Colorado Flood Threat Bulletin – 2020 Final Report

DECEMBER 15, 2020

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2020 Colorado Flood Threat Bulletin

Final Report

1) INTRODUCTION

The 2020 season (May 1st to September 30th) was the 4th year of a 5-year award given to Dewberry to produce the Colorado Flood Threat Bulletin (hereafter, Program) on behalf of the Colorado Water Conservation Board (CWCB). Dewberry began providing this service for the CWCB back in 2012 and each season, we aim to improve and add innovative ideas to further the success of the Program. Through these changes, there are three core features that remain unchanged for the user community:

(i) the daily Flood Threat Bulletin (FTB) that both describes and visualizes the flood threat across the state of Colorado;

(ii) the bi-weekly (Monday/Thursday) 15-day Flood Threat Outlook (FTO) that highlights the flood threat from rapid snowmelt and local heavy rainfall, or conversely, the development of drought conditions;

(iii) the daily State Precipitation Map (SPM) that recaps the past 24- to 72-hours of hydrometeorological conditions and includes flood reports.

For the 2020 operational season, the majority of the forecast were developed or overseen by Dewberry meteorologists Dana McGlone (FTB, FTO, SPM), Josh Aikins (FTB, SPM) and Brad Workman (FTB, SPM). A handful of forecasts (FTB, FTO, SPM) were produce by former Dewberry employee, Dmitry Smirnov (HydroMet Consulting, LLC). Archived forecasts remain available through the Program's website www.coloradofloodthreat.com. Dana McGlone served as the primary contact and project meteorologist for Dewberry, Danny Elsner served as the Project Manager and Ken Cecil served as Principle-in-Charge.

This Final Report was created to provide validation metrics for the daily flood forecasts, summarize the weather over the 2020 warm season, evaluate Program viewership, and to document upgrades made to the Program prior to May 1, 2020.

Daily Flood Threat Bulletin (FTB)

The FTB is designed for daily issuance during the contract period by 11:00 AM. When possible, FTB forecasts are issued as early as possible to provide more lead time to community users, which is especially important on days where there is an elevated flood threat. The FTB outlines the daily threat level of flooding across the state, the nature of the threat and the time period in which the threat of flooding would be the greatest in a zone-specific manner. Additional information provided by the FTB includes a characterization of the threat of attendant severe weather (tornadoes, high winds, hail, etc.), the probability and intensity of thunderstorm rainfall rates and expected totals. Table 1 summarizes the now six-tier category system that is used to characterize the flood threat. The first five-tiers indicate the flood threat: None, Low, Moderate, High, and High Impact. The last tier, NWS Warning, specifies if there are any active NWS Flood Warnings (riverine flood threat) at the time of the FTB post. Continued from 2017, an upgrade to the FTB was the inclusion of daily updates to the first five-tiers, as warranted, during situations with a particularly threatening and/or rapidly evolving flood threat. No updates to forecasts were needed this season, but on occasion, social media updates were issued to notify community users that the forecasts from the morning were on track. These extra social media posts are critical for communication when the morning FTB mentions the possibility of a PM update.

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

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

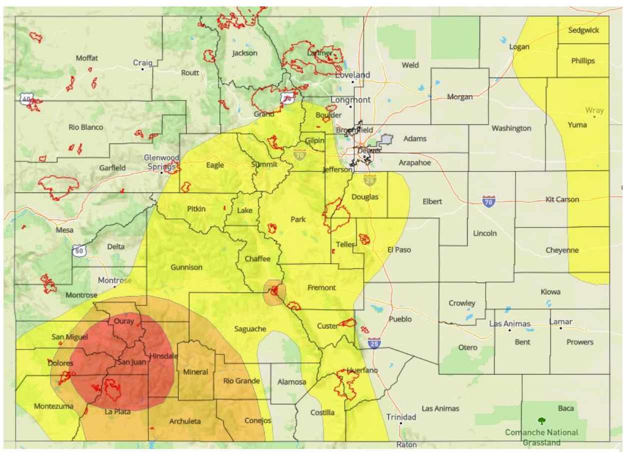

Figure 1: Example of the FTB map from July 25th, 2020. The Low, Moderate and High threats are highlighted in yellow, orange and red, respectively.

The threat of daily flooding is conveyed to the user community through the use of graphics and text. The graphical component to the product includes a map of the state of Colorado with county boundaries and a color-coded threat to succinctly illustrate the range of flooding threats across Colorado (Figure 1). The evolution of this presentation to a more communicative graphical format enhances the threat area visualization and possible impact. All forecasts continue to be archived in a blog-style manner and are available on the product's website.

Wildfire Burn Areas

As always, there is a particular concern for flash flooding, mud flows and debris slides over recent wildfire burn located over steep terrains; especially those near population centers and highly-traveled roads. So, also included on the daily FTB threat map are all recent burn areas across the state. In order for a burn area to be included in the maps, the fire had to occur over steep terrain, have occurred in the last 5 years and burned at least 700 acres. For the larger, complex and more historic wildfires (such as the Hayman Fire in 2002), Dewberry worked with the Colorado State Forest Service, and they informed Dewberry if burn areas had recovered enough to be removed from the map through an internal process. Ideally, each wildfire burn area would be the subject of a dedicated flood threat, but in practice, limited resources imply the need to focus on the most impactful burn areas for the daily FTB: those which are relatively large in scale (corresponds to a higher runoff threat) and those that are in close proximity to high population and/or major roads. New to 2020, interactive FTB, FTO and help maps allow the community users to click on a burn area to see its name, year of occurrence and the number of acres burned.

This season there were four wildfire burn areas monitored by Dewberry (Figure 2): 416 (2018), Lake Christine (2018), Spring Creek (2018) and Decker (2019). Because of the active wildfire season due to the worsening drought, on August 26^{th}, four new fires were added as hazardous burn wildfire burn areas. These burn areas were forecast for through September 30^{th}: Pine Gulch, Grizzly Creek, Williams Fork, Cameron Peak. Other fires, such as

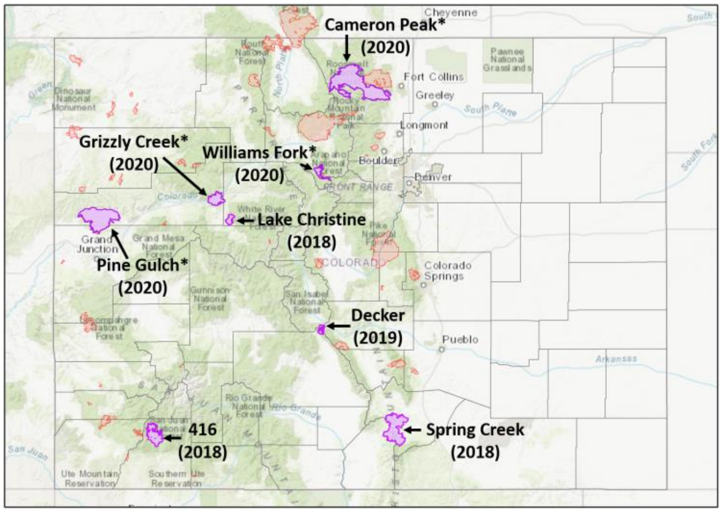

Figure 2: Wildfire burn areas that were featured on the daily FTB maps during 2020. The labeled burn areas (purple shade) were identified as the most hazardous and received daily dedicated flood threats by Dewberry. The asterisk next to a fire name denotes new 2020 burn areas that were added to the forecasting after August 26th. Note: The East Troublesome and Mullen fires are included on the map, but did not begin or enter the state until after the end of the FTB season. Source: National Interagency Fire Center

the Mullen and East Troublesome fires, are included in Figure 2 for completeness, but since they did not start or enter into the state until after September, they were not included in this seasons' forecasts. Once again, we have attempted a validation for burn area threats issued to the best of our ability. This continues to be a necessary step as there were 34 days that a burn area flood threat was issued this season, and on 9 of those days, the burn area threat was the only threat issued in the FTB. More information and guidelines on this process can be found in the Verification Metrics section of this report (page 9 and Appendix B).

Flood Threat Outlook (FTO)

The FTO is a bi-weekly product issued on Mondays and Thursdays by 3PM to address the 15-day threat of flooding across the state. This product addresses both the extended threat of flooding (snowmelt and precipitation driven) and a precipitation outlook by region. The FTO continues to be structured in an event-based manner, where rainfall is partitioned by its forcing features and presented in a timeline. Although it was a quiet runoff season from the snowpack, the snowmelt flood threat was added to the threat timeline, and all NWS Flood Warnings were added to the daily FTB threat maps as their own category. Carried over from last season, specific snowpack/riverine forecasts from May to June were issued in their own section of the FTO as warranted. New to this season, riverine flooding events from snowmelt, could be reported through the "Report a Flood" tab at the top of the website. This "Report a Flood" tool was created to fill the gray area between what the Program forecasts (i.e., flooding caused by rainfall) and what the Program does not forecast (i.e. riverine flooding caused by other factors such as snowmelt, ice jams, dam releases, etc.).

An example of a threat "timeline" is shown below in Figure 3 from May 25th. This FTO illustrates the addition of the snowmelt riverine flood threat, which will be an ongoing feature for the Program at the beginning of each season. Reservoir levels and other metrics important to categorize drought conditions were also tracked throughout the season in the FTOs, alongside our typical monthly departures from average temperature and precipitation. Upgrades to the FTO maps, similar to the FTB map, now allows for more interaction by community users.

FTO 05-25-2020: Afternoon Rainfall Returns to the Forecast with Hot Temperatures by Next Weekend

May 25, 2020 by Dana McGlone ·

Issue Date: Monday, May 25th, 2020
Issue Time: 1:25PM MDT
Valid Dates: 5/26 – 6/9

Colorado Flood Threat Outlook

Next 15 Days	Tue 26-May	Wed 27-May	Thu 28-May	Fri 29-May	Sat 30-May	Sun 31-May	Mon 1-Jun	Tue 2-Jun	Wed 3-Jun	Thu 4-Jun	Fri 5-Jun	Sat 6-Jun	Sun 7-Jun	Mon 8-Jun	Tue 9-Jun
Precipitation		Event #1			Event #2										
Snowmelt															

No Apparent Threat | Elevated Threat | High Threat
FLOOD THREAT LEGEND
Twitter: @COFloodUpdates

Figure 3: Example of an FTO headline from 2020 illustrating the threat "timeline" with the snowmelt forecast.

State Precipitation Map (SPM)

In July of 2017, Dewberry upgraded from the State Total Precipitation (STP) map to the State Precipitation Map (SPM). The SPM product expanded the Quantitative Precipitation Estimate (QPE) to include 48- and 72-hour accumulations as well as maximum 1-, 3- and 6-hour precipitation over the past 24-hour period at 500-meter resolution. The new QPE, called MetStorm Live, was obtained from sub-consultant DTN, and data is visualized through the use of a custom built, Dewberry-hosted webmap using Mapbox API. Daily monitoring of the SPM performance in 2017 suggested that the product underestimated rainfall to the west of the Continental Divide during several monsoonal events. On June 11, 2018, a bias adjustment was added to the 24-, 48- and 72-hour rainfall accumulations. The enhancement combines daily CoCoRaHS precipitation data, a basemap and a radar estimated rainfall grid to produce a bias adjustment to the original 24-hour MetStorm Live grid. The bias adjustment greatly improved the underestimation of rainfall over the San Juan Mountains and southeast corner of the state due to topography and radar ranging issues. It also helps improve overestimations of rainfall associated with hail contamination, especially over the eastern plains. In early 2019, an update was made to the gauge quality control (QC) algorithm to better handle remote station locations and high elevation QPE. Dewberry will continue to work with DTN to see if the new radars in Alamosa and Durango (coming May 2021) can be implemented into MetStorm Live, which would help fill other well-known data holes over southwest and southcentral Colorado next season.

An example of the daily SPM layout is shown in Figure 4. In addition to the map-based visualization, Dewberry forecasters provided text-based summaries of recent hydrometeorological conditions (including extreme rainfall values, flooding, debris slides, hail, wind, tornadoes and wildfire activity). Discussions are also supplemented with gauge data from CoCoRaHS, COOP, Mile High Flood District's ALERT, SNOTEL and NWS Local Storm Reports. Unfortunately, usage of the new "Report a Flood" tool on the website was low this season. However, should this feature become popular, it may be a useful addition to the interactive QPE maps in the future. For the 2021 season, Multi-Radar/Multi-Sensor (MRMS) 24-hour QPE will be available on the SPM map, which will provide another estimation of daily precipitation.

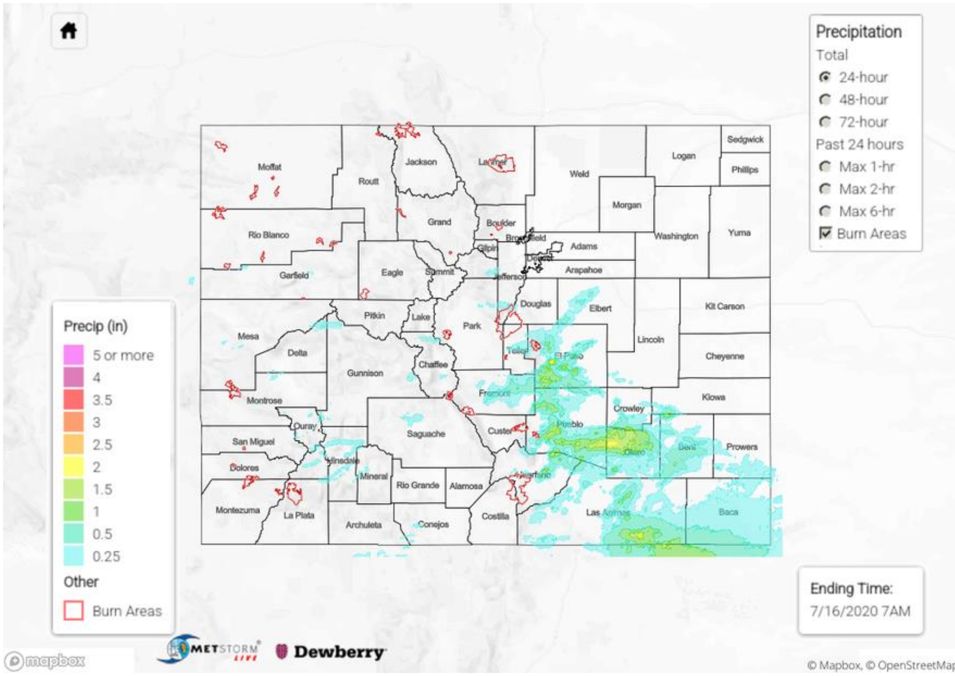

Figure 4: Example of SPM from July 16th, 2020.

Performance metrics

Table 2 shows the final year-to-date number of all products provided, and the percent provided on time. Out of 349 total products delivered, 341 were delivered on-time or ahead of time. The three late products were 4 SPMs, 2 FTBs and 2 FTOs, all of which were posted within an hour (FTB/SPM) or two (FTO) of their deadline. Note that Table 2 also shows September performance, since there was no monthly Progress Report prepared. All necessary information for the September Progress Report is contained within this Final Report. Other monthly Progress Reports were prepared for May through August and sent to the CWCB Project Manager no later than 2 weeks after the end of the month.

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

		Products to Date	Products on Time	Products Late	Percent on Time			Products to Date	Products on Time	Products Late	Percent on Time
September	SPM	30	30	0	100%	YTD	SPM	153	149	4	97%
	FTB	30	30	0	100%		FTB	153	151	2	99%
	FTO	8	8	0	100%		FTO	43	41	2	95%
	TOTAL	68	68	0	100%		TOTAL	349	341	8	98%

2) VERIFICATION METRICS

Data Sources and Methodology

The daily FTB flood threat forecasts were verified on their ability to both (i) identify days when flood threats were realized and (ii) specify the approximate location of the potential flooding without grossly overestimating the flood threat area. Dewberry continues to place substantial effort on verification to increase robustness and, in turn, improve future forecasts. A couple additional forecast metrics were added to this year's verification, which will help shed light on where progress needs to be made. Note that improvements beginning in 2017 included: creation of comprehensive daily validation maps (see Figure 6), the use of more quality controlled rain gages and more effort spent on manual day-by-day quality control to ensure that a threat is properly classified. The data sources and methodology used to verify 2020 forecasts are described below.

Observational Data Sources

a) Daily precipitation accumulation reports from about 1300 CoCoRaHS observers across Colorado. This data is generally reported in the morning and encompasses the previous 24-hours. We use only reports that are received from 6AM to 9AM to ensure that measurement is consistent with the forecast period. Questionable observations were noted and discarded based on comparison with other data.

b) Natural Resources Conservation Service (NRCS) SNOTEL hourly precipitation, which was aggregated into daily accumulation at approximately 65 high-elevation sites across Colorado. Questionable observations were noted and discarded based on comparison with other data.

c) The University of Utah's MesoWest hourly precipitation data, which has many contributing networks. The majority of the data came from: Colorado Agricultural Meteorological Network (CoAgMet), Climate Reference Network (CRN), Hydrometeorological Automated Data System (HADS), Interagency Remote Automatic Weather Stations (RAWS) and Soil Climate Analysis Network (SCAN). Hourly data was aggregated into 24-hour totals, and questionable observations were noted and discarded based on comparison with other data.

d) United States Geological Survey (USGS) sub-hourly precipitation data, which is particularly helpful over the higher terrains and more populated areas of Teller and El Paso Counties. The sub-hourly data was aggregated into a rolling 1-hour totals. This methodology allows for the true 1-hour rainfall to be retained, which in year's prior, has been truncated at the hour. This fixes a potential underestimation of the true 1-hour rainfall value.

e) NOAA Stage IV gridded precipitation data (hereafter Stage IV), which is a publicly available hourly product based on a radar-estimated, gage-adjusted technique using all National Weather Service NEXRAD radars and many quality controlled rain gages. The horizontal resolution is about 4 km (2.6 miles). In addition to using the 24-hour total precipitation, maximum 1- and 2-hour amounts were calculated to better understand the nature of the precipitation (convective vs stratiform). Often times the 2-hour amounts exceeded 24-hour amounts (post-processing differences), so 2-hour QPE was utilized with caution.

f) Local storm reports (LSRs) obtained from the four NWS offices that are responsible for Colorado: Boulder, Pueblo, Grand Junction and Goodland (KS) from the Iowa Environmental Mesonet. Reports were only included if they contained the following phrases: "Heavy Rain", "Flash Flood", "Flood" or "Debris Slide". Reports involving the term "Heavy Rain" were retained only when the magnitude of rainfall exceeds 0.50 in. Similar to CoCoRaHS data, reports of 24-hour accumulation were only retained if the report ending time was between 6AM and 10AM. If a "Heavy Rain" report did not specify a magnitude, it was dismissed unless the observer's note contained a specific reference to flooding.

g) NWS warning and advisory shapefiles (obtained from the Iowa Environmental Mesonet), including metadata such as when the product was issued. Only Flash Flood Warning, Riverine Flood Warning and Areal Flood Advisory products were included in the analysis.

Verification Methodology (FTB)

To determine if a flood threat was accurate, a "Flood Day" classification system was developed to describe whether flooding and/or rainfall intensity capable of causing flooding was observed. **A Flood Day is defined as a binary variable: it is either one (1) when flooding and qualifying rainfall intensity is observed, or zero (0) otherwise**. Note that, in practice, flooding often goes undocumented, and that adding a measure based on rainfall intensity ensures a more comprehensive treatment of the issue. Given the large variance in the rainfall-runoff relationship across Colorado (see Appendix C), more than one rainfall threshold is required. Thus, a Flood Day is hereby defined when one of following two criteria is met in the issued flood threat area (*Figure 6*):

1) Gridded or observation based 1-, 2- and/or 24-hour rainfall exceeds (see Figure 5):
    a. 1.00 in. west of the 1,600 meter (5,250 foot) contour over the eastern plains
    b. 1.50 in. east of the 1,600 meter (5,250 foot) contour over the eastern plains

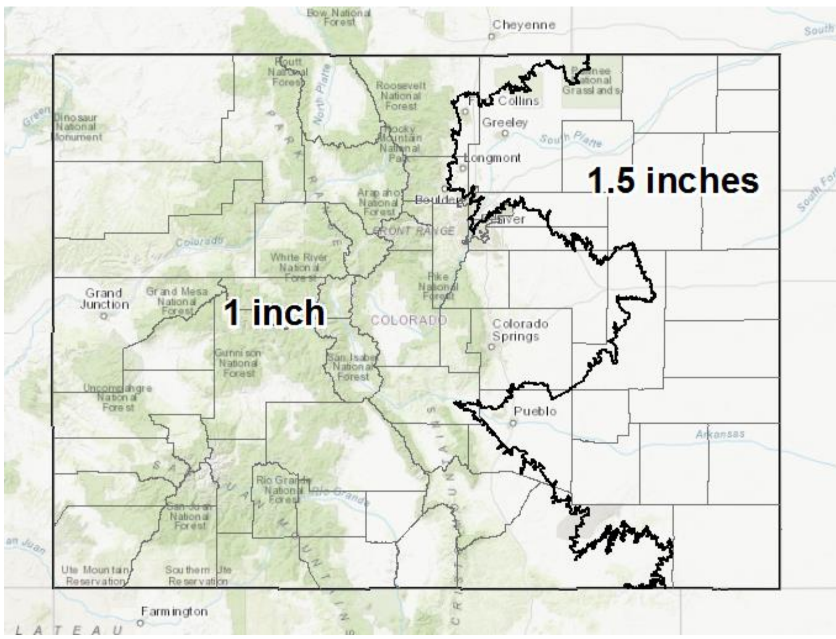

Figure 5: Colorado county map with thick black line showing the 1,600 meter (5,250 foot) elevation contour line east of the Continental Divide, which acted as the demarcation in rainfall-runoff sensitivity. To the east, a rainfall threshold of 1.50 inches per day was used to denote a "Flood Day"; to the west, it was 1.00 inch.

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

Despite the desire to create a purely objective Flood Day index, there are numerous reasons where the protocol above may yield an erroneous Flood Day classification. Thus, after objective calculation of Flood Day using the protocol above, a manual quality control procedure was completed to account for the overriding conditions shown in Table 3. Note that multiple conditions could be met on any given day, reiterating the importance of having a manual quality control. In total, there were 28 days where overriding conditions were used, and three of those days had multiple overriding conditions. Note that in years past, an overriding condition was "BURN", which described days where threat(s) were only issued for burn areas. Due to the separate burn validation analysis, this overriding condition is no longer needed.

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

Condition	Label	Outcome	# Occurrences
Snowfall results in a qualifying 24-hour precipitation total, but minimal runoff does not support flooding.	Snow (SNOW)	Flood Day = 0	4
Long-duration low intensity precipitation causes qualifying 24-hour precipitation total but runoff does not support flooding.	Low Intensity (LI)	Flood Day = 0	5
There is no rainfall but antecedent conditions and/or snowmelt cause riverine flooding.	Riverine (RIV)	Flood Day = 0	1
Hail likely causes an overestimate in Stage IV resulting in qualifying precipitation totals.	Hail (H)	Flood Day = 0	0
The area of qualifying Stage IV precipitation exceeds 50 sq. mi. but is spread out over multiple (independent) areas, limiting flooding potential.	Multiple areas (AREA)	Flood Day = 0	23

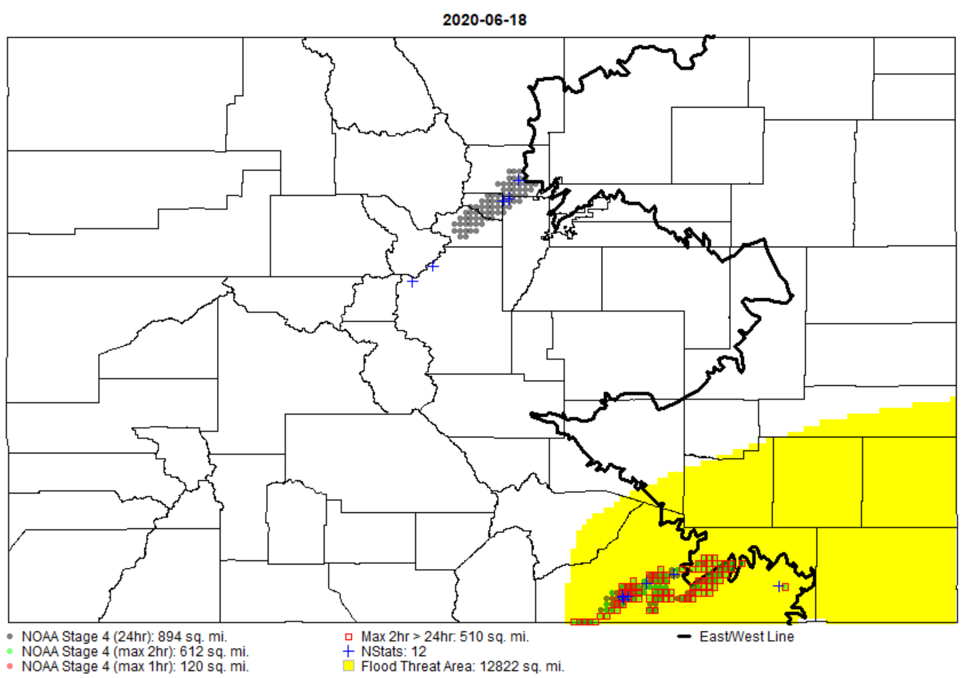

Figure 6: Example of daily validation map from May 18th, 2020 showing qualifying 24-hour NOAA Stage IV pixels (gray), rain gages (blue crosses) and threat area (yellow color fill). For reference, qualifying Stage IV maximum 1-hour (red dot) and 2-hour (green dot) estimates are also shown, but note these were not solely used in defining a "Flood Day". Red squares denote areas where maximum 2-hour Stage IV estimates exceeded the 24-hour estimate, an indication of the potential existence of hail and/or very high radar reflectivity. Note that the threat area does not distinguish between different threat levels.

Verification Methodology (Burn)

In 2017, Dewberry began to forecast threats over burn areas known to have flooding issues that put people and property at risk. High-risk burn areas are identified at the beginning of each season and are typically relatively large in scale (corresponds to a higher runoff threat), over steeper terrain and are in close proximity to high population and/or major roads. The general rule of thumb for burn areas between 0 and 1 year old is that they need only rain rates of 0.25 inches per hour to trigger mud flows, debris slides and local stream flash flooding. After 1 year, the rain rates that burn areas are able to withstand increases at a rate of about 0.2 inches per hour per additional year. Exponential recovery is typical after year 1 and 2, and in most cases, burn areas fully recovery to the FTB forecasting metric (1 inch per hour over the mountainous west) after about 5 years.

In the preseason analysis, there were four high-risk wildfire burn areas identified and specifically monitored by Dewberry (Figure 1): 416 (2018), Spring Creek (2018), Lake Christine (2018) and Decker (2019). Additional well-known wildfires (Waldo Canyon, West Fork Fire Complex, Junkins, etc.) were not specifically mentioned in the FTB posts, but were still internally monitored on higher threat days. These historical burn areas still tend to flood more frequently than surrounding areas when heavy rainfall falls directly overhead. During the preseason analysis, we used the prior season's QPE to determine the 1-hour rain rate thresholds that caused flooding issues for each of the aforementioned burn areas for the previous season. Due to the constant recovery of the burn areas or rainfall not directly falling over the center of a burn area, these previous season rain rates may not always cause flooding issues; however, this is still the best process to determine thresholds prior to the season starting. Well-established thresholds also allow for a more well-rounded validation process at the end of the season. Of course, how burn areas responded to specific rain rates are internally monitored throughout the season, and threshold levels can be adjusted as needed. Prior to the start of the season, the Program reached out to NWS offices in the area, and Tony Anderson (Hydrologist) of NWS Pueblo (email, April 2020) confirmed they were using similar thresholds for burn area forecasting for the burn areas located within their CWA. Typically, NWS thresholds tend to be slightly different due to their monitoring process and warning system.
Water Year 2020 began with abnormally dry and moderate drought conditions over most of western Colorado after a flash drought developed at the end of WY2019 (Figure 7). By early May, severe drought (D2) had expanded across southern and eastern Colorado. Generally, this area of severe drought received between 25-70% of normal precipitation from February to April. Expansion and worsening of the drought throughout the FTB season continued, which was intensified by the early melt-out. Generally, below average precipitation and above average temperatures helped foster the worst wildfire season on record in terms of acreage burned. This led to the FTB updating burn area maps at the end of August to account and forecast for four new burn areas (Table 4): Pine Gulch, Grizzly Creek, Williams Fork and Cameron Peak. These fires are not included in the validation since stats were not collected for the full season.

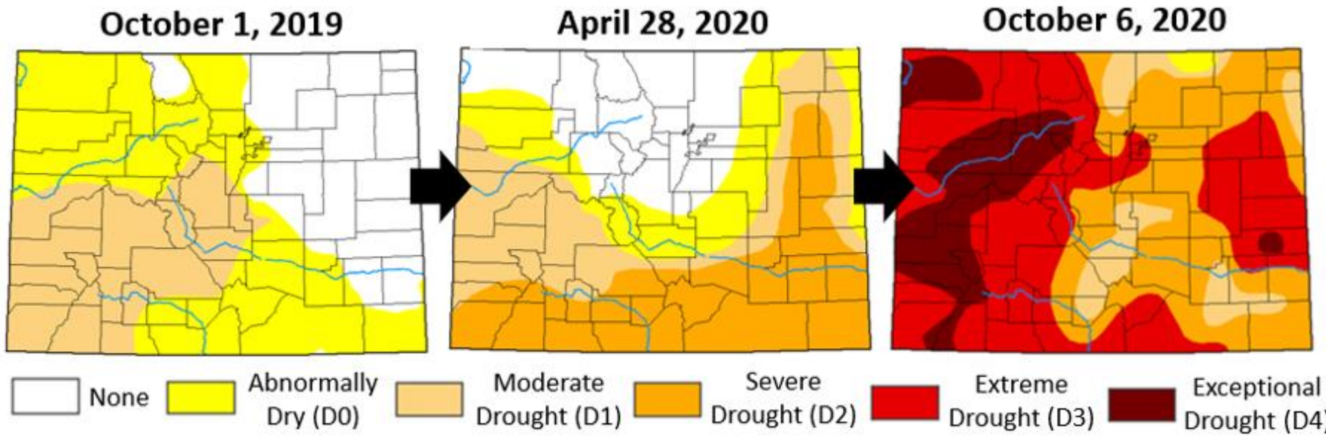

Figure 7: Drought maps for the state of Colorado ending on 1 October 2019 (left), 28 April 2020 (center), and 6 October (right). Source: U.S. Drought Monitor

There is no industry standard protocol on how to validate such a forecast, so liberties continue to be taken in regards to validation criteria. Stage IV data was used for QPE, and max QPE values were obtained both directly over the burn area and within a 10-mile radius of the burn area (QPE buffer). QPE buffer allows for errors in the imperfect, but improving, nature of heavy rainfall forecasts for the validation. Even with a 10-mile buffer, there are difficulties forecasting for such a small burn area. For example, the Decker burn area is only about 40 sq. mi., which is smaller than the ~250 sq. mi. scale at which current forecasts begin to show skill. The burn area QPE (no buffer) was collected to allow for a post-season analysis of rain rate thresholds that were known to trigger flash flooding, mud flows and/or debris slides. A secondary benefit of QPE (no buffer) is insight to the recovery of the burn area from the previous season(s).

To determine if a burn area flood threat was accurate, a similar "Flood Day" classification system was developed to describe whether burn area flooding occurred. **A Burn Area Flood Day is defined as a binary variable: it is either one (1) when flooding is observed, or zero (0) otherwise**. Since flooding often goes undocumented in these remote areas, and the burn areas themselves are small in scale, max QPE is given a 10-buffer (QPE-buffer) to help better quantify the maximum rainfall intensity from a storm. It is important to note that the accuracy of burn area flood threats will likely be lower, possibly significantly lower than regular flood threats due to their small areal extent. Off-season work pertaining to burn areas will continue to be attempted with the NWS, which could help improve the burn area forecasting procedures and address discrepancies between the burn scar forecast areas. For now, a Burn Area Flood Day is hereby defined when at least one of the following three criteria is met for any listed burn area:

1) A qualifying NWS Local Storm Report (LSR) report described is received. For more information, see item (5) under Observational Data Sources, above.
2) An NWS Flash Flood **Warning** is issued that day that has a storm report within the **Warning**, which was not present in the LSR database. An NWS **advisory or Warning**, alone, does not qualify as a Flood Day.
3) Stage IV 1- and/or 2-hour QPE-buffer exceeds the assigned threshold for a burn area (see Table 4). 24-hour Stage IV QPE-buffer is used to QC the 2-hour QPE as it has less QC, comparatively.

*Table 4: Burn areas forecast by the FTB for the 2020 season with their rain rate thresholds that are known to cause flash flooding issues. Burn areas with an asterisk denote a new 2020 burn area that was added to the FTB forecast after August 26th. These are **not** included in the burn area validation. Local Storm Reports (far right) indicate the number of mud flows, debris slides or flash flooding reported to NWS (or by local officials) over the given burn area this season.*

Burn Area (Year)	Threshold (in/hour)	Local Storm Reports
416 (2018)	0.75	0
Spring Creek (2018)	0.50	12
Lake Christine (2018)	0.40	0
Decker (2019)	0.25	2
*Pine Gulch (2020)	0.25	2
*Grizzly Creek (2020)	0.25	0
*Williams Fork (2020)	0.25	0
*Cameron Peak (2020)	0.25	0

Results

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. So, this validation does NOT include any afternoon updates to the flood threat.

As there is no single number that can comprehensively measure forecast accuracy, Table 6 shows the seven metrics that are used in this report, all based on the contingency table approach shown in

Table 5. In brief, there are two possible outcomes when a Flood Day forecast is issued: (i) a Flood Day is observed (case a in

Table 5), a "Hit", (ii) a Flood Day is not observed (case c in Table 3), a "False Alarm". There are two additional scenarios that complete the set of all outcomes. First, if a "Flood Day" is not forecasted, but is observed, this results in a "Miss" (case b in

Table 5). Second, if a non-Flood Day is forecasted and a non-Flood Day is observed, this also results in a "Hit", although a dry one, which is often referred to as a correct negative (case d in Table 5). Historically, the CWCB has always advocated for minimizing the Miss rate, which, given the uncertainties with heavy rainfall forecasting, necessarily results in a higher False Alarm rate. As shown in Table 6, target percentages for each metric have been established based on values accepted as reasonable within the forecasting community. These metrics only apply for the general flood forecasting, and they are used as loose guidance for the burn area verification.

Table 5: 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 6: Description of metrics used for validating forecast accuracy.

Metric	Abbreviation	Calculation (see Table 5)	Summary	Goal
Accuracy or "Hit" rate	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 Rate	F	$\frac{c}{c+d}$	Measures probability that a Flood Day (Dry Hit) is forecast but a non-Flood Day is observed. Perfect forecast value is 0%.	<20%
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 Rate	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 7 shows the individual monthly and yearly aggregated forecast verification during the 2020 season. Over the course of the 2020 season, forecast performance achieved or exceeded four of the six targets established in Table 6, and there was one metric only 1% below the target (POD). With an overall Hit Rate (Hit %) of 89%, forecast performance continued to be **well above** the >75% target. This metric was partially helped by the high number of Dry Hits or correct negatives during this quiet flood season. The Probability of Detection (POD) was at 74%, which is 1% from the goal (>75%). The False Alarm Rate (F) was similar to 2019, so at 5%, it continues to be well below the goal of <20%. The Miss Rate (Miss %) of 26% continues to be much above the goal of <15%, so extra emphasis will continue to be placed upon lowering this metric for the 2021 season. On Miss days, the average 24-hour QPE (greater than the Flood Day thresholds) was only about ~180 square miles and were mostly located over more rural areas, so the Misses may have not been too impactful.

Looking at the month-to-month performance in Table 7, heavy rainfall occurrence was highest in July (18 days) and then August (13 days). Combined, these two months account for 67% of Flood Days, which is expected with the monsoon season typically peaking during this period. The 13 Flood Days in August is quite impressive given that it was the 5th driest August on record statewide (NCEI National Temperature and Precipitation Maps, 2020). Additionally, only 2 of the 13 August Flood Days recorded heavy rainfall over western Colorado, which is surprising given this is when the monsoon climatologically peaks over this region. Further, Rio Blanco, Mesa, Montrose, Ouray, San Juan and Archuleta Counties had their driest August on record and the state experienced a rapid expansion of Extreme Drought (D3) conditions. More about the monsoon season can be found below (Section 3: Characterization of Forecast Period Weather).

There was some variability in the monthly performance statistics, as can be expected due to smaller sample sizes. For example, during September, there were only two Flood Days, so the two missed flood forecasts led to a 100% Miss Rate. Conversely, during July, 3 of the 18 Flood Days were missed resulting in a much lower Miss Rate of 17% due to the higher sample size. Generally speaking, metrics across the board were more sensitive this season due to the reduced number of Flood Days. Overall, there was slight improvement in the month-to-month False Alarm Rates (F) and Miss Rates (Miss %) when compared to last season. Once again, only the False Alarm Rate (F) and Hit Rate (Hit %) were the only two of these four metrics that performed up to industry standard in every month.

Table 7: 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	5	5	15	9	0	34
(b) No Flood / Flood	1	2	3	4	2	12
(c) Flood / No Flood	0	2	2	0	1	5
(d) No Flood / No Flood	25	21	11	18	27	102
Total Days	31	30	31	31	30	153
Hit %	97%	87%	84%	87%	90%	89%
POD	83%	71%	83%	69%	0%	74%
F	0%	9%	15%	0%	4%	5%
Miss %	17%	29%	17%	31%	100%	26%

Table 8 shows the yearly performance summaries from 2012 through the present with two additional metrics added for 2019 and 2020 (Threat Score and False Alarm Ratio). Both of these metrics take out the Dry Hits or correct negatives in their calculation, which makes them more dependent on the climatological frequency of heavy rainfall events. Overall, 2020 continues to show the success of the Program when all measures are taken collectively, and it also shows slight improvement across all metrics when compared to 2019. Accuracy was the highest in Program's history at 89%, which likely was aided by the number of correct negatives. Paired with another year of a low False Alarm Rate (5%), this can be interrupted as high confidence in a forecast on the days that threats were issued. The higher Miss Rate (26%) continues to stick out as an area of improvement needed for the 2021 season, since this is more of a priority to CWCB than keeping a low False Alarm Rate (F). It is likely that this will cause the False Alarm Rate (F) to increase since this is a tradeoff between the two metrics. However, with the False Alarm Rate well below industry standards, there should be a way to keep the False Alarm Rate below industry standards (<20%) while decreasing the Miss Rate.

It is noted that the number of Misses did decrease by three (3) when compared to last season, and out of the 12 misses over the course of this season, the qualifying Flood Day average area was less than 200 sq. mi. (24-hour QPE). This implies relatively localized areas of heavy rainfall, so widespread events were properly forecast by the Program. The one exception to this statement was the overnight training storm system on July 23rd over Yuma County, which caused widespread flooding. To improve the forecast for future training events, an analysis was completed to identify important atmospheric ingredients that could have been better identified in the morning hours. Going forward, on days that these ingredients are present during the morning hours, a PM update will be issued.

While validation and flood classification has undergone changes season to season, since the start of the Program, on average a forecast season experiences a Flood Day on ~71 of the 153 forecast days (46%). In 2020, only 30% of the forecast days (46 days) experienced flooding criteria, which is the lowest in Program history. In fact, from 2018 to 2020, on average the forecast season has only experienced Flood Days on 50 of the 153 forecast days (~33%). The lower number of Flood Days is expected to slightly impact validation statistics due to the lower sample size. Finally, the Bias for this season is under 1 again, which signifies some under-forecasting of the flood threat. So once again, the focus of the Program for 2021 will be to reduce Misses as slight over-forecasting is preferred to under-forecasting.

Table 8: Summary of yearly forecast performance since 2012. Note that the validation procedure was significantly enhanced in 2014, which makes it difficult to compare pre-2014 statistics to 2014-present.

	Hit %	TS	F	FAR	POD	Miss %	Threats Issued	Flood Days	Bias
2012	86%	N/A	18%	N/A	84%	16%	65	64	1.02
2013	84%	N/A	13%	N/A	85%	15%	83	85	0.98
2014*	76%	N/A	18%	N/A	73%	27%	75	84	0.89
2015	77%	N/A	25%	N/A	78%	22%	85	88	0.97
2016	84%	N/A	21%	N/A	88%	12%	93	91	1.02
2017	86%	N/A	15%	N/A	86%	14%	76	74	1.03
2018	87%	N/A	11%	N/A	82%	18%	52	50	1.04
2019	86%	65%	6%	13%	72%	28%	48	54	0.83
2020	**89%**	**67%**	**5%**	**13%**	**74%**	**26%**	41	34	**0.85**

Table 9 shows the forecast performance as a function of threat level. Note, the threat level in the table represents the highest threat issued over a non-burn area for a day. A robust forecast system should show higher skill as the threat level increases due to more confidence that flooding will be realized. Similar to previous seasons, Table 9 shows this to be the case with a 76% verification when Low threats were issued. This is slightly lower than last season where Low threat forecasts verified 88% of the time, but still above industry standards. **Moderate and High threats verified 100% of the time they were issued**. There were no days when a High Impact threat was issued this season.

Table 9: 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%)	5 (17%)	29
Moderate	11 (100%)	0	11
High	1 (100%)	0	1
High Impact	0	0	0
Total	34 (83%)	5 (12%)	41

Burn Area Results

Table 10 shows the individual and aggregated forecast verification for burn area threats issued during the 2020 season. Reminder that flooding did not have to occur for a Flood Day to be recorded. Currently, there are no established targets for burn areas as an industry standard, so the goals for FTB forecast validation are used as a loose guideline (Table 6). For burn area performance metrics, one should expect much lower skill than the FTB forecasts due to the small area of the burn areas. Additionally, the aggregated burn areas should perform better than the individual burn areas since the burn areas are combined each day. For example, if three threats were issued on a day, only one of those burn area threats need to verify for a "Hit" to be recorded on that day. Lastly, very low sample size for the individual burn areas should warrant caution when interpreting the forecast metrics.

For a second season, the aggregated burn area forecasts performed very well with validation standards exceeded for five of seven metrics. Over the 153 days, 31 days were classified as a Hit over at least one of the burn areas (Appendix B). Aggregated forecasts were Accurate 89% of the time; however, the number of Dry Hits likely boosted this metric. The Threat Score was added to supplement this shortcoming, which removes the correct negatives (Dry Hits). The Threat Score drops to 59%, but this is still much higher than expected given the small size of the burn areas. The False Alarm Ratio and Miss Rate were slightly above industry standards, but are also more sensitive to the low climatology of Flood Days observed in a season. One of the goals for the 2020 season was to drop the Miss Rate, which was attained at 23% (-10% from 2019). This only slightly increased the False Alarm Rate (1%) making this the most noticeable metric for burn scar forecasting. A Bias of 1.1 indicates only slight over-forecasting for the aggregated burn areas. To increase accuracy, next season, we plan to explore adding an areal extent of the heavy rainfall over each burn area.

A quick verification was also completed for the NWS offices over the FTB burn areas (Table 10, bottom row). The NWS Grand Junction WFO issued no Flash Flood Warnings or flood advisories for the Lake Christine or 416 burn area this season, so they are not included in this analysis. Key differences in verification methodology exists between the FTB and NWS, so this is not a straight forward or equivalent comparison. For one, the FTB issues threats with a much greater lead time, while NWS forecasts for burn areas as the event occurs in a nowcasting environment or if an event is currently occurring (automatic "Hit" for the latter). Secondly, NWS forecasts with slightly different metrics than the Program. Typically, NWS is more liberal in their forecasting thresholds and issuance of warnings and advisories. This is due to their stated mission, which is the protection life and property. This means that any Miss is not an acceptable outcome.

Since the NWS forecast metrics are not readily available, Flash Flood Warnings and Flood Advisories are validated with Local Storm Reports (LSRs), which include flash flooding, mud flows or debris slides. For a closer comparison to the FTB burn area validation, burn areas are combined or aggregated each day in a similar manner. While Accuracy was high (92%), the Threat Score for NWS dropped to 32%. The False Alarm Rate was measured at 8%, but the False Alarm Ratio increased to 67% indicating over-forecasting for the Decker and Spring Creek burn areas. This is also corroborated by the Bias at 2.6. NWS nearly achieved their goal of zero missed events except for the July 24th flood event over the Decker burn area. This missed event increased their Miss Rate to 14%, which shows the sensitivity of the metrics to the low sample size of Flood Days.

Table 10: Summary of burn area forecast performance by individual burn area and aggregated. Verification of NWS Flood Warnings and advisories are shown in the last row for comparison.

Burn Area	Hit %	TS	F	FAR	POD	Miss %	Threats Issued	Flood Days	Bias
416 (2018)	94%	9%	7%	91%	100%	0%	11	1	11
Spring Creek (2018)	88%	47%	10%	45%	76%	24%	29	21	1.4
Lake Christine (2018)	93%	15%	5%	80%	40%	60%	10	5	2
Decker (2019)	87%	33%	9%	55%	56%	44%	22	18	1.2
Aggregated Total	89%	59%	8%	29%	77%	23%	34	31	1.1
NWS	92%	32%	8%	67%	86%	14%	21	7	2.6

Burn Area Discussion

First and foremost, there were (thankfully) no human injuries reported within burn areas this season. Similar to 2019, the Spring Creek burn area over the Southeast Mountains recorded the most Flood Days (21 days). This was due in part to the burn area's fairly low flood threshold (0.50 inches), but also due to its larger areal size and juxtaposition between the climatologically active Southeast Mountains and Raton Ridge (south side). Interestingly, flash flooding or debris slides (LSRs) were only observed on 6 of the 21 Flood Days. Of those six days reporting LSRs, max QPE (no buffer) for three of those days was under the 0.50 inch per hour threshold. However, two of these three events were on back to back days that occurred after 1.40 inches fell over the burn area (July 26th), which effectively saturated the soils. The other low QPE LSR event on August 15th (0.23 inches) occurred after 11 straight dry days. Radar indicates that a storm tracked over the southern burn area, which triggered a minor debris flow onto Highway 12. Pre-season analysis for 2021 will look into the susceptibility for debris flows and flash flooding on the south end of the scar, especially because 9 of the 12 LSRs throughout the season were submitted on the southeastern portion of the burn area. This indicates that there may be a need for the burn area to have different flooding thresholds across it for next season, which has not yet been considered by the Program.

Over the Decker burn area, there were 18 observed Flood Days with 2 LSRs on July 24th and 26th. Heading into the season, it was unknown how the Decker burn area would react to heavy rainfall. This area is well-known for its outdoor recreation, so the burn area was added to the 2020 forecasting slate. The flash flood event on July 24th was reported by Greg Felt of Chaffee County, so a special thank you to Greg. Pictures of minor flooding were sent to the Program Manager just west of Bear Creek, which ran about 70 feet from the river. Additionally, on July 24th, Highway 101 was washed out near Highway 50. With only 2 LSRs and QPE (no buffer) exceeding the forecast threshold 9 times, it may make sense to significantly raise the flooding threshold prior to next season to reduce the false alarm rate.

There was a surprise debris flow near the Junkins burn area over the Wet Mountains on August 29th. This burn area was removed from forecasting at the beginning of the season, and all signs pointed to it being fully recovered to the 1 inch per hour threshold. Upon further investigation, QPE indicates that up to 1 inch of rain fell over this area on August 28th, which likely helped saturate soils. As a strong thunderstorm passed overhead the next day and dropped a quick 0.50 inches of rain, a debris slide quickly followed. This is a good reminder to keep an eye on recent burn areas and antecedent moisture conditions, as well as mentioning these conditions in the FTB post.

As mentioned above, NWS Grand Junction did not issue any Flash Flood Warnings or advisories for the 416 and Lake Christine burn areas this season, and neither burn area recorded any LSRs. NWS Grand Junction did issue their only Flash Flood Warning for the Pine Gulch burn area on August 26th over, which ended up causing two shallow debris flows. The Lake Christine burn area really only had one strong thunderstorm track over it this season on August 29th. The 2-hour QPE indicates up to 0.50 inches fell, which is 0.10 inches above the forecast threshold. No flooding indicates that the threshold may have been slightly low, but it's also hard to draw any conclusions with only one event.

Finally moving south, the 416 burn area recorded zero LSRs for the 2020 season after a quiet 2019 season as well. Interestingly, the burn area recorded between 2.5 to just over 4 inches of rain from July 25th to 27th, but it seems the low intensity of the rainfall prevented any flash flooding issues. This suggests that it may be time for this burn area to be removed from the FTB forecasting in 2021, which will be considered with input from the Forest Service. This was the only true test event for the 2020 season, although it was a fairly rigorous one. However, as seen with the Junkins burn area, all recent burn areas need to be monitored after decent antecedent rainfall conditions. Perhaps if a more vigorous thunderstorm was able to develop during the late July event, a different outcome would have been possible.

3) CHARACTERIZATION OF FORECAST PERIOD WEATHER

Overview

As mentioned previously, the 2020 warm season can be summarized with much above normal temperatures and dry to record dry conditions (Figure 8). Only isolated stations within the San Luis Valley and pockets of the eastern plains were able to accumulate near normal precipitation, and large portions of the Northwest Slope and Northern Mountains experienced their driest season on record. A couple back-to-back events in June gave the Northwest Slope and Northern Mountains near normal precipitation, but the next widespread precipitation event wasn't for another month and a half. As reported by NWS offices and local media outlets, record breaking heat was also an issue across the state. Denver broke its record for the number of 90+F days at 75, and Grand Junction observed 82 days with 90+F temperatures (top 5).

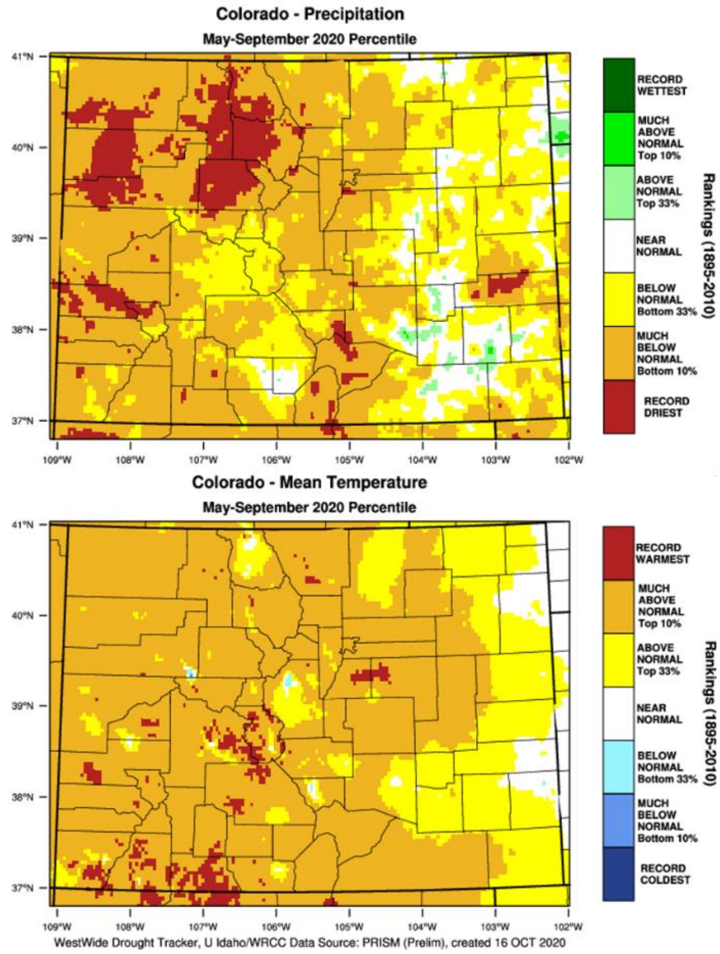

Figure 8: Precipitation (top) and temperature (bottom) anomalies (PRISM) ranked by percentile for May-September 2020. Source: The West Wide Drought Tracker

Not surprisingly, the consequence of abnormally dry and warm conditions meant a worsening Colorado drought (Figure 7), which in turn created horrific fire weather conditions by producing very dry fuels. The North American Monsoon (NAM) season was short and weak in duration when compared to year's past. A quick look at the July and August 500 mb height anomaly (tracks the NAM) indicates an anomalously strong ridge resided over the central Pacific Ocean that spread to west coast by August. This may have helped block upper troughs from reaching the area, which is a necessary ingredient to help pull tropical moisture northward. As previously mentioned, a strong monsoon moisture plume was pulled into the southern tier of Colorado at the end of July. This Precipitable Water (PW) surge helped provided a multi-day precipitation event that helped the Southwest Slope, San Luis Valley and Southeast Plains recover to near or above normal precipitation for the month (more below).

Detailed Summary

Statewide snowpack started out with near normal conditions at the beginning of May (Figure 9), and the higher snowpack going into the warm season was located over northern Colorado and the Front Range with a noticeable deficit over southwestern and western Colorado. Above average temperatures and warm spells at the end of April and throughout May and June helped speed up melting despite a couple brief cool periods. The Upper Rio Grande basin had completely melted out by May 25th, which is about a month before average. Nearly complete melt-out for the state occurred in early June, which was a couple weeks earlier than normal. As discussed, riverine flooding was not a major issue this season, although there was some brief, minor flooding of local streams in northern Colorado during early June.

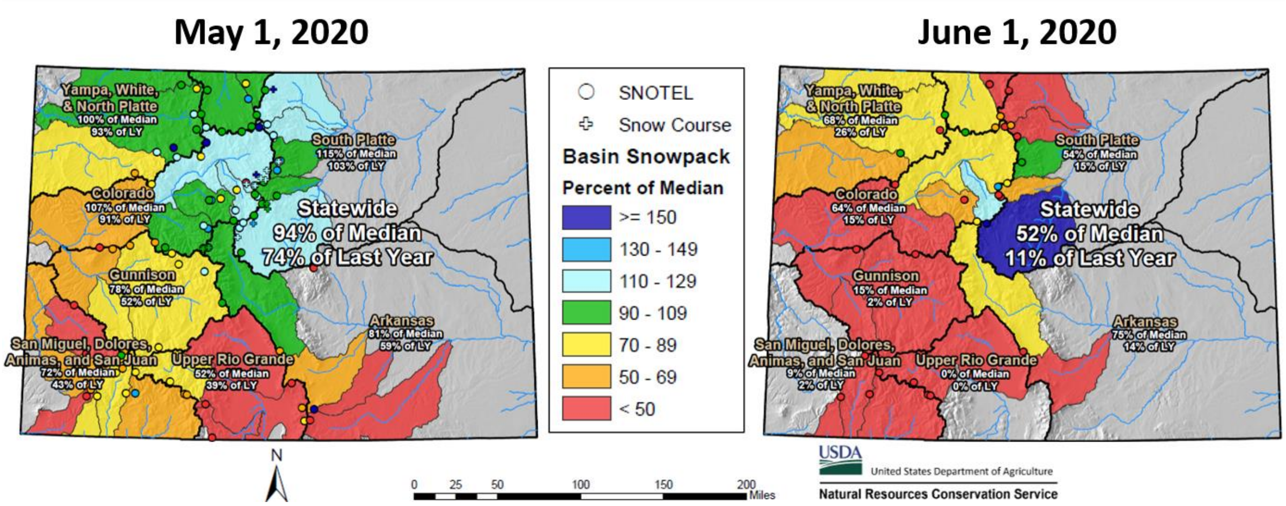

Figure 9: Colorado and basin-wide snowpack percentages of median on May 1st, 2020 (left) and June 1st, 2020 (right). Individual SNOTEL stations (circles) and snow course observations (plus signs) are overlaid for reference as this is what tracks the snowpack. Source: Natural Resources Conservation Service

During May, the Palmer Ridge and northern border of the Northern Mountains picked up slightly above normal precipitation with the rest of the state about 1 to 2 inches below normal. The above average precipitation over the Palmer Ridge was largely due to a heavy precipitation event on May 30th that brought between 1 to 3 inches of rain in the storm cores. At Fort Carson, a rain gauge picked up 0.72 inches of rain in 10 minutes, which is about a 10 to 25-year storm for the area. This heavy rainfall caused flooding of roadways in the area, including I-25, which stalled some vehicles.

For June, near normal to slightly below normal precipitation was observed over the mountains, Raton Ridge and Western Colorado, while the eastern plains and Southeast Mountains received up to 2.5 inches below normal rainfall. On June 6th, a rare derecho (high wind) event occurred, which began over eastern Utah and spread across the mountain and into the eastern plains by the early evening hours. The derecho produced of a line of fast-moving convection that produced between 0.25 and 1 inch of rain over the far western border. As the line moved from SW to NE, it most notably generated strong wind gusts between 55 and 80 mph. A maximum wind gust of 110 mph was recorded in Winter Park at 12,000 feet. As expected, there were several wind damage reports including broken tree limbs, downed trees, an overturned gazebo and roof damage.

Just a couple days later on June 8th and 9th, a strong cold front passed through the state and dropped measurable snowfall over the mountains (up to 13 inches). This 2-day event produced just over an inch of precipitation across pockets of the Northern Mountains, Front Range, and Northeast Plains. Northern Washington County in the Northeast Plains picked up just under 2.5 inches of rainfall, which accounted for ~80% of the area's monthly precipitation total. Additional passing cold fronts brought increased moisture to the eastern plains on June 18th and 26th, which caused localized flooding over the Raton Ridge and Denver Metro/Colorado Springs area, respectively.

July saw an uptick in precipitation across the southern border and eastern border counties, and these areas received between 1 and 2 inches above normal. A unique flooding event occurred overnight on July 23rd into the 24th over a very localized area of Yuma County and eastward into Kansas. A training or nearly stationary storm formed that produced up to 6.3 inches of rain between 8pm and 1am in the town of Wray. Flash flooding caused extensive damage in town and rivers in the area remained elevated for a couple of days as afternoon storms continued to form in the area during the afternoon and evening hours. Meteorologically, the Yuma event was caused by a combination of the low-level jet, a high moisture environment and a cold pool from the convection initiating additional storms.

The largest monsoon moisture surge of the season (unsurprisingly) occurred in late July, which is a well-defined peak in the PW timeseries below (Figure 10). The monsoon surge, which lasted from about July 22^{nd} to 27^{th}, helped setup a multi-day rain event from July 25^{th} to 27^{th}. This event produced between 2 and 5 inches of rain over the San Juan Mountains and 1 to 3 inches of rain over the Southeast Mountains and Front Range. The storm total over the San Juan Mountains was about ~90% of the monthly precipitation and the precipitation that fell over the Southeast Mountains accounted for about ~80% of the monthly total. This event alone helped push precipitation 150-250% above normal across the Southwest Slope, San Luis Valley and Southeast Plains. The San Luis Valley had several gauges record between 1 and 2 inches of rainfall over this period, which is about 20% of their annual 5-10 inches of precipitation. Despite the event being mostly stratiform, the magnitude, steadiness and embedded afternoon convection caused several debris slides and mud flows across the San Juan Mountains. The heavy rainfall even stranded a couple hiking groups near Silverton due to rapidly rising water and rock slides. Flash flooding also occurred near the Decker burn area where a county road was washed out after up to 2 inches of rain fell in a couple hours on July 26th.

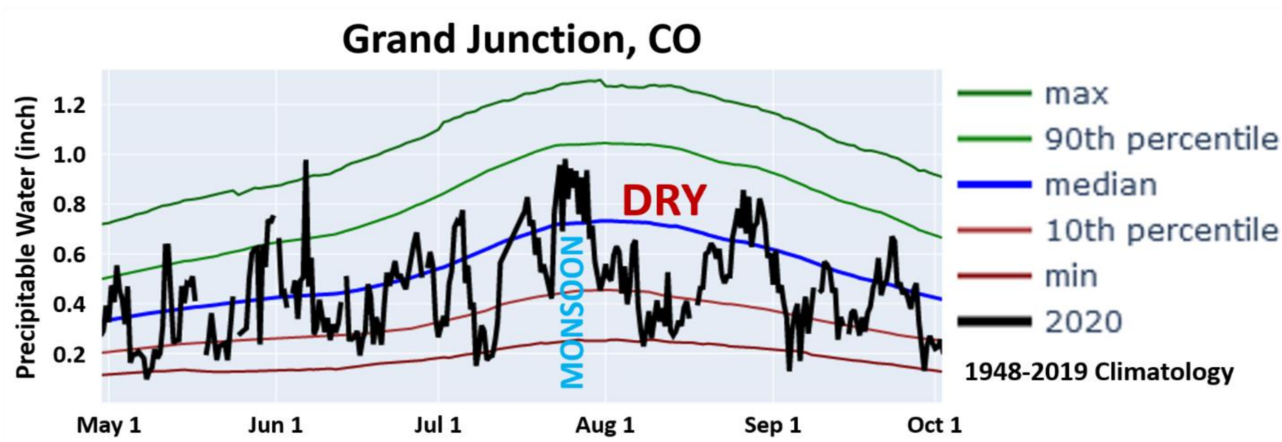

Figure 10: Precipitable Water (inches) from the Grand Junction soundings from May to October 2020 (black line). Also included for reference is the 30-day moving averaged min (dark brown), max (dark green), median (blue), 10th percentile (light brown) and 90th percentile (light green) normals (1948-2019). Source: Colorado Climate Center

It was a quiet August with an early shutdown of the NAM as the 500mb High (ridge) shifted west and placed Colorado under drier northwest flow. A deep trough over the eastern US kept shortwaves moving through the northwest flow, but with little moisture available, not much rainfall occurred. The exception was over the eastern plains where enough moisture remained to produce measurable rainfall on 27 of the 31 days. The heaviest rainfall event during the month was on August 28th when an organized convective system dropped up to 2.5 inches of rain over 24 hours over the Southeast Plains. Due to dry soils, large crops, the prolonged period of rainfall (> 1 hour) and the remote area impacted, flooding was not reported. Despite the occasional rainfall event, almost the entire state had below average rainfall (5^{th} driest on record) and record dry conditions were documented over western Colorado. Paired with much above average temperatures, drought conditions continued their deterioration and the Extreme Drought (D3) area expanded from 27% to 37% of the state.

Tranquil weather continued into September without much change to overall atmospheric setup. Precipitation for the month ended up being above average for portions the San Luis Valley, southern San Juan Mountains, northern Southeast Mountains, and southern Central Mountains. This was mostly due to a very early season snow event from September 8th to 9th that dropped up to 1 to 2 feet of snow over these areas. Convective storms prior to the cold air arrival allowed additional precipitation to fall over the southern San Juan Mountains. The Denver Metro area received approximately 2-3 inches of snow from this storm with the Front Range recording between 4 to 10 inches. Unfortunately, this was the most significant and widespread precipitation that Colorado would see for the rest of the month. The return to dry and windy weather provided an environment for rapid fire growth and plagued the state with poor air quality from several ongoing wildfires. Table 11 (below) lists the wildfires that burned over 10K acres this season for reference.

Table 11: Colorado 2020 wildfires greater than 10,000 acres.

Wildfire	Rank (Acres Burned)	Total Acres Burned	Start Date
Cameron Peak	**1**	208,913	13-Aug
East Troublesome	**2**	193,812	14-Oct
Pine Gulch	**3**	139,007	31-Jul
Grizzly Creek	17	32,631	10-Aug
Middle Fork	24	20,517	6-Sep
Williams Fork	40	14,833	14-Aug
CalWood	62	10,106	17-Oct

Seasonal Stats

Over the 153-day operational season, heavy rainfall activity was historically low when compared to previous seasons. Table 8 shows that oly 34 Flood Days were observed this season, which is more than 50% below the average of 74 days (2012-2019). Over the course of the season, only 41 threats where issued, which is also a historical low. Appendix D shows the number of flood threats issued for a given locale over the last four years. Once again in 2020, the burn areas, especially the Spring Creek burn area, stick out as the locations where the most threats are issued. A secondary maximum was found over the Palmer and Raton Ridges as well as the eastern plains, which is consistent with the seasonal review completed above and the climatology of summertime precipitation in Colorado. The lower number of threats issued over the Palmer Ridge continued to drop when compared to previous seasons, which may reflect more precisely drawn threat areas or a higher Miss Rate. For preparation next season, Dewberry may overlay Local Storm Reports from the last few years on these threat area images to idenify active flood areas that may be overlooked when drawing the threat maps.

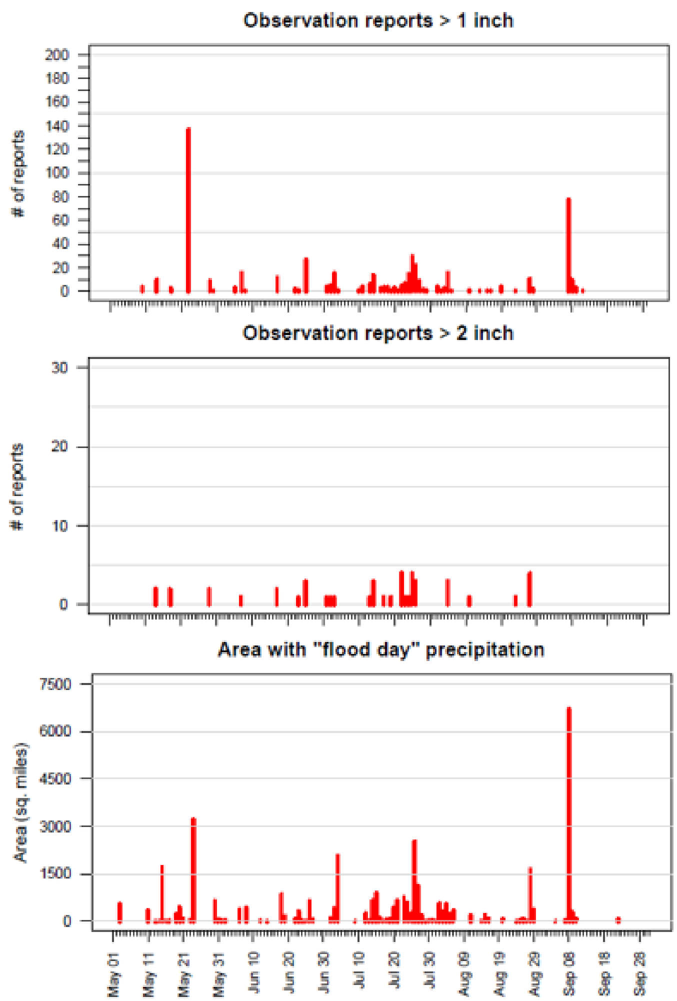

Figure 11: The number of daily observation reports exceeding (top) 1 and (middle) 2 inches, and (bottom) the coverage of Flood Day precipitation, in sq. miles, from the gridded precipitation product. For reference in (c), the total area of Colorado is about 104,000 sq. miles.

Figure 11 shows the daily number of rain gage reports over 1 and 2 inches of rainfall, along with the area exceeding Flood Day thresholds as measured by the Stage IV gridded product. There were only 52 days where at least 1 station measured a qualifying precipitation amount and 36 days where at least two stations measured a qualifying amount (see "NStats" column in Appendix A). As for widespread events, only 14 days had at least 10 stations measured qualifying precipitation. Similar to last season, there were only one day (May 24th) where over 100 gages measured qualifying precipitation. It should be noted that this event was associated with snow and low intensity rainfall, so flooding was not reported. There was no day in which 5 or more stations received at least 2 inches of rainfall, indicating that widespread heavy rainfall was not experienced over a large population center this season.

As for Flood Day area (Figure 11, bottom), there were only 6 days where over 1,500 sq. mi. recorded rainfall greater than 1.50 inches (1 inch) east (west) of the 1,600 meter contour. All metrics continue to point to a slow flood season. There were two days where Flood Day area exceeded 3,000 sq. mi., and both events were stratiform precipitation mixed with snowfall.

4) USER ENGAGEMENT

Social media and online presence continue to be at the forefront of importance each season as it is a critical piece of the Program's success. Even a perfect forecast can have little to no value if it is not properly disseminated, so Dewberry continues to participate in forecast communication through many outlets. During 2020, Dewberry provided users with four outlets to receive forecast updates and other flood threat information (Table 12). First and foremost is the program website, which has been the main communication form since the program began. Second, starting in 2017, Dewberry began providing an email alert option that sent the Flood Threat Bulletin's headline to user's inbox each morning. We also continue to embrace the Twitter social media platform to provide forecast updates and other informational messages. Finally, in 2018, we created a Facebook page to reach a separate demographic from Twitter (note: Facebook posts used similar or identical posts to Twitter). All four forms of communication continue to evolve with encouraging outcomes, which are described in more detail below. Of the 64 Colorado counties, 18 counties have at least one OEM, Police, Fire or government entity that follow one of our accounts (Table 12), and we plan to do outreach to other OEMs prior to next season.

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

Platform	Account	Engagement
Website	www.coloradofloodthreat.com	169 Subscribers
Twitter	@COFloodUpdates	1,404 Followers
Facebook	@COFloodUpdates	323 Followers & 298 Likes

Website

Figure 12 shows daily website usage during 2020 (black) overlaid with the previous four seasons. As has been seen in the past, average daily site visits continue to be highest on days that flood threats are issued (59 vs 37 users per day). While this flood threat day user number (59 users per day) is down from last season (84 users per day), days with an elevated threat (Moderate or High) had 82 visitors, which means the message is being received on the more threatening days. The largest viewership this season was during an active period from July 21st to 30th where threats were issued on 9 of the 10 days. Average viewership was 111 users a day with a peak of 212 users on July 25th (High threat). This was the same period the monsoon moisture surge, discussed above, caused several flooding issues over the San Juan and Southeast Mountains (July 24th to 28th). The Program's forecast was picked up by the Durango Herald, which also likely helped boost viewership. As always there can be improvements with how to best communicate high flood risks, but overall this event was executed well and likely contributed to increased confidence in the Program. Outside of this peak in website viewership, usage was around average of slightly below. This is to be expected considering the slow flood season, especially over the highly populated Denver Metro area. Going forward, new techniques will continue to be implemented in 2021 to ensure the website continues to discuss relevant and diverse flood and/or drought content.

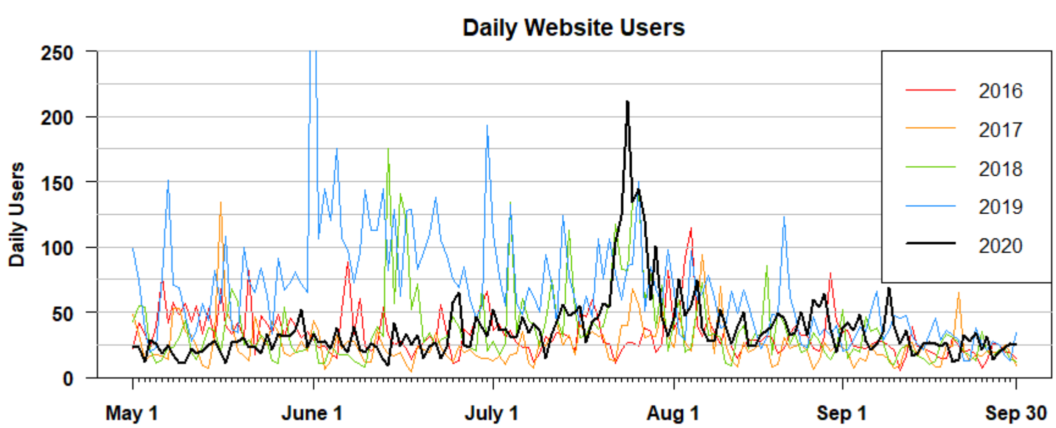

Figure 12: Daily website users during 2016 (red), 2017 (orange), 2018 (green), 2019 (blue) and 2020 (black).

Social Media

During the historic floods of September 2013, the Program noted an opportunity to expand the outreach of the Flood Threat Bulletin to better inform the public of the current and forecasted flood situation. The method that was selected was the Twitter social media platform, with the top-level goal being to provide updates on any impending flood-related threat across Colorado in a concise, headline matter. The Twitter account was a great success during the September floods, and was expanded into daily operations starting in 2014 to provide (i) meteorological information in the form of links to our forecast products (FTB and FTO), (ii) "nowcasts," of interesting flood-related weather conditions, and (iii) the most current heavy rain/flooding reports from the public and National Weather Service offices. Additionally, due to the wealth of hydrometeorological data that is collected in support of daily FTB operations, the Program's social media strategy attempts to maximize the way this data is leveraged in unique posts. For example, Figure 13 shows a Tweet that highlights a mid-June, statewide minimum in rainfall as the atmospheric setup transitions to the NAM. Messages such as these have shown their value by the number of retweets and impressions. Additionally, the post was picked up by The Denver Post. All of this extra exposure helps increase program viewership.

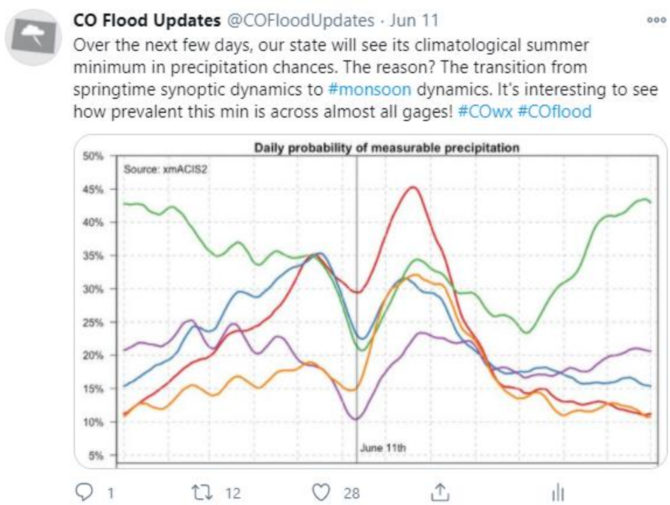

Figure 13: Example of a tweet with a unique image providing insight to a Colorado precipitation minimum in mid- June from the 2020 season. This tweet was retweeted 12 times, liked 28 times and had over 10K impressions, which helped increase Program viewership.

The FTB's Twitter account, **@COFloodUpdates**, continued to gain viewership since its inception with the total number of followers up to 1,404 by the end of the 2020 season (an increase of ~70 followers this season). A good portion of the Program's success can be attributed to the number of retweets from well-followed accounts like the Colorado Emergency Management (60K+ followers). **@COFloodUpdates** also continues to be featured in the 9NEWS Local Market science section and mentioned by their associated twitter account (@LocalMarket9; 17K+ followers). Retweets by media accounts quickly add to the viewership of the Program's website and typically increase Twitter followers.

Arguably, the most useful data variable from Twitter Analytics is "impressions." Impressions are defined as the number of times Twitter users saw a particular tweet and demonstrates the effectiveness of the use of specific hashtags and interactions (retweets) from other accounts that may have more followers. Figure 14 shows the daily impressions received during 2020 (black line) as well as those for the 2016 through 2019 seasons. There is a slight decrease in the number of overall daily impressions, which the below average number of Flood Days likely contributed to. During the 2020 season, the Program disseminated 227 Tweets (about 10 more than 2019 and on par with 2018) and received a total of about 243K impressions. Of the 227 Tweets, only 52 of them received over 1,000 impressions. The ever-changing nature of social media makes it difficult to find a formula that works best, so during the off season, we'll take a look to see which posts are the most successful as well as the commonality of the less successful Tweets on important flood threat days.

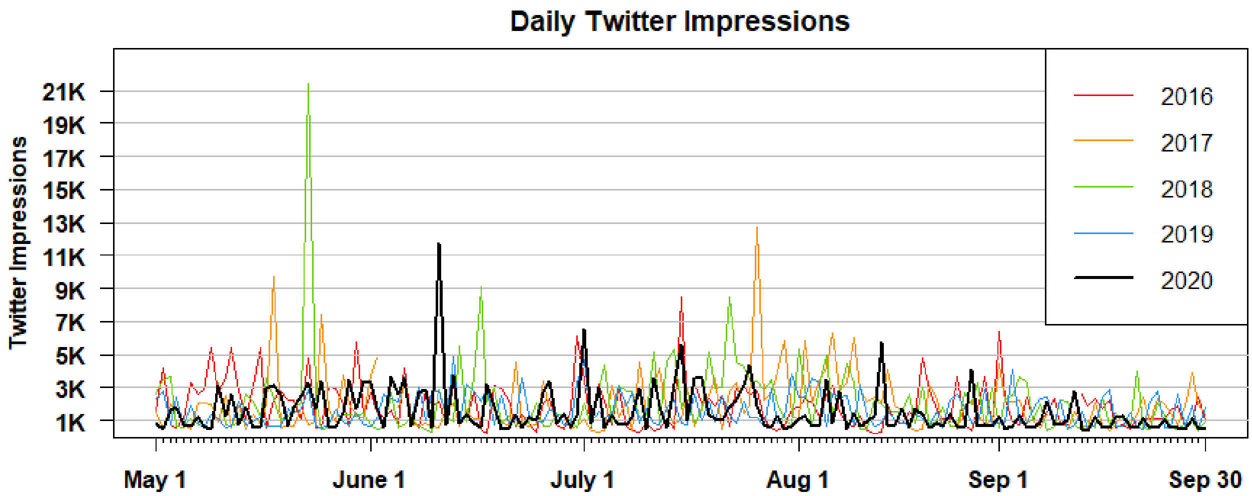

Figure 14: Daily Twitter impressions during 2020 (black), 2019 (blue), 2018 (green), 2017 (orange), and 2016 (red).

Our most notable followers of our Twitter account remain steady: Colorado Emergency Management, Colorado Flood DSS, READY Colorado, 9News Denver, CoCoRaHS, ESRI, AAA Colorado, Red Cross Denver, Colorado State Patrol Troop 1E, Denver Sheriff, Colorado.gov, NWS – Grand Junction, NWS – Pueblo, NWS – Goodland, NWS – Boulder, Colorado Climate Center, CU Boulder, Durango Herald, Forest Service ARP, KDVR FOX31 Denver, FOX31/CW Pinpoint Weather, CBS Denver, KKTV 11 News, CASFM, Pikes Peak Red Cross, Northern Colorado Red Cross, Colorado National Guard, CASFM, Denver Water, The Disaster Channel, Weather West, Colorado Wildfire Info, GMUG National Forests, and Colorado Springs Gazette. Although not mentioned by name, various police precincts, city/county government offices, TV and newspaper reporters and meteorologists from across the state, radio stations, academia meteorologists, individual citizens of Colorado, private meteorologists, fire and rescue units also follow the FTB Twitter account. We will continue to engage local media as new accounts continue to be created each season.

Since the Twitter account was so successful at disseminating the FTB products, it was decided that Dewberry would open a Facebook account and create a Colorado Flood Threat Bulletin page at the beginning of the 2018 season. The main push behind the idea was that the Facebook page would reach a different demographic of potential users. On top of that, Facebook continues to be the most popular social media platform in America, while Twitter has more limited audience made up of millennials, companies and organizations. It remains to be seen what impact, if any, the 46 state antitrust lawsuit will have to Facebook efficacy. The **@COFloodUpdates** handle was reused for the Facebook page to keep uniformity across the social media accounts. All posts on Facebook were also updated simultaneously with the Twitter account, so information exchange would be consistent.

Facebook, similar to Twitter, has its own set of analytics called Insights, which can be used to evaluate the success of the additional social media account. By the end of its third season, the Facebook account gained an additional ~50 Likes and Followers putting the total at 323 Likes and 298 Followers. While this number continues to be quite a bit lower than the Twitter account, it increased another ~20% in Followers, which shows the media platform has value. The most similar analytic to Twitter impressions are post "Reaches". Reaches are defined as the number of people who had any posts from our page enter their screen, and they can also assess the effectiveness of each post. This is most important on days when threats are issued, and, in fact, the late July event mentioned above reached as many as 5,269 users (organically) with 60 shares of the High threat post. For the 2020 season, the average number of reaches per day was 442, which is down about 200 users from last season.

This is likely due to a combination of the evolving nature of this platform, a slow flood season and posts not being in chronological order on Facebook in the News Feed.

The Facebook page will continue to be used in 2021 as it does not take much effort to write posts since the posts are close to, if not identical, to the Tweets. Secondly, a cross-reference of account names, indicate that many of the individuals who liked the Facebook page do not have Twitter accounts. This means the Facebook page is achieving its goal of reaching a different demographic. Also, the majority of the “Likes” on the page are from individuals, rather than companies and organizations, since Facebook accounts are, by and large, for personal use.

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 we commonly use, and has become almost completely dedicated to our products. Hashtags are searchable through Twitter and Facebook, and using relevant popular hashtags such as #COwx or #COFlood allows people looking for specific information to be directed to our tweets. The following is a list of common tags that were used in 2020: #FTB, #FTO, #COwx, #COFlood, #COFire, #Monsoon and #CODrought.

It’s always important to keep in mind social media trends are very fluid, so the Program will continue to monitor and reassess (i) whether Twitter and Facebook are the most effective platforms they can be for the FTB service, and (ii) the best way to keep posts dynamic and relevant for end-users. It can also valuable to note the similarities and differences between the social media platforms for optimal usage by the end-users. For example, Facebook users tend to engage more in conversation, while Twitter users are more interested in quick updates and concise details. This will be an important topic for continued discussion as it may not make sense that posts on the two social media platforms are always identical. The fact that the link to the FTB website was placed on every post, and it continues to only be clicked a fraction of the time (compared to photo views), also points to the same conclusion.

Email Alerts

A subscription for receiving daily FTB headline to a user’s email began on April 28, 2017. As of November 30, there were 169 active subscribers, which is an additional 42 users from last season. During the off-season we will assess the value of sending out a similar email for the FTO headline (threat timeline), as it may drive viewership up to another successful aspect of the Program. Likewise, content and quality of the information provided in the emails will be discussed. It is interesting that the email alert has not significantly decreased website traffic, which means users are still interested in the content of the FTB forecast and not just a quick threat level check. Continuing to increase the number of subscribers will continue to be a key objective for the Program. Dewberry will consider other methods on how to better advertise the email subscription option, such as reaching out to local OEMs that do not follow the Program. Finally, a reminder email will be sent out to subscribers in mid-April alerting them of the return of the FTB May 1st, 2021 and inform of any additional upgrades to the products.

5) CONCLUSIONS

- The 2020 season was the quietest flood year on record (2012 onwards) with only 34 Flood Days and 41 (non-burn area) threats issued. This is more than 50% below the average of 74 Flood days (2012-2019). For burn areas, there were 34 threats issued and a total of 31 Burn Area Flood Days, which is also below last season (42 Burn Area Flood Days).

- Forecast accuracy during 2020 continues to show the Program's success when all metrics are combined. Forecast performance achieved or exceeded four of the six targets established in Table 6, and one metric was only 1% below the target goal. Accuracy was at 89%, which is the highest in Program history, and the Threat Score (removes correct negatives) remained high at 67%. The Probability of Detection was at 74%, which is 1% from the goal (>75%). The False Alarm Rate increased slightly to 13%, which is still well below the goal of <20%. The Miss rate was 26%, which is 2% higher than last year, but still above the goal of <15%. Work will continue to be done to reduce the Miss Rate as minimizing this is likely more of a priority to CWCB than decreasing the False Alarm Rate. As far as threats issued, Moderate and High threats verified 100% of the time they were issued, and Low threats verified 76% of the time.

- Surprisingly, burn area forecast metrics were on par with the forecast goals, which is quite surprising given the small forecast area. Over the 153 days, 31 days classified as a Hit over at least one of the burn areas. The Hit Rate was 89%, Threat Score at 59%, and the Probability of Detection measured at 77%. The False Alarm Rate was at 8% and the Miss Rate dropped 10% from last season to 23%. The most active burn area was Lake Christine, which had 12 Local Storm Reports (Flash flooding, mud flow or debris slide).

- Warm temperatures and below average precipitation, especially in August, caused the drought to spread across Colorado. By the end of the season a large portion of the state was under Extreme and Exceptional Drought. A sizable area of northwest Colorado, along with smaller portions of western Colorado and the Southeast Mountains, recorded their driest May-September on record. This helped cause extreme fire danger with very dry fuels, and three new fires this season, moved into the top 3 largest fires in Colorado history (Cameron Peak, East Troublesome and Pine Gulch). A total of seven (7) fires this season burned over 10K acres, which (by acreage burned) caused the worst wildfire season on record.

- The longest stretch of flooding occurred from mid-July to early August during the height of the shortened monsoon season. From July 12th to August 6th, a Flood Day occurred on 20 days of the 26 days, and the most notable flood event of 2020 occurred from July 25th to 27th. During this late July NAM event, the lone (non-burn) High threat day of the season was issued. Consistent straitiform rainfall with occassional afternoon convection caused 2 to 5 inches of rain to accumulate over the San Juan Mountains and 1 to 3 inches of rain to fall over the Southeast Mountains and Front Range. This caused numerous debris slides, mud flows and flash flooding over these areas.

- Website viewership continues to remain steady with average daily usage at 37 users per day, and this number increases to 59 users per day when a threat is issued. Average daily site visits continue to be highest on days elevated flood threats (Moderate or High) are issued (~82 users per day). The email list has a total of 169 active subscribers, which is up 42 subscribers from last season. The Program's Twitter account (@COFloodUpdates) continues to expand with 1,404 followers. The Facebook account also increased with 323 Followers. More work will be completed in the off season to make sure all OEMs are aware of the Program and our social media outlets.

6) REFERENCES

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APPENDIX A – FORECAST VERIFICATION WORKSHEET

Table 13 is a daily verification worksheet documenting the intensity and coverage of heavy precipitation, along with whether a Flood Threat was issued. The columns of Table 13 are described below.

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

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

Rain Gages: Contains the sub-categories below.

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

NWS Issues: Contains the sub-categories below.

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

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

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

Threat: Highest category of the Flood Threat.

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

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

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

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

Table 13: Daily FTB Verification Worksheet

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	inches	inches	inches	inches	inches	inches	square miles	inches	inches	number	number	number					
1-May	0.74	1.44	0.61	1.17	0.97	0.74	0	0.17	0.5	0	0	0	0				
2-May	0.71	1.45	0.48	0.87	0.99	0.75	0	0.4	0.44	0	1	0	0				
3-May	0.98	1.93	0.84	1.66	2.12	1.84	554	1.35	0.85	0	0	0	HIT			AREA; LI	
4-May	0.29	0.57	0.14	0.25	0.40	0.64	0	0.29	0.5	0	0	0	HIT			LI	
5-May	0.10	0.19	0.13	0.24	0.03	0.14	0	0.03	0.3	0	0	0	0				
6-May	0.00	0.04	0.00	0.04	0.00	0.00	0	0	0.1	0	0	0	0				
7-May	0.00	0.04	0.01	0.04	0.00	0.02	0	0.07	0.1	0	0	0	0				
8-May	0.08	0.16	0.06	0.12	0.26	0.13	0	0	0.2	0	0	0	0				
9-May	0.04	0.06	0.04	0.07	0.00	0.11	0	0	0.2	0	0	0	0				
10-May	0.02	0.04	0.12	0.22	0.00	0.30	0	0.82	0.1	0	0	0	0				
11-May	0.16	0.32	0.44	0.84	0.51	1.53	342	0.32	1.2	4	0	0	0			LI	
12-May	0.14	0.27	0.05	0.10	0.07	0.05	0	0.01	0.6	0	0	0	HIT				
13-May	0.92	1.65	0.81	1.18	1.42	1.55	6	1.33	0.2	0	0	0	0				
14-May	1.50	2.94	0.57	1.14	1.59	0.87	6	1.42	0.47	0	0	0	0				
15-May	2.07	3.86	1.35	2.70	3.09	1.69	1722	2.7	1.67	10	0	0	0	Yes	Low		Hit
16-May	0.75	1.38	1.02	1.69	0.21	1.29	12	0.35	0.7	0	0	0	HIT			AREA	
17-May	0.41	0.78	1.21	2.21	0.41	1.28	29	0.01	0.4	0	0	0	0			AREA	
18-May	0.00	0.04	0.01	0.04	0.00	0.01	0	0.02	0.5	0	0	0	0				
19-May	1.68	3.10	1.08	1.86	1.87	1.29	242	2.15	0.42	3	1	0	0	Yes			Miss
20-May	1.09	2.14	1.33	2.38	2.68	2.88	454	0.42	0.1	0	0	0	0	Yes	Low		Hit
21-May	1.30	2.54	1.03	2.02	2.27	1.16	83	1.2	0.4	0	0	0	0	Yes	Low		Hit
22-May	0.03	0.07	0.03	0.04	0.06	0.03	0	0.02	0.1	0	0	0	0				
23-May	1.49	2.94	0.16	0.25	1.82	0.30	41	0.17	0.1	0	0	0	0			AREA	
24-May	1.63	3.21	1.75	3.39	1.73	1.84	3232	1.13	1.94	137	1	0	HIT	Yes	Low		Hit
25-May	0.06	0.11	0.17	0.32	0.06	0.36	0	0.03	0.47	0	0	0	HIT				

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	inches	inches	inches	inches	inches	inches	square miles	inches	inches	number	number	number					
26-May	0.00	0.04	0.03	0.05	0.00	0.05	0	0.01	0.2	0	0	0	0				
27-May	0.27	0.44	0.51	0.99	0.44	0.78	0	0.07	0.53	0	0	0	0				
28-May	0.40	0.76	0.70	1.39	0.38	0.87	0	0.04	0.64	0	0	0	0				
29-May	0.84	1.67	0.66	1.15	0.91	0.74	0	0.44	0.6	0	2	0	0				
30-May	2.90	5.31	1.69	3.05	3.66	3.24	649	1.88	2.65	9	5	0	HIT	Yes	Mod		Hit
31-May	0.96	1.59	1.00	1.83	1.34	1.66	65	0.75	1.04	1	1	0	0			AREA	
1-Jun	0.72	1.24	0.90	1.34	0.91	1.35	47	0.12	0.96	0	2	0	0			AREA	
2-Jun	1.02	1.92	0.98	1.94	1.48	1.15	35	0.38	0.3	0	2	0	0		Low	AREA	False Alarm
3-Jun	0.73	1.43	0.84	1.39	0.94	0.86	0	0.71	0.41	0	0	0	0				
4-Jun	0.69	1.36	0.48	0.84	0.71	0.48	0	0.06	0.2	0	0	0	0				
5-Jun	0.65	1.14	0.43	0.78	0.75	0.73	0	0.13	0.6	0	0	0	0				
6-Jun	0.49	0.93	0.90	1.54	0.58	1.45	378	0.51	1.2	3	8	1	HIT	Yes	Mod		Hit
7-Jun	0.00	0.04	0.13	0.22	0.00	0.18	0	0	0.7	0	0	0	0		Low	RIVERINE	False Alarm
8-Jun	0.86	1.53	0.83	1.46	1.44	1.22	448	2.5	1.2	16	0	0	0			LI; SNOW	
9-Jun	0.51	1.04	0.43	0.77	1.44	0.76	0	1.5	0.81	1	0	0	0				
10-Jun	0.04	0.07	0.05	0.09	0.04	0.02	0	0.02	0.6	0	0	0	0				
11-Jun	0.00	0.04	0.05	0.10	0.00	0.08	0	0.01	0.8	0	0	0	0				
12-Jun	0.14	0.24	1.10	2.10	0.15	1.13	29	0.02	0.4	0	0	0	0			AREA	
13-Jun	0.50	0.90	0.37	0.62	0.53	0.58	0	0.08	0.7	0	0	0	0				
14-Jun	1.45	2.57	0.20	0.35	1.53	0.20	6	0.46	0.3	0	0	0	0			AREA	
15-Jun	0.15	0.22	0.51	0.88	0.18	0.52	0	0	0.4	0	0	0	0				
16-Jun	0.33	0.54	0.31	0.62	0.33	0.31	0	0.14	0.1	0	0	0	0				
17-Jun	0.01	0.04	0.06	0.12	0.01	0.13	0	0.3	0.2	0	0	0	0				
18-Jun	1.56	3.04	1.75	2.82	1.76	2.37	861	1.48	2.8	12	1	0	0	Yes	Low		Hit
19-Jun	1.08	1.92	1.22	2.40	1.25	1.71	165	0.74	0.68	0	0	0	HIT	Yes	Mod		Hit
20-Jun	0.05	0.07	0.00	0.04	0.05	0.00	0	0.04	0.4	0	0	0	0				

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	inches	inches	inches	inches	inches	inches	square miles	inches	inches	number	number	number					
21-Jun	0.27	0.53	0.37	0.73	0.27	0.39	0	0.07	0.61	0	0	0	0				
22-Jun	1.28	2.52	1.06	2.05	1.58	1.48	94	1.42	0.46	0	0	0	0	Yes			Miss
23-Jun	1.78	3.28	1.86	3.66	1.91	2.15	336	0.62	1.16	2	5	0	0	Yes	Low		Hit
24-Jun	0.55	1.05	0.87	1.70	0.86	1.17	29	0.52	3.3	1	2	0	0			AREA	
25-Jun	0.86	1.61	1.09	1.85	1.14	1.42	24	0.36	0.3	0	4	0	HIT			AREA	
26-Jun	1.31	2.58	1.44	2.81	1.57	1.52	655	1.61	2.75	27	5	0	HIT	Yes	Low		Hit
27-Jun	1.21	2.38	0.72	0.82	1.82	0.89	71	0.36	0.2	0	0	0	HIT	Yes			Miss
28-Jun	0.37	0.68	0.34	0.67	0.51	0.49	0	0.14	0.23	0	0	0	0				
29-Jun	0.28	0.47	0.14	0.26	0.00	0.30	0	0	0.3	0	0	0	0				
30-Jun	0.56	1.08	0.51	0.99	0.58	0.94	0	0.07	0.2	0	0	0	0				
1-Jul	0.01	0.04	0.03	0.04	0.04	0.25	0	0.01	0.8	0	0	0	0				
2-Jul	1.70	3.32	0.91	1.69	2.05	1.27	106	3.38	0.1	4	2	0	HIT	Yes			Miss
3-Jul	2.42	4.51	1.20	2.22	3.34	1.46	425	2.05	1.04	5	3	0	0	Yes	Low		Hit
4-Jul	2.78	5.16	2.21	4.14	3.45	3.03	2070	2.13	1.78	16	10	0	HIT	Yes	Low		Hit
5-Jul	0.80	1.57	0.93	1.76	0.81	0.94	0	0.01	1.07	1	0	0	HIT				
6-Jul	0.70	1.39	0.90	1.71	0.88	0.99	0	0.44	0.3	0	0	0	0				
7-Jul	0.79	1.51	0.60	1.10	1.19	0.94	0	0.34	0.16	0	0	0	0				
8-Jul	0.90	1.75	0.01	0.04	1.19	0.01	0	0.02	0.5	0	0	0	0				
9-Jul	1.00	1.96	0.88	1.70	1.48	1.03	12	0.21	0.4	0	0	0	0		Low	AREA	False Alarm
10-Jul	0.18	0.36	0.01	0.04	0.25	0.01	0	0	0.91	0	0	0	0				
11-Jul	0.07	0.09	0.53	1.05	0.07	0.57	0	0.01	1.01	1	0	0	0				
12-Jul	1.48	2.74	1.39	2.25	2.17	1.42	260	1.8	0.59	4	2	0	HIT	Yes	Low		Hit
13-Jul	1.21	2.40	0.77	1.52	1.23	1.12	29	1.23	0.79	0	0	0	0			AREA	
14-Jul	1.78	3.45	2.59	4.87	1.99	2.92	667	2.11	1.35	6	1	0	HIT	Yes	Mod		Hit
15-Jul	1.89	3.74	2.00	3.48	1.99	2.29	908	2.06	2.36	14	7	0	HIT	Yes	Low		Hit
16-Jul	1.24	2.19	1.13	2.02	1.72	1.63	142	1.15	0.9	0	0	0	HIT	Yes	Low		Hit

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	inches	inches	inches	inches	inches	inches	square miles	inches	inches	number	number	number					
17-Jul	0.18	0.30	0.71	1.37	0.27	1.08	18	0.04	1.64	3	1	0	0		Low	AREA	False Alarm
18-Jul	1.11	1.95	1.87	3.20	1.19	1.99	65	0.02	2	4	2	0	0			AREA	
19-Jul	1.37	2.69	1.56	2.98	1.62	1.96	83	1.83	0.44	4	3	0	0	Yes	Mod		Hit
20-Jul	1.43	2.65	1.75	3.46	1.71	2.87	425	1.2	2.36	1	4	0	HIT	Yes			Miss
21-Jul	1.37	2.66	1.30	2.23	2.07	2.13	649	1.45	1.4	3	2	0	0	Yes	Mod		Hit
22-Jul	0.90	1.62	0.74	1.28	0.92	0.98	0	0.19	1.16	1	2	0	HIT	Yes	Low		Hit
23-Jul	2.20	3.99	0.48	0.84	5.65	0.83	767	3.91	0.8	5	3	0	HIT	Yes	Low		Miss
24-Jul	1.20	2.24	1.08	1.96	1.45	1.54	590	1.01	2.3	7	1	0	HIT	Yes	Mod		Hit
25-Jul	1.06	2.11	1.16	2.22	1.95	1.39	260	1.67	3.28	15	3	0	HIT	Yes	High		Hit
26-Jul	1.77	3.54	1.52	2.79	2.51	2.91	2536	2.21	3.5	30	11	0	HIT	Yes	Mod		Hit
27-Jul	2.09	3.83	0.74	1.43	2.39	2.05	1121	3	2.2	22	9	0	HIT	Yes	Mod		Hit
28-Jul	1.00	1.95	1.34	2.49	1.18	1.64	206	1.56	1.8	9	3	0	HIT	Yes	Low		Hit
29-Jul	1.08	2.04	0.29	0.55	1.56	0.39	6	0.28	1.3	2	0	0	0			AREA	
30-Jul	0.70	1.23	1.38	2.62	0.86	1.53	35	1.53	0.62	1	1	0	HIT	Yes	Low		Hit
31-Jul	0.77	1.38	0.82	1.51	1.05	1.20	53	1.06	0.58	0	1	0	0			AREA	
1-Aug	0.30	0.57	1.40	2.72	0.61	1.40	18	0.6	0.36	0	2	0	0			AREA	
2-Aug	1.89	3.76	2.19	4.12	1.89	2.26	572	1.73	1.25	4	0	0	0	Yes	Mod		Hit
3-Aug	0.89	1.73	1.56	3.08	0.90	1.81	319	0.13	1.3	1	5	0	HIT	Yes	Low		Hit
4-Aug	1.17	2.20	1.12	2.19	1.59	1.79	549	1.69	1.53	3	2	0	0	Yes	Low		Hit
5-Aug	1.10	2.13	0.95	1.88	1.59	1.83	230	1.66	2.54	16	3	0	HIT	Yes	Low		Hit
6-Aug	1.33	2.64	1.10	2.07	2.03	1.64	354	1.1	1.05	1	1	0	HIT	Yes	Low		Hit
7-Aug	1.09	1.98	0.07	0.13	1.45	0.09	0	0.04	0.55	0	0	0	0				
8-Aug	1.01	1.90	0.10	0.19	1.40	0.14	0	0	0.1	0	0	0	0				
9-Aug	0.90	1.70	0.16	0.29	0.99	0.18	0	0	0.18	0	0	0	0				
10-Aug	1.07	1.90	0.73	1.37	1.08	0.73	0	0.03	0.1	0	0	0	0				
11-Aug	1.32	2.65	0.63	1.24	3.15	0.65	183	2.21	0.2	1	0	0	0	Yes			Miss

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	inches	inches	inches	inches	inches	inches	square miles	inches	inches	number	number	number					
12-Aug	0.92	1.78	0.34	0.66	0.97	0.63	0	0.13	0.6	0	0	0	HIT				
13-Aug	0.73	1.42	0.04	0.07	0.79	0.24	0	0.11	0.6	0	0	0	0				
14-Aug	1.75	3.06	0.34	0.60	1.92	0.36	24	0.54	1.1	1	0	0	0			AREA	
15-Aug	1.71	2.94	1.46	2.69	1.87	1.78	218	0.4	0.54	0	1	0	HIT	Yes	Low		Hit
16-Aug	1.35	2.56	1.05	1.97	1.60	1.90	94	0.63	1.3	1	4	0	HIT	Yes	Low		Miss
17-Aug	0.25	0.48	0.70	1.28	0.26	0.97	0	0.03	1.2	1	0	0	0				
18-Aug	0.09	0.16	0.74	1.16	0.11	0.74	0	0.02	0.9	0	0	0	0				
19-Aug	1.16	2.20	0.86	1.46	1.16	0.94	0	0.3	0.63	0	0	0	0				
20-Aug	0.96	1.77	1.34	2.58	1.05	1.51	77	1.21	1.57	4	1	0	HIT	Yes			Miss
21-Aug	0.01	0.04	0.13	0.22	0.01	0.22	0	0	0.3	0	0	0	0				
22-Aug	0.00	0.04	0.43	0.66	0.00	0.58	0	0	0.2	0	0	0	0				
23-Aug	0.00	0.04	0.13	0.19	0.00	0.17	0	0	0.3	0	0	0	0				
24-Aug	0.11	0.21	1.07	1.83	0.13	1.21	18	0	3.13	1	0	0	0			AREA	
25-Aug	0.39	0.97	1.16	2.07	0.64	1.27	59	0.09	0.88	0	1	0	0	Yes		AREA	Miss
26-Aug	0.87	1.51	1.33	2.13	1.17	1.43	100	0.25	0.8	0	1	0	HIT	Yes	Low		Hit
27-Aug	0.44	0.83	1.54	2.82	0.50	1.58	12	0.02	0.44	0	0	0	0			AREA	
28-Aug	2.22	4.32	1.66	3.22	3.07	1.98	1646	2.55	1.81	11	3	0	HIT	Yes	Mod		Hit
29-Aug	1.30	2.47	2.14	4.26	1.32	2.70	389	1.35	1.49	2	2	0	HIT	Yes	Low		Hit
30-Aug	0.13	0.22	0.64	1.19	0.13	0.69	0	0.03	0.6	0	0	0	0				
31-Aug	0.21	0.43	0.39	0.73	0.25	0.63	0	0.18	0.6	0	0	0	0				
1-Sep	0.03	0.05	0.17	0.23	0.00	0.21	0	0.2	0.4	0	0	0	0				
2-Sep	0.00	0.04	0.06	0.10	0.00	0.00	0	0	0.9	0	0	0	0				
3-Sep	0.00	0.04	0.00	0.04	0.00	0.00	0	0.36	0.3	0	0	0	0				
4-Sep	0.00	0.04	1.06	1.68	0.00	1.10	6	0.02	0.42	0	0	0	0			AREA	
5-Sep	0.00	0.04	0.24	0.47	0.00	0.25	0	0	0.5	0	0	0	0				
6-Sep	0.00	0.04	0.00	0.04	0.00	0.00	0	0	0.1	0	0	0	0				
7-Sep	1.22	2.40	0.39	0.72	1.69	0.74	59	0.62	0.18	0	0	0	0	Yes			Miss

	NOAA Stage IV Quantitative Precipitation Estimate							Rain Gages			NWS Issues						
Date	Max1hr-E	Max2hr-E	Max1hr-W	Max2hr-W	Max24hr-E	Max24hr-W	Flood Area	Max East	Max West	NStats	FA_FF	FL_HY	Reports	Flood Day	Threat	Flags	Outcome
Units	inches	inches	inches	inches	inches	inches	square miles	inches	inches	number	number	number					
8-Sep	0.29	0.57	0.48	0.95	1.18	2.42	6730	1.35	1.9	78	0	0	0		Low	LI; SNOW	False Alarm
9-Sep	0.42	0.83	0.38	0.73	0.67	1.48	301	0.8	1.4	10	0	0	HIT			SNOW	
10-Sep	0.25	0.47	0.27	0.53	0.61	1.48	88	0.43	1.2	3	0	0	HIT			SNOW	
11-Sep	0.10	0.19	0.20	0.38	0.18	0.56	0	0.06	0.69	0	0	0	0				
12-Sep	0.00	0.04	0.01	0.04	0.00	0.01	0	0.01	1.2	1	0	0	0				
13-Sep	0.00	0.04	0.01	0.04	0.00	0.01	0	0	0.4	0	0	0	0				
14-Sep	0.00	0.04	0.03	0.04	0.00	0.03	0	0	0.4	0	0	0	0				
15-Sep	0.00	0.04	0.09	0.17	0.00	0.09	0	0	0.3	0	0	0	0				
16-Sep	0.00	0.04	0.00	0.04	0.00	0.00	0	0.01	0.8	0	0	0	0				
17-Sep	0.00	0.04	0.02	0.04	0.00	0.05	0	0.01	0.2	0	0	0	0				
18-Sep	0.00	0.04	0.02	0.04	0.00	0.04	0	0	0.1	0	0	0	0				
19-Sep	0.01	0.04	0.07	0.14	0.00	0.12	0	0	0.2	0	0	0	0				
20-Sep	0.22	0.41	0.23	0.42	0.24	0.24	0	0	0.2	0	0	0	0				
21-Sep	0.11	0.18	0.69	1.24	0.12	0.88	0	0.07	0.5	0	0	0	0				
22-Sep	0.78	1.50	1.27	2.54	1.09	1.50	77	0.1	0.46	0	0	0	0	Yes			Miss
23-Sep	0.14	0.22	0.23	0.29	0.15	0.23	0	0	0.7	0	0	0	0				
24-Sep	0.00	0.04	0.00	0.04	0.00	0.00	0	0.01	0.2	0	0	0	0				
25-Sep	0.00	0.04	0.01	0.04	0.00	0.01	0	0.6	0.2	0	0	0	0				
26-Sep	0.16	0.22	0.02	0.05	0.47	0.07	0	0.01	0.1	0	0	0	0				
27-Sep	0.17	0.31	0.09	0.18	0.28	0.18	0	0.03	0.24	0	0	0	0				
28-Sep	0.00	0.04	0.01	0.04	0.00	0.01	0	0	0.3	0	0	0	0				
29-Sep	0.00	0.04	0.01	0.04	0.00	0.01	0	0	0.1	0	0	0	0				
30-Sep	0.00	0.04	0.00	0.04	0.00	0.00	0	0	0.23	0	0	0	0				

APPENDIX B – BURN AREA VERIFICATION WORKSHEET

Table 14: Daily Burn Area Verification Worksheet a daily verification worksheet documenting heavy precipitation and flash flooding over burn areas, along with whether a Burn Area Flood Threat was issued. Not all worksheets are included, but are available upon request. The columns of Table 14 are described below.

Burn Area: The names of the five burn areas that were forecast this season. "YES" denotes that the day qualified as a Flood Day.

Threat Issued: A number indicates that that a Flood Threat was issued. The number "1" corresponds to a "Low" threat, "2" to a Moderate threat, "3" to a High threat, and "4" to a Very High threat.

Threat: Highest category of the Burn Area Flood Threat.

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

Outcome: Classification of Flood Threat into the following three categories. Note that a blank implies a correct forecast though no Flood Day occurred (dry case).
False Alarm: A Flood Day was forecasted, but a non-Flood Day was observed,
Miss: A Flood Day was observed but not forecasted,
Hit: A Flood Day was observed and forecasted correctly.

Table 14: Daily Burn Area Verification Worksheet

	Burn Area				Threat Issued				Threat		
Date	Lake Christine	416	Spring Creek	Decker	Lake Christine	416	Spring Creek	Decker		Flood Day	Outcome
1-May											
2-May											
3-May											
4-May											
5-May											
6-May											
7-May											
8-May											
9-May											
10-May											
11-May	YES				1				Low	YES	Hit
12-May											
13-May											
14-May											
15-May											
16-May							1		Low		False Alarm
17-May											
18-May											
19-May											
20-May											
21-May											
22-May											
23-May											
24-May											
25-May											
26-May											

	Burn Area				Threat Issued				Threat		
Date	Lake Christine	416	Spring Creek	Decker	Lake Christine	416	Spring Creek	Decker		Flood Day	Outcome
27-May							1	1	Low		False Alarm
28-May			YES							YES	Miss
29-May							1	1	Low		False Alarm
30-May					1	2	1	1	Mod		False Alarm
31-May							1	1	Low		False Alarm
1-Jun			YES	YES			1	1	Low	YES	Hit
2-Jun							1		Low		False Alarm
3-Jun											
4-Jun											
5-Jun											
6-Jun				YES	1	2			Mod	YES	Hit
7-Jun											
8-Jun											
9-Jun											
10-Jun											
11-Jun											
12-Jun											
13-Jun						1		1	Low		False Alarm
14-Jun											
15-Jun											
16-Jun											
17-Jun											
18-Jun											
19-Jun								1	Low		False Alarm
20-Jun											
21-Jun											
22-Jun											
23-Jun			YES				2		Mod	YES	Hit

	Burn Area				Threat Issued				Threat		
Date	Lake Christine	416	Spring Creek	Decker	Lake Christine	416	Spring Creek	Decker		Flood Day	Outcome
24-Jun											
25-Jun				YES						YES	Miss
26-Jun											
27-Jun											
28-Jun											
29-Jun											
30-Jun											
1-Jul											
2-Jul											
3-Jul							1		Low		False Alarm
4-Jul	YES		YES				2	2	Mod	YES	Hit
5-Jul											
6-Jul											
7-Jul											
8-Jul											
9-Jul											
10-Jul											
11-Jul											
12-Jul											
13-Jul											
14-Jul											
15-Jul			YES				1		Low	YES	Hit
16-Jul			YES			1	1	1	Low	YES	Hit
17-Jul				YES	1	2		1	Mod	YES	Hit
18-Jul			YES	YES			1		Low	YES	Hit
19-Jul				YES			1		Low	YES	Hit
20-Jul											
21-Jul			YES				2	1	Mod	YES	Hit

	Burn Area				Threat Issued				Threat		
Date	Lake Christine	416	Spring Creek	Decker	Lake Christine	416	Spring Creek	Decker		Flood Day	Outcome
22-Jul	YES				1		1	1	Low	YES	Hit
23-Jul					1	1	1	1	Low		False Alarm
24-Jul				YES	1	2	1	2	Mod	YES	Hit
25-Jul				YES	1	3	1	2	High	YES	Hit
26-Jul		YES	YES	YES	1	2	3	3	High	YES	Hit
27-Jul			YES	YES		3	2	2	High	YES	Hit
28-Jul			YES	YES			2	1	Mod	YES	Hit
29-Jul											
30-Jul											
31-Jul			YES							YES	Miss
1-Aug			YES							YES	Miss
2-Aug			YES	YES			2	1	Mod	YES	Hit
3-Aug			YES	YES			1		Low	YES	Hit
4-Aug											
5-Aug											
6-Aug											
7-Aug											
8-Aug											
9-Aug											
10-Aug											
11-Aug											
12-Aug											
13-Aug											
14-Aug											
15-Aug			YES	YES						YES	Miss
16-Aug			YES				1		Low	YES	Hit
17-Aug				YES						YES	Miss
18-Aug											

	Burn Area				Threat Issued				Threat		
Date	Lake Christine	416	Spring Creek	Decker	Lake Christine	416	Spring Creek	Decker		Flood Day	Outcome
19-Aug											
20-Aug											
21-Aug											
22-Aug											
23-Aug											
24-Aug											
25-Aug	YES		YES	YES			1		Low	YES	Hit
26-Aug				YES	1	1	1	1	Low	YES	Hit
27-Aug			YES							YES	Miss
28-Aug			YES				3	2	High	YES	Hit
29-Aug	YES		YES	YES			1	2	Mod	YES	Hit
30-Aug											
31-Aug											
1-Sep											
2-Sep											
3-Sep											
4-Sep											
5-Sep											
6-Sep											
7-Sep											
8-Sep											
9-Sep											
10-Sep											
11-Sep											
12-Sep											
13-Sep											
14-Sep											
15-Sep											

	Burn Area				Threat Issued				Threat		
Date	Lake Christine	416	Spring Creek	Decker	Lake Christine	416	Spring Creek	Decker		Flood Day	Outcome
16-Sep											
17-Sep											
18-Sep											
19-Sep											
20-Sep											
21-Sep											
22-Sep											
23-Sep											
24-Sep											
25-Sep											
26-Sep											
27-Sep											
28-Sep											
29-Sep											
30-Sep											

APPENDIX C - COLORADO CLIMATE

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

a) Importance of Continental Divide

The most important control of heavy rainfall potential in Colorado (even more important than elevation, by itself) is arguably the position relative to the Continental Divide (hereafter, CD). Figure 15 (Atlas 14, 2017) shows the stark differences in rainfall recurrence statistics at Denver (east of the CD) compared to Silt (west of the CD). While both locations have a similar elevation of about 5,300 feet, the 30-minute 10-year rainfall at Denver (1.09 inches) is 81% higher than the analogous value for Silt (0.60 inches). Similarly, the 30-minute 100-year rainfall at Denver (1.91 inches) is 80% higher than the analogous value at Silt (1.06 inches). In short, despite other possibly counteracting factors, this contrast consistently results in more flood threats east of the CD compared to its Western counterpart (also see

in Appendix D).

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

b) *Seasonality*

Seasonality is likely the second most important factor in controlling heavy rainfall potential in Colorado. As shown in Figure 16, early in the operational season (May), the highest potential for heavy rainfall is almost exclusively east of the Continental Divide, and in particular the northeast quadrant of the state (PRISM, 2017). During early June (not shown), snow is significant factor in the Front Range and Gore Mountains. Meanwhile, by August (Figure 16 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.

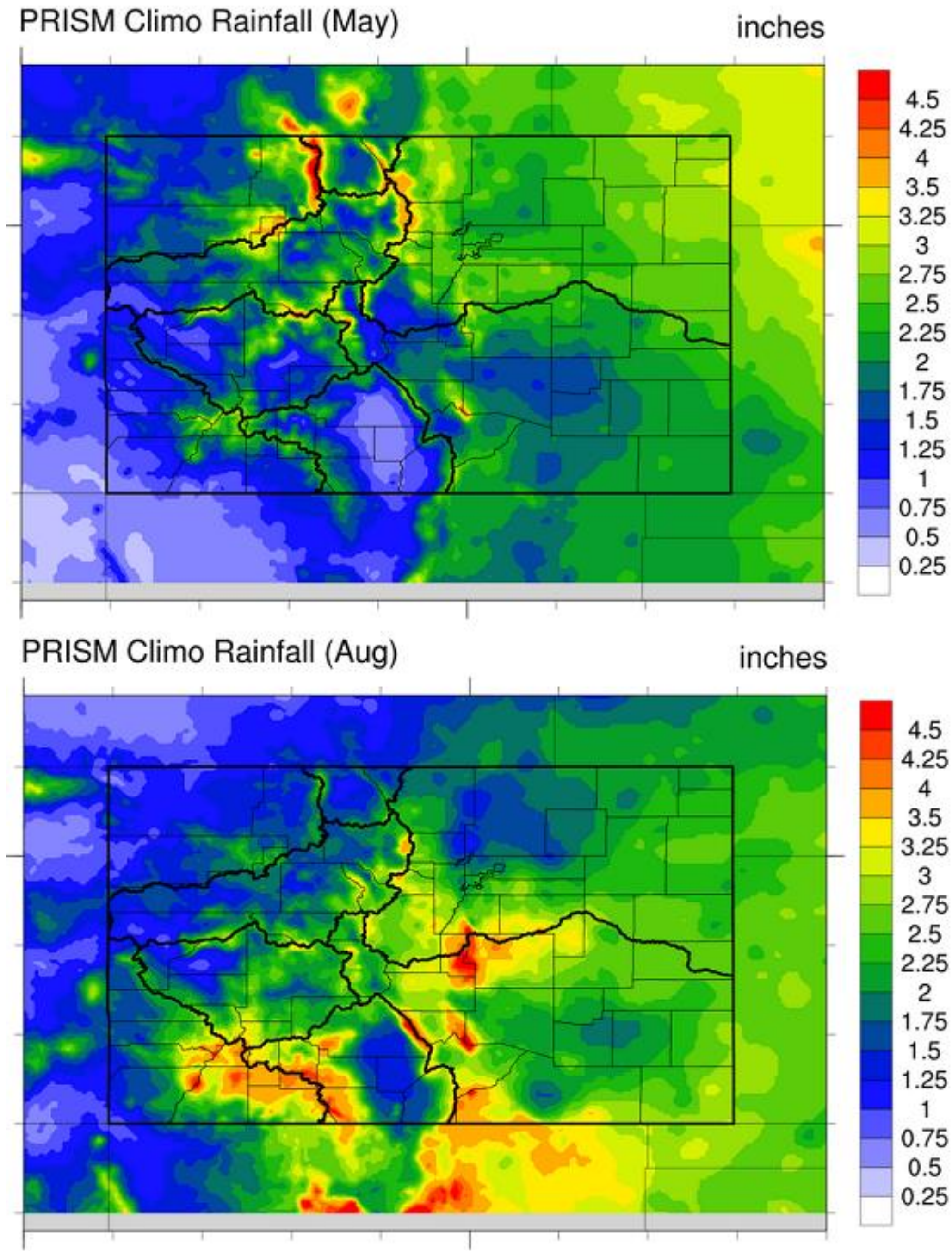
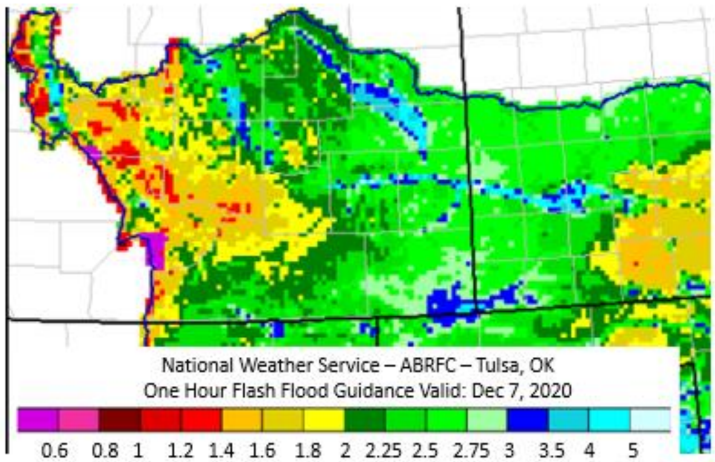


Figure 16: Monthly average precipitation for (top) May and (bottom) August. Source: Oregon State University PRISM group.

c) *Surface characteristics*

While a significant focus of the Flood Threat Bulletin is only heavy rainfall potential, an equally important factor is surface characteristics such as slope, ground cover type, soil type, antecedent rainfall, etc. Collectively, these factors can cause significant sensitivity when translating between rainfall and runoff. *Figure 17* shows the 1-hour Flash Flood Guidance (FFG) for central and eastern Colorado from their respective River Forecast Centers. These products are updated daily by the National Weather Service River Forecast Centers. Note that, in general, FFG is significantly higher over the eastern Plains compared to the higher terrain. For example, along the Kansas border, the 1-hour FFG could be just under 6 inches, while over the northern Front Range, it is between 1 and 2 inches. An even starker example of the importance of surface characteristics is over a fresh fire burn area, where the burnt, and now resultant hydrophobic soil mass, can cause significant flooding concerns for even 0.25 inches of rainfall per hour. This can be seen over Huerfano and Fremont County where the Spring Creek and Decker burn areas reside, respectively (pink in the top figure). Surface characteristics play an integral role in the translating the heavy rainfall threat to a flooding potential.



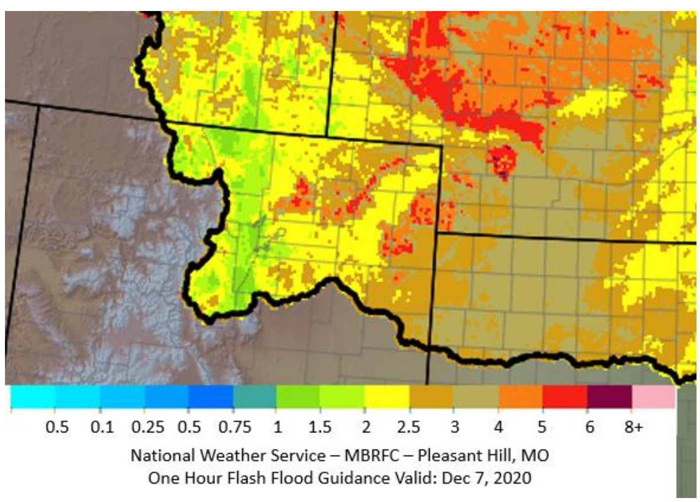
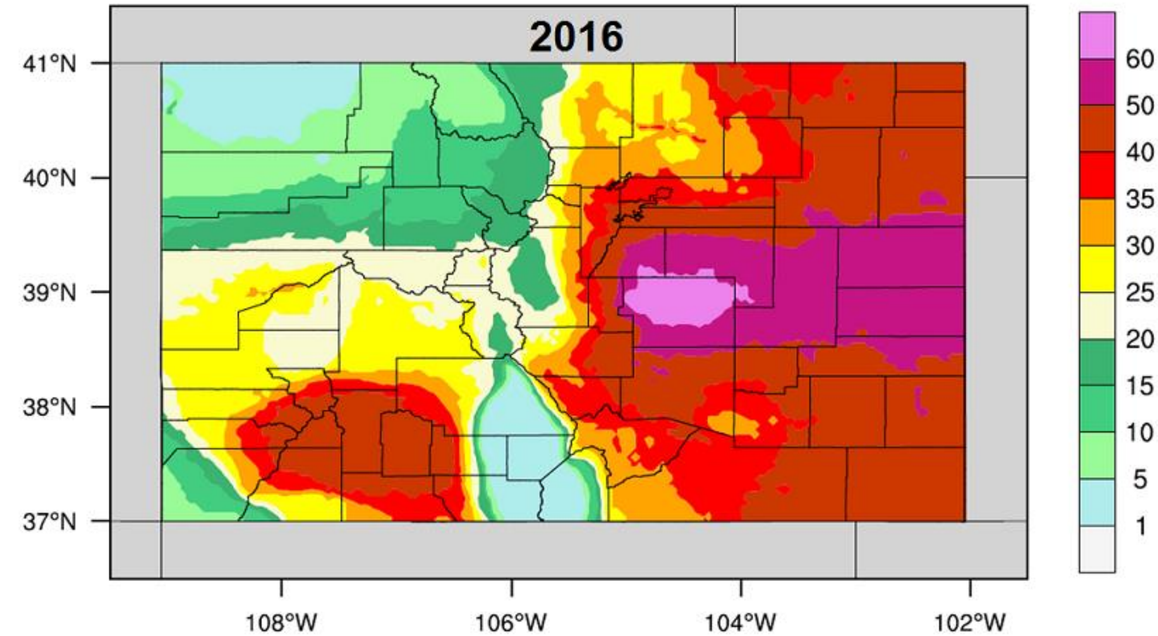
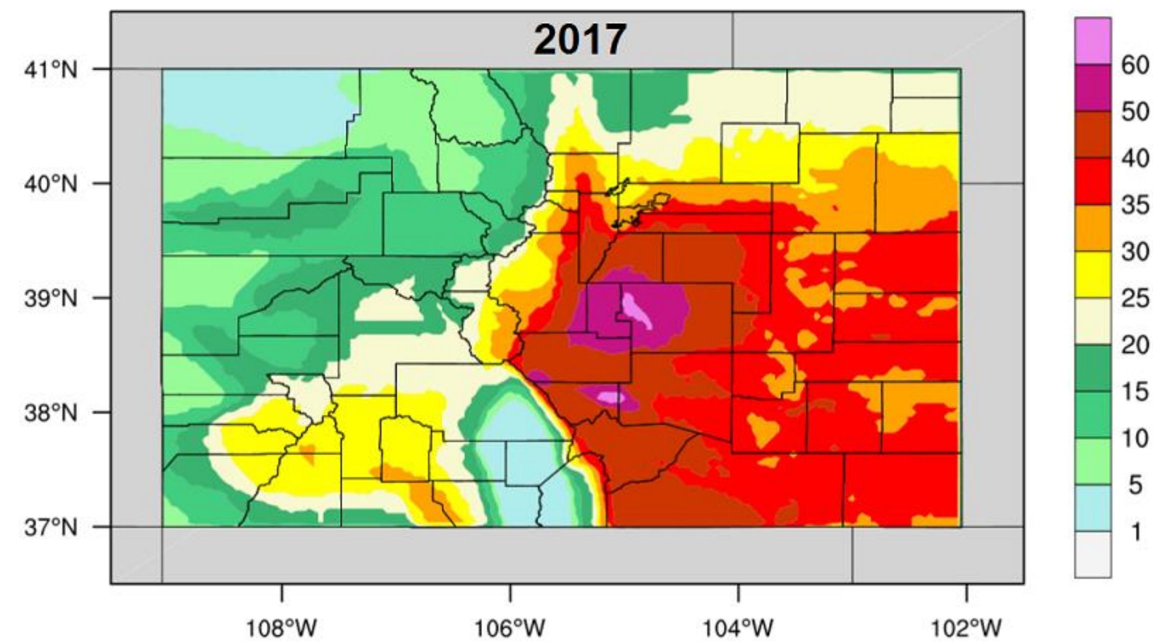


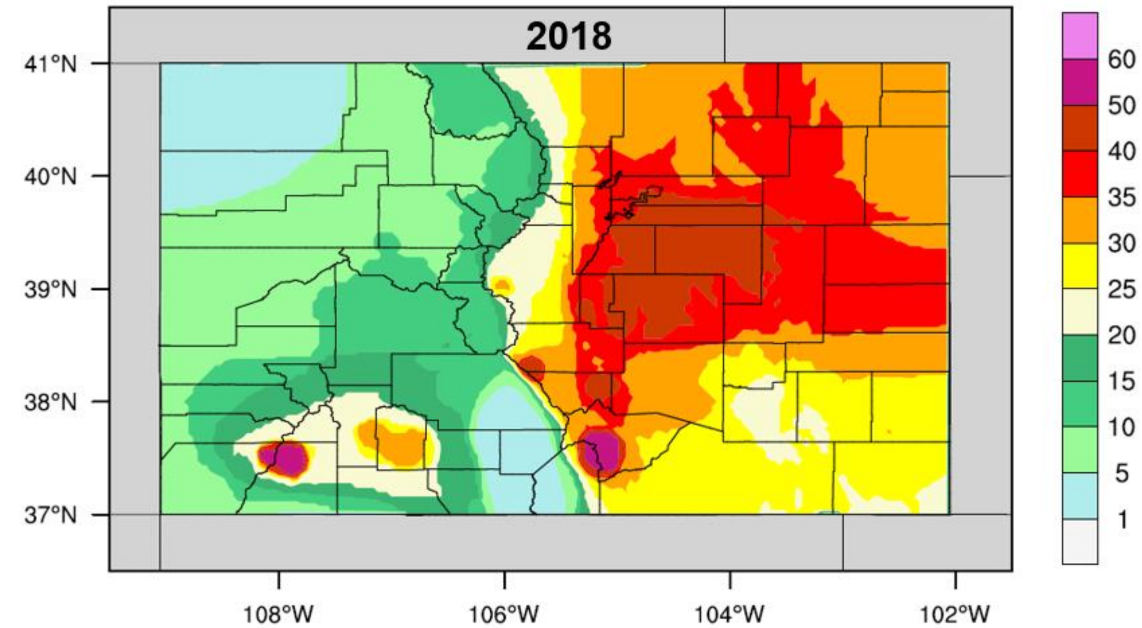
Figure 17: 1-hour Flash Flood Guidance for central and eastern Colorado, valid December 7th, 2020. Source: National Weather Service River Forecast Centers.

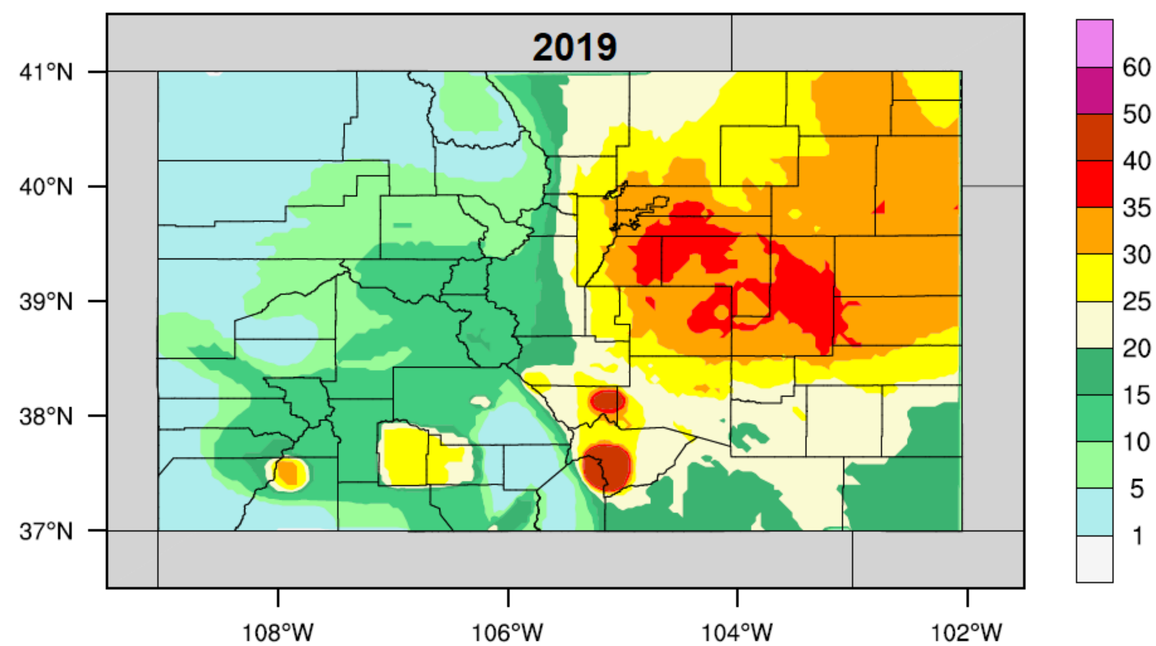
APPENDIX D – FLOOD THREATS ISSUED

shows the total number of days when a given location was under a flood threat during the 2016 to 2020 operational seasons in descending order. 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.


2016
41°N
40°N
39°N
38°N
37°N
108°W
106°W
104°W
102°W
60
50
40
35
30
25
20
15
10
5
1


2017
41°N
40°N
39°N
38°N
37°N
108°W
106°W
104°W
102°W
60
50
40
35
30
25
20
15
10
5
1


2018
41°N
40°N
39°N
38°N
37°N
108°W
106°W
104°W
102°W
60
50
40
35
30
25
20
15
10
5
1


2019
41°N
40°N
39°N
38°N
37°N
108°W
106°W
104°W
102°W
60
50
40
35
30
25
20
15
10
5
1

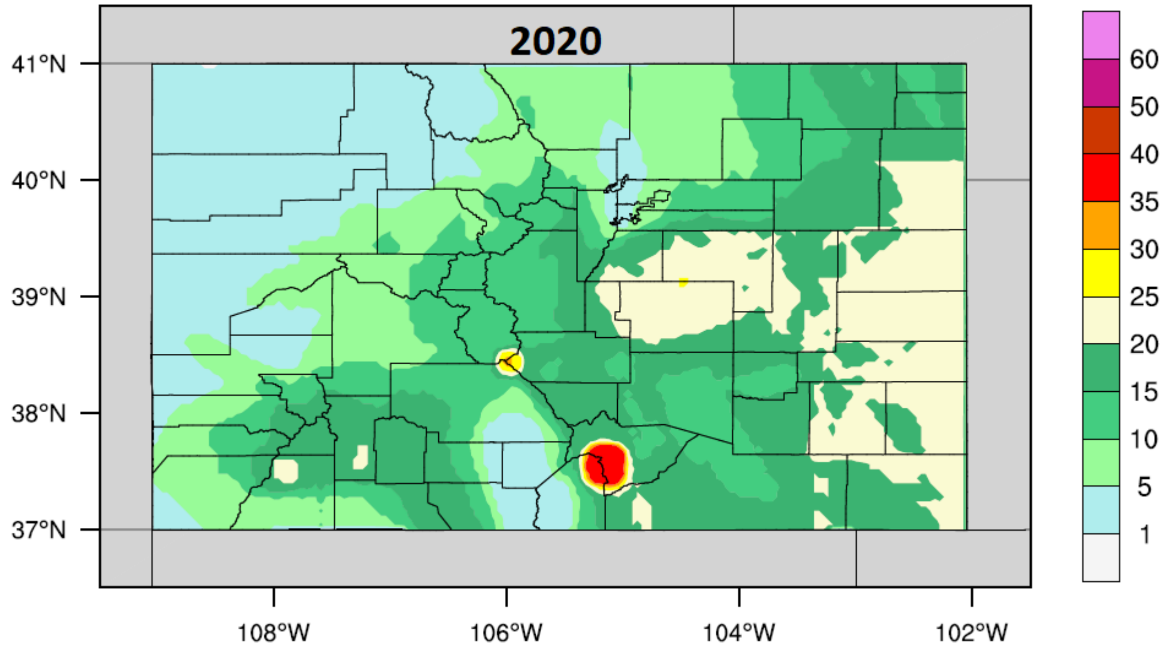


Figure 18: Number with days with a flood threat issued, burn area or otherwise, during 2016 to 2020 operational season (order is descending from top to bottom with the same scale for comparison).