 season, the Program created 279 unique Tweets, 22 fewer than 2023. The #cowx hashtag on X was also the main source of social media reports in the SPM, though its utility has diminished from previous seasons since the change in ownership of the company. The Program sponsored a verified account this season to combat issues with posting and viewing limitations.

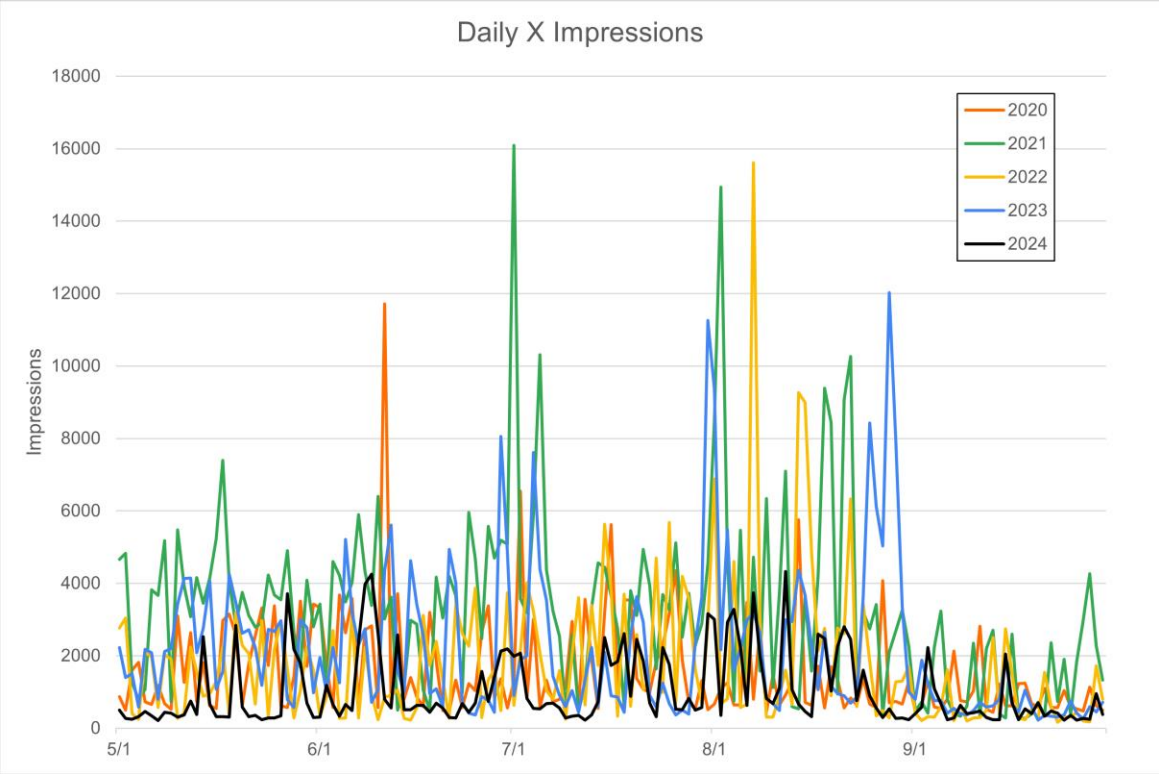

Figure 19: Daily X Impressions during 2020 (orange), 2021 (green), 2022 (yellow), 2023 (blue), and 2024 (black)

The most notable Followers of the Program's X account as of this year are: Colorado Emergency Management, FEMA Region 8, Colorado Flood DSS, READY Colorado, CoCoRaHS, ESRI, Denver Sheriff, Colorado.gov, NWS – Grand Junction, NWS – Pueblo, NWS – Goodland, NWS – Boulder, Boulder Office of Disaster Management, Boulder County Sherriff's Office, Denver Office of Emergency Management, Mesa County Sherriff, Colorado Climate Center, CU Boulder, Durango Herald, Forest Service ARP, KUNC Colorado, CBS Colorado, KKTV 11 News, CASFM, Denver Water, City of Boulder, The Disaster Channel, Weather West, Colorado Wildfire Info, GMUG National Forests, Larimer Sherriff, and Denver7 News. 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 X account. We will continue to engage local media as new accounts continue to be created each season.

Since the X 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 X account, so information exchange would be consistent. One drawback to Facebook is that posts do not show up on the News Feed chronologically, 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 and special in-season analyses, since these are not as time sensitive as ongoing forecasts.

Facebook, like X, has its own set of analytics called Insights, which can be used to evaluate the success of an additional social media account. By the end of its sixth season, the Facebook account gained several new Followers putting the total at 673. While this number continues to be quite a bit lower than the X account, the number of Followers increased approximately 10% from the end of the 2023 season, which shows the media platform still has utility despite the changes to the platform over this season. The most similar analytic to X Impressions is 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 X 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 2024: #FTB, #FTO, #SPM, #COwx, #COFlood, #COFire, and #CODrought.

Since current social media platforms continuously evolve while new platforms are developed, the Team will create a two-part social media strategy before the 2025 season. The goal will be to address diminishing impressions on X as well as investigating new platforms that may help support the Program.

Email Alerts

A subscription for receiving the daily FTB headline to an end-user's email began on April 28th, 2017. As of October 1st, there are 286 active subscribers, which is an increase of 9 subscribers from last season. Careful deletion of inactive subscribers (e.g. bounced-back emails) was also done this season. 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 a prior idea of reaching out to local Emergency Managers 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, 2025 and inform end-users of any additional upgrades to the products.

Outreach

Under the Outreach Task, Dewberry attended and presented "Colorado Flood Threat Bulletin – Where We've Been, Where We Are, and Where We are Going" at the Association of Stormwater and Floodplain Administrators (ASFPM) Conference in Salt Lake City, UT on June 25th, 2024. The ASFPM presentation was very well received and provided a great opportunity to highlight the program.

The SPM team responded to a CWCB request and put together figures illustrating 24-hour, 72-hour and 10-day rainfall for the events that occurred during August 5th –15th in the Upper Uncompahgre basin around Ouray that were shared with community officials on August 16th, 2024. All information came from QPE developed for the SPM, flood reports collected in the Team's database, and gridded precipitation frequency estimates from CO-NM REPS. An example map shared with CWCB and Ouray County is seen in Figure 20.

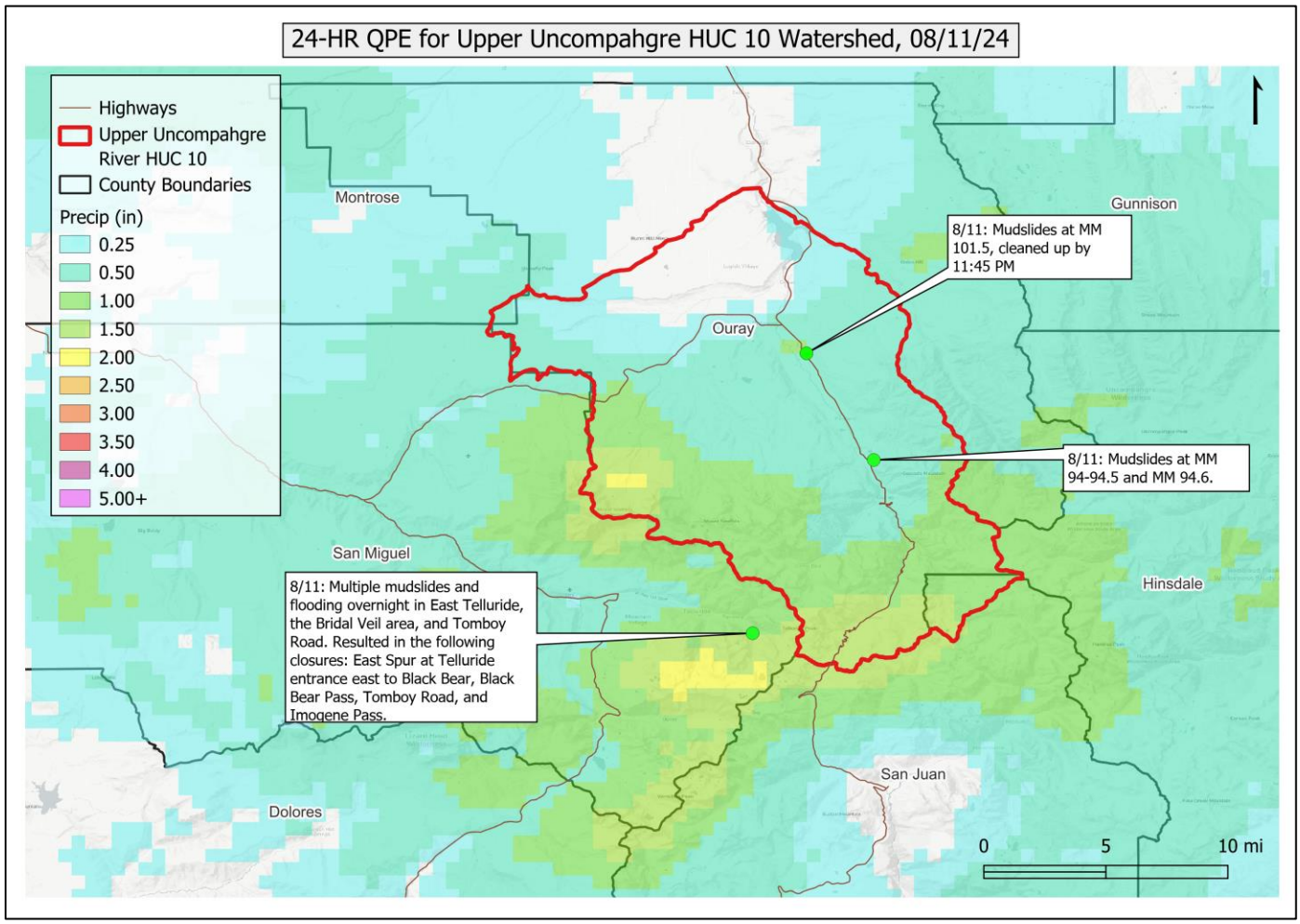

Figure 20. 24-hour SPM QPE provided to Ouray County, overlayed with the Upper Uncompahgre River HUC10 watershed and multiple debris flow reports on August 11, 2024.

5) CONCLUSIONS

1. Precipitation was highly variable this season, in terms of both location and timing (Figure 10). The western portion of the state, especially southwest, saw much above average rainfall, particularly during June. However, the eastern half of the state, had a non-existent July monsoon and several months of below average precipitation. This led to Severe drought and significant fire danger for zones east of the Continental Divide, especially the Front Range.

    a. Despite a good rainfall season for western Colorado, there were less flood reports this season (129 flood reports vs. 279 in 2023). This is partially due to fewer rainfall events over highly populated areas. August, with the peak of the NAM, had the highest number of flood reports at 60.

2. Despite a short and late monsoon season, there were several impressive rainfall events during the NAM in June and August. Overall, there were 59 flood threats issued, so a slightly below average season. Of these threats, 30 were Low threats, 26 Moderate and 3 High threats. Two of these threats issued were considered a "Miss" because the threat issued did not overlap the area that experienced heavy rainfall or underwent a flash flood event (LSR). Areas over the Palmer Ridge and San Juan Mountains saw up to 35 days with flood threats issued, but the Front Range area was dry with only 5 to 10 threat days (see Figure 24, Appendix E). This is the lowest number of flood threats issued for the Front Range since 2020, which was another significant drought year.

3. The FBF continued to be a successful addition to the Program with high viewership on disseminated forecasts. A total of 8 burn areas from 2023 were forecast for again this season, with adjusted rainfall intensity thresholds (Table 3), and 3 new burns were added mid-season. There was only one debris flow on the Alexander Mountain burn area this season, prior to its inclusion in the FBF table.

4. This was the first time in Program history that the Team hit back-to-back verification metric goals for the season, and this is the fourth time since 2014 that all the Programs goals were met (Table 11). The False Alarm rate was slightly higher than last season (9% to 14%), but the Miss % dropped (14% to 11%), which is more important for the Program goals. The Probability of Detection also went slightly up (86% to 89%). Unlike past seasons, the PM Updates slightly dinged the metrics, but all Moderate to High threat PM Update days did have significant hits.

5. This season saw a small increase in website subscribers, up 9 users from last season, but overall viewership was down. User engagement continued to spike predictably on days with a threat issued but average use across the season was the lowest in Program history. Thankfully, High threat days viewership, arguably the most impactful and important, did increase when compared to last year. Social media accounts on X and Facebook also saw small follower count increases, proving there still is value in disseminating Program information across more than one platform.

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APPENDIX A – FORECAST VERIFICATION WORKSHEET

Table 16 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 update 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 (**) indicate 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). Dates where an NWS Flood or Flash Flood Watch was issued due to rainfall, not snowmelt or riverine flooding, are shaded in green. These have been filtered to exclude burn area only Flash Flood Watches. Lastly, new 24-hour flood thresholds were created for the Program this season (2.75 inches west & 5 inches east). These values are bolded when exceeded in the worksheet for Max 24hr-E and Max 24hr-W for ST4 and MRMS data.

The columns in the table are described below.

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

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

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

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

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

Max2 4hr-E (inches): Maximum 24-hour precipitation east of the 5,250 ft. elevation contour.

Max 24hr-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.

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

Max 24hr-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. All values shown are 24-hour totals.

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.

RIVERINE: 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)

MAN MISS: Although a Flood Day occurred within the state, the threat that was issued did not overlap the area that experienced the flood event.

Flood Day Classifications: Indicates the leading source that led to the assignment of a Flood Day.

LSR: NWS Local Storm Report(s) indicating flooding. New to 2024, this now includes any major flood reports manually added from the SPM.

GAUGE: Quality Controlled rainfall gauge(s) reporting a qualifying rainfall rate.

GRIDDED: Gridded QPE (MRMS or ST4) reporting a qualifying rainfall rate over a ~50 square mile area.

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 (FA)*:* A Flood Day was forecasted, but a non-Flood Day was observed,

Miss: A Flood Day was observed but not forecasted or the flood threat was not issued over the region that received heavy rainfall,

Hit: A Flood Day was observed and forecasted correctly.

Table 16: Daily FTB Verification Worksheet

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 Quantitative Precipitation Estimate		QPE	Rain Gauges			Flood Reports								
Date	Max1hr E	Max2hr E	Max1hr W	Max2hr W	Max24hr E	Max24hr W	Max24hr E	Max24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat AM	Threat PM	Total Threat Area	Flags	FD Classification	Outcome
Units	inches	inches	inches	inches	inches	inches	inches	inches	points	number	inches	inches	number					Miles			
1-May	1.8	2.61	0.61	0.76	2.67	0.76	**7**	**29**	34	2.15	0.7	25	34						BIAS		
2-May	0.24	0.24	0.11	0.14	0.28	0.24	0	0	0	0.22	0.35	0	0								
3-May	1.86	1.9	1.09	1.09	1.92	1.1	**5**	**12**	12	1.32	1.11	1	12						BIAS		
4-May	0.03	0.03	0.35	0.41	0.04	0.57	0	0	0	0.03	0.53	0	0								
5-May	0	0	0.3	0.49	0	1.1	0	0	7	0	0.87	0	7								
6-May	0.13	0.13	0.15	0.21	0.17	0.7	0	0	0	0.08	1.46	23	23								
7-May	0	0	0.16	0.28	0	0.73	0	0	0	0	1.05	0	0								
8-May	0	0	0.05	0.07	0	0.14	0	0	0	0	0.24	0	0								
9-May	0.26	0.48	0.6	0.8	1.31	2.31	0	0	725	1.22	2.51	667	725								
10-May	0.61	0.73	0.61	0.64	0.84	1.24	0	0	40	0.46	1.46	49	49								
11-May	0.81	1.08	0.76	1.19	1.19	1.54	0	1	83	0.67	1.76	100	100								
12-May	1.59	1.94	0.57	0.82	2.41	1.57	3	**17**	100	2.08	1.82	198	198						BIAS		
13-May	0.73	0.8	0.77	0.77	0.95	1.08	0	0	0	0.92	0.77	0	0								
14-May	0.93	0.99	1.3	1.39	1.18	1.5	2	**6**	11	0.9	1.06	1	11						BIAS		
15-May	1.28	1.38	2.03	2.38	1.57	2.46	**6**	**14**	19	2.18	2.09	16	19		Yes	Low		18			Hit
16-May	0.34	0.34	0.64	0.64	0.48	0.67	0	0	0	0.25	0.75	0	0								
17-May	0.01	0.01	0.07	0.07	0.01	0.07	0	0	0	0.01	0.05	0	0								
18-May	2.4	2.78	0.83	0.83	3.01	1.05	**17**	**25**	42	1.69	0.95	1	42		Yes					GRIDDED	Miss
19-May	1.81	2.07	0.89	0.94	2.27	1.26	**5**	**12**	15	2.17	0.89	12	15			Low		2	BIAS		FA
20-May	2.93	3.74	0.89	0.9	4.46	1.74	**179**	**338**	486	2.96	1.56	398	486	Yes	Yes	Mod		12		LSR	Hit
21-May	0.66	0.66	0.98	1.26	1.32	1.33	0	2	7	0.77	1.31	6	7			Low		7			FA
22-May	0.49	0.65	0.05	0.06	0.67	0.06	0	0	0	0.54	0.1	0	0								

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 Quantitative Precipitation Estimate		QPE	Rain Gauges			Flood Reports							
Date	Max1hr E	Max2hr E	Max1hr W	Max2hr W	Max24hr E	Max24hr W	Max24hr E	Max24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat AM	Threat PM	Total Threat Area	Flags	FD Classification	Outcome
Units	inches	inches	inches	inches	inches	inches	inches	inches	points	number	inches	inches	number					Miles			
23-May	0.03	0.03	0.16	0.25	0.04	0.45	0	0	0	0.03	0.59	0	0								
24-May	0.02	0.02	0.03	0.04	0.05	0.07	0	0	0	0.01	0.35	0	0								
25-May	1	1	0.99	1.02	1.07	1.2	0	1	1	0.92	0.97	0	1								
26-May	0.42	0.42	0.04	0.04	0.48	0.07	0	0	0	0.29	0.02	0	0								
27-May	0.11	0.13	0.12	0.14	0.22	0.19	0	0	0	0.15	0.11	0	0								
28-May	2.7	3.31	1.31	1.44	3.93	1.81	**82**	**185**	238	2.65	1.16	69	238	Yes	Yes	Mod		25		LSR	Hit
29-May	2.63	3.43	2.32	2.65	3.52	**3.06**	**79**	**205**	268	2.69	1.83	113	268	Yes	Yes	Low		25		LSR	Hit
30-May	2.22	3.22	2.44	2.91	3.65	**2.91**	**70**	**149**	193	2.29	2.3	61	193	Yes	Yes	Low		35		GRIDDED	Hit
31-May	1.69	1.94	2.15	2.2	2.01	2.28	**33**	**61**	76	3.32	1.55	57	76	Yes	Yes	Low		24		GAUGE	Hit
1-Jun	2.56	4.06	1.16	1.3	**5.57**	1.46	**42**	**67**	72	2.84	0.68	29	72	Yes	Yes	Low		5		LSR	Hit
2-Jun	2.57	3.05	0.63	0.72	3.14	0.94	**28**	**61**	70	1.7	0.63	3	70	Yes					BIAS		
3-Jun	1.22	1.61	0.15	0.26	2.09	0.32	0	2	4	0.92	0.37	0	4								
4-Jun	0.03	0.03	0.08	0.08	0.03	0.08	0	0	0	0.02	0.15	0	0								
5-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	Yes							
6-Jun	0.25	0.28	0.18	0.18	0.39	0.21	0	0	0	0.22	0.1	0	0	Yes					RIVERINE		
7-Jun	1.89	2.31	1.04	1.39	2.5	1.5	4	**8**	10	1.9	1.22	4	10						RIVERINE		
8-Jun	3.02	3.08	1.78	2.23	3.55	**3.17**	**189**	**326**	555	3.03	2.6	173	555	Yes	Yes	Mod				LSR	Hit
9-Jun	1.89	2.31	3.3	3.78	2.57	**4.31**	**196**	**339**	551	3.2	3.32	290	551	Yes	Yes	Mod				LSR	Hit
10-Jun	1.54	1.77	2.17	2.84	2.19	**2.92**	**18**	**46**	71	1.33	1.63	12	71	Yes	Yes	Low				GRIDDED	Hit
11-Jun	1.25	1.82	2.21	2.82	2.04	**3.01**	**23**	**36**	37	0.9	1.71	4	37	Yes	Yes	Low				GRIDDED	Hit
12-Jun	0.14	0.15	0.38	0.46	0.2	0.86	0	0	0	0.11	0.47	0	0						RIVERINE		
13-Jun	1.35	1.36	1.01	1.02	1.39	1.05	1	1	1	0.76	0.58	0	1						RIVERINE		
14-Jun	2.8	4.66	1.46	1.65	**5.33**	1.84	**94**	**223**	289	3.88	1.31	159	289	Yes	Yes	Mod				GAUGE	Hit
15-Jun	1.65	1.68	1.36	1.74	1.68	1.74	**9**	**14**	14	1.09	1.02	0	14						BIAS		

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 Quantitative Precipitation Estimate		QPE	Rain Gauges			Flood Reports								
Date	Max1hr E	Max2hr E	Max1hr W	Max2hr W	Max24hr E	Max24hr W	Max24hr E	Max24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat AM	Threat PM	Total Threat Area	Flags	FD Classification	Outcome
Units	inches	inches	inches	inches	inches	inches	inches	inches	points	number	inches	inches	number					Miles			
16-Jun	0.8	1.02	0.22	0.22	1.36	0.25	0	0	0	1.08	0.17	0	0						RIVERINE		
17-Jun	1.56	2	0.02	0.02	2.04	0.22	1	**6**	6	0.82	0.01	0	6						BIAS		
18-Jun	0.39	0.51	0.11	0.13	0.78	0.17	0	0	0	0.65	0.13	0	0				Low				
19-Jun	0.66	0.78	0.7	0.74	1.23	1.04	0	0	0	0.47	0.68	0	0								
20-Jun	1.4	1.85	1.96	3.65	2.05	**4.35**	**23**	**66**	614	1.33	2.66	824	824	Yes	Yes	Mod		62		LSR	Hit
21-Jun	1.5	1.5	1.52	1.74	1.5	2.7	**20**	**54**	252	0.98	2.44	239	252		Yes	Mod		59		LSR	Hit
22-Jun	0.29	0.29	1.45	1.68	0.29	2.58	**22**	**30**	39	0.16	1.7	22	39	Yes	Yes					LSR	Miss
23-Jun	1.65	1.74	1.19	1.43	2.05	1.76	**9**	**16**	17	1.75	1.26	4	17	Yes					BIAS		
24-Jun	0.92	1.02	1.82	2.12	1.02	2.39	**14**	**27**	34	0.9	1.58	26	34	Yes					BIAS		
25-Jun	0.33	0.33	1.08	1.44	0.36	2.49	2	**3**	3	0.21	1.02	1	3	Yes					BIAS		
26-Jun	2.61	3.52	2.24	2.58	4.14	**3.7**	**31**	**48**	56	2.62	2.16	31	56		Yes	High		47		GAUGE	Hit
27-Jun	1.97	2.05	1.58	1.74	2.11	2.5	**19**	**57**	205	1.45	2.33	200	205	Yes	Yes	Mod		68		LSR	Hit
28-Jun	0.75	0.76	2.26	2.67	1.33	**2.86**	**32**	**54**	76	0.7	1.68	23	76	Yes	Yes	Low		8		LSR	Hit
29-Jun	2.98	4.35	2.66	3.85	**6.35**	**4.61**	**83**	**179**	332	4.29	3	211	332	Yes	Yes	Mod	High	29		LSR	Hit
30-Jun	2.33	3.11	2.03	2.52	3.94	**3.46**	**169**	**351**	601	3.18	2.61	514	601	Yes	Yes	Mod		54		LSR	Hit
1-Jul	1.4	2.09	0.99	1.09	2.28	1.79	0	**15**	35	1.99	1.17	13	35	Yes	Yes	Low		19		LSR	Hit
2-Jul	2.04	2.28	1.31	1.61	2.8	1.68	**12**	**48**	111	3.06	1.31	70	111	Yes	Yes	Low		13		GRIDDED	Hit
3-Jul	1.74	2.86	2	2.21	3.49	2.3	**66**	**154**	171	2.85	1.63	84	171	Yes	Yes	Low		31		GAUGE	Hit
4-Jul	0.33	0.46	0.9	0.99	0.55	1.25	0	0	4	0.4	0.78	0	4								
5-Jul	0.71	0.83	1.04	1.63	1.11	1.94	4	**11**	26	0.85	1.48	14	26						BIAS		
6-Jul	2.1	3.91	0.18	0.23	**5.22**	0.29	**15**	**28**	31	5.3	0.17	42	42	Yes	Yes						
7-Jul	1.88	2.88	1.92	2.16	3.33	**3.04**	**51**	**138**	273	3.12	2.39	198	273	Yes	Yes	Mod		18		LSR	Hit
8-Jul	0.17	0.27	0.43	0.46	0.27	0.72	0	0	0	0.05	0.67	0	0			Low		2			FA
9-Jul	0.64	1.11	1.35	1.35	1.34	1.6	**6**	**7**	10	1.12	1.04	0	10						BIAS		

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 Quantitative Precipitation Estimate		QPE	Rain Gauges			Flood Reports							
Date	Max1hr E	Max2hr E	Max1hr W	Max2hr W	Max24hr E	Max24hr W	Max24hr E	Max24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat AM	Threat PM	Total Threat Area	Flags	FD Classification	Outcome
Units	inches	inches	inches	inches	inches	inches	inches	inches	points	number	inches	inches	number					Miles			
10-Jul	0.26	0.26	1.35	1.61	0.35	1.77	3	**3**	6	0.19	1.15	1	6						BIAS		
11-Jul	1.51	1.54	1.41	1.74	1.62	1.74	3	**4**	4	1.17	1.09	1	4						BIAS		
12-Jul	1.08	1.66	0.65	0.94	1.7	0.99	0	2	2	0.98	0.88	0	2								
13-Jul	0.75	0.95	0.73	0.8	1.34	1.16	0	0	1	0.89	0.85	0	1								
14-Jul	1.98	2.54	1.52	1.58	2.8	1.68	**23**	**55**	58	2.65	1.11	29	58						BIAS		
15-Jul	2.44	2.52	1.36	1.68	2.7	2.05	**21**	**48**	65	1.77	1.11	13	65	Yes					BIAS		
16-Jul	1.46	1.97	1.46	1.63	2.1	1.83	**27**	**63**	105	1.91	1.39	18	105	Yes	Yes	Mod		56		LSR	Hit
17-Jul	2.97	4.55	1.95	2.1	4.73	2.32	**55**	**119**	205	2.84	1.82	80	205	Yes	Yes	Mod		55		GAUGE	Hit
18-Jul	1.5	1.5	1.54	1.98	1.72	2.35	**31**	**67**	102	1.15	1.42	24	102	Yes	Yes	Mod		25		LSR	Hit
19-Jul	1.96	2.9	1.23	1.25	2.9	1.87	**9**	**31**	52	2	1.34	14	52	Yes	Yes	Low		31		GAUGE	Hit
20-Jul	1.51	1.8	1.56	1.78	2.44	2.7	**52**	**121**	342	2	2.43	294	342	Yes	Yes	Low		17		LSR	Hit
21-Jul	2.3	2.38	2.32	2.59	2.84	**3.39**	**41**	**88**	159	1.84	1.84	85	159	Yes	Yes	Mod		45		LSR	Hit
22-Jul	0.8	0.87	0.94	1.21	1	1.39	0	1	3	0.59	1.6	6	6		Yes	Low		24			FA
23-Jul	0.04	0.04	0.54	0.8	0.25	0.96	0	0	0	0.01	0.4	0	0								
24-Jul	0.21	0.21	0.8	0.96	0.21	1.05	0	0	1	0.02	0.67	0	1								
25-Jul	0.06	0.06	0.78	0.86	0.06	0.96	0	0	0	0.05	0.76	0	0			Low		37			FA
26-Jul	1.86	2.67	1.52	2.3	3.13	2.69	**29**	**75**	114	2.08	2.37	56	114	Yes	Yes	Mod		44		LSR	Hit
27-Jul	1.77	2.17	1.17	1.92	2.47	1.99	**7**	**23**	72	1.98	1.66	13	72	Yes	Yes	Low		12	MAN MISS	GAUGE	Miss
28-Jul	0.63	0.63	0.28	0.28	0.63	0.28	0	0	0	0.44	0.13	0	0								
29-Jul	0.42	0.5	0.11	0.18	0.72	0.34	0	0	0	0.44	0.21	0	0								
30-Jul	0.41	0.51	0.22	0.22	0.51	0.23	0	0	0	0.4	0.15	0	0								
31-Jul	0.15	0.17	0.05	0.06	0.18	0.06	0	0	0	0.13	0.02	0	0								
1-Aug	1.89	2.4	1.61	2.04	2.83	2.34	**28**	**70**	84	1.57	1.7	12	84	Yes	Yes	Low	Low	9		GAUGE	Hit
2-Aug	1.8	2.05	1.78	2.35	2.58	2.73	**46**	**75**	98	1.97	2.08	61	98		Yes	Low		47		GRIDDED	Hit

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 Quantitative Precipitation Estimate		QPE	Rain Gauges			Flood Reports							
Date	Max1hr E	Max2hr E	Max1hr W	Max2hr W	Max24hr E	Max24hr W	Max24hr E	Max24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat AM	Threat PM	Total Threat Area	Flags	FD Classification	Outcome
Units	inches	inches	inches	inches	inches	inches	inches	inches	points	number	inches	inches	number					Miles			
3-Aug	0.42	0.42	0.95	1.12	0.42	1.18	0	2	2	0.12	1.11	2	2								
4-Aug	2.04	2.52	1.13	1.58	2.51	1.8	4	**10**	21	1.75	1.8	12	21	Yes	Yes	Low		24		LSR	Hit
5-Aug	2	2.08	1.59	1.88	2.69	**3.09**	**44**	**106**	204	1.36	2.15	120	204	Yes	Yes	Mod		22		GAUGE	Hit
6-Aug	2.43	2.43	1.79	2.27	2.7	2.72	**66**	**115**	141	1.92	1.75	67	141	Yes	Yes	High				GAUGE	Hit
7-Aug	2.78	3.31	2.29	2.51	3.58	2.51	**110**	**218**	276	2.3	1.63	61	276	Yes	Yes	Mod		23	MAN MISS	LSR	Miss
8-Aug	1.7	3.07	1.53	1.97	3.27	2.23	**19**	**69**	108	2.54	1.37	67	108		Yes	Mod		42		GAUGE	Hit
9-Aug	1.33	1.87	2.02	2.86	2.89	**3.66**	**17**	**48**	504	2.07	2.87	542	542	Yes	Yes	Mod		66		LSR	Hit
10-Aug	0.5	0.53	2.19	2.24	0.63	**2.75**	**31**	**60**	207	0.49	2.52	218	218		Yes	Mod		53		LSR	Hit
11-Aug	1.35	1.35	1.11	2.03	1.74	2.17	2	**8**	29	1.14	2.67	45	45	Yes	Yes	Mod		36		LSR	Hit
12-Aug	2.8	4	2.97	3.74	**5.84**	**4.76**	**212**	**406**	588	3.79	4.21	509	588	Yes	Yes	Mod	High	44		LSR	Hit
13-Aug	1.97	2.13	1.83	3.11	2.45	**3.32**	**50**	**157**	283	2.09	2.17	175	283	Yes	Yes	High		72		LSR	Hit
14-Aug	1.36	1.37	1.3	1.33	1.39	1.42	1	**4**	5	1.23	0.65	0	5	Yes					BIAS		
15-Aug	0.67	0.84	0.34	0.34	0.88	0.38	0	0	0	0.65	0.3	0	0								
16-Aug	0.57	0.77	1.07	1.24	0.77	1.43	1	**4**	4	0.55	1.3	3	4						BIAS		
17-Aug	1.7	1.91	0.61	0.78	2.46	1.46	2	**5**	13	1.5	2.11	28	28	Yes	Yes					LSR	Miss
18-Aug	1.78	2.65	1.28	1.32	2.69	1.67	**5**	**20**	29	1.5	1.69	9	29		Yes	Low		15		LSR	Hit
19-Aug	4.26	5.18	2.17	3.61	**5.37**	**5.81**	**118**	**212**	266	3.38	4.11	136	266	Yes	Yes	Mod		37		LSR	Hit
20-Aug	2.3	2.59	2.06	2.46	2.61	2.46	**53**	**92**	182	1.43	1.69	59	182	Yes	Yes	Low		16		LSR	Hit
21-Aug	1.5	1.72	1.41	1.77	1.85	2.72	**10**	**40**	104	1.59	1.73	61	104	Yes	Yes	Low		16		LSR	Hit
22-Aug	2.91	4.16	1.75	1.91	4.52	2.18	**41**	**112**	166	3.3	1.56	111	166	Yes	Yes	Mod		55		LSR	Hit
23-Aug	1.37	1.67	1.24	1.24	1.81	1.28	**5**	**6**	10	1.4	1.66	70	70	Yes		Mod		18	BIAS		FA
24-Aug	0.33	0.35	0.43	0.5	0.37	1.01	0	0	0	0.29	0.85	0	0			Low		8			FA
25-Aug	0.65	0.72	0.79	1.11	1.17	1.77	0	2	25	0.85	1.86	118	118	Yes	Yes	Low		16		LSR	Hit
26-Aug	1.89	2.34	1.66	2.42	4.07	**4.58**	**33**	**80**	151	2.04	2	31	151	Yes	Yes	Low		14		GRIDDED	Hit

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 Quantitative Precipitation Estimate		QPE	Rain Gauges			Flood Reports								
Date	Max1hr E	Max2hr E	Max1hr W	Max2hr W	Max24hr E	Max24hr W	Max24hr E	Max24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat AM	Threat PM	Total Threat Area	Flags	FD Classification	Outcome
Units	inches	inches	inches	inches	inches	inches	inches	inches	points	number	inches	inches	number					Miles			
27-Aug	0.5	0.52	0.79	0.9	0.82	1.28	0	0	0	0.55	0.52	0	0								
28-Aug	0.69	0.74	0.62	0.71	0.76	0.96	0	0	0	0.51	0.9	0	0								
29-Aug	0.89	0.89	1.32	1.36	1.13	1.39	3	**4**	4	0.94	1.09	1	4						BIAS		
30-Aug	0.06	0.07	0.63	0.78	0.07	0.93	0	0	0	0.01	0.55	0	0								
31-Aug	0.02	0.02	0.57	0.65	0.02	0.73	0	0	0	0	0.49	0	0								
1-Sep	0.11	0.11	0.59	0.6	0.13	0.68	0	0	0	0.05	0.45	0	0								
2-Sep	0.01	0.01	0.34	0.45	0.01	0.53	0	0	0	0	0.43	0	0								
3-Sep	0.03	0.03	0.22	0.22	0.1	0.28	0	0	0	0.04	0.41	0	0								
4-Sep	1.25	1.27	0.87	1.12	1.78	1.96	0	**4**	53	1.03	2.09	93	93		Yes	Low		9	BIAS	GAUGE	Hit
5-Sep	0.85	1.04	0.93	1.04	1.23	1.48	0	1	33	1.02	1.01	0	33								
6-Sep	0.01	0.01	0.2	0.25	0.02	0.38	0	0	0	0	0.24	0	0								
7-Sep	1.25	1.35	1.36	1.83	1.85	2.26	**15**	**46**	81	1	1.55	15	81		Yes					GAUGE	Miss
8-Sep	0.45	0.64	0.85	0.93	0.72	0.93	0	0	0	0.48	0.7	0	0								
9-Sep	1.85	1.95	0.44	0.55	1.95	0.82	1	1	1	1.17	0.52	0	1						BIAS		
10-Sep	0.71	0.85	0.81	1.13	0.93	1.45	0	1	1	0.85	0.93	0	1								
11-Sep	1.12	1.42	1	1.06	1.79	1.17	1	2	8	1.27	0.92	0	8						BIAS		
12-Sep	0.01	0.01	0.02	0.02	0.01	0.02	0	0	0	0.01	0.11	0	0								
13-Sep	0.01	0.01	0.06	0.07	0.03	0.07	0	0	0	0.01	0.06	0	0								
14-Sep	1.72	1.72	0.21	0.25	1.76	0.39	4	**4**	4	0.78	0.25	0	4						BIAS		
15-Sep	1.29	1.86	0.54	0.71	2.85	0.74	0	**3**	26	2.2	0.76	9	26								
16-Sep	0.3	0.39	0.56	0.57	0.59	0.93	0	0	0	0.26	1.49	69	69			Low		11			FA
17-Sep	1.19	1.67	1.24	1.59	2.06	**4.07**	1	**13**	87	1.97	2.16	89	89	Yes					BIAS		
18-Sep	0.01	0.01	0.06	0.06	0.02	0.06	0	0	0	0	0.01	0	0								
19-Sep	0	0	0.02	0.02	0	0.02	0	0	0	0	0.16	0	0								

	NSSL MRMS Quantitative Precipitation Estimate						NOAA ST4 Quantitative Precipitation Estimate		QPE	Rain Gauges			Flood Reports								
Date	Max1hr E	Max2hr E	Max1hr W	Max2hr W	Max24hr E	Max24hr W	Max24hr E	Max24hr W	24hr Flood Area (Max)	NStats	Max-E	Max-W	Reports	NWS Warning or Advisory	Flood Day	Threat AM	Threat PM	Total Threat Area	Flags	FD Classification	Outcome
Units	inches	inches	inches	inches	inches	inches	inches	inches	points	number	inches	inches	number					Miles			
20-Sep	0.24	0.24	0.06	0.07	0.42	0.14	0	0	0	0.41	0.11	0	0								
21-Sep	0.52	0.66	0.82	0.93	1.06	1.57	0	0	184	0.93	2.35	289	289								
22-Sep	0.41	0.6	0.19	0.28	0.98	0.33	0	0	0	1.18	0.31	0	0								
23-Sep	0.08	0.08	0.13	0.21	0.11	0.27	0	0	0	0.04	0.18	0	0								
24-Sep	0.01	0.01	0.02	0.04	0.02	0.04	0	0	0	0	0.18	0	0								
25-Sep	0.01	0.01	0.03	0.03	0.01	0.04	0	0	0	0	0.02	0	0								
26-Sep	0.05	0.05	0.07	0.07	0.17	0.08	0	0	0	0	0.03	0	0								
27-Sep	0.35	0.35	0.39	0.53	0.37	0.67	0	0	0	0.29	0.71	0	0								
28-Sep	0	0	0.4	0.56	0	0.56	0	0	0	0	0.42	0	0								
29-Sep	0.04	0.04	0.25	0.25	0.08	0.25	0	0	0	0	0.29	0	0								
30-Sep	0.27	0.29	0.14	0.2	0.29	0.25	0	0	0	0.23	0.19	0	0								

APPENDIX B – BURN AREA VERIFICATION WORKSHEET

Table 17 is a daily verification worksheet documenting heavy precipitation and associated 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 17 are described below.

Burn Area: The names of the 11 burn areas that were forecast this season. Reminder that Alexander Mountain, Oak Ridge and Stone Canyon were added on August 10th. More information can be found in Table 3.

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

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:

Alexander Mountain (2024), Oak Ridge (2024) & Stone Canyon (2024): **0.25 inches per hour**

Cameron Peak (2020), Grizzly Creek (2020) & East Troublesome (2020): **0.75 inches per hour**

Calwood (2020), Pine Gulch (2020), Spring Creek (2018), Sylvan (2021) & Williams Fork (2020): **1 inch per hour**

Table 17: Daily Burn Area Verification Worksheet

	0.25 in/hr			0.75 in/hr			1.0 in/hr				
Date	**Alexander Mountain**	**Oak Ridge**	**Stone Canyon**	**Cameron Peak**	**Grizzly Creek**	**East Troublesome**	**Calwood**	**Pine Gulch**	**Spring Creek**	**Sylvan**	**Williams Fork**
1-May	-	-	-								
2-May	-	-	-								
3-May	-	-	-								
4-May	-	-	-								
5-May	-	-	-								
6-May	-	-	-								
7-May	-	-	-								
8-May	-	-	-								
9-May	-	-	-								
10-May	-	-	-								
11-May	-	-	-								
12-May	-	-	-								
13-May	-	-	-								
14-May	-	-	-								
15-May	-	-	-								
16-May	-	-	-								
17-May	-	-	-								
18-May	-	-	-								
19-May	-	-	-								
20-May	-	-	-								
21-May	-	-	-								
22-May	-	-	-								
23-May	-	-	-								
24-May	-	-	-								
25-May	-	-	-								

	0.25 in/hr			0.75 in/hr			1.0 in/hr				
Date	**Alexander Mountain**	**Oak Ridge**	**Stone Canyon**	**Cameron Peak**	**Grizzly Creek**	**East Troublesome**	**Calwood**	**Pine Gulch**	**Spring Creek**	**Sylvan**	**Williams Fork**
26-May	-	-	-								
27-May	-	-	-								
28-May	-	-	-								
29-May	-	-	-								
30-May	-	-	-								
31-May	-	-	-								
1-Jun	-	-	-								
2-Jun	-	-	-								
3-Jun	-	-	-								
4-Jun	-	-	-								
5-Jun	-	-	-								
6-Jun	-	-	-								
7-Jun	-	-	-								
8-Jun	-	-	-	**QPE**							
9-Jun	-	-	-						**QPE**		
10-Jun	-	-	-								
11-Jun	-	-	-								
12-Jun	-	-	-								
13-Jun	-	-	-								
14-Jun	-	-	-	**QPE**							
15-Jun	-	-	-								
16-Jun	-	-	-								
17-Jun	-	-	-								
18-Jun	-	-	-								
19-Jun	-	-	-								
20-Jun	-	-	-		**QPE**			**QPE**			

	0.25 in/hr			0.75 in/hr			1.0 in/hr				
Date	**Alexander Mountain**	**Oak Ridge**	**Stone Canyon**	**Cameron Peak**	**Grizzly Creek**	**East Troublesome**	**Calwood**	**Pine Gulch**	**Spring Creek**	**Sylvan**	**Williams Fork**
21-Jun	-	-	-						QPE		
22-Jun	-	-	-								
23-Jun	-	-	-								
24-Jun	-	-	-								
25-Jun	-	-	-								
26-Jun	-	-	-								
27-Jun	-	-	-								
28-Jun	-	-	-			QPE					
29-Jun	-	-	-								
30-Jun	-	-	-		QPE						
1-Jul	-	-	-								
2-Jul	-	-	-								
3-Jul	-	-	-								
4-Jul	-	-	-								
5-Jul	-	-	-								
6-Jul	-	-	-								
7-Jul	-	-	-								
8-Jul	-	-	-								
9-Jul	-	-	-								
10-Jul	-	-	-								
11-Jul	-	-	-								
12-Jul	-	-	-								
13-Jul	-	-	-								
14-Jul	-	-	-								
15-Jul	-	-	-								
16-Jul	-	-	-		QPE			QPE			

	0.25 in/hr			0.75 in/hr			1.0 in/hr				
Date	Alexander Mountain	Oak Ridge	Stone Canyon	Cameron Peak	Grizzly Creek	East Troublesome	Calwood	Pine Gulch	Spring Creek	Sylvan	Williams Fork
17-Jul	-	-	-								
18-Jul	-	-	-			QPE					
19-Jul	-	-	-	QPE	QPE						
20-Jul	-	-	-								
21-Jul	-	-	-	QPE		QPE					
22-Jul	-	-	-								
23-Jul	-	-	-								
24-Jul	-	-	-								
25-Jul	-	-	-								
26-Jul	-	-	-	QPE	QPE						
27-Jul	-	-	-								
28-Jul	-	-	-								
29-Jul	-	-	-								
30-Jul	-	-	-								
31-Jul	-	-	-								
1-Aug	-	-	-								
2-Aug	-	-	-								
3-Aug	-	-	-								
4-Aug	-	-	-								
5-Aug	-	-	-	QPE							
6-Aug	-	-	-		QPE				QPE		
7-Aug	-	-	-	QPE					QPE		
8-Aug	-	-	-								
9-Aug	-	-	-	QPE							
10-Aug	QPE	QPE		QPE	QPE			QPE			
11-Aug											

	0.25 in/hr			0.75 in/hr			1.0 in/hr				
Date	**Alexander Mountain**	**Oak Ridge**	**Stone Canyon**	**Cameron Peak**	**Grizzly Creek**	**East Troublesome**	**Calwood**	**Pine Gulch**	**Spring Creek**	**Sylvan**	**Williams Fork**
12-Aug	QPE			QPE							
13-Aug			QPE		QPE						
14-Aug											
15-Aug											
16-Aug											
17-Aug											
18-Aug											
19-Aug											
20-Aug											
21-Aug					QPE						
22-Aug											
23-Aug											
24-Aug											
25-Aug					QPE			QPE			
26-Aug											
27-Aug											
28-Aug											
29-Aug		QPE									
30-Aug											
31-Aug											
1-Sep											
2-Sep											
3-Sep											
4-Sep											
5-Sep											
6-Sep											

	0.25 in/hr			0.75 in/hr			1.0 in/hr				
Date	**Alexander Mountain**	**Oak Ridge**	**Stone Canyon**	**Cameron Peak**	**Grizzly Creek**	**East Troublesome**	**Calwood**	**Pine Gulch**	**Spring Creek**	**Sylvan**	**Williams Fork**
7-Sep		**QPE**									
8-Sep		**QPE**									
9-Sep											
10-Sep											
11-Sep											
12-Sep											
13-Sep											
14-Sep											
15-Sep											
16-Sep											
17-Sep											
18-Sep											
19-Sep											
20-Sep											
21-Sep	**QPE**	**QPE**			**QPE**						
22-Sep											
23-Sep											
24-Sep											
25-Sep											
26-Sep											
27-Sep											
28-Sep											
29-Sep											
30-Sep											

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 IEM. 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 Geographic Information Systems (GIS) data. Obtained from the IEM, 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. Figure 21 (Atlas 14, 2017) shows the stark differences in rainfall recurrence statistics at Denver (east of the Continental Divide) compared to Silt (west of the Continental Divide). 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 Continental Divide 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 21: 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. Note that the intensities shown here are broadly similar to the more recent Colorado / New Mexico Regional Extreme Precipitation Study (2018).

b) Seasonality

Seasonality is likely the second most important factor in controlling heavy rainfall potential in Colorado. As shown in Figure 22, 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 a significant factor in the Front Range and Gore Mountains. Meanwhile, by August (Figure 22 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.

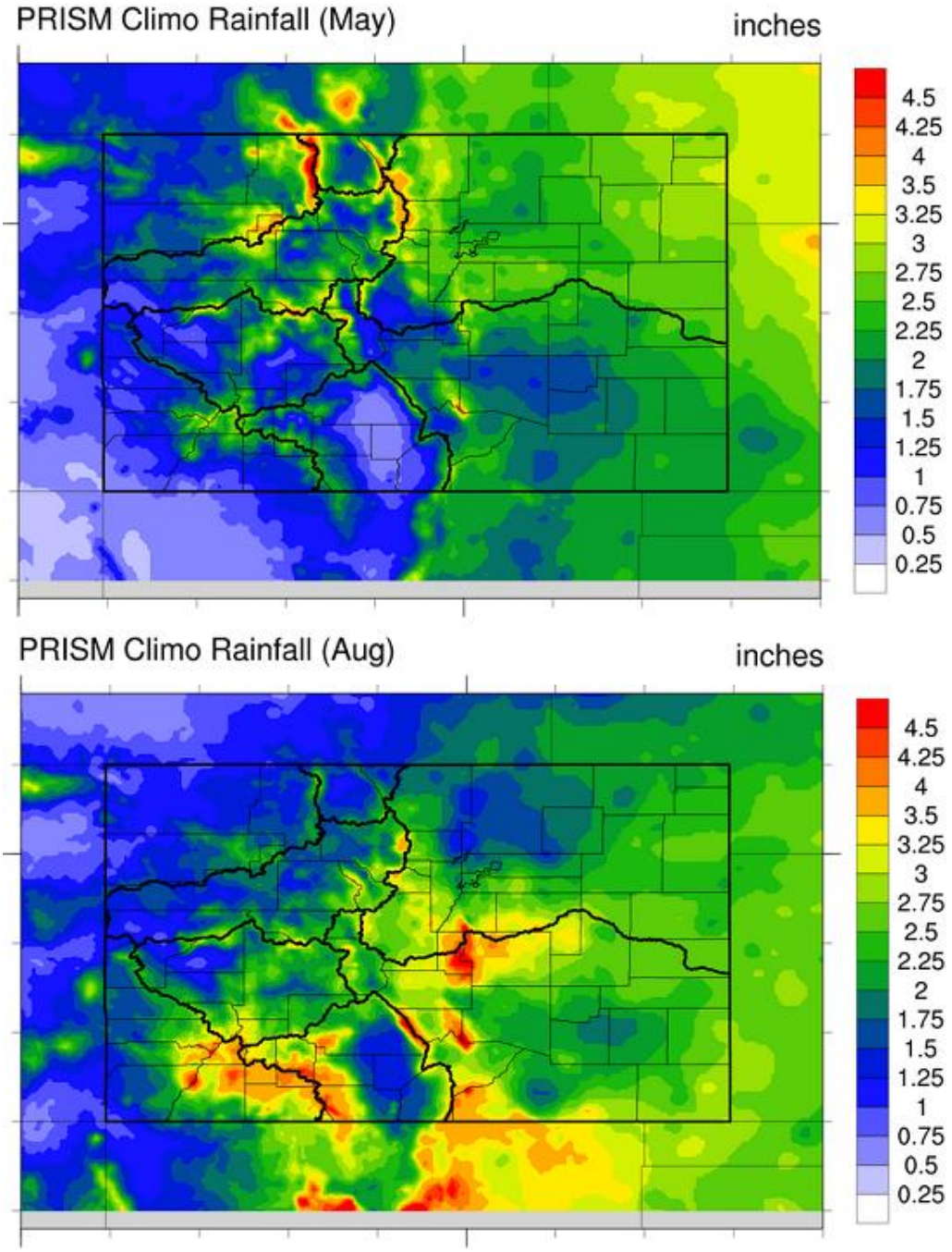


Figure 22: Monthly average precipitation for (top) May and (bottom) August. Source: Oregon State University PRISM group.

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 23 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 translating the heavy rainfall threat to a flooding potential.

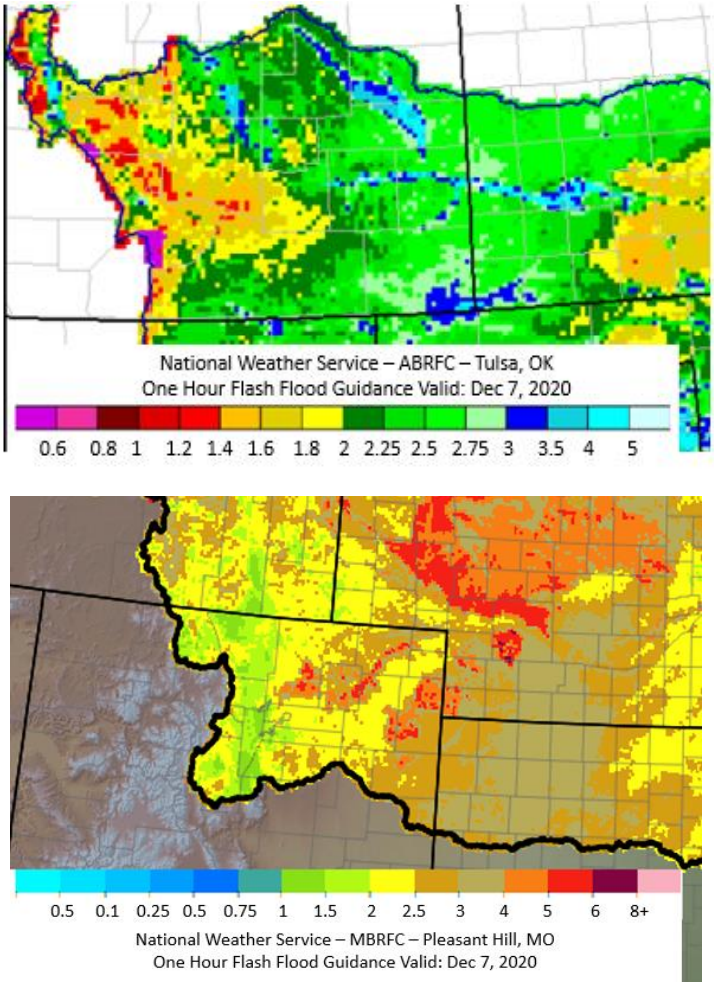
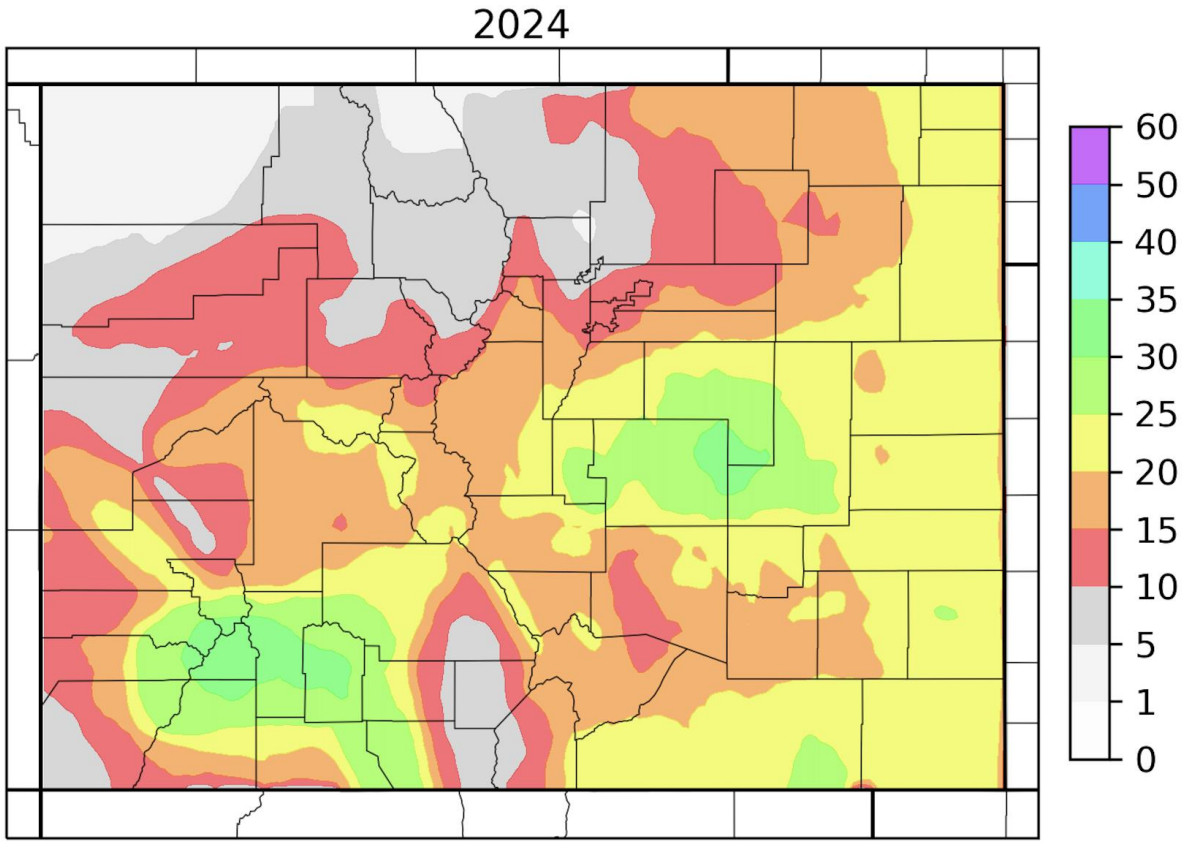


Figure 23: 1-hour Flash Flood Guidance for central and eastern Colorado, valid December 7th, 2020. Source: National Weather Service River Forecast Centers.

APPENDIX E – FLOOD THREATS ISSUED

Figure 24a showed the total number of days when a given location was under a flood threat during the 2024 operational season with the historical seasons from 2016 to 2023 on the following page. 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. The maps also include riverine NWS Flood Warnings which were present a total of 21 days of the 2023 season. As a result, portions of Elkhead Creek and the Elk River in Routt County can be seen in 2023 image. There is also a secondary maximum in Mesa County along the Dolores River, which had a Flood Warning for 11 days this season.

(a)



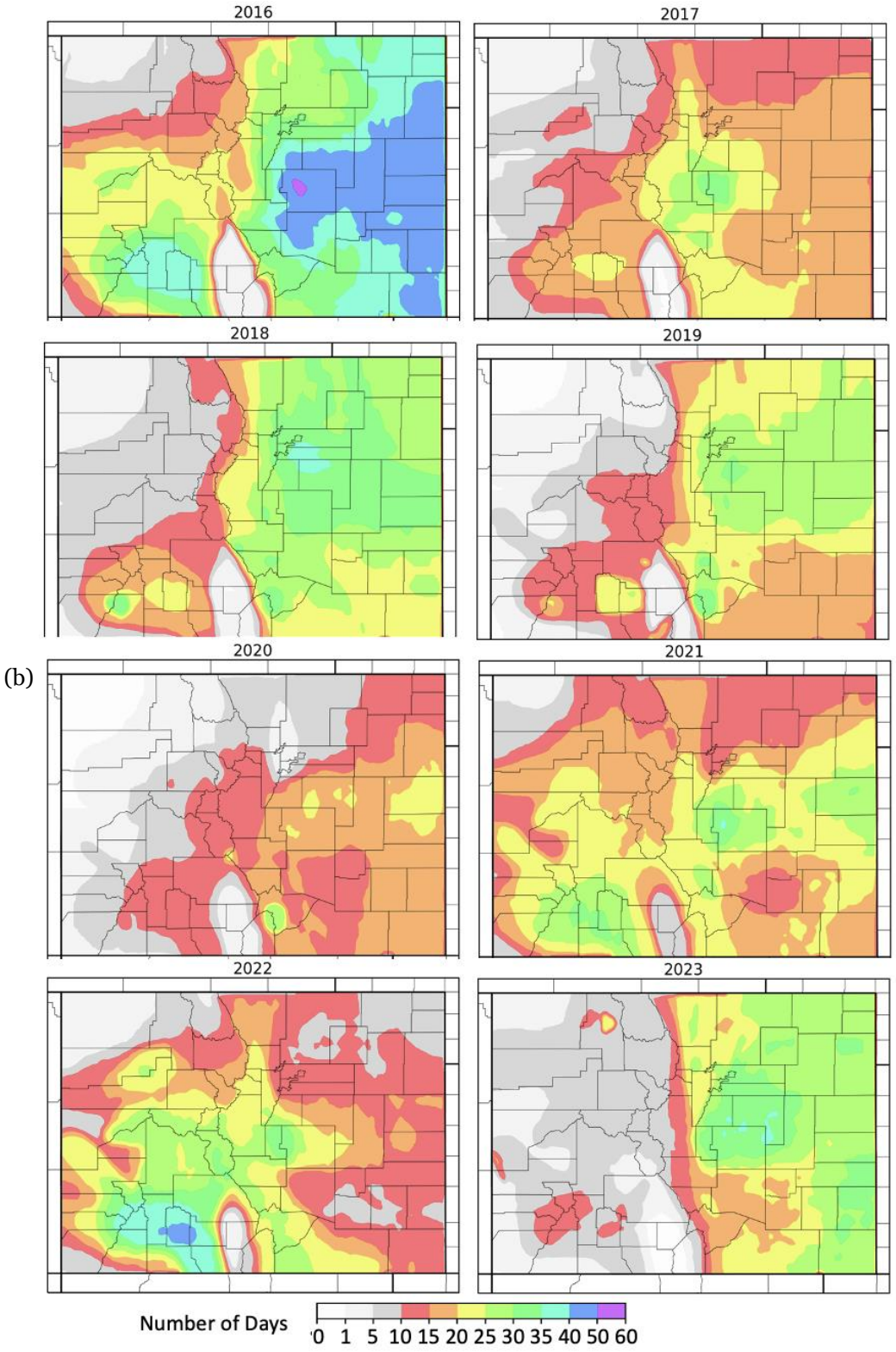


Figure 24: (a) Number of days with a flood threat issued in 2024. (b) Same as (a) except from 2016 to 2023. Note that until 2021, burn areas were considered within the FTB. After 2020, they were covered by the FBF.

APPENDIX F – QPE BIAS ASSESSMENT

An assessment of QPE product bias over the 2023 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. This is similar to findings from last season. Interestingly, as shown in Figure 25 over the course of the season, the MRMS product overestimated and underestimated precipitation about the same amount (50%). However, the overestimations by MRMS were great enough that the mean wet bias was about 0.61 inches.

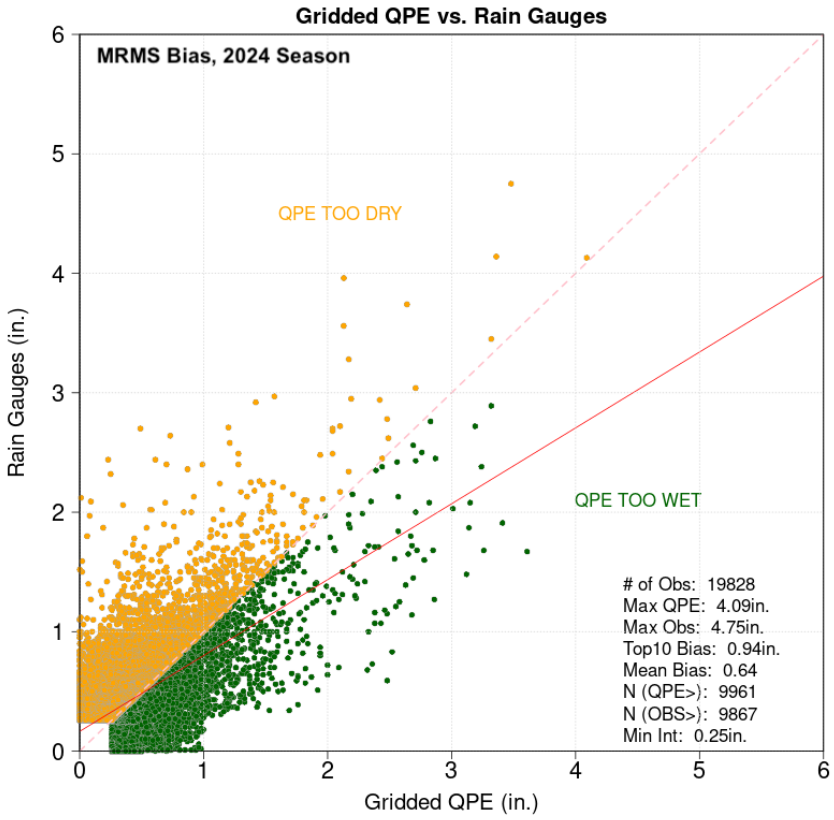
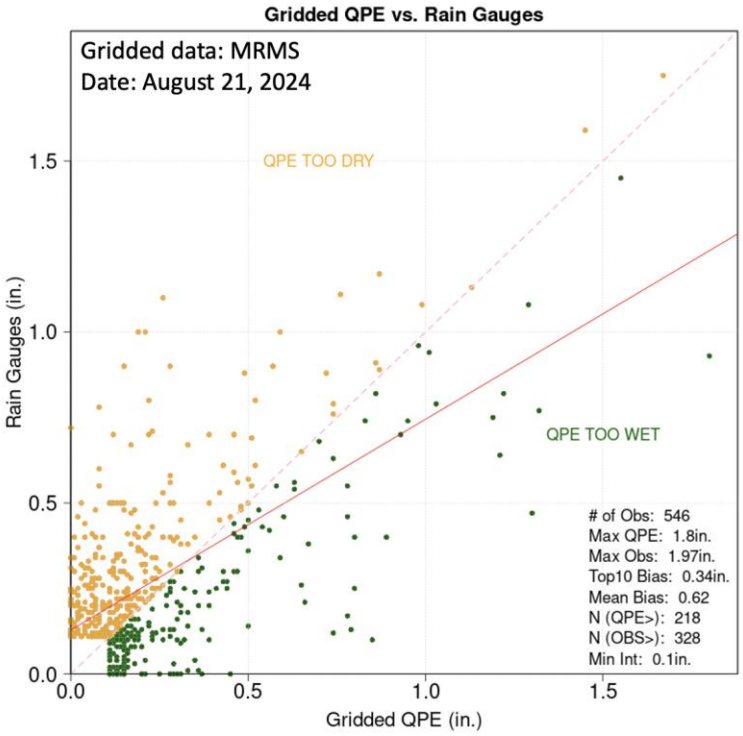


Figure 25: 2024 Seasonal (May-September) MRMS QPE vs Rain Gauge plot that shows overestimation of the gridded QPE product.

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, dynamic Z-R relationships within a storm, distance from radar sites, the presence or absence of hail, as well as cloud temperature. To gain some perspective on how the overall MRMS bias can vary, two events are provided below (Figure 26). On August 21st (top) the monsoon ridge moved slightly eastward and rotated in some mid-level lift and moisture for widespread rainfall over western Colorado and the Southeast Mountains. There were additional storms from a system that clipped the far Northeast Plains. The scatter plot cannot discern the two storm types, but there were a couple modes of convection. Of the 546 stations with measurable rainfall over 0.25 inches, QPE overestimated rainfall at 218 stations (40%), while underestimating rainfall at the remaining 326 stations (60%). The MRMS overestimation was greatest across all observations (wet bias of 0.62 inches), but this bias was reduced for the top 10 observations (wet bias of 0.34 inches), which indicates MRMS did slightly better for higher-end observations. Conversely, on May 12th (bottom), widespread, stratiform rainfall developed over the Front Range and Urban Corridor thanks to a cut-off Low pressure system. The mean bias (0.92 inches) was again higher than top 10 bias (0.75 inches), and the number of observations increased to 866 due to a higher population center. This increase in observations helped to reduce the bias in the stronger rainfall

core estimations but once again shows the tendency of MRMS to overestimate the storm cores when the event is not sampled well by gauges. Because of these small discrepancies in event type, MRMS and Stage IV biases were subjectively assessed for each event, to determine Flood Day classification.



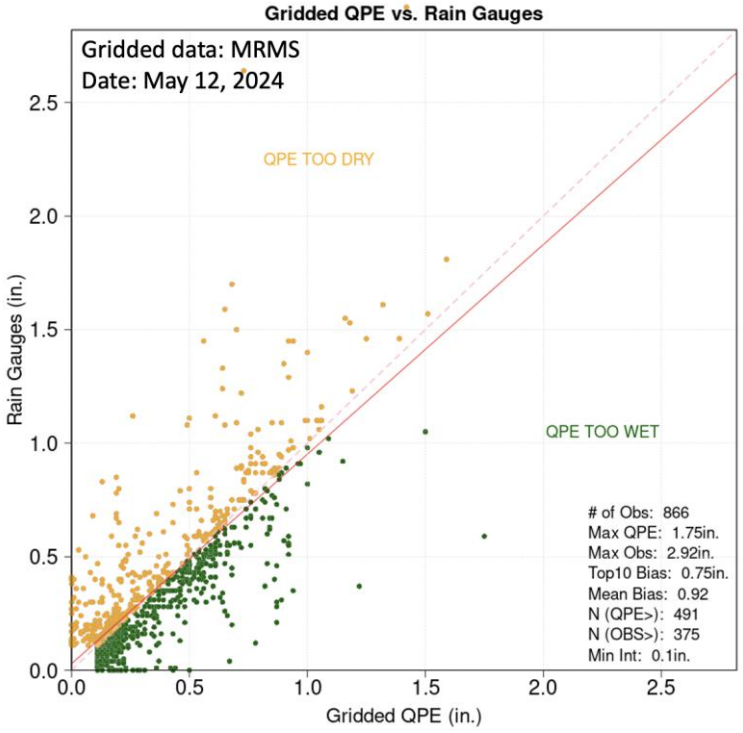


Figure 26: An example of MRMS gridded QPE versus rain gauge scatter plots from June 14th (top) and June 16th (bottom). The images show that the QPE bias is not constant and must be assessed on a daily level to help assign the Flood Day classification.

Finally, Figure 27 looks at the MRMS mean daily bias across each county for the 2024 forecast season from June to September. May was excluded due to snowfall events skewing 24-hour totals. The blue shades, mostly east of the Continental Divide, indicate an overestimation of precipitation for select counties. There is a 0.1 to 0.25 inch bias for Conejos County, indicating a slight overestimation by MRMS. This may be somewhat related to the lack of sample size with only 12 observations available this season that exceeded 0.25 inches. The light red shades indicate a slight underestimation of rainfall by MRMS with dark red, as seen over northwest and southwest Colorado, indicating as much as a 0.25 to 0.50 inch underestimation of daily precipitation for days where rainfall exceeded 0.25 inches. The same analysis, but for Stage IV in Figure 28 indicates a similar spatial pattern though the mean bias trends much lower than MRMS, except over Pueblo and Otero Counties where the bias is wetter. Generally, the ingestion of CoCoRaHS data into this QPE, especially over areas with large population centers, helps Stage IV outperform MRMS in this analysis as seen in Teller County.

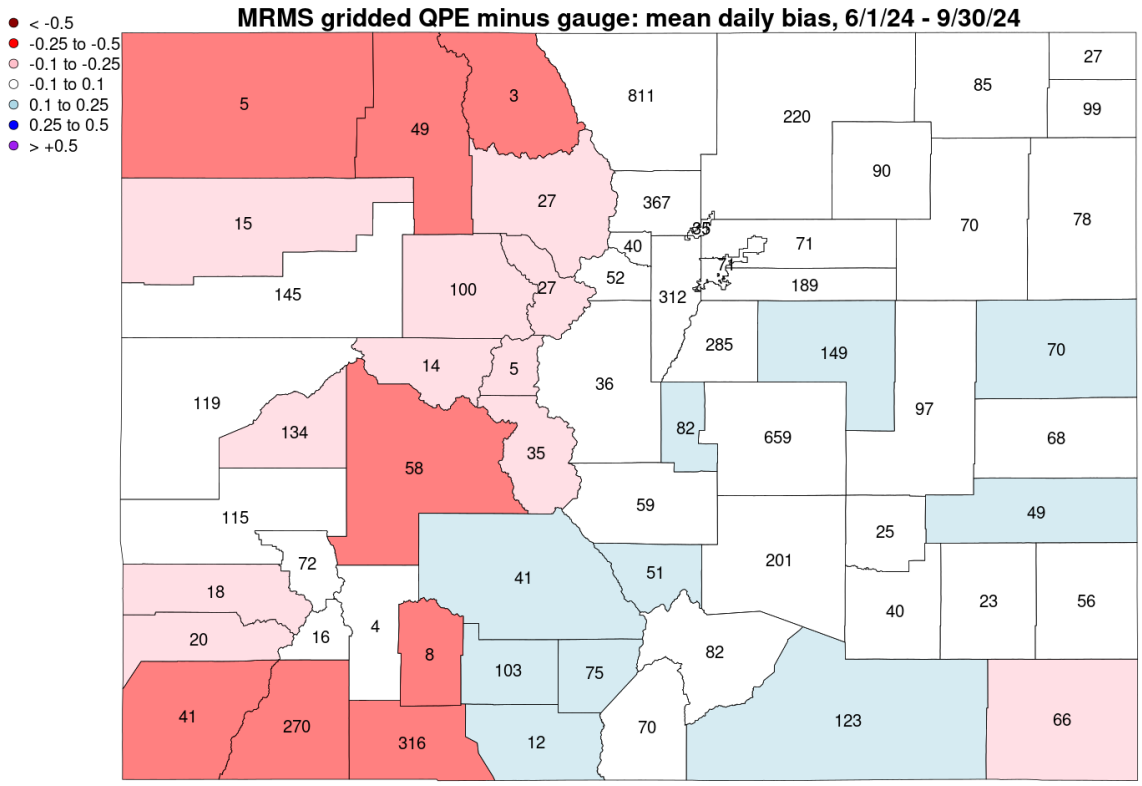


Figure 27: MRMS mean daily bias within each county from June to September of 2024. Blue (red) shading represents an overestimation (underestimation) of precipitation and the numbers in each county represent the number of observations OR estimates over 0.25 inches going into the calculation.

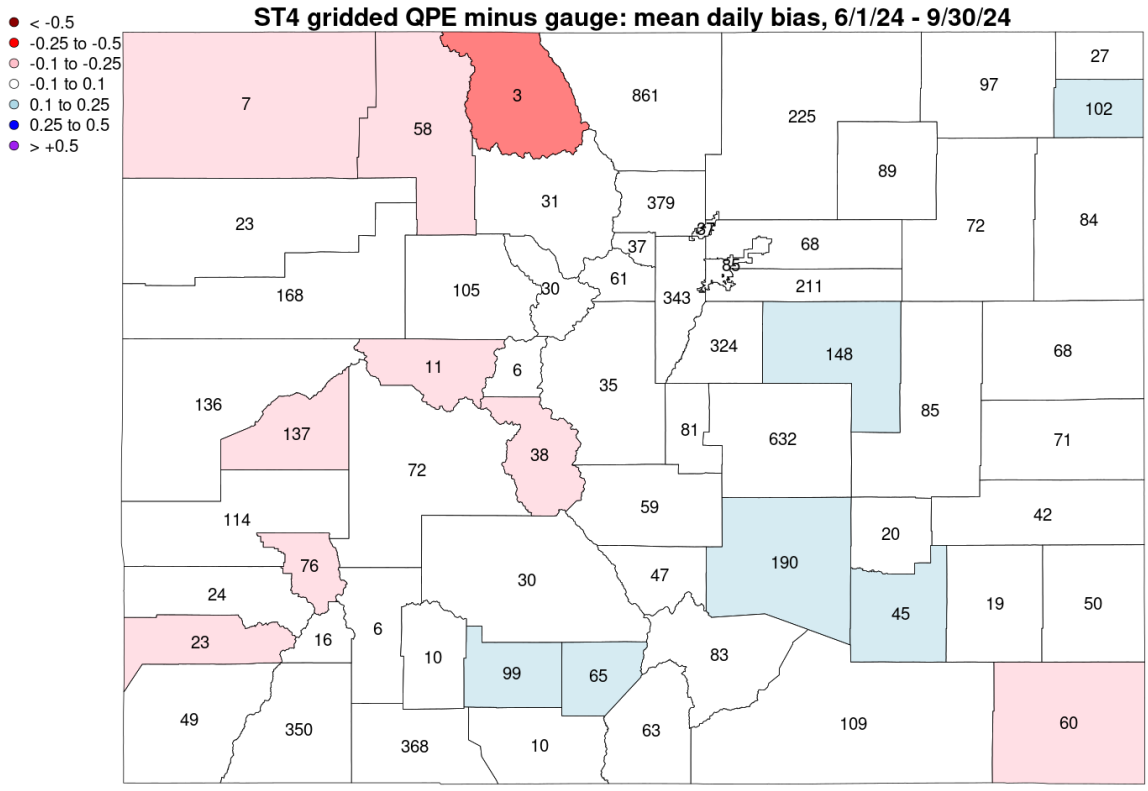


Figure 28: Stage IV mean daily bias within each county from June to September of 2024. Blue (red) shading represents an overestimation (underestimation) of precipitation and the numbers in each county represent the number of observations OR estimates over 0.25 inches.

As a takeaway, the general underestimation of precipitation by both datasets across western Colorado 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. This is especially true this season in Jackson County. Additionally, the number of observations within a given county can vary quite drastically. Counties that have only a few observation points should be interpreted with caution. The higher number of observations over southwest Colorado this season speaks to the more widespread nature of the precipitation this season and more multi-day synoptic events. Over the same area, the ingestion of CoCoRaHS data seems to greatly improve the Stage IV QPE product when compared to MRMS. As seen in past seasons, higher population centers where more gauges are available, tend to have much lower to no bias (-0.10 to 0.10 inches). This continues to be true over the Front Range and Urban Corridor where CoCoRaHS was founded.