Submitted to:

The Town of Jamestown

BOULDER COUNTY

Design Development Services For
Automated Flood Warning System (AFWS)
FEMA HMGP-4145 Project 28-F

Technical Report

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Introduction

In the wake of the damage from the September 2013 Jamestown flooding, the Town of Jamestown (the Town) has been working to improve and augment its Flood Early Warning System. Lynker Technologies has been supporting the Town in this endeavor to optimize new and existing flood warning resources. During the initial phase of the AFWS Design Development, the Lynker team performed a detailed spatial analysis and field evaluation to determine the feasibility of installing additional rainfall and stream gauge monitoring equipment. The analysis identified one new rain gauge installation near Walker Mountain as the opitmal gauging solution for Jamestown. A preliminary reanalysis of the September 2013 gauge observations also identified potential refinements to the rainfall alert thresholds for monitoring James Creek flooding hazards. Lynker presented its initial project findings to the Town Board in September of 2017.

This follow-on project evaluation builds on these initial project findings, and is intended to further assess the rainfall and flood warning systems currently in place and develop potential improvements to that system. Based on the results of the initial project findings and input from the Town and Boulder County OEM, the Lynker team targeted four key project goals – provided below. Figure 1.1 summarizes the current Jamestown AFWS , along with newly proposed components. This multiphase suite of tools attempts to provide a robust flood monitoring system that can provide the necessary warning lead time to keep the Jamestown community safe from future flood events. While this AFWS aims to provide the necessary monitoring and alert data, the communication aspect of the system is equally important. As part of this project, Lynker faciliated several project meetings to encourage the development of a communications protocol to be adopted for operational use by Boulder County OEM and the Town. Onging communications between the Town and Boulder County will be essential to the overall success of implimenting the new/revised aspects of the AFWS.

Project Goals

- Generate a refined list of rainfall thresholds tailored to Jamestown's early warning flood alert needs
- Provide guidance/input for an updated flood alert emergency monitoring and response plan between Boulder OEM and Jamestown
- Evaluate the potential application of the National Water Model as a hydrologic forecast tool for the James Creek basin
- Provide recommendations for potential implementation of NWM data for operational hydrologic forecasts

Results of our initial analysis (Phase I) revealed opportunities for flood alert improvement using the rain gauge network near the James Creek watershed. In particular, reanalysis of available hydrologic data from 2013 flood found that existing rainfall thresholds did not provide an adequate level of warning lead time to be directly effective. This finding may be largely due to the abnormally prolonged nature of the rainfall event with relatively moderate rainfall intensities. To achieve a reliable and adequate flood alert lead time, Lynker has proposed a more comprehensive system of "conditional" rainfall alerts to be included with standard thresholds currently used by Urban Drainage Flood Control District (UDFCD) and

Boulder County OEM. These conditional ("if this then that") alerts would rely on a continuous calculation of rainfall accumulation data to determine whether saturated soil conditions exist (antecedent rainfall conditions) and subsequently adjust alert threshold values in real time.

Currently for Jamestown, the nearest National Weather Service Advanced Hydrologic Prediction Service (AHPS) operational streamflow forecast location is positioned on the Saint Vrain Creek near Longmont. In a significant step forward to transform and enhance water prediction services (particularly for locations currently not forecasted by the NWS), the new National Water Model (NWM) was implemented in 2016. Accordingly, the Lynker team examined the potential for the NWS National Water Model (NWM) to augment current flood forecasting capabilities for James Creek. Lynker evaluated the current NWM forecasting feasibility for the James Creek basin by using the 23-year retrospective NWM simulation dataset. Our evaluation of the NWM compared simulated and observed streamflow data from the James Creek stream gauge to analyze the historical model performance with particular focus on the September 2013 event. The goal of this model evaluation analysis is to provide Jamestown and Boulder County OEM with a general understanding of the historical model performance (timing and magnitude statistics) for James Creek along with recommendations and suggestions for potential inclusion of the NWM into the existing flood monitoring system.

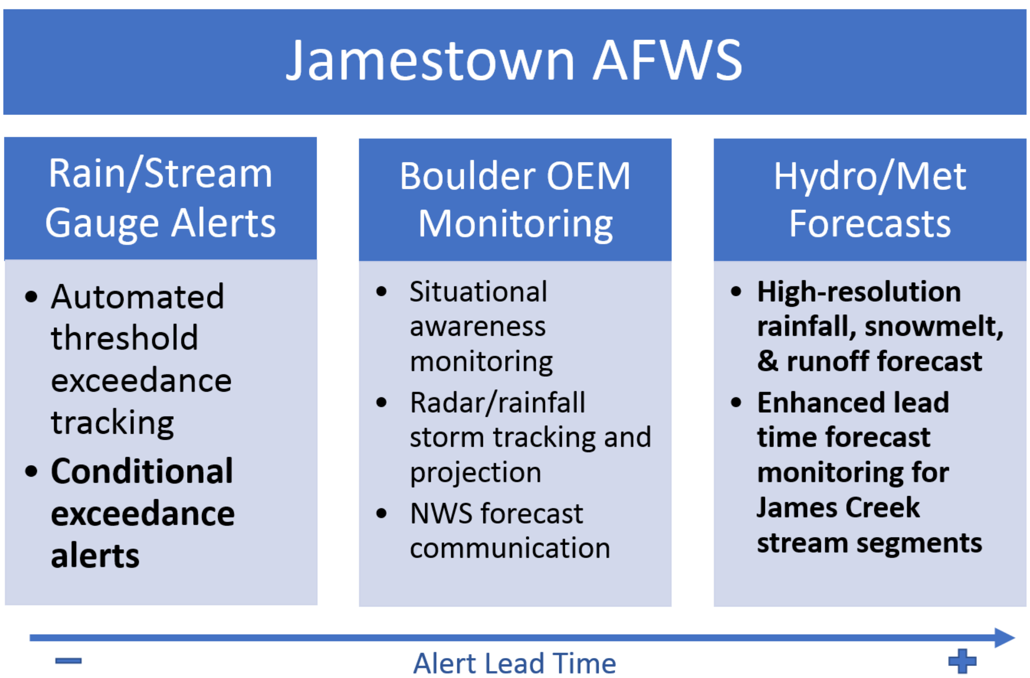


Figure 1.1.Overview of the proposed Jamestown AFWS primary components (new and revised components in bold)

The remainder of this report is organized into three main sections. Section 1 is an upfront summary of the results and recommendations of the project. Section 2 outlines the detailed development and evaluation of the rainfall thresholds for James Creek. Section 3 describes the analysis of the NWM as a forecasting tool for James Creek and other Boulder County locations.

1 Final Recommendations

Based on the analysis of rainfall thresholds and an evaluation of flood/debris flow warning needs in Jamestown, Lynker recommends the following actions:

- Incorporate the live DWR data stream for the Left Hand Ditch diversion into the Contrail monitoring configuration for Jamestown
- Incorporate the modified standard rainfall threshold values along with the new conditional threshold values into the Contrail alert configuration for Jamestown
- Adapt the current Jamestown Volunteer Fire Department Flood Safety Plan to formalize communication and response actions to include the new/revised automated alerts
- Encourage public enrollment in automated hazard notifications through systems like the Boulder County Emergency Notification System (www.boco911alert.com) – how it works

National Water Model analysis summary:

- The NWM simulated streamflow shows variable skill for James Creek and nearby gauge locations
- The 2013 flood event is the only significantly impactful event in the ~30 year observed data record; thus, ongoing evaluation of the NWM is necessary to better determine model skill for high flow events.
- While the overall flow magnitude/timing forecast skill still needs improvement, current NWM forecasts have the potential to provide extended monitoring lead-time for tracking flash flood conditions for the James Creek basin
- Boulder County OEM should consider incorporating the NWM forecast as a component of their daily flash flood outlook toolset

2 Development and Evaluation of Optimized Rainfall Alert Thresholds

2.1 Task Objectives

As the most significant event within the timeframe of observed data, the September 2013 rainfall event was the primary focus of the threshold analysis. This rainfall event included a prolonged period of light to moderate rainfall intensities leading to saturated soils and triggering debris flows well before the elevated streamflow impacts were observed in the river channel. Figure 2.1 illustrates the chronology of events to help understand what information was available during the event and where improvements may be best focused. Note the ideal alert window (Sep 11, 2013 18:00-22:00 MDT) is an estimated time frame for providing the Jamestown community with sufficient time to take preventive measures prior to the flooding and debris flow impacts. The alert window is based on OEM's current targeted preparedness timeframe. The timeline below also highlights the initial Flash Flood warning issued by the local National Weather Service (NWS) office prior to reported debris flow and flooding impacts in Jamestown. Based on conversations with community members, the initial Flash Flood warning likely went unnoticed (for some time) by most of the community.

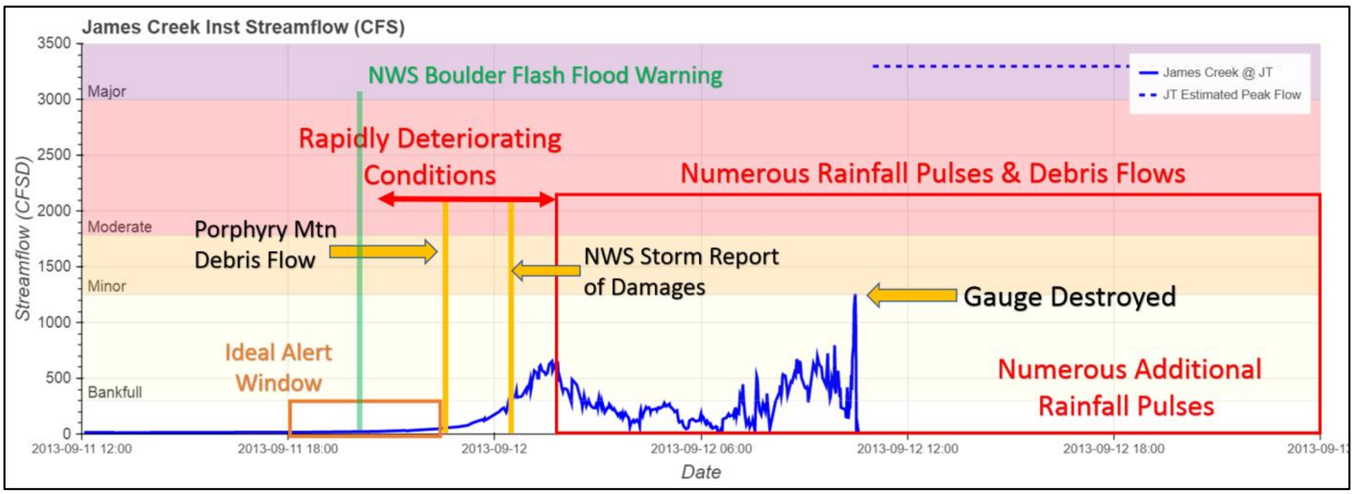


Figure 2.1. James Creek at Jamestown annotated hydrograph overview of the September 2013 flood event (9/11/2013 12pm – 9/13/2013 12am MDT)

The preliminary analysis of the rainfall thresholds primarily focused on a reanalysis of the current default alert values currently used across the Front Range (UDFCD ALERT System). For visualization purposes, Figure 2.2 plots the NOAA Atlas 14 Precipitation Frequency Estimates (interpolated from the James Creek basin centroid location) along with the September 2013 event peak rainfall intensities from nearby stations for storm durations from five minutes to seven days. The plot illustrates the relatively low return period values (<25-year return period) for storm duration bins less than three hours compared to the significant return period values (>100-year return period) for storm duration bins greater than 6-hours. In other words, precipitation intensities were not particularly extreme throughout the September 2013 event, but the event was exceptionally rare in terms of overall rainfall accumulation duration. This finding largely explains why many of the default alert short-duration thresholds were not exceeded during the September 2013 event.

Key to Improvement

To provide Jamestown with useful rainfall alerts for an event like September 2013, a more robust monitoring system should be incorporated to better account for the combination of saturated soil conditions and moderate rainfall intensities.

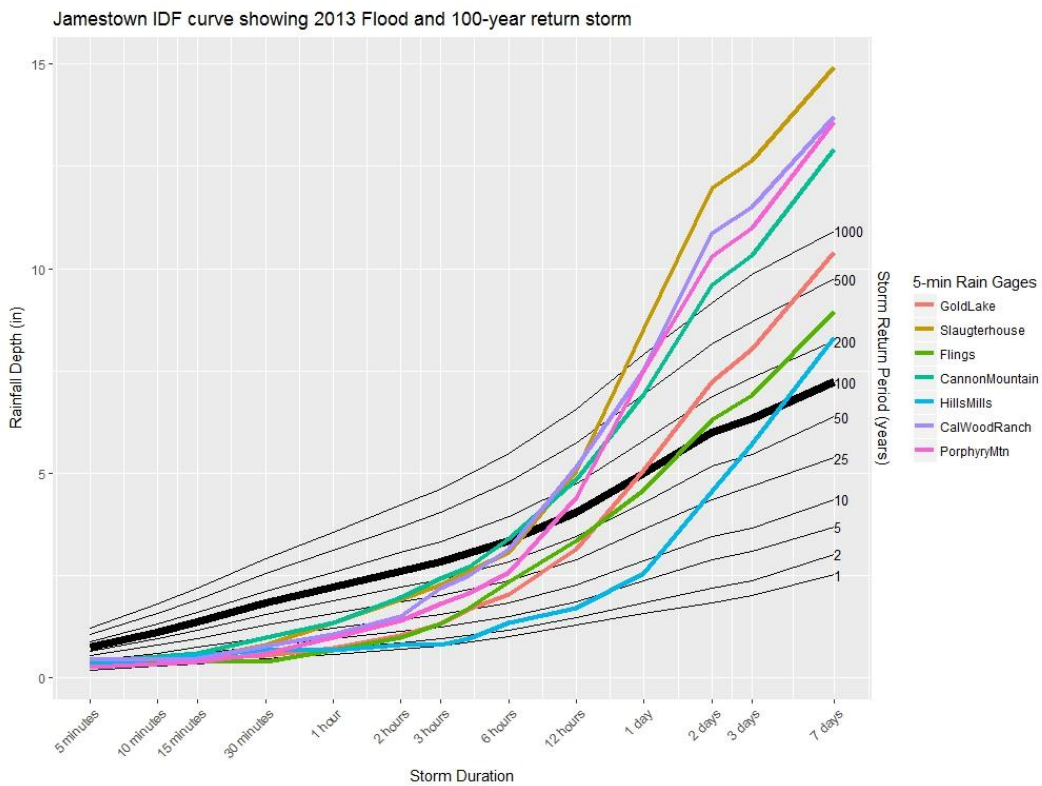


Figure 2.2. NOAA Atlas 14 Precipitation Frequency Estimates (black lines) and observed rainfall depths for rain gauges near Jamestown (colored lines)

2.2 James Creek Hydrography and Data Overview

During the initial review of the rain gauge network for James Creek, 11 nearby gauges were identified for potential inclusion in the review and development of updated thresholds (Table 2.1). To determine the appropriate gauge representation across the James Creek basin, we used a Thiessen Polygon analysis (refer to Phase 1 report). Based on this analysis, we included the rain gauges identified by red circles in Figure 2.3 in the James Creek alert/threshold analysis. The new Walker Mountain rain gauge location was identified from the design and development phase of the Jamestown AFWS project. Data for this gauge location should be included as part of the Jamestown AFWS monitoring network when the gauge becomes operational. The James Creek @ Jamestown historical streamflow and stage data along with two nearby stream gauge records were evaluated as part of the threshold alert analysis (Figure 2.5). Also note the presence of a DWR gauge near the western boundary of the James Creek basin. The DWR gauge provides observations of flow diverted from the South Saint Vrain into James Creek via the Left Hand Ditch.

Table 2.1. Rain gauge stations within and near the James Creek watershed

Station ID	Station Name	Data Type	Start	End	ALERT Station Link
4180	Gold Lake	Precip	1999	2017	UDFCD-OneRain
4850	Porphyry Mtn	Precip	2004	2017	UDFCD-OneRain
4190	Slaughterhouse	Precip	1999	2017	UDFCD-OneRain
4220	Flings	Precip	1999	2017	UDFCD-OneRain
4270	Cannon Mountain	Precip	1999	2017	UDFCD-OneRain
4710	Ward (Hills Mills)	Precip	1999	2017	UDFCD-OneRain
4770	CalWood Ranch	Precip	1999	2017	UDFCD-OneRain
4150	Gold Hill	Precip	1999	2017	UDFCD-OneRain
4240	Sunset	Precip	1999	2017	UDFCD-OneRain
4160	Sunshine	Precip	1999	2017	UDFCD-OneRain
4230	Golden Age	Precip	1999	2017	UDFCD-OneRain

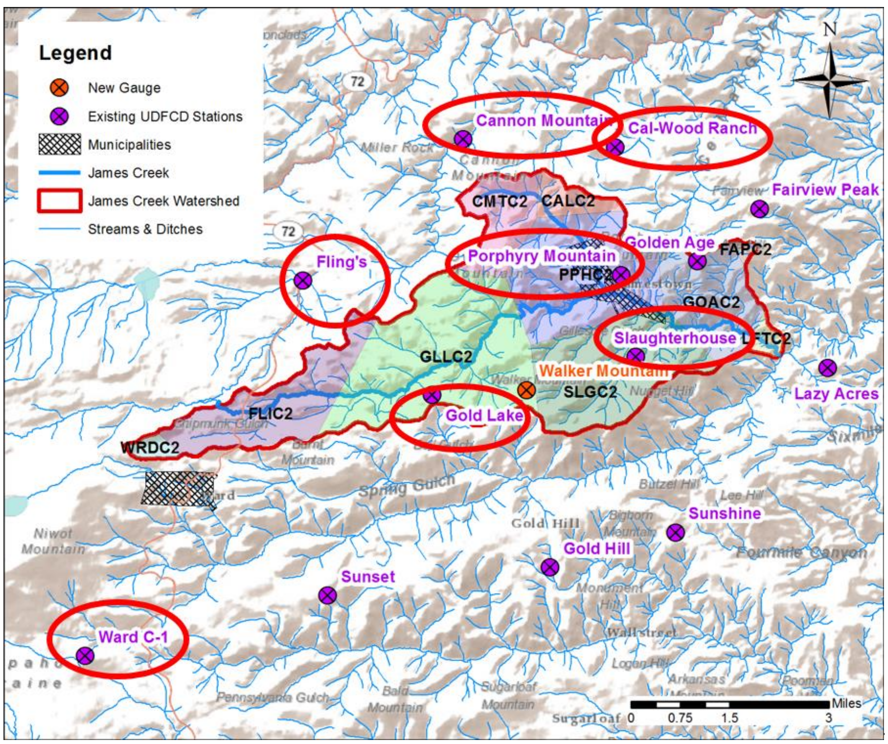


Figure 2.3. Location of existing automated rain gauges in the James Creek basin vicinity, the corresponding Thiessen polygons (colored polygons), and the location of the newly proposed rain gauge installation site at Walker Mountain

Unfortunately, the James Creek gauge was destroyed during the morning of 9/12/2013 which likely occurred before James Creek peaked in Jamestown. To help estimate the general timing of the 2013 flood event, Figure 2.4 provides a timeseries plot of the James Creek @ Jamestown observed stage along with two nearby gauges – Rowena (located on Left Hand Creek below Gold Lake) and Lower Left Hand (located near the mouth of the canyon below the James Creek and Left Hand confluence).

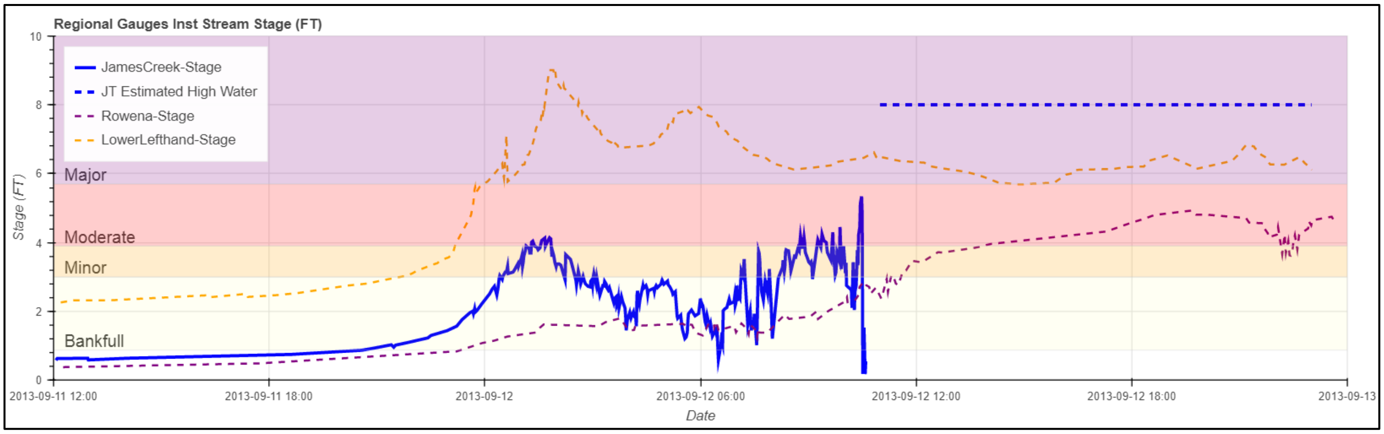


Figure 2.4. Overlay of the James Creek @ Jamestown (10017), Rowena (4430), and Lower Left Hand (10018) observed stage 9/11/13 12pm – 9/13/13 12am

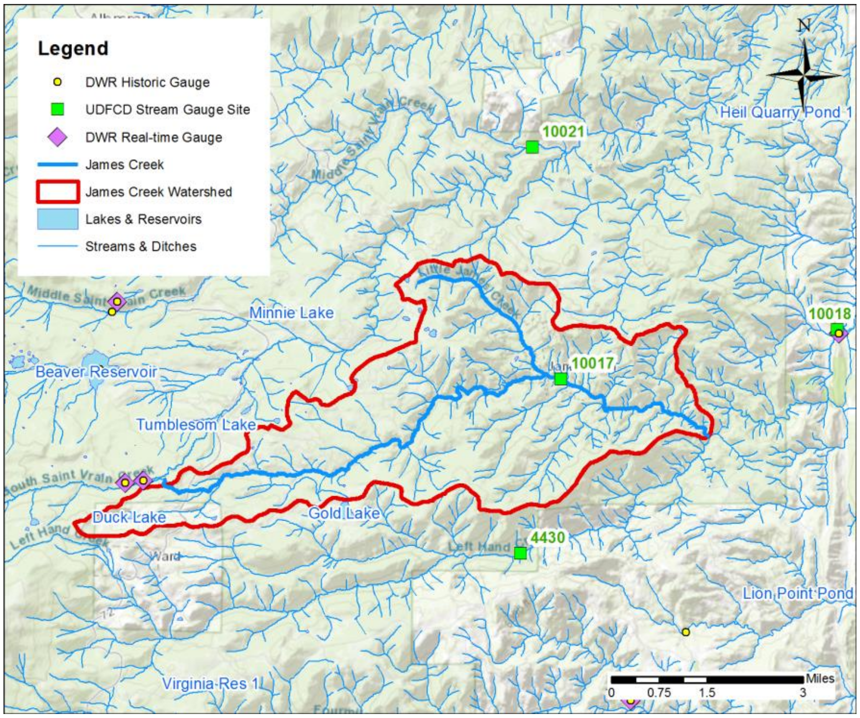


Figure 2.5. Location of three stream gauge sites within the James Creek region (note: Left Hand Diversion Ditch segment crosses the watershed boundary north of Ward).

As noted by the James Creek Watershed Initiative website, there are three active diversion features impacting the James Creek Watershed (http://jamescreekwatershed.org/about/

1. South St. Vrain Diversion – The main diversion is the South St. Vrain Creek water diverted into the headwaters of James Creek. (Figure 2.6)
2. Gold Lake Fill Ditch -The Gold Lake Fill Ditch diverts a small amount of water from James Creek to Gold Lake, which lies on the divide separating the James Creek and Left Hand Creek watersheds. The water in Gold Lake is used as a winter reserve for domestic supply along Left Hand Creek and can be released into the Left Hand Creek watershed when necessary. (Figure 2.7)

3. Jamestown Irrigation Ditch – The town of Jamestown diverts water from James Creek at both an irrigation ditch and at a water plant intake for municipal drinking water use.

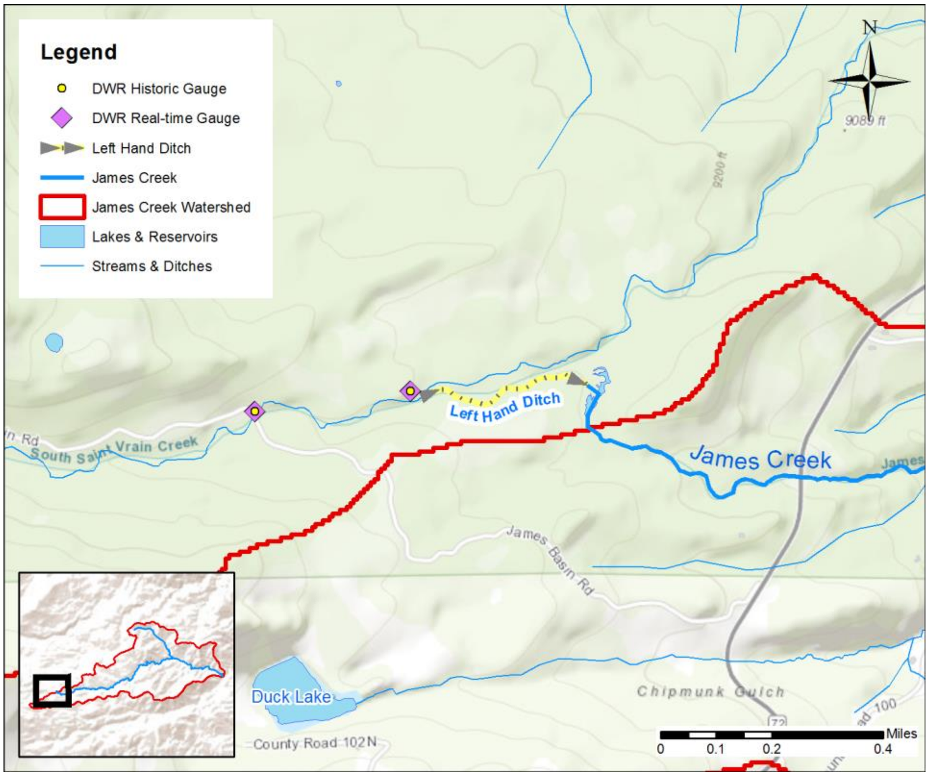


Figure 2.6. Map view of the Left Hand Ditch diverting flow from the South Saint Vrain Creek to James Creek

The following excerpt was provided by the Colorado Department of Water Resources (DWR) regarding the Left Hand Diversion into James Creek: "This gage measures water diverted from the South St. Vrain Creek (W.D. 5) into the Boulder Creek watershed (W. D. 6) by way of James Creek and Lefthand Creek. It has an appropriation date of 1863, which makes it senior to nearly all downstream water rights. The current gage and measurement structure was put into operation May 21, 1992. Satellite monitoring was installed in 1994. Water is diverted to the gage by a dam & 10 ft radial gate on South St. Vrain Creek about 55 ft. upstream from the control. The position of the gate can affect approach velocities coming to the gage & control. Flows for this gage are controlled by a radial gate just upstream of gage. The ditch typically takes the entire flow of the South Saint Vrain. Only with the highest flows is the radial gate lowered so that the remainder continues down the natural channel. Flooding is not typically an issue unless the rise is so quick that the gate has not been lowered. Historic flood of September 11, 2013, arrived but the Ditch Operator lowered the gate before the massive flows could cause damage. Flows were diverted down the natural channel."

The Left Hand Diversion plays an important role in the overall magnitude of flow in James Creek during the warm season months. While the maximum released flow during the September 2013 event was kept in check, it's still important to actively monitor this diversion out of an abundance of safety. The live data link to the observed flow entering the Left Hand Ditch can be found on the DWR website (http://www.dwr.state.co.us/SurfaceWater/data/detail_graph.aspx?ID=LEFTHDCO&MTYPE=DISCHRG).

More information regarding the Gold Lake Fill Ditch is needed to fully understand the expected operating pattern for the diverted flow from James Creek (including diverted flow from the Left Hand Ditch diversion). The DWR website does not indicate an active data link to any flow measurements at this diversion site.

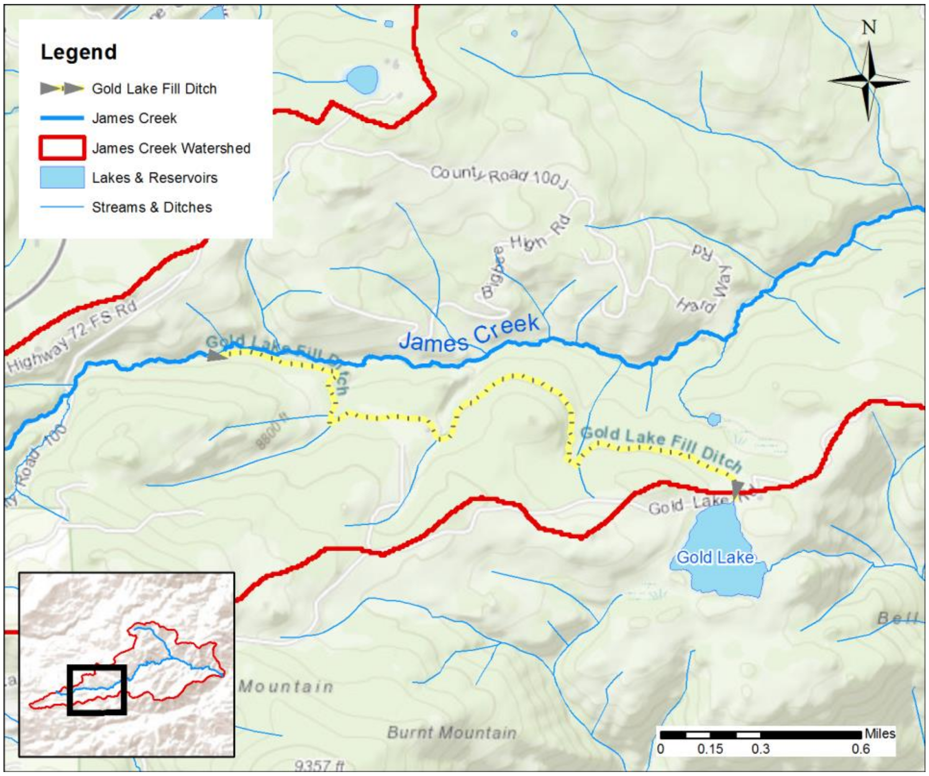


Figure 2.7. Map view of the Gold Lake Fill Ditch diverting water from James Creek to Gold Lake and into Left Hand Canyon watershed

2.3 Alert Thresholds Development

Finely tuned precipitation and stream gauge thresholds are an important element of a well-designed flood monitoring and alert system. The Lynker Team used the historical database of the existing Boulder County precipitation and stream gauges in and around the James Creek watershed to evaluate the viability of using rainfall alarm thresholds for the Jamestown community. The goal for this threshold/alarm evaluation is to provide emergency managers and the Jamestown community with recommendations for a robust toolset of action-based alerts while limiting false alarm occurrences.

Throughout the Colorado Front Range (foothills and plains), UDFCD implements a set of default rainfall accumulation thresholds (Table 2.2) to alert key personnel of heavy rainfall and potential flooding via email and SMS messaging services. Rolling window rainfall accumulation calculations are performed every 5 minutes for each gauge. Additional info from UDFCD: http://alert5.udfcd.org/notifications/alert-alarms/)

Table 2.2. UDFCD ALERT alarm notification thresholds

Rainfall Accumulation (inches)	Time Interval
0.5 in	10-minutes
1.0 in	1-hour
3.0 in	2-hours
5.0 in	6-hours
5.0 in	24-hours
10.0 in	72-hours

OneRain also provided the current river stage flood impact thresholds configured within the Boulder County Contrail system (Table 2.3). The post September 2013 event analysis by Yockum & Moore (2013) produced an estimated peak stage value of 8.0 feet that was derived from average cross-section high water marks within Jamestown.

Table 2.3. Flooding impacts currently configured for the Jamestown stream stage

Streamflow (cfs)	River Stage Height (feet)	Category Impact	Description*
300	***0.88 ft***	Bank Full (Action)	Approximate Q10
1252	***3.0 ft***	Minor Flooding	Potential scour and debris buildup impacting bridge
1785	***3.9 ft***	Moderate Flooding	Approximate Q50
3000	***5.7 ft***	Major Flooding	Estimated max capacity of bridge (<Q100)
3300	***~8.0 ft***	Est. Peak – Sep 2013	High water estimate (USGS estimated Q50-Q100)

**Rating curve info developed by Water and Earth Technologies (2015); estimated return frequency denoted by "Q"*

For this task, Lynker developed a series of Python scripts to perform a graphical and statistical analysis of the historical rainfall and river stage data for the James Creek region. The following processes were used to generate a series of calculations and customizable plots:

- Format and import and the incremental precipitation QA/QC'ed data (non-equidistant time steps) and instantaneous streamflow data
- Bin/group the precipitation data (5-minute intervals) to allow for simplified processing
- Perform a rolling accumulation calculation using a range of time durations (example provided in Figure 2.8)
    - Rolling accumulation durations: 10-min, 1-hour, 2-hour, 3-hour, 6-hour, 12-hour, 24-hour, and 72-hour
- Plot the rainfall accumulation data in alignment with the river stage time series as well as the default and modified alert thresholds

Time	...	12:30	1:00	13:30	2:00	14:30	3:00
30-Min Rainfall	...	0.00	0.22	0.75	0.64	0.14	0.04
1-Hour Rolling Accumulation	...	...	0.22	0.97	1.39	0.78	0.18

Figure 2.8. Example of the rolling accumulation calculation

The initial rainfall accumulation threshold analysis was performed using the seven representative rain gauges identified during the Thiessen Polygon analysis. These rainfall gauges provide a representative areal coverage within the James Creek basin upstream of Jamestown (Figure 2.3). While some of these gauges are positioned outside the basin boundary, the close proximity to the basin can provide an added data buffer for heavy precipitation along the fringes of the basin. Tracking multiple gauges in the James Creek vicinity as a system of alarms for the Jamestown community can also allow emergency managers to track and verify the spatial coverage of a storm event.

Eight accumulation duration thresholds were examined using a reanalysis of the September 2013 event as well as a historical evaluation (1999-2016). The range of time span accumulation thresholds aim to provide a robust alert system that can track a wide range of precipitation events (e.g. 1-hr heavy rainfall vs. multi-day moderate rainfall events). Generally, the shorter duration time intervals are in place to provide a warning for flash flooding type of events (short term – high intensity rainfall) while also alerting emergency managers of primed conditions for rapid runoff of future rainfall. The moderate duration (3-hour and 6-hour) alarms are intended to provide emergency managers with a notice of potential widespread flood conditions and debris flow conditions while also providing a warning to closely evaluate the potential for any future rainfall. Lastly, the 12-hour and 24-hour alarms are primarily in place to alert for high volume and longer duration flood events (e.g. September 2013). The 72-hour alarm in the case of the September 2013 event is largely irrelevant as a preemptive warning tool for Jamestown due to the fast hydrologic response of this mountainous basin; however, the 72-hour accumulation data can provide a useful proxy for soil saturation conditions that could contribute to rapid runoff and landslide conditions.

Figure 2.9 illustrates the standard rainfall exceedance alert instances overlaid on the James Creek streamflow timeseries. This plot illustrates when the default (UDFCD) rainfall alerts were triggered during the September 2013 event. By overlying all seven precipitation sites for the range of accumulation durations, these plots can help summarize the total alert network status from the James Creek gauge network. Note that the opacity of the shaded alert columns represents the number of overlapping gauges exceeding threshold values at each time interval (i.e. darker colors indicate more gauges exceeded thresholds). Note that the first rainfall alerts were not triggered until 11:05pm on September 11th, and there were few alert instances on the rising limb of the hydrograph. This finding highlights the limitations of using the standard set of rainfall exceedance values for James Creek.

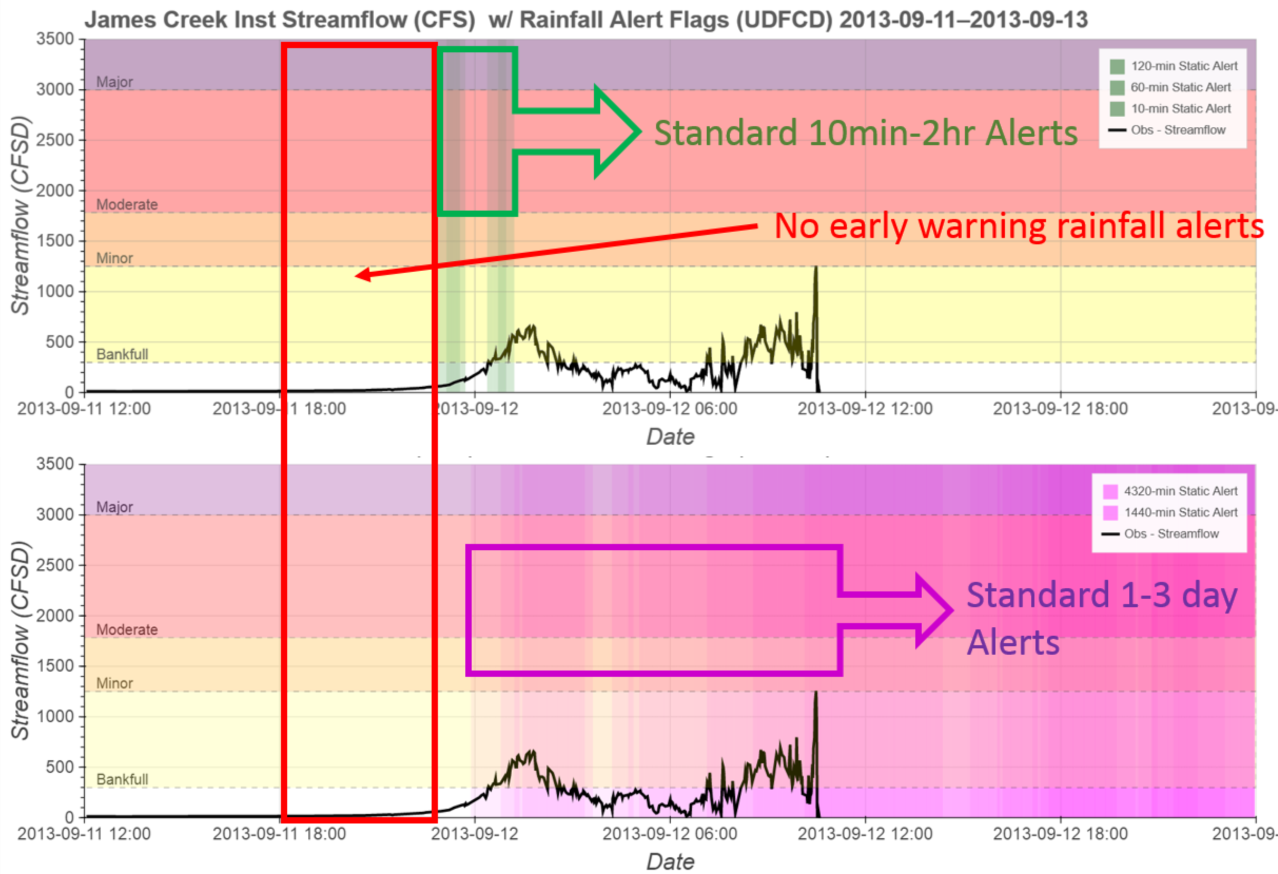


Figure 2.9. September 2013 James Creek observed stage with total binned threshold alert instances for all accumulation duration periods (green and pink shaded columns)

Alert Analysis & Refinements

To improve the rainfall accumulation alert system, we developed and tested a new system of "conditional" (also referred to as "saturated") rainfall thresholds using the historical rainfall data for the James Creek gauge network. By using the longer duration (e.g. 24-hour and 72-hour) rainfall accumulation data as a proxy for saturated soil conditions, the shorter-duration rainfall threshold values are treated as a dynamic threshold that can be reduced when conditions are prime for rapid runoff and/or debris flow potential. The system of conditional thresholds is intended to be configured in tandem with the traditional (static) threshold values. The resulting combined rainfall alerts would ideally provide a more robust monitoring system of flood and debris flow scenarios. Figure 2.5 illustrates an example workflow for a 2-hour standard and conditional alert calculation/determination.

We developed initial estimates of soil saturation values using SSURGO soil properties. Figure 2.11 illustrates the SSURGO estimated available water storage (surface to 25cm soil column weighted average). Typical estimates across the basin vary from 1.5-4.6 cm (0.6-1.8 in). While this data was not directly applied as the saturation threshold, the SSURGO estimates provided a general range to ensure tested saturation values were physically realistic.

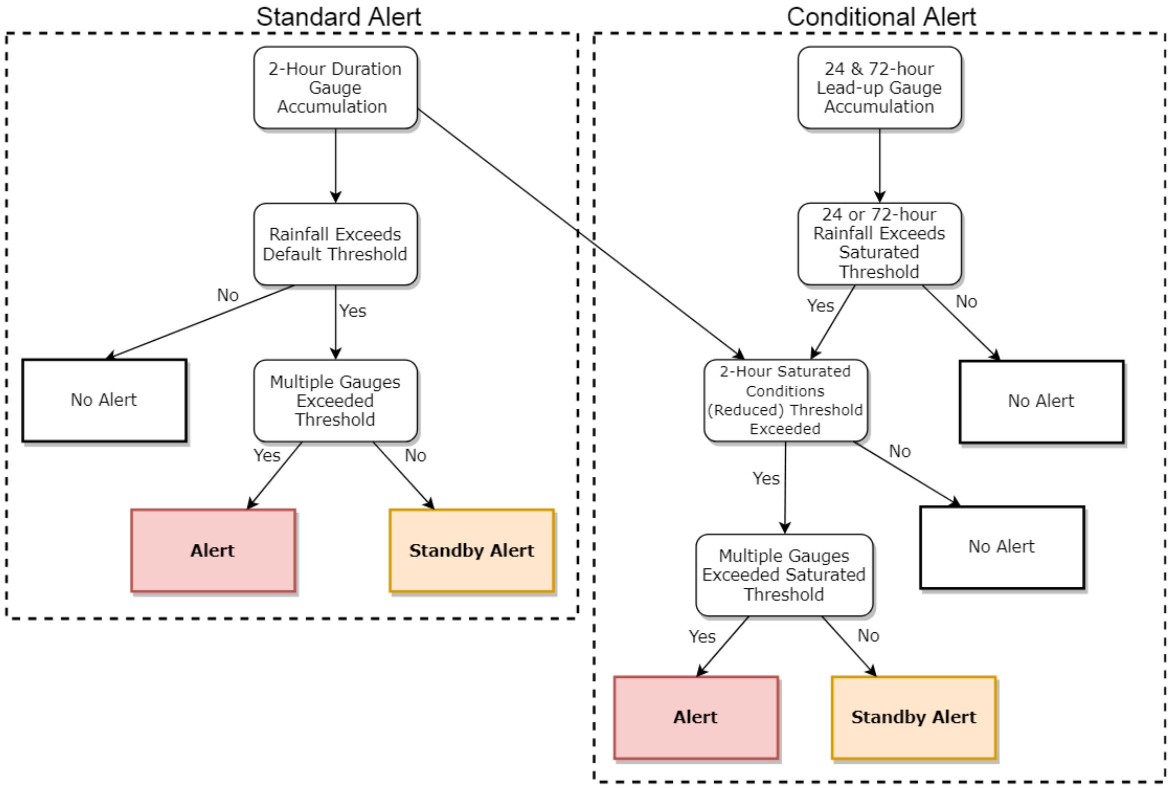


Figure 2.10. Example flow chart of the 2-hour alert threshold calculations

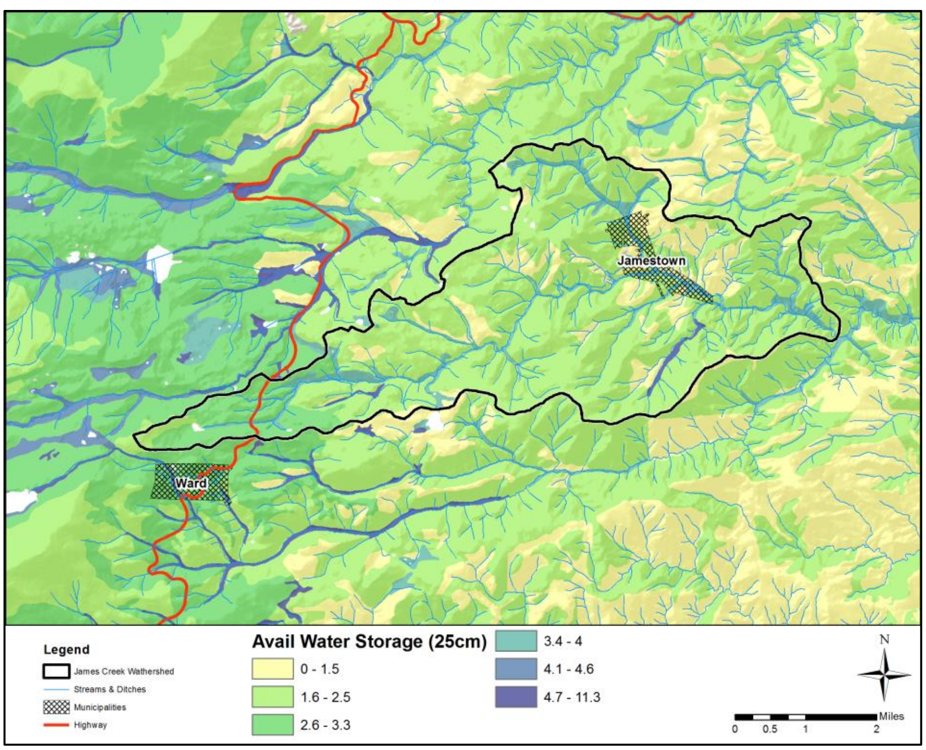


Figure 2.11. SSURGO soil classification map showing estimated available water storage for the top 25 cm soil column

After evaluating the default thresholds and testing several variations of modified threshold values for the September 2013 event, the Lynker Team examined the 17-year historical rainfall record (1/1/1999-10/1/2016) to document the frequency and timing of alerts when applying the modified and saturated thresholds. While the historical period encompasses only one significant flooding event (Sep. 2013), this analysis can provide valuable insight into the expected alert frequency. As a secondary comparison tool, the historical list of official NWS Flood Hazards issued for Jamestown (Appendix C) was surveyed along with the tested rainfall alert instances.

The analysis examined numerous rainfall alarm thresholds in preparation for providing emergency managers and Jamestown personnel with insight and recommendations for rainfall monitoring in the future. The graphical approach applied to this development/evaluation aims to focus alert thresholds on potential threats related to flooding on James Creek as well as hillslope saturation and subsequent debris flow risks (based on the chronology of observed impacts during the Sep. 2013 event). The rainfall analysis largely focused on the following criteria when testing and evaluating threshold values:

- Timing of threshold exceedances for the Sep. 2013 event
- Quantity of alert instances in the historical evaluation
- Overlapping alert instances for multiple gauges
- Overlapping alert instances for the range of duration periods

Along with the addition of a new 3-hour threshold, a 12-hour duration threshold was tested during the rainfall analysis. The 12-hour time window threshold was exceeded only during the September 2013 event; however, it largely replicated the timing of the 24-hour threshold exceedance. For this reason, the 12-hour duration was dropped from the final recommended thresholds. Table 2.4 and Figure 2.12 outline the default, modified and new conditional rainfall thresholds developed from the historical analysis. Modified values represent changes to the standard "default" thresholds while the conditional thresholds represent the newly proposed accumulation monitoring technique described above. Note that the 24-hour and 72-hour conditional threshold values are only applied as a proxy for determining when to apply the 1-hr, 2-hr, and 3-hr conditional thresholds (no saturated alerts are generated for the 24 & 72-hour durations).

Table 2.4. Summary of the default, modified, and conditional rainfall accumulation thresholds

Time Duration	Default Rainfall Accumulation Alert (inches)	Modified Rainfall Accumulation Alert (inches)	Conditional Rainfall Accumulation Alert (inches)
10-minutes	0.5	0.5	--
1-hour (60)	1.0	1.0	**0.5**
2-hours (120)	3.0	**1.75**	**0.75**
**3-hours (180)*	--	**2.5**	**1.0**
6-hours (360)	5.0	**3.0**	--
24-hours (1440)	5.0	5.0	**2.0 (tracking only)**
72-hours (4320)	10.0	10.0	**3.5 (tracking only)**

* New threshold duration (3-hour); highlighted values indicate new or modified values developed from this project

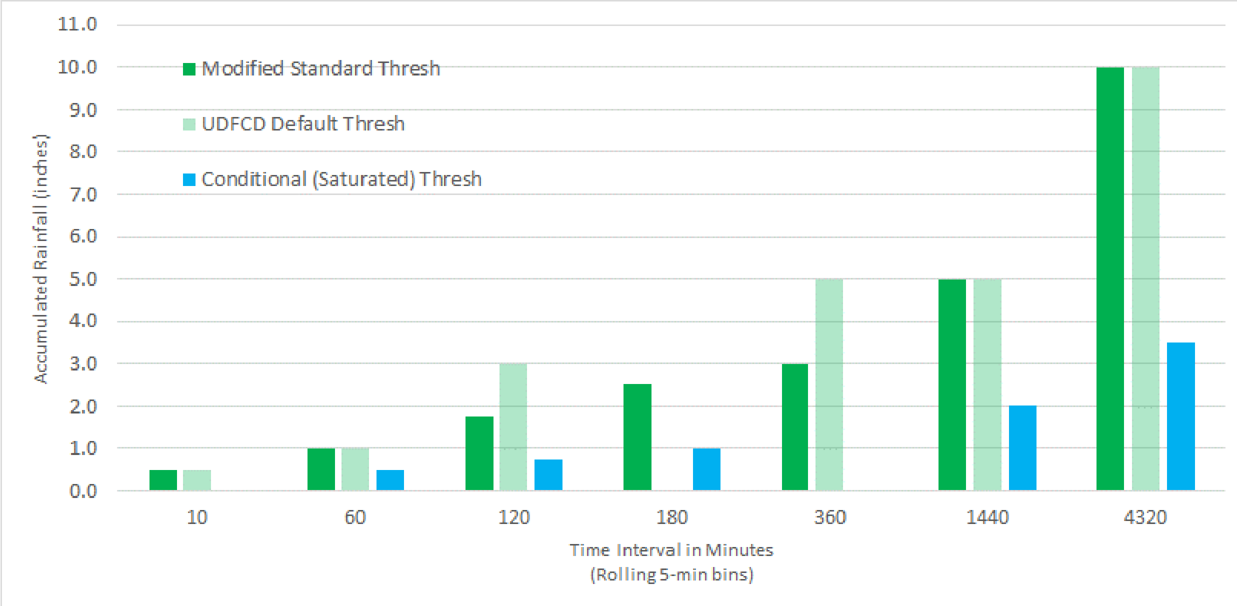


Figure 2.12. Summary bar chart of the default, modified, and conditional rainfall accumulation thresholds

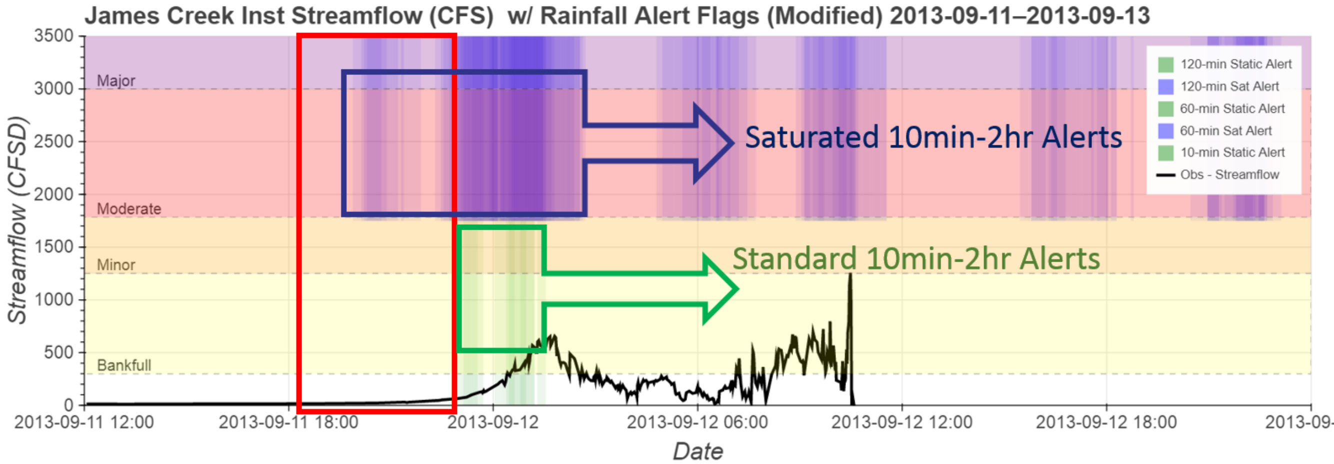


Figure 2.13. September 2013 James Creek observed stage with total binned threshold alert instances for all accumulation duration periods (blue columns = conditional/saturated alerts; green columns = modified standard alerts)

Table 2.5 provides a summary of the timing of the first threshold exceedance by each time duration. The color code of the cells indicates the earliest alert instances (dark orange) corresponding to the three conditional alert duration periods. The conditional alerts correspond well with the first NWS flood warning that was issued at 19:58 MDT on 9/11/2013.

Table 2.5. Summary of the date/time of the first alert instance during the Sep. 2013 event (times in MDT)

Time Duration	September 2013 First UDFCD Alert Instance	September 2013 First Standard Alert Instance	September 2013 First Saturated Alert Instance
10-minutes	--	--	na
1-hour (60)	9/11/2013 22:50	9/11/2013 22:50	9/11/2013 19:55
2-hours (120)	--	9/12/2013 0:05	9/11/2013 20:15
**3-hours (180)*	na	9/12/2013 0:35	9/11/2013 21:40
6-hours (360)	--	9/12/2013 0:10	na
24-hours (1440)	9/11/2013 23:55	9/11/2013 23:55	na
72-hours (4320)	9/12/2013 7:10	9/12/2013 7:10	na

The following tables provide a detailed breakdown of the final rainfall threshold results and provide a summary of the frequency and magnitude of each alert category. Table 2.6 and Table 2.7 outline the breakdown of unique alert instances (multiple gauge alerts within 5-minute bin are counted as a single alert) and the total count of all gauge exceedances (total alert count for all gauges and all periods). These tables provide a historical summary of the number of alert occurrences for each threshold duration. Note that the 180, 360, 1440, and 4320-minute alerts did not occur during the 1999-2016 period except during the Sep. 2013 event. This information can provide some insight to the expected frequency and relative performance of the new/modified alert values.

Table 2.8 and Table 2.9 provide a summary of calendar dates with rainfall exceedance occurrences. Note that the majority of dates listed with standard alerts were the result of 60-minute and 10-minute exceedances, and the threshold values for these two periods were not modified from the original UDFCD values (unchanged alert instances). It is also important to recognize that even with the increased number of overall alert instances under the proposed system, the total number of calendar days with a rainfall alert remains unchanged from the original (UDFCD) alert instances. The new conditional alerts did not produce any new alert dates from the default UDFCD list, while still providing a substantial alert lead-time improvement during the September 2013 event. Each rainfall alert date was also cross-checked for any Jamestown flood hazard issuance from the NWS. It's important to note that the NWS Flood Hazard products have evolved over time (e.g. storm-based warnings implemented in 2008), and a direct comparison of rainfall alerts and NWS alerts has several limitations.

Table 2.6. Threshold exceedance summary for the historical analysis (1999-2016)

Rolling Window Duration (min)	4320	1440	360	180	120	60	10
Standard Threshold Value	10.00	5.00	3.00	2.50	1.75	1.00	0.50
Saturated Threshold Value	3.50	2.00		1.00	0.75	0.50	
Total Alert Date/Time Instances	711	391	57	197	213	230	25
Standard Alert Date/Time Instances	711	391	57	11	38	115	25
Saturated Alert Date/Time Instances	--	--	--	197	191	136	--
Overlapping Sat/Static Alert Date/Time Instances	--	--	--	11	16	21	--
Standard Alert Count	2182	1386	100	11	40	154	26
Saturated Alert Count	--	--	--	580	550	291	--

Table 2.7. Threshold exceedance summary for the historical analysis (1999-2016) excluding September 2013

Rolling Window Duration (min)	4320	1440	360	180	120	60	10
Standard Threshold Value	10.00	5.00	3.00	2.50	1.75	1.00	0.50
Saturated Threshold Value	3.50	2.00	0.00	1.00	0.75	0.50	0.00
Total Alert Date/Time Instances	0	0	0	0	22	96	25
Standard Alert Date/Time Instances	0	0	0	0	22	94	25
Saturated Alert Date/Time Instances	--	--	--	0	0	2	--
Overlapping Sat/Static Alert Date/Time Instances	--	--	--	0	0	0	--
Standard Alert Count	0	0	0	0	22	125	26
Saturated Alert Count	--	--	--	0	0	2	--

Table 2.8. Summary of standard rainfall alert dates, durations exceeded, and NWS hazard issuance for the 1999-2016 evaluation period

Standard Alert Dates:	Threshold Durations Exceeded (minutes)	NWS Flood Hazard Alert Issued
7/30/1999	120,60,10	FALSE
7/31/1999	60,10	FALSE
4/5/2000	10	FALSE
7/16/2000	10,	FALSE
8/29/2003	120,60	FALSE
7/23/2004	10	FALSE
8/18/2004	10	TRUE
7/25/2005	60,10	FALSE
7/2/2006	10	FALSE
7/20/2006	10	TRUE
7/26/2007	60	TRUE
NWS Switch to Storm Based Warnings		
7/4/2009	10	FALSE
7/13/2011	60,10	TRUE
7/7/2012	60,10	TRUE
7/30/2012	60,10	TRUE
7/14/2013	60,10	TRUE
8/3/2013	10	TRUE
9/11/2013	1440,60	TRUE
9/12/2013	4320,1440,360,180,120,60	TRUE
9/13/2013	4320,1440	TRUE
9/14/2013	4320	TRUE
5/9/2015	10	TRUE

Table 2.9. Summary of conditional rainfall alert dates, durations exceeded, and NWS hazard issuance for the 1999-2016 evaluation period

Conditional Alert Dates:	Threshold Durations Exceeded (minutes)	NWS Alert Issued
7/8/2012	*60	FALSE
9/11/2013	180,120,60	TRUE
9/12/2013	180,120,60	TRUE

** 7/8/2012 alert produced by only one gauge (Ward) – NWS Areal Flood Advisory issued 7/7/2012*

Current Jamestown Flood Safety Plan

The new and modified threshold developed from this project can help provide Jamestown with a localized monitoring system, but the communication element of the alert system is imperative for the system to be effective in Jamestown. For this reason, the following recommendations and suggestions focus on providing the Jamestown Volunteer Fire Department (JVFD) with information to help implement the thresholds in the Town's operation Flood Safety Plan.

To help connect the newly recommended rainfall thresholds to the existing JVFD flood safety guidelines (JVFD, 2010), Lynker generated recommendations for categorizing the rainfall alert categories into the predefined flood response levels (Flood Modes 0-4). An outline of the "Flood Mode" categories documented in the current JVFD flood safety booklet is provided below:

- *Flood Mode 0*: Normal operations and monitoring in effect.
- *Flood Mode 1*: The meteorological potential of a flood-producing storm is being observed. Rain may or may not be occurring; stream levels are substantially below flood levels.
- *Flood Mode 2*: The possibility of flooding in the near future is recognized. Boulder Communications (911) notifies affected agencies (like the JVFD) to mobilize for possible flood warning. The JVFD begins monitoring rain gauge and stream levels, as well as weather updates on the 911 radio channel and the 24-hour weather radio channel. The Floodplain Residents' Phone List (Hazard Zones A through C) is assigned to specific JVFD members.
- *Flood Mode 3*: Flood warning is issued for specific areas with estimated levels of severity; affected hazard areas are notified to execute appropriate warning and evacuation measures. JAMESTOWN LOUDSPEAKER WILL SOUND AN ALERT. The JVFD Incident Command System is initiated, and a Command Post is set up at the Jamestown Elementary School. Fire trucks and personnel are stationed on the north side of James Creek and at the school, if possible. Rain gauges and stream levels are monitored and documented.
- *Flood Mode 4*: FLOODING IS OCCURRING. The JVFD makes assessments of resident rescue requirements and Evacuation Center (Jamestown Elementary School) needs; the status of roads, bridges, and the water plant are documented. Structure and utility damage control are initiated with sandbagging, mobilizing heavy equipment, and the use of civilian volunteers. The JVFD notifies the County concerning the resource status in town.

2.4 Recommendations

Based on the analysis of rainfall thresholds and an evaluation of flood/debris flow warning needs in Jamestown, Lynker recommends the following actions:

- Incorporate the live DWR data stream for the Left Hand Ditch diversion into the Contrail monitoring configuration for Jamestown
- Incorporate the modified standard rainfall threshold values along with the new conditional threshold values into the Contrail alert configuration for Jamestown
- Adapt the current Jamestown Volunteer Fire Department Flood Safety Plan to formalize communication and response actions to the automated alerts
- Encourage public enrollment in automated hazard notifications through systems like the Boulder County Emergency Notification System (www.boco911alert.com) – how it works

The following tables are provided as an example framework for formalizing an updated flood communication and response plan between Jamestown and Boulder County OEM. Flood Mode categories refer to the current (2010) JVFD Flood Safety Plan.

Time Duration	Modified Rainfall Accumulation Alert (inches)	Saturated Rainfall Accumulation Alert (inches)	Automated Alert Communication	JVFD/OEM Emergency Response
10-minutes	0.5 in	--		*Flood Mode 1*
1-hour (60)	1.0 in	0.5		*Flood Mode 1 / Flood Mode 2*
2-hours (120)	1.75 in	0.75		*Flood Mode 2*
3-hours (180)	2.5 in	1.0		*Flood Mode 3*
6-hours (360)	3.0 in	--		*Flood Mode 3*
24-hours (1440)	5.0 in	2.0		*Flood Mode 3*
72-hours (4320)	10.0 in	3.5		N/A

Stream Gauge	Data Source	Alert Criteria	Alert Communication	JVFD /OEM Emergency Response
Left Hand Div	DWR	> 400 cfs		*Flood Mode 2*
James Creek @ JT	UDFCD/OEM	> 300cfs (Bankfull Stage)		*Flood Mode 3*

NWS Hazard Alert	Alert Communication	JVFD /OEM Emergency Response
Flash Flood Warning		*Flood Mode 3*
Areal Flood Warning		*Flood Mode 2*
Areal Flood Advisory		*Flood Mode 2*
Flash Flood Watch		*Flood Mode 2*

NWS flood product explanations provided here: https://www.weather.gov/bmx/outreach_flw

3 Evaluation of the National Water Model (NWM) Simulation Performance for Future Operational Monitoring of James Creek

3.1 Introduction

Based on the results of the rain gauge alert analysis, it is apparent that monitoring observed precipitation and stream stage may not always provide an adequate lead time for alerting Jamestown to the possibility of flooding and debris flow hazards. Monitoring forecasted precipitation and simulated runoff/streamflow conditions could extend the alert lead time for a range of flood-related hazard scenarios within the James Creek watershed. The current approach to flood monitoring performed by the Boulder County OEM team relies on early warning storm initiation monitoring and subsequent radar storm track/progression tools. Given the short-duration rainfall-runoff response of the mountainous James Creek watershed and the subsequent threat of debris flow hazards, there is a heightened need for reliable hydrologic forecasts with enhanced spatial and temporal resolution. **The combination of reliable streamflow forecasts, radar rainfall tracking/projection monitoring, and a well-maintained automated rain gauge alert network would most likely provide Boulder County OEM with the ideal toolset to safeguard the Jamestown community for future rainfall events.**

NOAA-National Weather Service (NWS) provides operational flood hazard warnings to enhance public protection and safety for all locations in the U.S. NWS forecasters use a gridded Flash Flood Guidance (FFG) product (Figure 3.1) to track the potential for rapid runoff and issue Flash Flood hazard notifications. The FFG is a numerical estimate of the average rainfall over a given time duration (i.e. one, three, and six hour), required to initiate flooding along small streams over a specific area. These estimates are based on current soil moisture conditions computed by the River Forecast Centers. The NWM is not actively implemented to the flash flood hazards issued by the NWS, and in its current development state, the NWM should only be used as prototype forecast product to help relate weather/rainfall forecasts to estimates of subsequent runoff and streamflow. Additional FFG info: http://www.nws.noaa.gov/oh/hrl/ffg/modflash.htm)

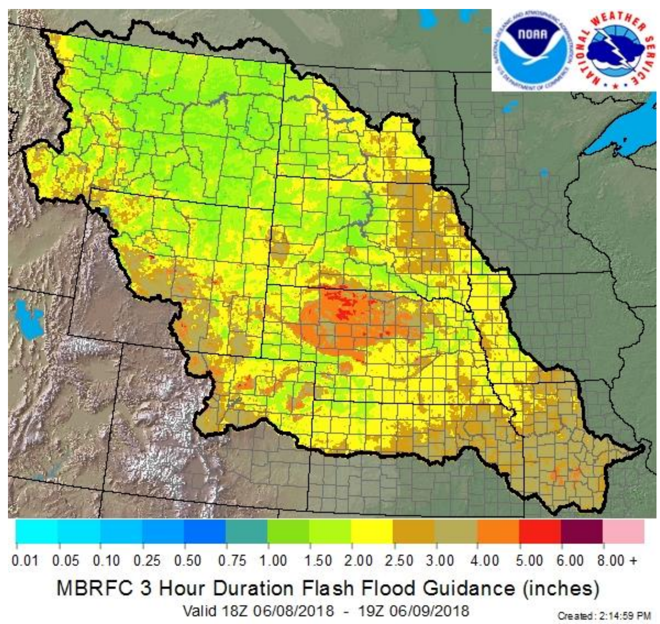


Figure 3.1. Map of the MBRFC 3-hour Flash Flood Guidance grid (https://www.weather.gov/mbrfc/ffg)

Developing and maintaining a comprehensive flood forecasting system tailored to local needs is typically unattainable for many communities, especially small towns, due to the level of effort and resources required to build and maintain a system; thus, the federally supported National Water Model (NWM) has the potential to provide an additional flood forecasting resource for communities like Jamestown. Although significant NWM development and validation remains to be done over the next several years, it is sensible and strategic for locations like Jamestown to begin to monitor and evaluate the NWM as a potential tool for flash-flood forecasting.

3.2 Data Collection and Processing

What is the NWM?

The NWM is a continental-scale water resources model founded on the Weather Research and Forecasting Model Hydrological modeling system (WRF-Hydro) architecture and developed by the National Center for Atmospheric Research (NCAR) in Boulder, CO. Model output includes hourly short-range forecasts out to 18-hours, medium-range forecasts out to 10-days, and long-range ensemble forecasts out to 30-days. The current USGS National Hydrography Dataset Plus (NHDPlus) river reach network (NWM forecasted river reach segments) for the James Creek basin includes eleven forecasted river segments.

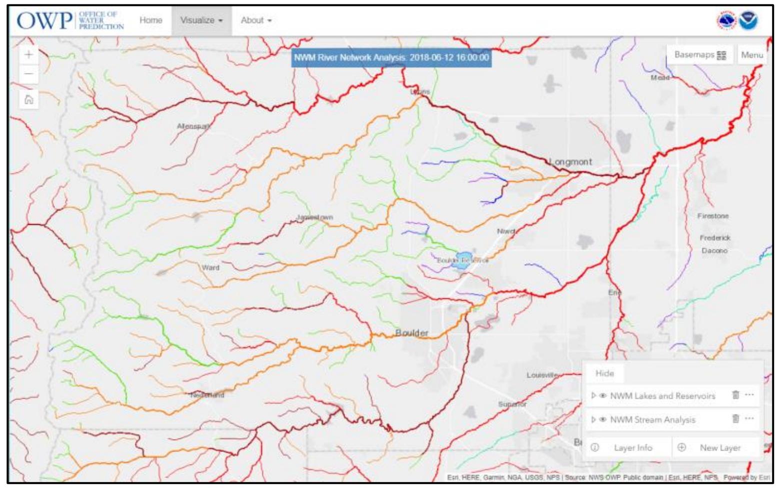


Figure 3.2. Example of NWM map interface showing flow anomalies by river reach for Boulder County stream segments on 6/12/2018

For this initial evaluation, we used version 1.0 of the NWM. This version of the NWM has the following caveats:

- Baseline simulation with limited calibration efforts
- Current model framework does not directly account for reservoir operations, artificial diversions, or irrigation impacts
- Retrospective simulation period limited to 1993-2016
- Small routing/timing outlier errors can significantly inflate model performance statistics for small mountainous basins

NWM Retrospective Data

To evaluate the NWM, the NOAA National Water Center (NWC) created a retrospective simulation to generate a continuous time series of simulated flow for the 1993-2016 period. This retrospective simulation uses historical input forcing (e.g. precipitation and temperature) derived from reconstructed observed data. This differs from the operational NWM forecast simulation which uses forecasted inputs from atmospheric models to predict the future short-term hydrologic response. To prepare the NWM simulated streamflow data (SQIN) and the observed streamflow data (QIN) for evaluation and analysis, we performed several data processing and quality control checks:

- We aggregated instantaneous observed flow to mean hourly flow (QIN)
- We used a linear interpolation to fill in missing hourly QIN data (for data gaps < 12 hours)
- We converted hourly SQIN data from GMT to Mountain Time
- We generated a time series of overlapping SQIN and QIN (ignoring periods with missing observed data)
- We developed automated Python scripts to perform statistical calculations and generate statistical analysis plots
- We developed Python bokeh scripts to produce interactive time series plots of SQIN, QIN, and precipitation data (html plot files)

We selected six Boulder County stream gauge locations for NWM analysis (Figure 3.3). These gauge locations are a part of the UDFCD/Boulder County Alert network and have an archived record of instantaneous streamflow/stage data.

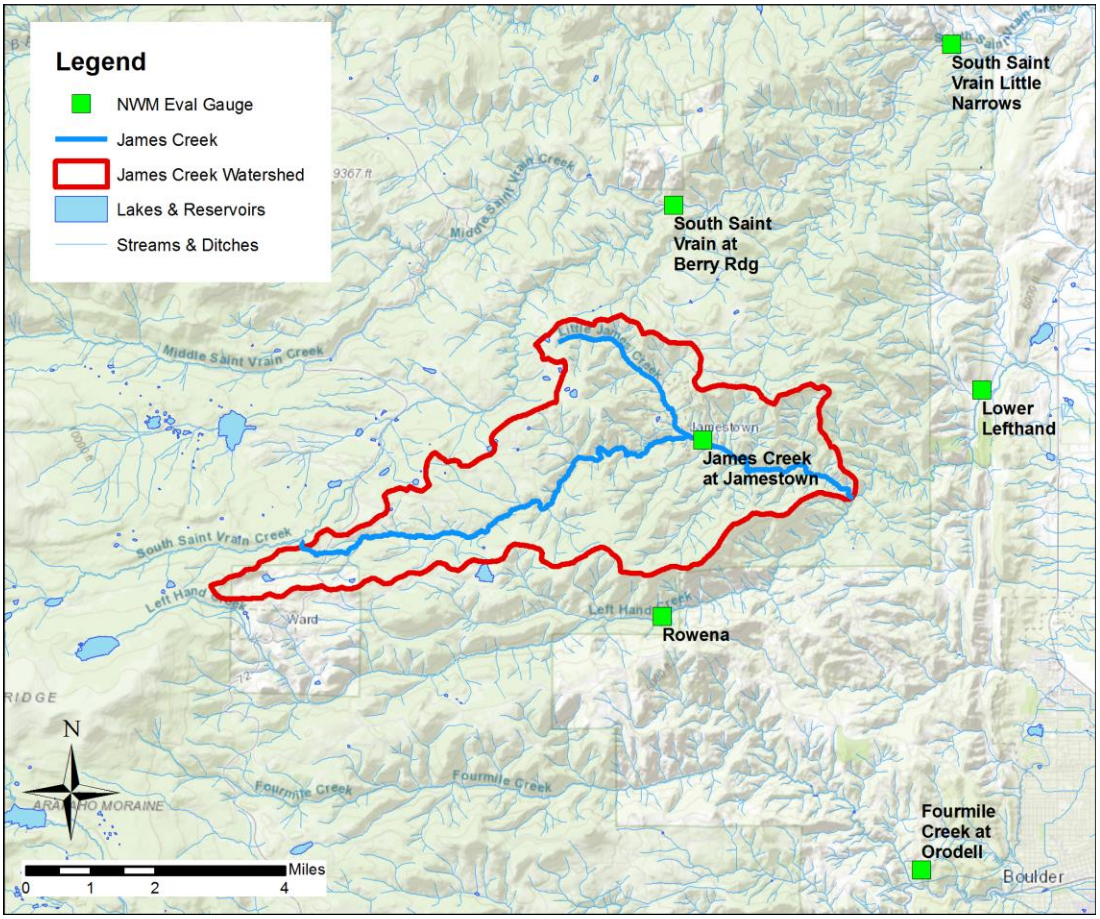


Figure 3.3. Map of stream gauge locations used in the NWM evaluation

3.3 Model Performance Evaluation for James Creek

We completed a thorough analysis of the historical simulated flow data for the James Creek basin. The analysis included both a visual interpretation via the time series hydrograph plots as well as an evaluation of statistical metrics for a range of flow criteria. While much of the focus of the visual analysis was targeted on the September 2013 event, the data evaluation quantifies the model performance for the full duration of observed and simulated flow data (1993-2016 period). It's important to note several prominent data uncertainties associated with the observed streamflow record for James Creek at Jamestown:

- The gauge was relocated after 2013 flood recovery
- The rating curve changed between the pre-2013 vs post-2013 data
- The post-2013 rating curve has a baseline flow of ~50cfs below the minimal sensor reading (gauge placement limitation)
- The gauge was destroyed during the September 2013 event (with possible debris impacted readings leading up to the gauge malfunction)

While the items above likely play an important role in the overall NWM performance metrics, there are several simulated flow trends and characteristics that can be inferred from the analysis.

Figure 3.4 illustrates the NWM 1-hr simulated flow alongside the observed flow for James Creek at Jamestown (instantaneous observed flow converted to aggregated 1-hr averaged flow). The simulated flow from the Little James Creek and "Central" James Creek reaches are also plotted to illustrate the flow components from the two reaches just upstream of the confluence in Jamestown. While the initial flow response and peak from the NWM appears several hours prior to the gauge observed peak, the simulation does provide a reasonable estimate of the flow magnitude. The secondary simulated peak also aligns relatively well with the general timing and estimated magnitude of the pulse of flow that generated the high-water mark during the afternoon/evening of 9/12/2013. The simulation failed to produce a streamflow pulse during the morning of 9/12/2013 as indicated by the gauge observations (prior to gauge loss). There are several potential explanations for the simulated errors during the event. Errors in the reconstructed rainfall data are the most likely culprit behind the timing and missing flow events when considering the relatively small scale meteorological dynamics of the James Creek basin.

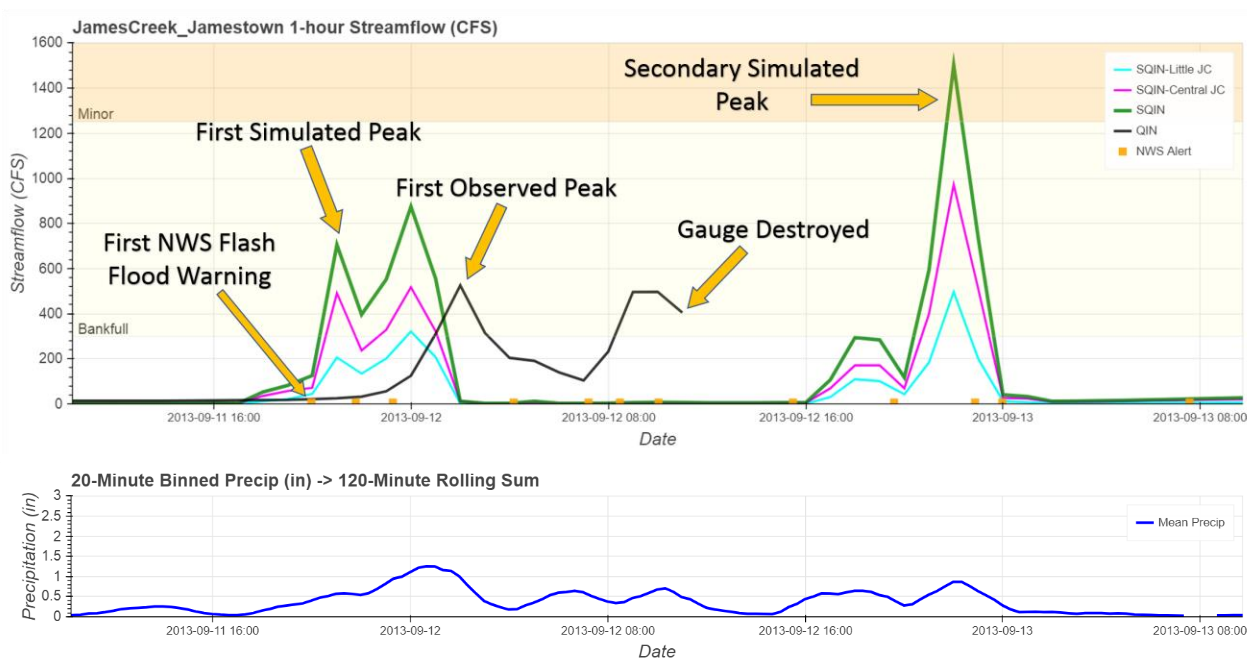


Figure 3.4. SQIN and QIN timeseries for the September 2013 event along with NWS flood hazard issuances (orange squares) and the 2-hour rolling precipitation accumulation (bottom plot)

To help provide a more regional perspective, Figure 3.5 illustrates the simulated vs. observed flow for the South St Vrain at Little Narrows during the 9/11/2013-9/13/2013 period. Similar to the James Creek simulation, the NWM produces two separate streamflow peaks at similar times on the South St Vrain. At both locations, the simulated streamflow of the initial peak occurs a few hours prior to the observed streamflow. This timing artifact is also apparent at several of the other gauge locations we evaluated. The simulation also fails to produce any flow event midday on 9/12, and as mentioned for the James Creek results, is most likely an indication of inaccuracies in the reconstructed rainfall data input to the model. The slight uptick in simulated basflow conditions in the days after the peak flow events is also a noteworthy artifact of the NWM when compared to the relatively stable baseflow in the observations. This finding may indicate a land surface model parameterization that may not be in sync with the physical conditions of these mountainous basins.

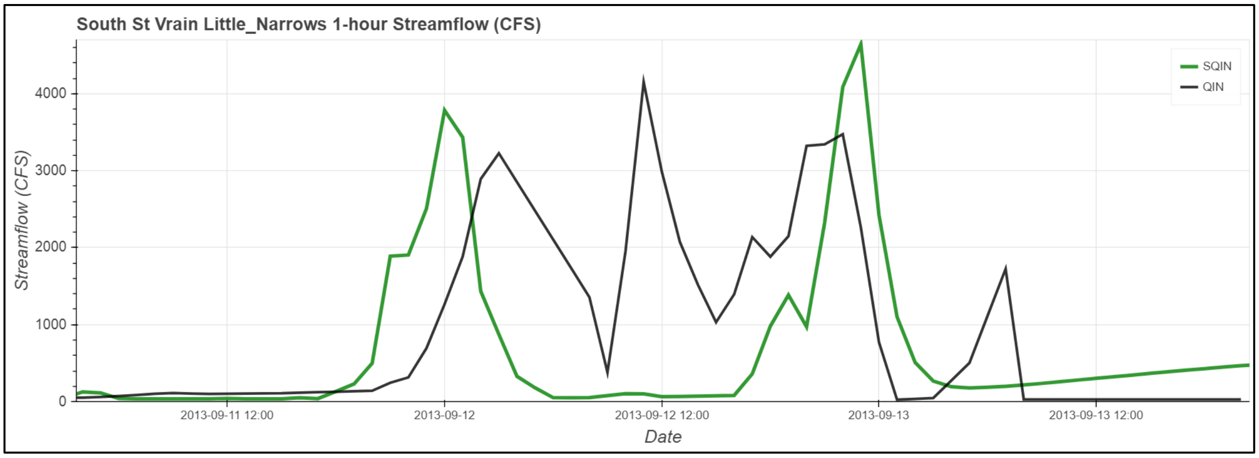


Figure 3.5. SQIN and QIN timeseries for the September 2013 event for the South St Vrain gauge location at Little Narrows.

Figure 3.6 outlines the full period of observed flow at James Creek (1999-2016) and the overlapping simulated flow. Outside of the September 2013 event, there are very few noteworthy observed streamflow events and the vast majority of simulated and observed flow values occur below 100cfs. This flow distribution is also evident within the statistical evaluation of the simulated and observed streamflow (Figure 3.7). Given the small sample size of streamflow events greater than 100cfs, future NWM evaluation efforts will be needed to better understand the skill of the model for a range of impactful streamflow events.

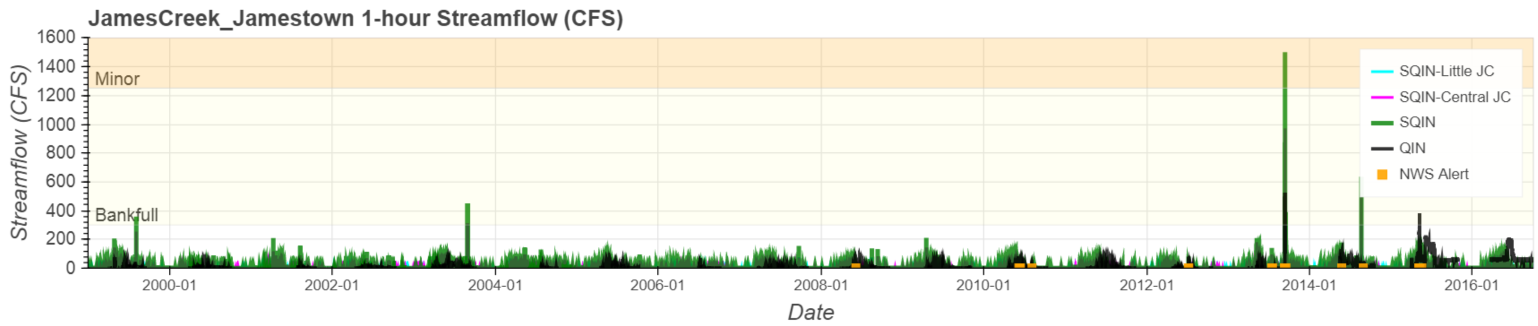


Figure 3.6. Simulated and observed James Creek streamflow at Jamestown for the 1999-2016 period

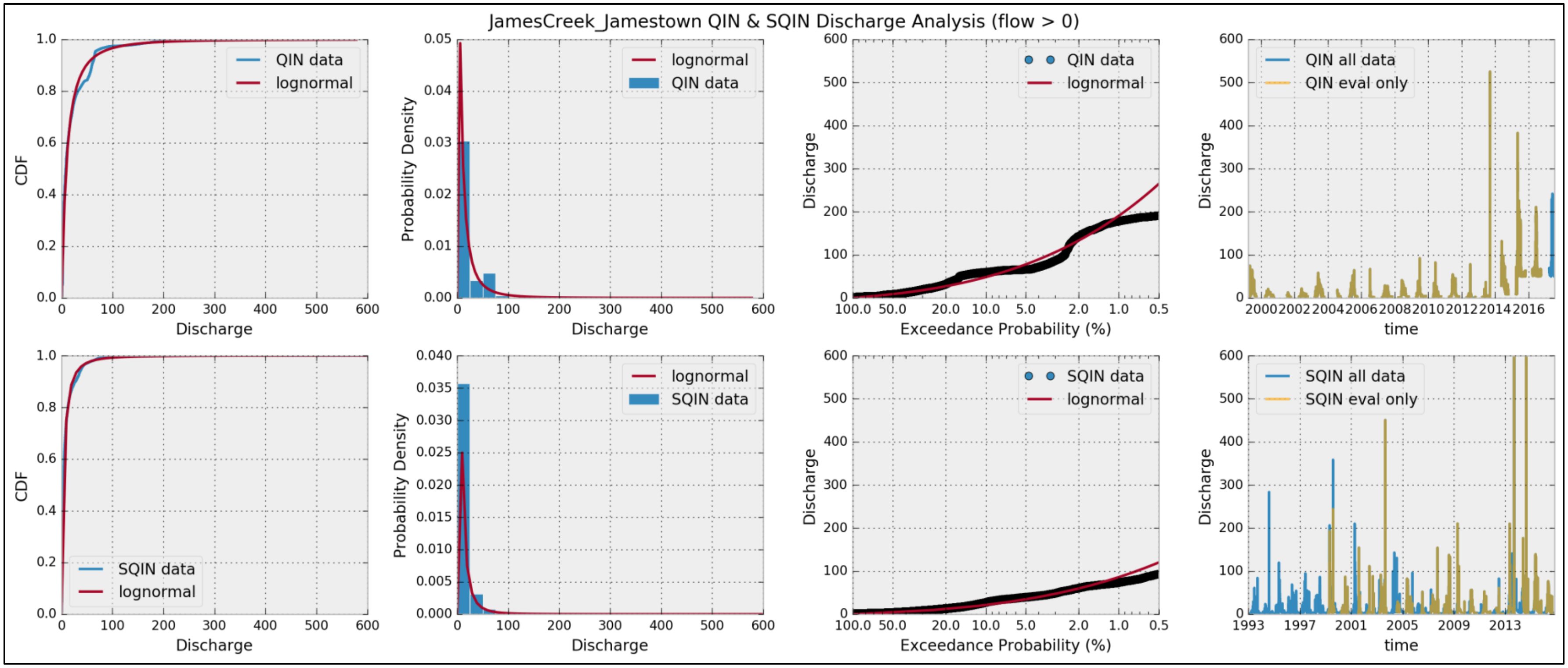
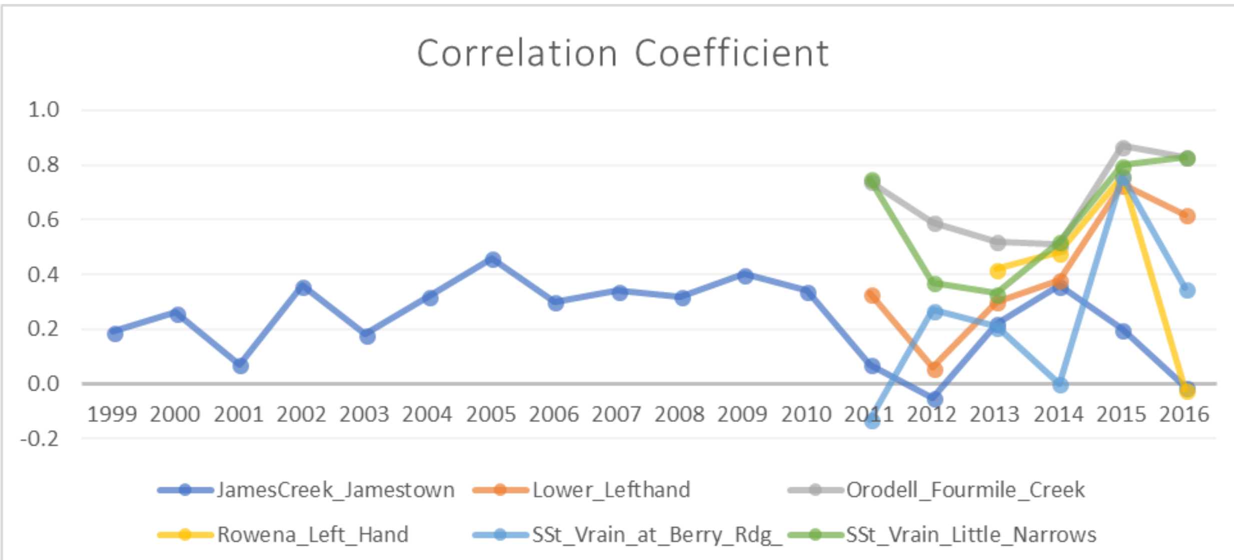
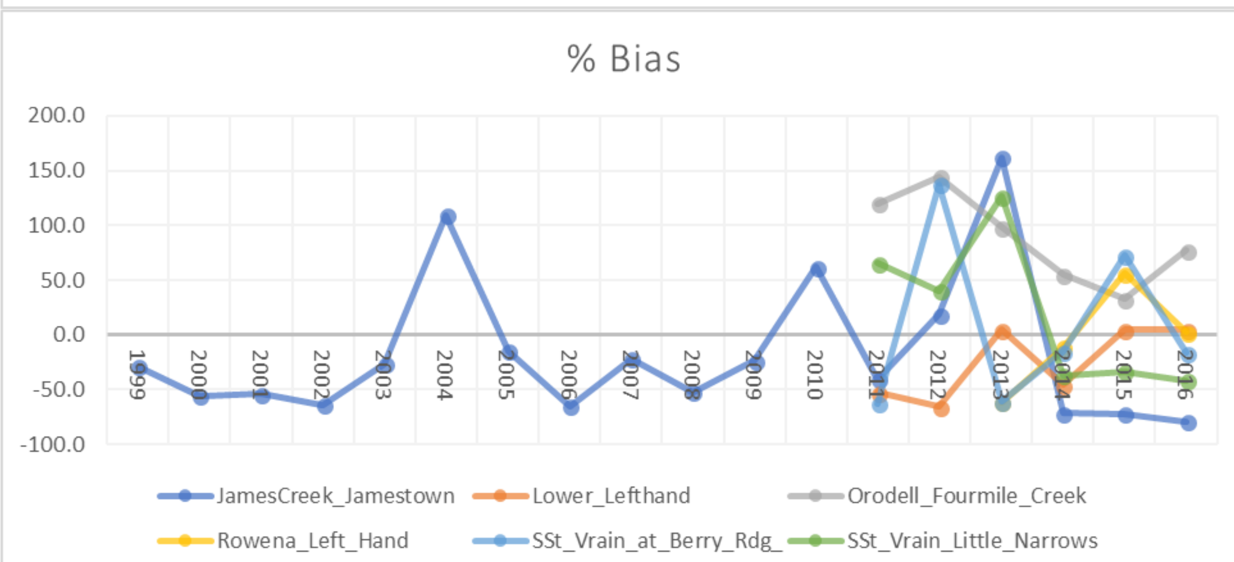


Figure 3.7. Cumulative distribution function (column 1), probability density (column 2), exceedance probability (column 3), and hydrograph plot (column 4) for the QIN (row 1) and SQIN (row 2).

The following statistical evaluation plots provide a summary of the NWM performance for the six gauge locations in Boulder County. Note that the evaluation period for the Jamestown gauge extends from 1999-2016 while the other locations use the 2011-2016 period (ALERT2 gauge archives begin in 2011 for most locations). To decipher any apparent trends in model performance the statistical analysis was generated for a calendar year distribution, warm-season monthly distribution, and a distribution of flow ranges. A chart of correlation coefficient and % bias values is provided for each of the three distribution categories on the following pages. An analysis for two additional USGS gauge locations on the Big Thompson and the Boulder Creek at 75th St USGS gauge was also generated for river scale comparison purposes (large river systems). Results from this analysis can be found in Appendix G.

Statistical analysis by calendar year:



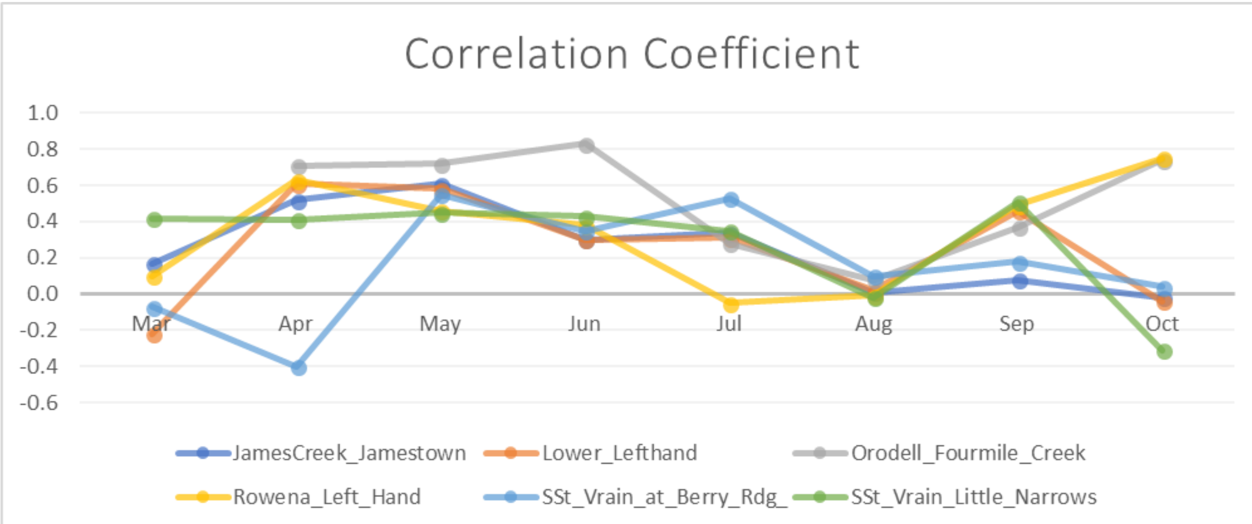


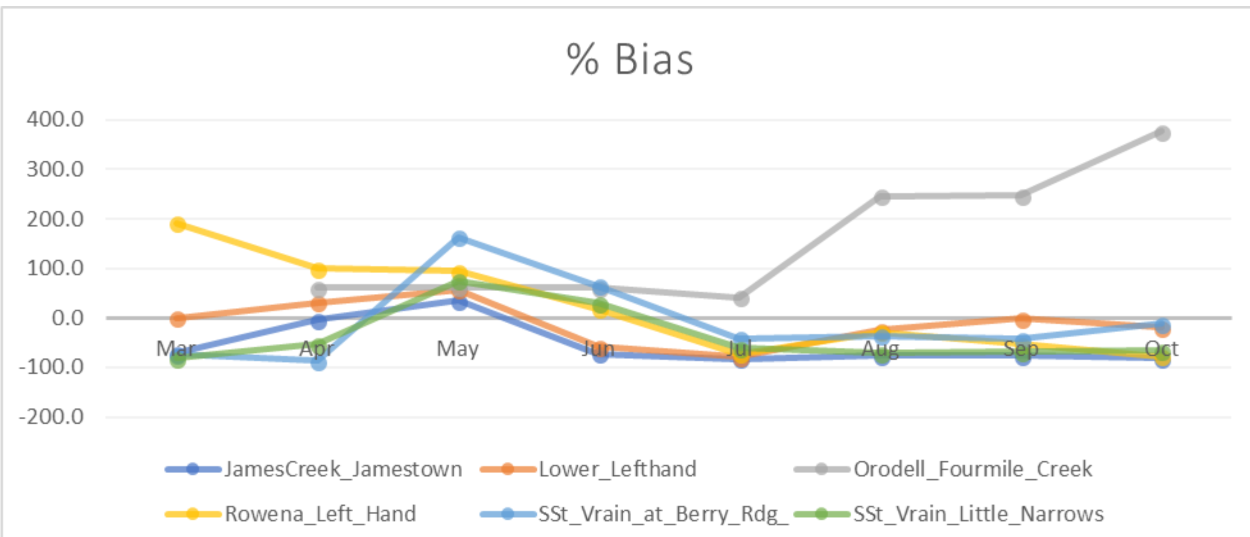
General findings:

- Considerable year-to-year variability in model performance

- Variable performance between gauges during the 2013 calendar year
- 2015 performance (correlation coefficient) was noticeably strong for most locations

Statistical analysis by warm season months:

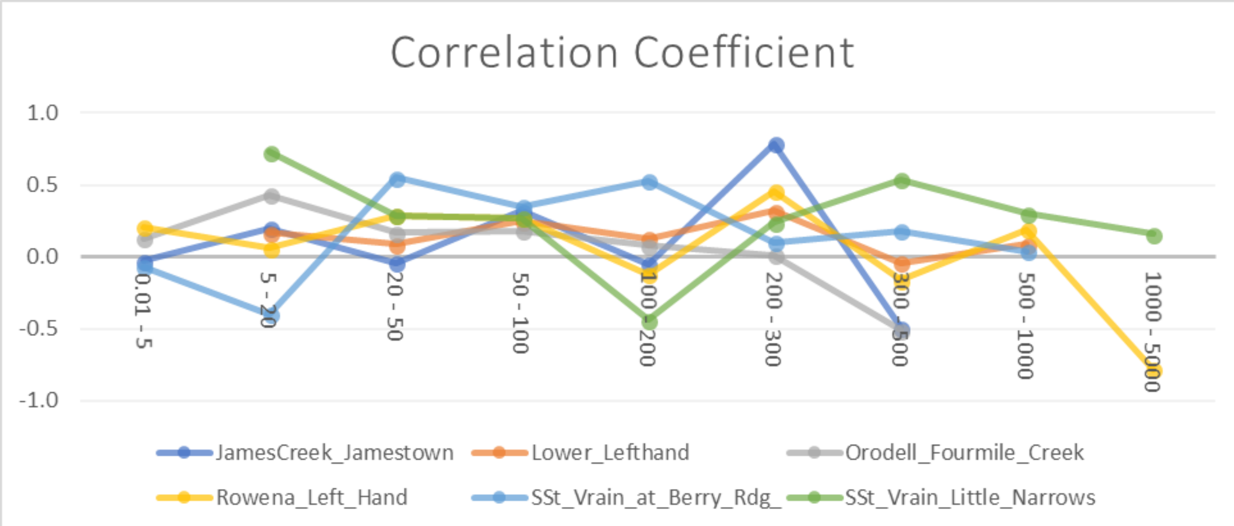


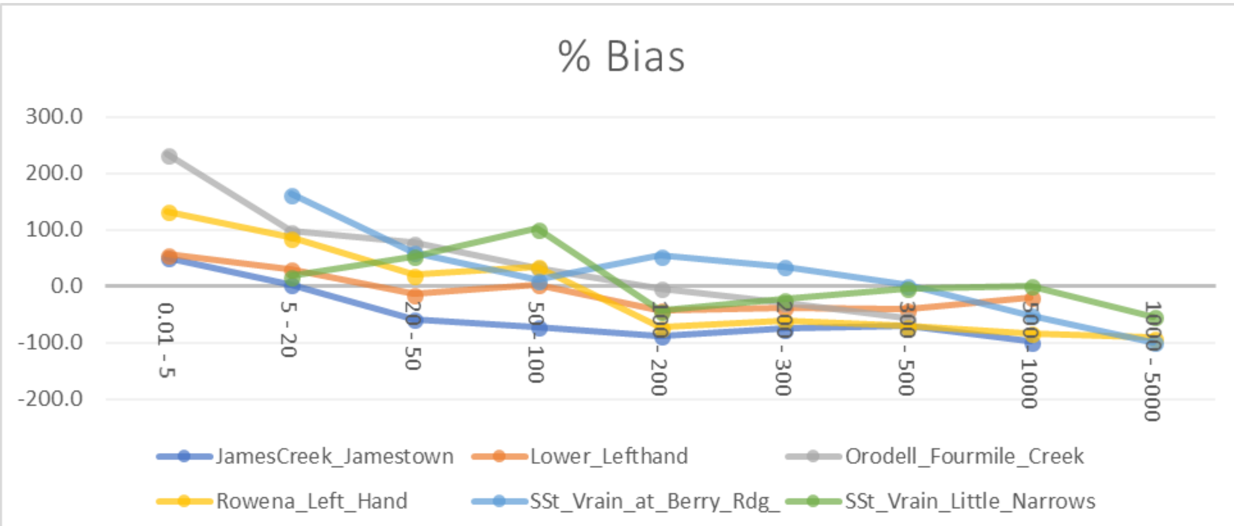


General findings:

- Optimal performance for most locations found during spring months (Apr-May) – likely snowmelt driven conditions compared to more dynamic convective rain showers during summer months
- Most locations have a consistent negative bias during the mid to late summer months (typical low flow conditions) – possibly influenced by reservoir releases and/or basin diversions

Statistical analysis by flow range:





General findings:

- Considerable performance variability between locations and flow ranges
- General trend of positive bias during low flows and slight negative bias for higher flow ranges

3.4 Recommendations

The NWM simulated streamflow performance for James Creek and other mountainous streams in Boulder County can best be described as variable. As noted above there are trends indicating when the NWM may be expected to perform better than other periods; however, the complex nature of these small mountainous streams causes some obvious challenges for the NWM in its current state of development. While the model skill for small mountainous watersheds is expectably underwhelming in some regards, there is potential for beginning to incorporate the NWM forecast output as a tool to help evaluate the potential for flash flood related threats on a short-term basis. Ongoing NWS evaluations have shown promising performance on larger, less flashy rivers. With ongoing development and testing the NWS has a strong commitment to improving the NWM well into the future, and we can expect improved performance on all scales of river systems over time.

How to view live NWM forecasts?

The current short, medium, and long range forecasted streamflow can be viewed directly from the Office of Water Prediction NWM webpage: http://water.noaa.gov/map. As the NWM is still undergoing extensive development and testing, the simulated data should be used with caution and a general understanding of the model’s limited ability to account for anthropogenic influences.

Even with its current limitations, it is still feasible to see a useful implementation of the NWM into daily forecast tracking activities for OEM flash flood monitoring activities. An example of a potential future development might include a live forecast data stream incorporated into an automated notification system to alert targeted emergency personnel to the forecasted potential for flooding on specific river reaches (e.g. James Creek). This type of monitoring and alerting could provide an additional layer of lead time monitoring to existing gauge network alert infrastructure while also expanding monitoring capabilities to remote areas or areas without gauges or reliable radar coverage.

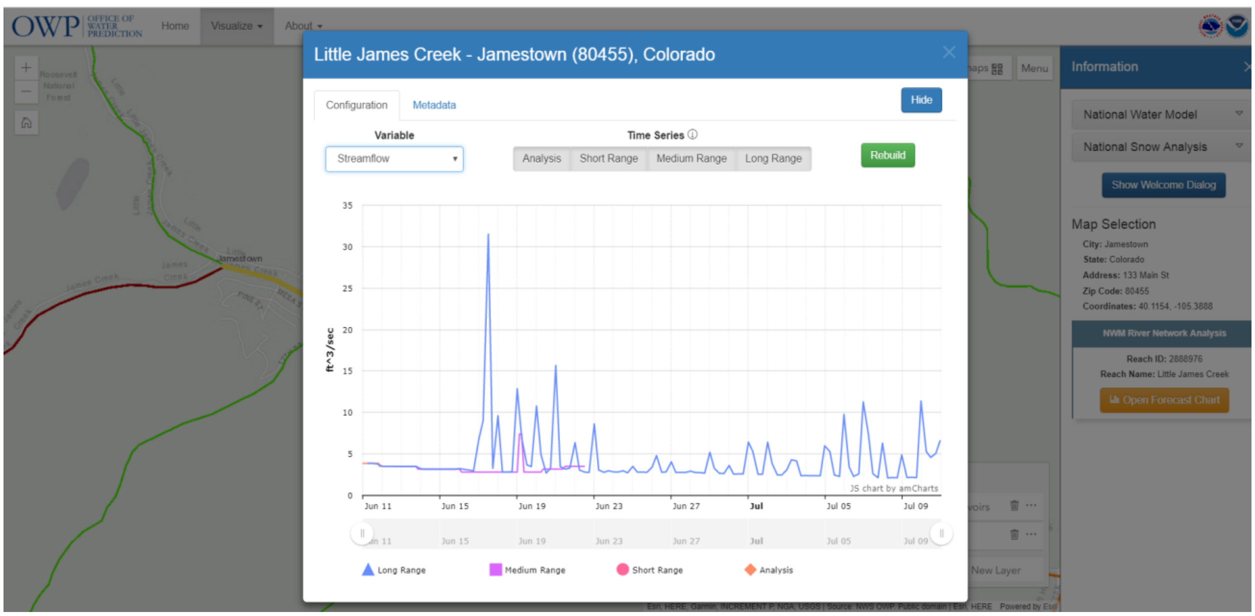


Figure 3.8. OWP NWM web map and chart generating tool showing the James Creek forecasted streamflow

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Yochum, S. E., & Moore, D. S. (2013). COLORADO FRONT RANGE FLOOD OF 2013 : Peak Flow Estimates at Selected Mountain Stream Locations.

Appendix A: James Creek Rating Curve Plot

Note that the James Creek stream gauge applied a different rating curve for the pre-2014 data and the replacement gauge (2014-present).

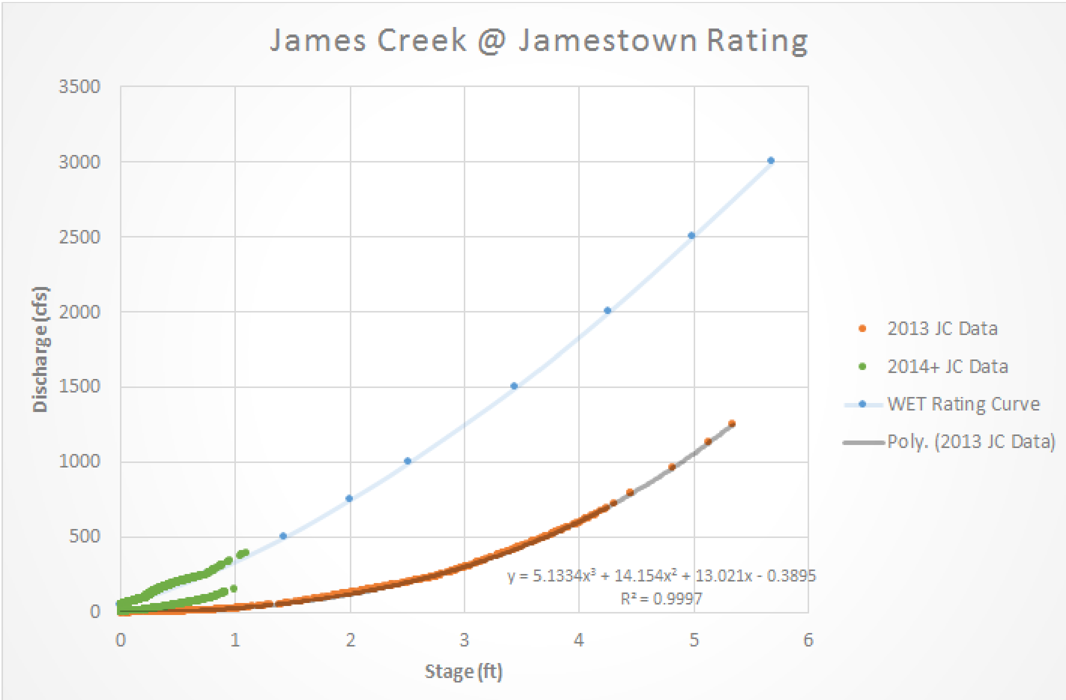
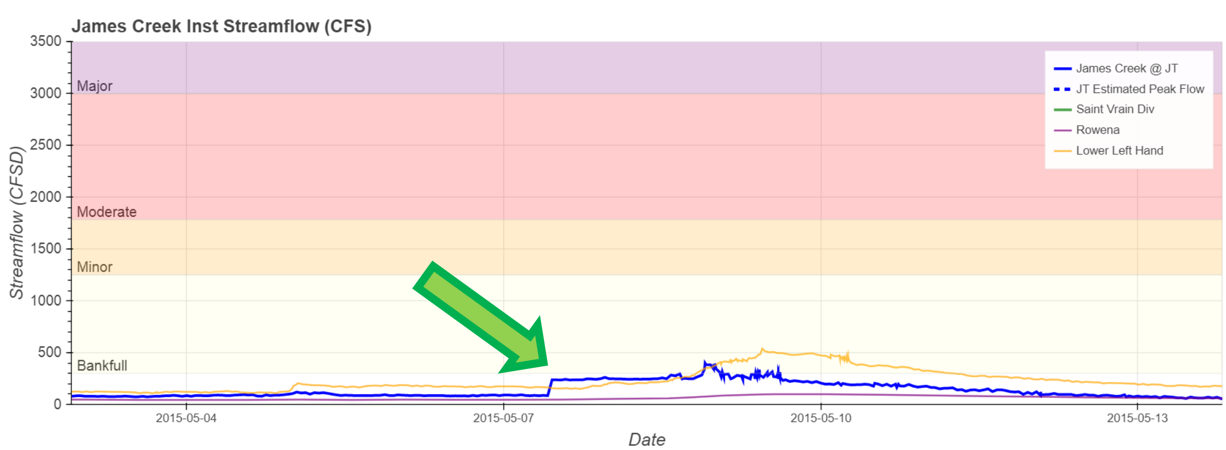


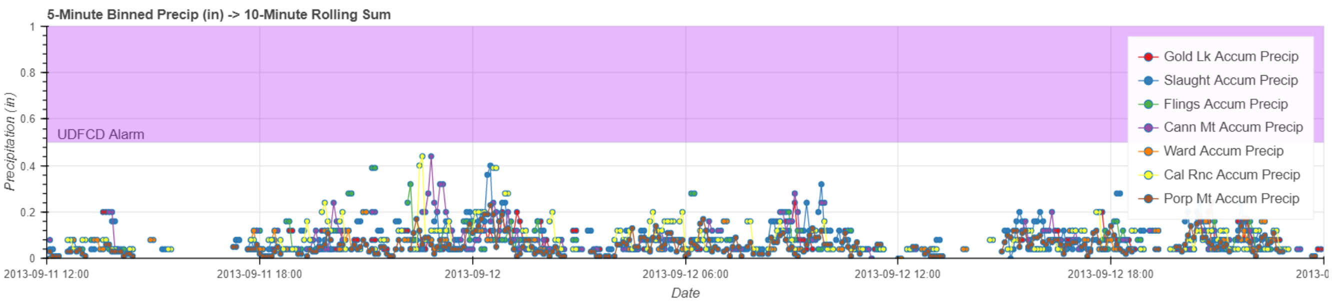
Figure 4.1. James Creek rating curve analysis for the 2013 gauge data and the post-2013 gauge data

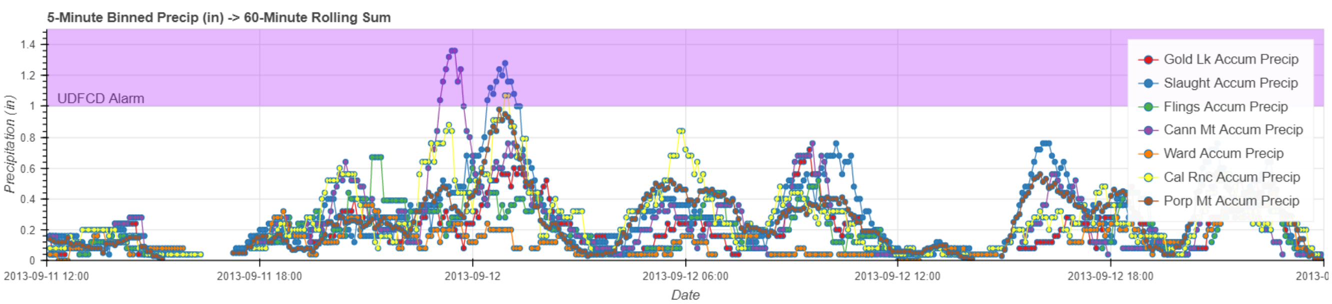


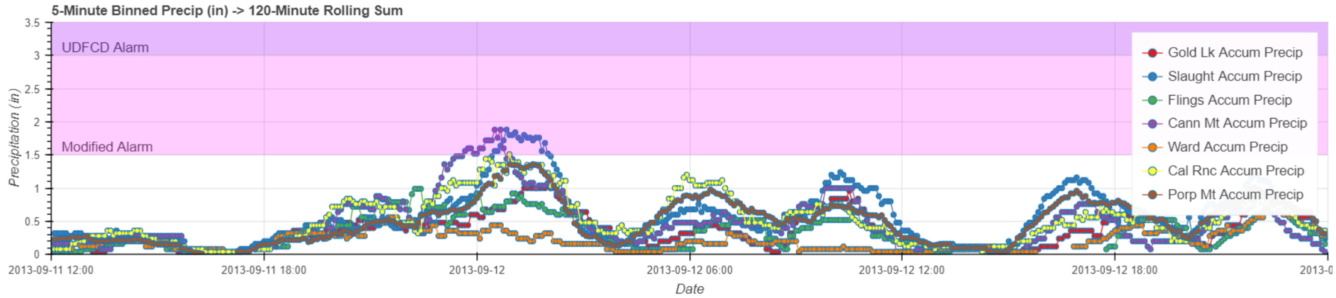
Appendix B: Analysis of the Sep 2013 Rainfall Data and Static Threshold Values

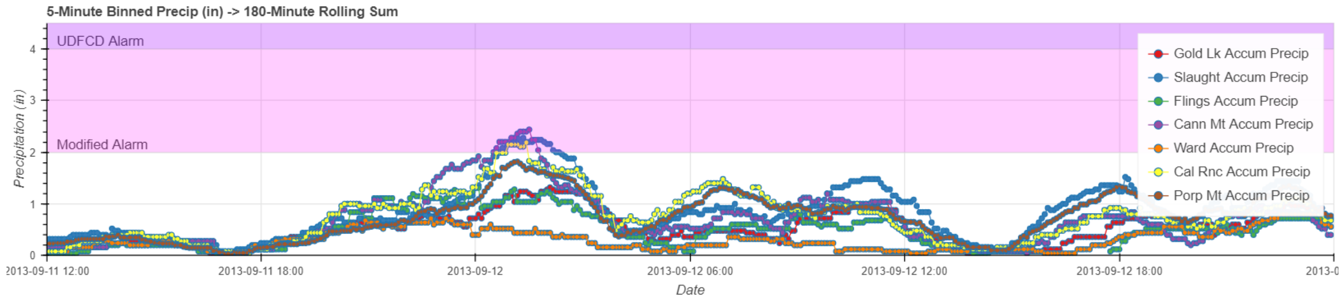
The following series of plots illustrate the rainfall accumulation time series for each gauge and for each accumulation duration for the September 2013 event. To help the timing of the rain gauge alarms in relation to the flow in James Creek, the rainfall accumulation plots are displayed in alignment with the observed river stage at the Jamestown gauge. The observed river stage plot is configured with the flood impact category thresholds (i.e. bankfull, minor, moderate, and major).

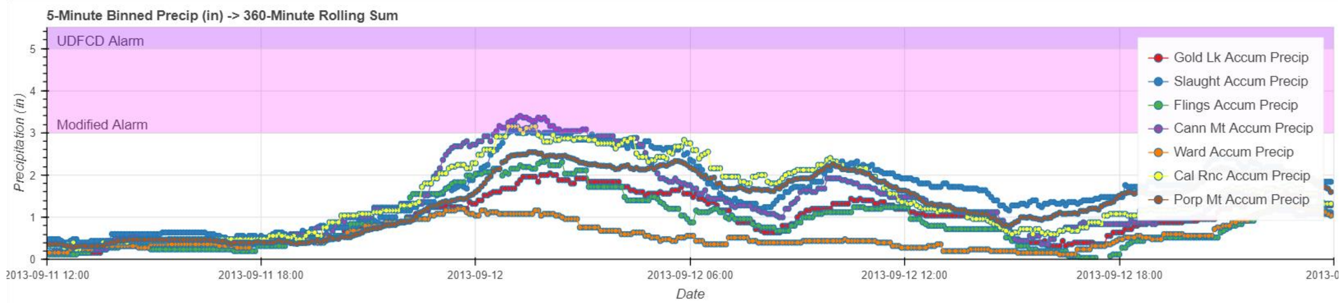
Each of the rainfall accumulation plots is configured with the default UDFCD threshold (dark purple) to illustrate if/when each duration alarm was exceeded during the rainfall event. The Lynker team also identified and tested two additional “Modified Alarm” thresholds (3-hour and 12-hour durations) to test as an augmentation to the current set of default UDFCD thresholds. Also, two of the existing duration alarms (2-hour and 6-hour) include a “Modified Alarm” value. These modified thresholds were reduced from the default UDFCD values in an effort to provide an alarm notification during the early stages of the flood event. The new and modified threshold alarms are identified in the plots with a pink band.

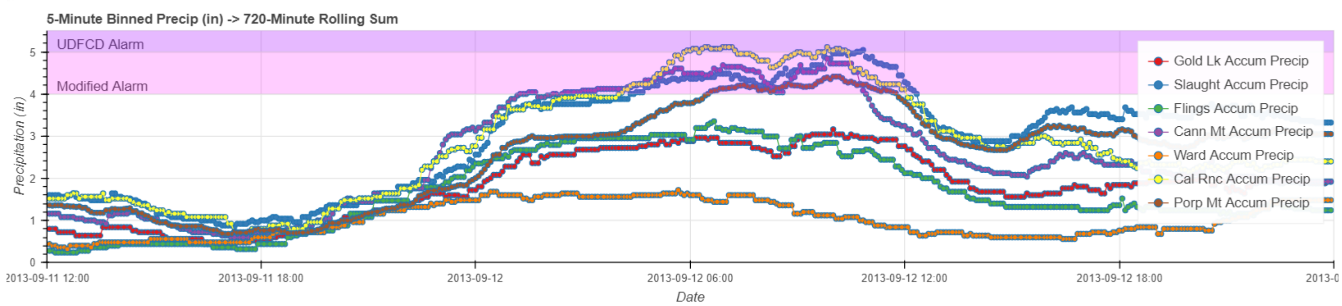


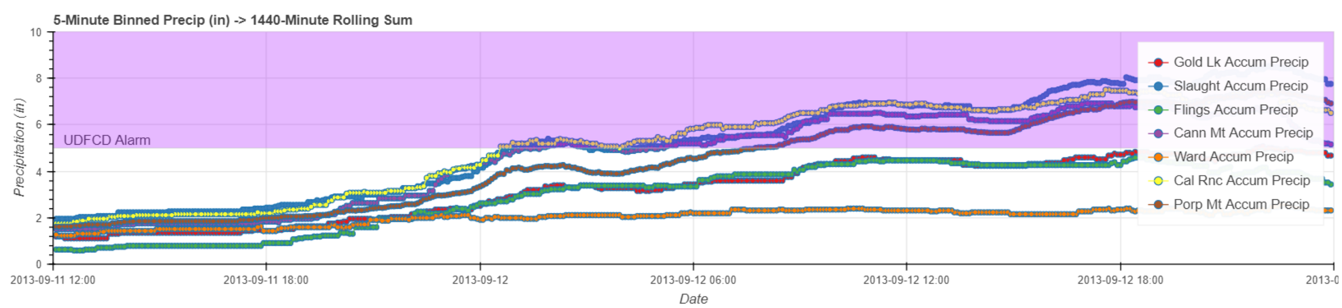



5-Minute Binned Precip (in) -> 120-Minute Rolling Sum
UDFCD Alarm
Modified Alarm
Precipitation (in)
2013-09-11 12:00
2013-09-11 18:00
2013-09-12
2013-09-12 06:00
2013-09-12 12:00
2013-09-12 18:00
Date
Gold Lk Accum Precip
Slaught Accum Precip
Flings Accum Precip
Cann Mt Accum Precip
Ward Accum Precip
Cal Rnc Accum Precip
Porp Mt Accum Precip


5-Minute Binned Precip (in) -> 180-Minute Rolling Sum
UDFCD Alarm
Modified Alarm
Precipitation (in)
2013-09-11 12:00
2013-09-11 18:00
2013-09-12
2013-09-12 06:00
2013-09-12 12:00
2013-09-12 18:00
Date
Gold Lk Accum Precip
Slaught Accum Precip
Flings Accum Precip
Cann Mt Accum Precip
Ward Accum Precip
Cal Rnc Accum Precip
Porp Mt Accum Precip


5-Minute Binned Precip (in) -> 360-Minute Rolling Sum
UDFCD Alarm
Modified Alarm
Precipitation (in)
2013-09-11 12:00
2013-09-11 18:00
2013-09-12
2013-09-12 06:00
2013-09-12 12:00
2013-09-12 18:00
Date
Gold Lk Accum Precip
Slaught Accum Precip
Flings Accum Precip
Cann Mt Accum Precip
Ward Accum Precip
Cal Rnc Accum Precip
Porp Mt Accum Precip


5-Minute Binned Precip (in) -> 720-Minute Rolling Sum
UDFCD Alarm
Modified Alarm
Precipitation (in)
2013-09-11 12:00
2013-09-11 18:00
2013-09-12
2013-09-12 06:00
2013-09-12 12:00
2013-09-12 18:00
Date
Gold Lk Accum Precip
Slaught Accum Precip
Flings Accum Precip
Cann Mt Accum Precip
Ward Accum Precip
Cal Rnc Accum Precip
Porp Mt Accum Precip


5-Minute Binned Precip (in) -> 1440-Minute Rolling Sum
UDFCD Alarm
Precipitation (in)
2013-09-11 12:00
2013-09-11 18:00
2013-09-12
2013-09-12 06:00
2013-09-12 12:00
2013-09-12 18:00
Date
Gold Lk Accum Precip
Slaught Accum Precip
Flings Accum Precip
Cann Mt Accum Precip
Ward Accum Precip
Cal Rnc Accum Precip
Porp Mt Accum Precip

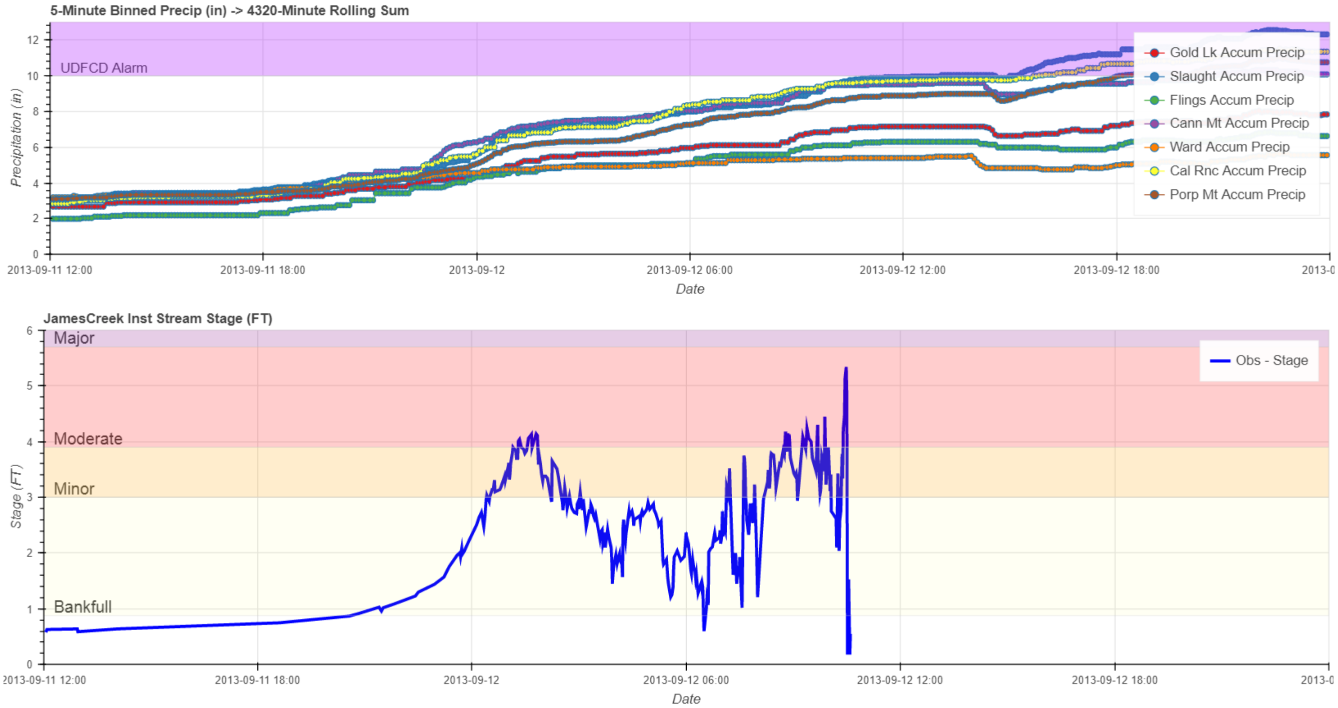


Figure 4.2. 10-min, 60-min, 120-min, and 180-min, 360-min, 720-min, 1440-min, and 4320-min rolling window rainfall accumulations with the observed river stage at Jamestown

Appendix C: NWS Storm Based Warnings List

The following table summarizes all flood related storm-based warnings issued for Jamestown, CO. Event times are provided in MDT. Data obtained from the Iowa Environmental Mesonet database. Note that the NWS switched from using a geopolitical (county) based warning dissemination to a storm-based system starting 10/1/2007. This list includes a total of 31 flood warnings/advisories (16 events outside of the Sep 11-15, 2013 period). Information regarding the first James Creek Flood Warning issued on 9/11/2013 (19:58 MDT) can be found here. The gauge alert issuance columns indicate which dates have a rainfall alert threshold instance using the modified static values and the new saturated alert thresholds.

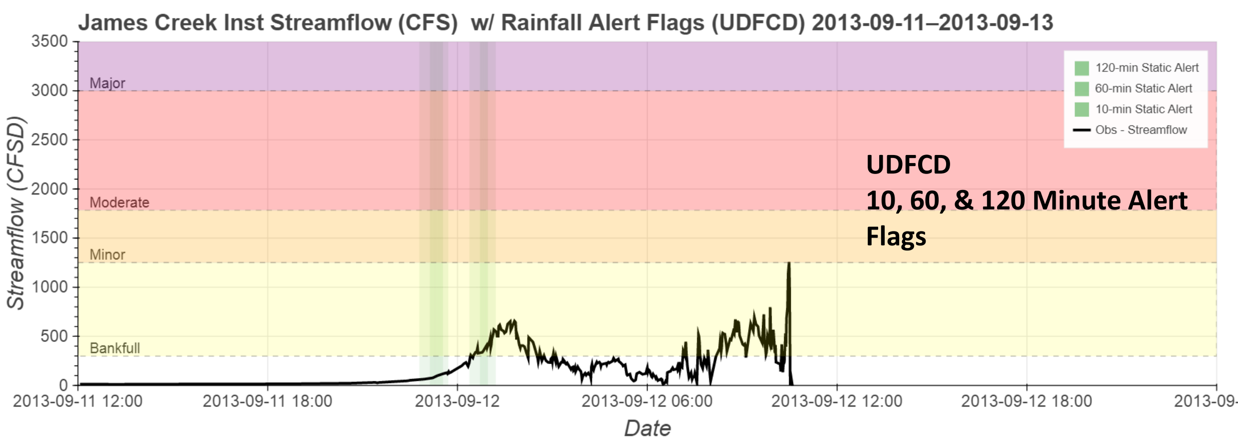
SBW Events for Lat: 40.1159 Lon: -105.3873						
Event ID	Phenomena	Significance	Issued Date	Issued Time	Static Gauge Alert Issuance	Saturated Gauge Alert Issuance
5	Areal Flood	Advisory	6/5/2008	10:33:00 AM	FALSE	FALSE
7	Areal Flood	Advisory	6/6/2010	2:00:00 PM	FALSE	FALSE
23	Areal Flood	Advisory	6/12/2010	9:58:00 AM	FALSE	FALSE
25	Areal Flood	Advisory	6/13/2010	10:12:00 AM	FALSE	FALSE
80	Areal Flood	Advisory	8/4/2010	3:38:00 PM	FALSE	FALSE
13	Areal Flood	Advisory	7/5/2012	4:42:00 PM	FALSE	FALSE
32	Areal Flood	Advisory	7/7/2012	5:35:00 PM	TRUE	FALSE
28	Areal Flood	Advisory	7/14/2013	9:38:00 PM	TRUE	FALSE
33	Areal Flood	Advisory	7/15/2013	2:27:00 PM	FALSE	FALSE
38	Areal Flood	Advisory	7/18/2013	3:03:00 PM	FALSE	FALSE
29	Flash Flood	Warning	9/11/2013	7:58:00 PM	TRUE	TRUE
31	Flash Flood	Warning	9/11/2013	9:46:00 PM	TRUE	TRUE
34	Flash Flood	Warning	9/11/2013	11:16:00 PM	TRUE	TRUE
40	Flash Flood	Warning	9/12/2013	4:10:00 AM	TRUE	TRUE
47	Flash Flood	Warning	9/12/2013	7:12:00 AM	TRUE	TRUE
5	Areal Flood	Warning	9/12/2013	8:28:00 AM	TRUE	TRUE
53	Flash Flood	Warning	9/12/2013	10:02:00 AM	TRUE	TRUE
58	Flash Flood	Warning	9/12/2013	3:29:00 PM	TRUE	TRUE
6	Areal Flood	Warning	9/12/2013	7:35:00 PM	TRUE	TRUE
66	Flash Flood	Warning	9/12/2013	10:52:00 PM	TRUE	TRUE
67	Flash Flood	Warning	9/12/2013	11:58:00 PM	TRUE	TRUE
7	Areal Flood	Warning	9/13/2013	7:34:00 AM	TRUE	FALSE
8	Areal Flood	Warning	9/14/2013	7:50:00 AM	TRUE	FALSE
9	Areal Flood	Warning	9/15/2013	9:10:00 AM	FALSE	FALSE
85	Flash Flood	Warning	9/15/2013	10:41:00 AM	FALSE	FALSE
17	Areal Flood	Advisory	5/24/2014	8:29:00 PM	FALSE	FALSE
148	Areal Flood	Advisory	8/29/2014	3:42:00 PM	FALSE	FALSE
5	Areal Flood	Advisory	5/4/2015	10:34:00 PM	FALSE	FALSE
7	Areal Flood	Advisory	5/8/2015	11:08:00 AM	FALSE	FALSE
2	Areal Flood	Warning	5/8/2015	9:24:00 PM	FALSE	FALSE
19	Areal Flood	Advisory	5/19/2015	2:15:00 PM	FALSE	FALSE

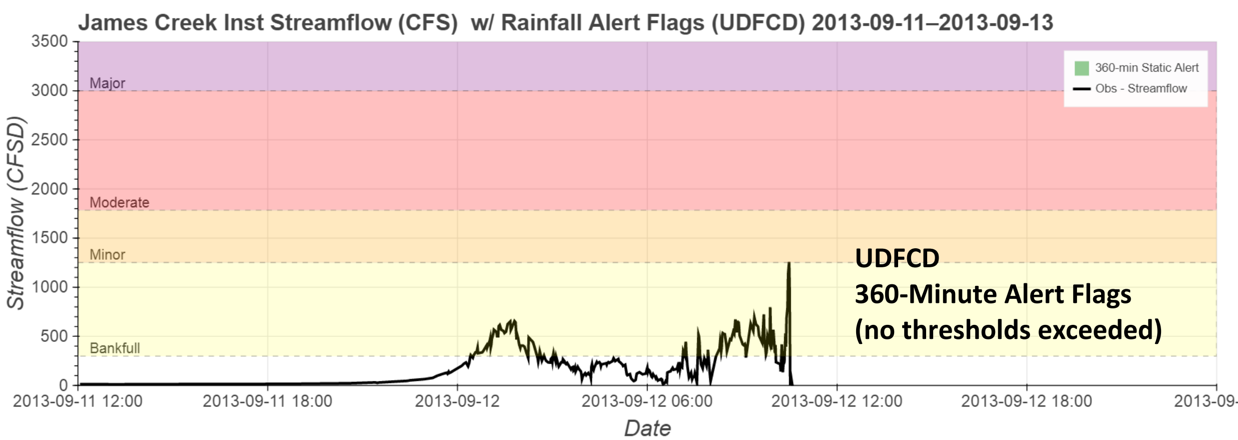
Appendix D: UDFCD Default & Modified Rainfall Duration Threshold Exceedance Plots

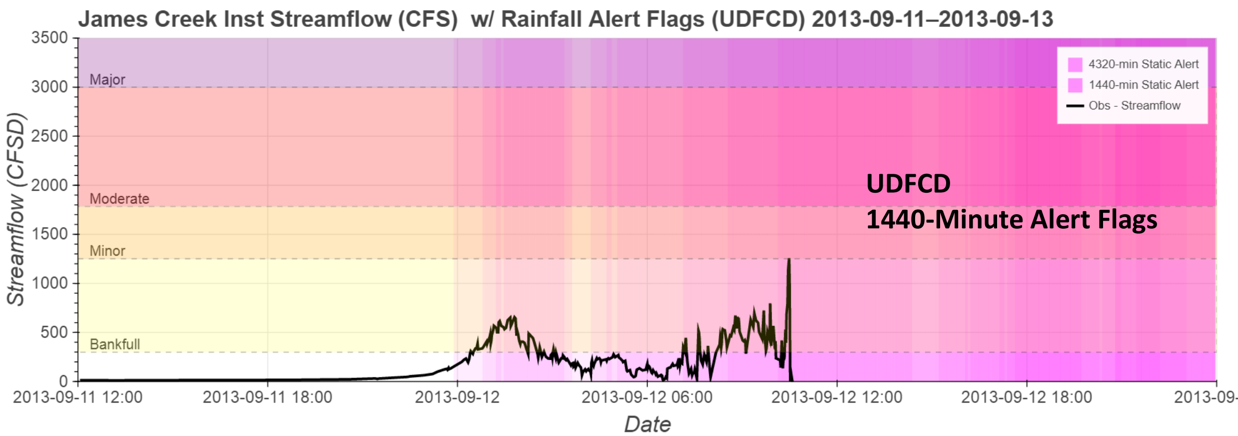
To help illustrate the overall number of instances in which a gauge exceeds a set threshold for the range of accumulation durations, the following plots were developed to evaluate the September 2013 event. Each 5-minute bin with an exceeded alarm threshold is displayed with a color shaded column:

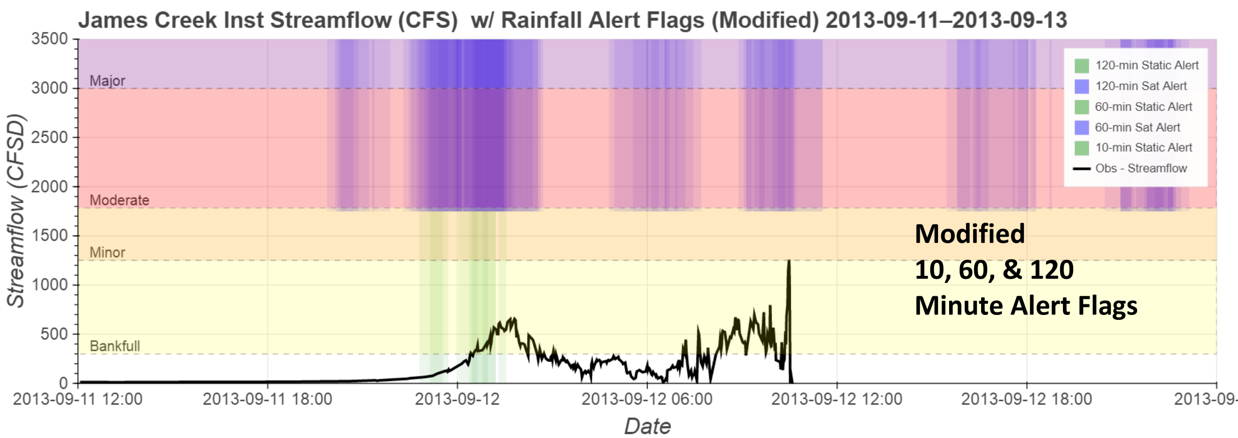
- Green: threshold exceeded for each of the 10-min, 60-min, 120-min, 180-min, and 360-min durations
- Purple: threshold exceeded for each of the 1440-min and 4320-min durations
- Blue: conditional threshold exceeded for each of the 60-min, 120-min, and 180-min durations
- Aqua: conditional proxy threshold exceeded for each of the 1440-min and 4320-min durations

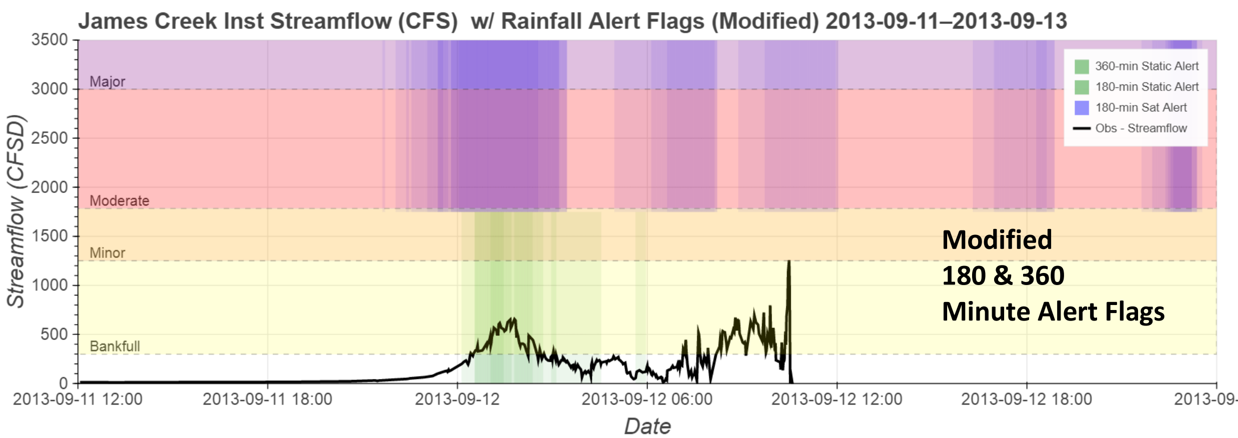
By overlying all seven precipitation sites for the range of accumulation durations, these plots can help illustrate the total alert network status from the James Creek gauge network. Note that the opacity of the shaded alert columns represent the number of overlapping gauges exceeding threshold values at each time interval (i.e. darker colors indicate more gauges exceeded thresholds). The following plots illustrate the UDFCD (default) and the modified alarm thresholds developed and evaluated for the September 2013 period.

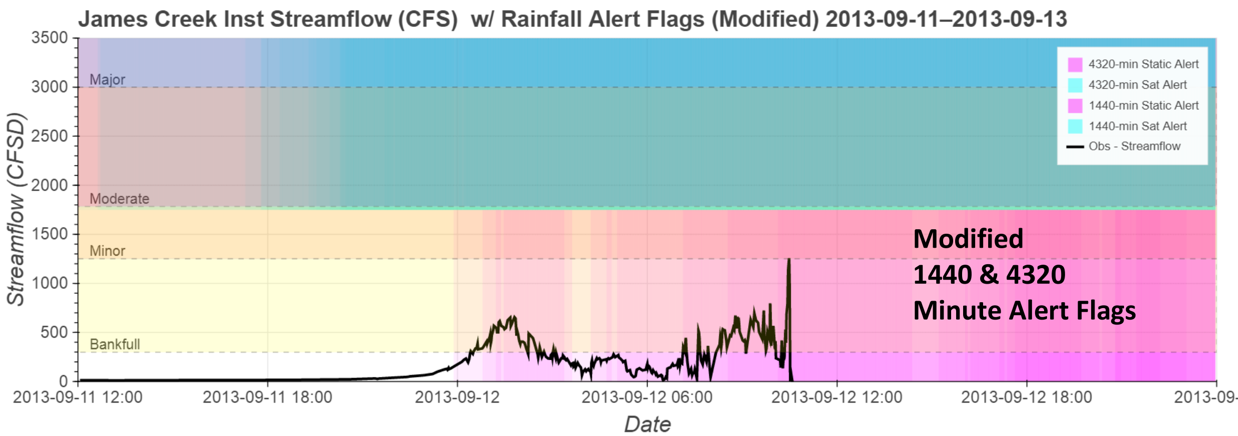





James Creek Inst Streamflow (CFS) w/ Rainfall Alert Flags (UDFCD) 2013-09-11–2013-09-13
Streamflow (CFSD)
Date
Major
Moderate
Minor
Bankfull
4320-min Static Alert
1440-min Static Alert
Obs - Streamflow
UDFCD
1440-Minute Alert Flags


James Creek Inst Streamflow (CFS) w/ Rainfall Alert Flags (Modified) 2013-09-11–2013-09-13
Streamflow (CFSD)
Date
Major
Moderate
Minor
Bankfull
120-min Static Alert
120-min Sat Alert
60-min Static Alert
60-min Sat Alert
10-min Static Alert
Obs - Streamflow
Modified
10, 60, & 120
Minute Alert Flags

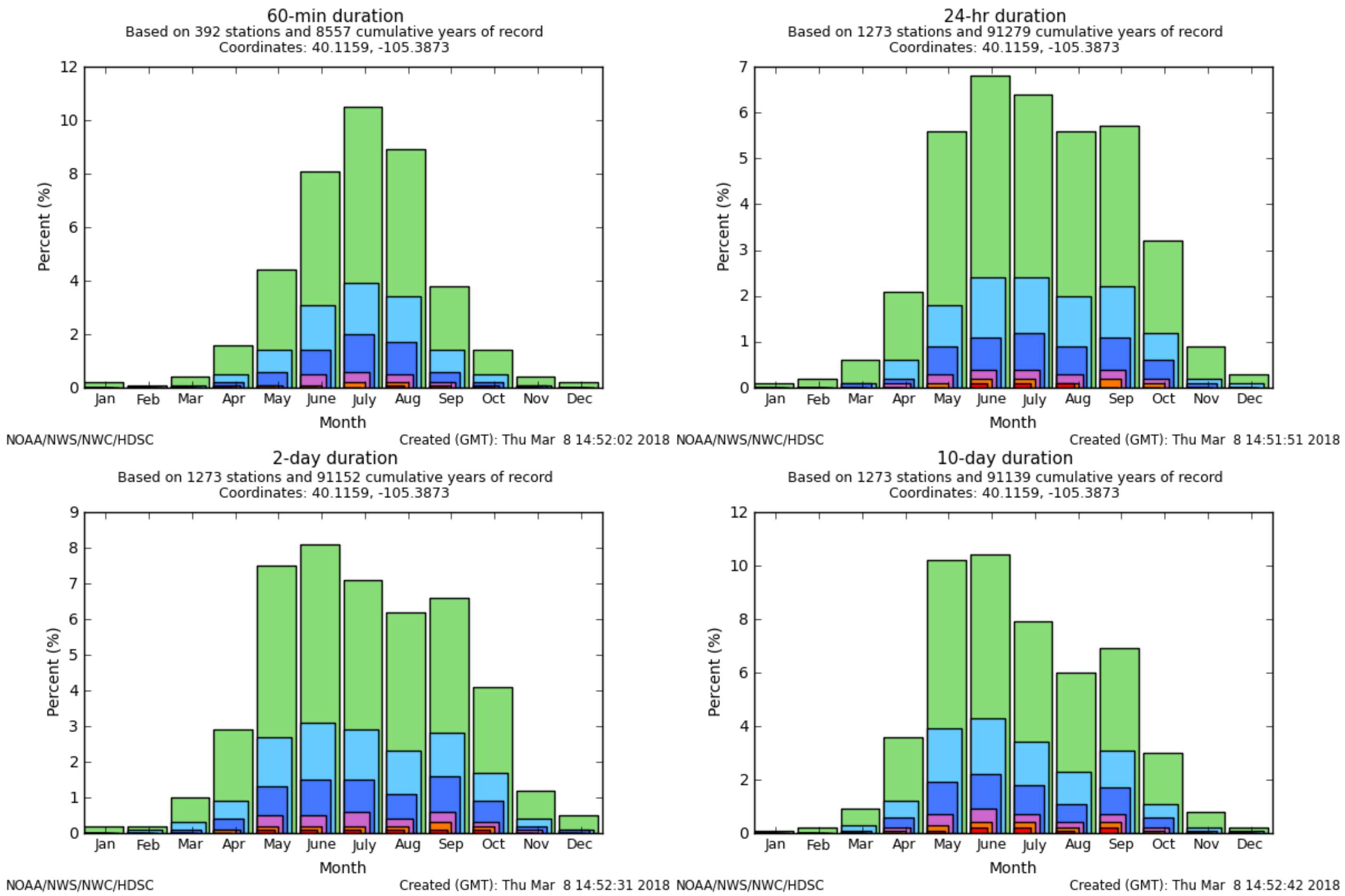

James Creek Inst Streamflow (CFS) w/ Rainfall Alert Flags (Modified) 2013-09-11–2013-09-13
Streamflow (CFSD)
Date
Major
Moderate
Minor
Bankfull
360-min Static Alert
180-min Static Alert
180-min Sat Alert
Obs - Streamflow
Modified
180 & 360
Minute Alert Flags



September 2013 James Creek observed stage with total binned alarm counts (modified threshold values)

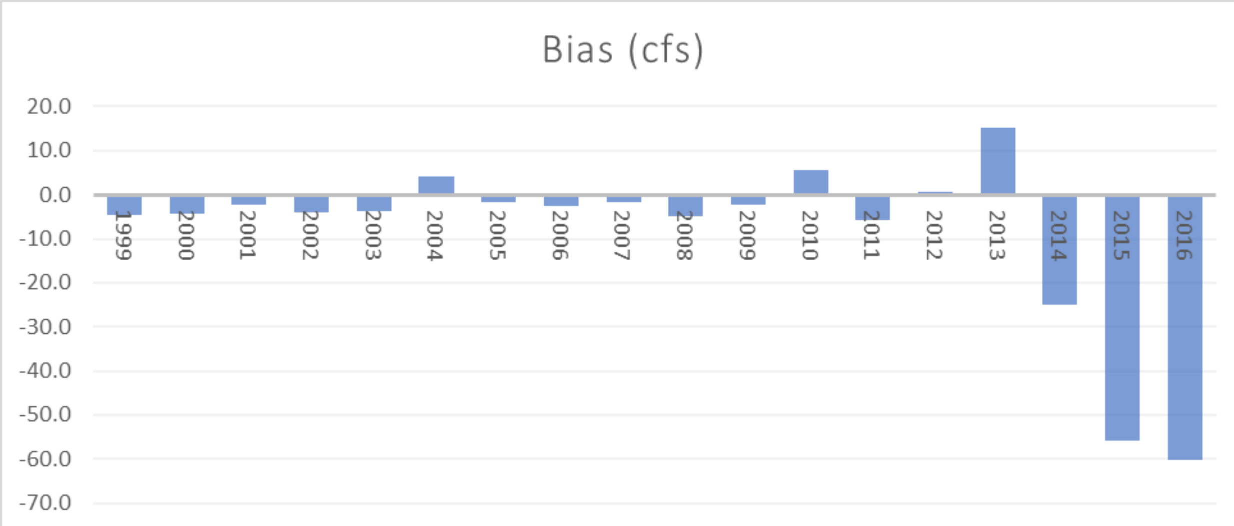
Appendix E: James Creek Precipitation Climatology

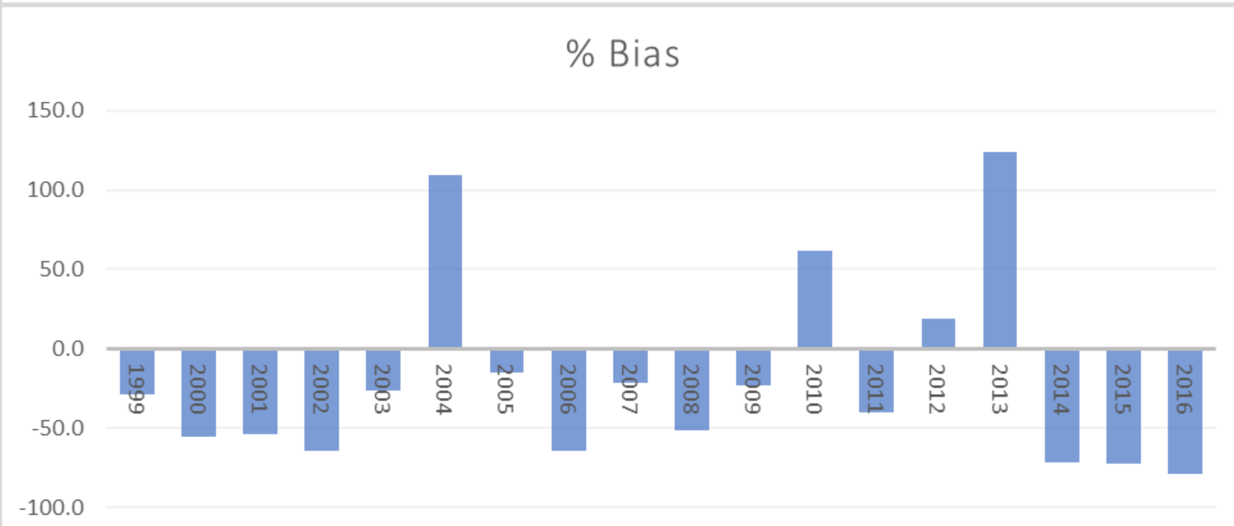
The following seasonality graphs show the percentage of precipitation totals for a given duration that exceeded the precipitation frequency for the duration and annual exceedance probabilities for each month. Data obtained from NOAA Atlas 14 Point Precipitation Frequency Estimates (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=co) for location 40.1159N, -105.3873 (Jamestown, CO). These plots give a general illustration of the months most susceptible to substantial precipitation periods.

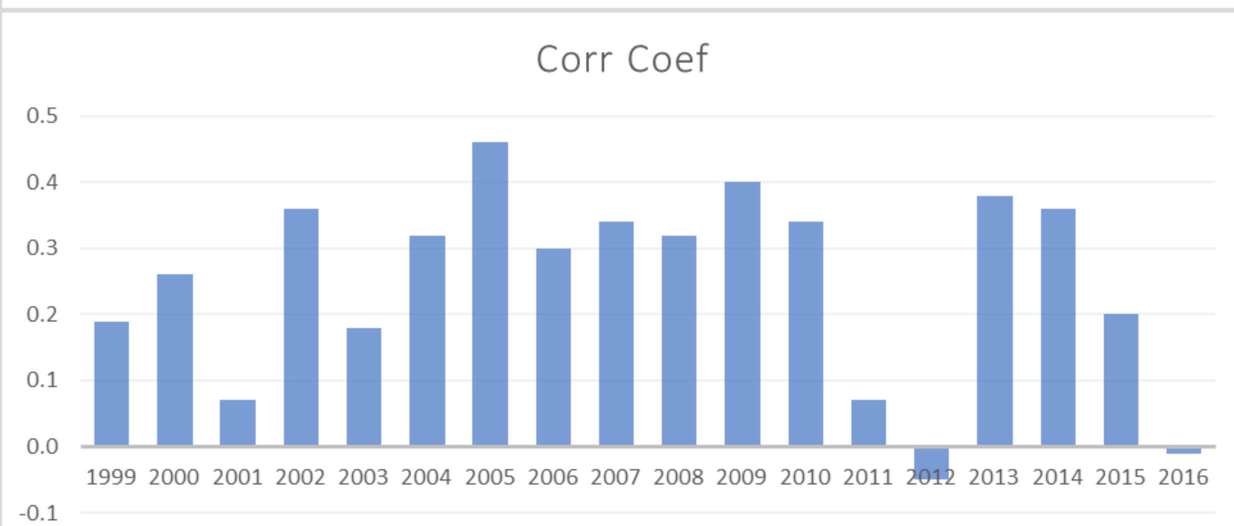


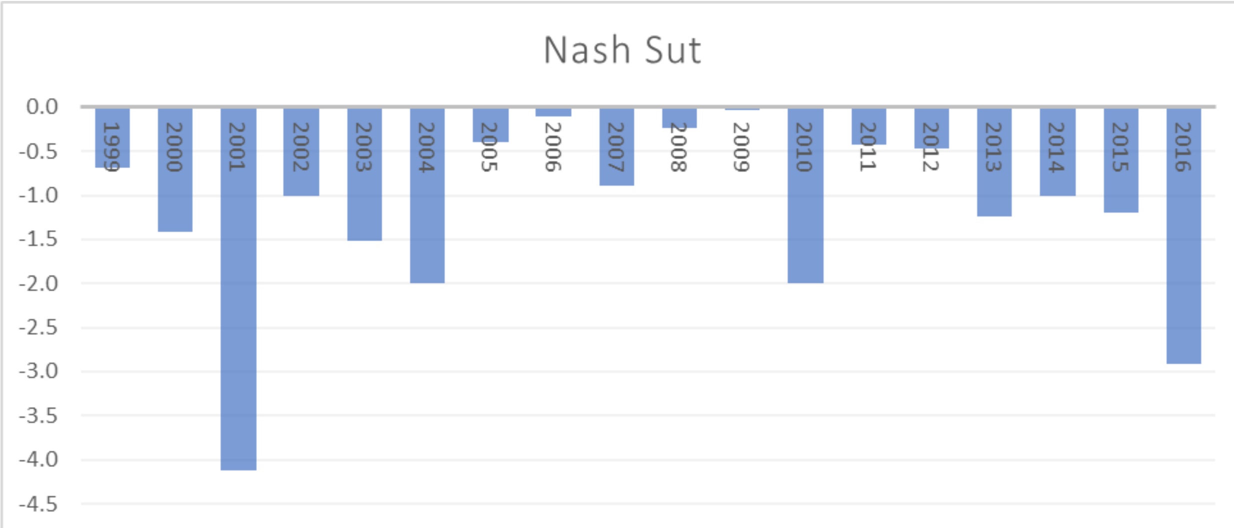
Appendix F: NWM Simulation Performance Statistics – James Creek at Jamestown

James Creek statistical analysis by calendar year



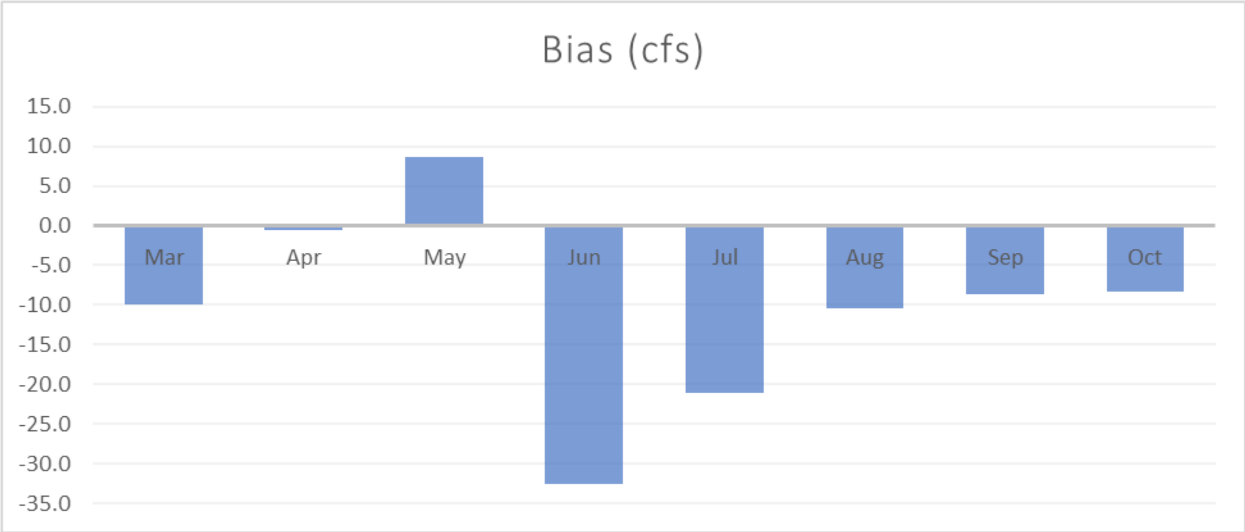


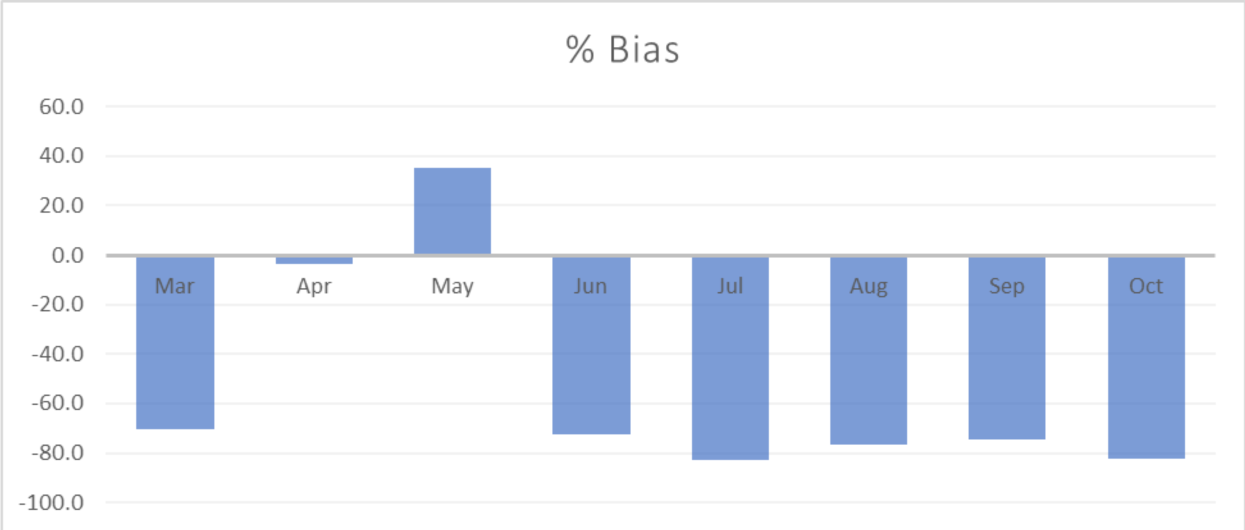


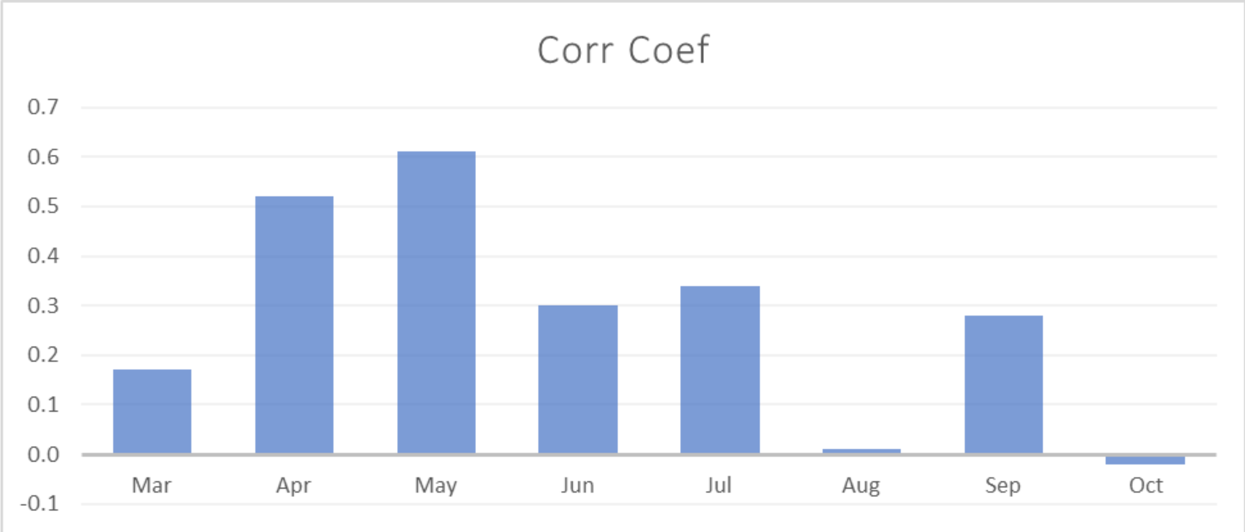


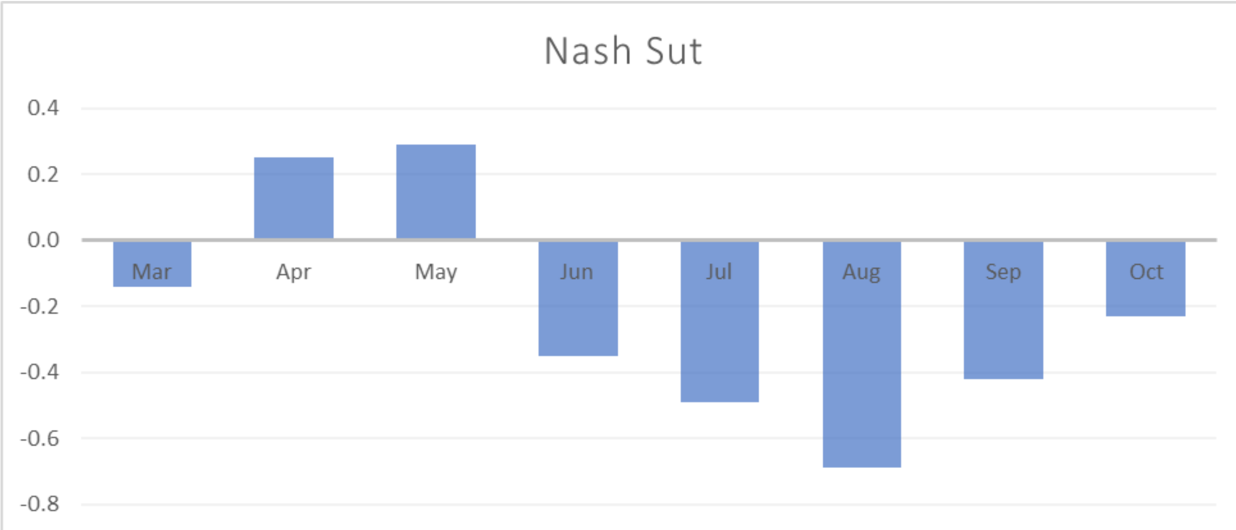
Year	Timestep	#obs	Avg QIN (cfs)	Avg SQIN (cfs)	Bias (cfs)	% Bias	MAE (cfs)	RMSE (cfs)	Corr Coef	Nash Sut
1999	1	2282	15.7	11.2	-4.5	-28.8	11.8	18.4	0.19	-0.68
2000	1	3612	7.5	3.3	-4.2	-55.8	5.3	6.4	0.26	-1.42
2001	1	1929	4.3	2.0	-2.3	-53.8	2.8	5.8	0.07	-4.12
2002	1	4086	6.1	2.2	-3.9	-64.1	4.2	5.6	0.36	-1.00
2003	1	4554	14.4	10.6	-3.8	-26.4	12.1	16.7	0.18	-1.52
2004	1	1565	3.7	7.8	4.1	109.3	4.6	5.0	0.32	-1.99
2005	1	3959	12.0	10.3	-1.8	-14.7	8.0	11.4	0.46	-0.39
2006	1	2271	4.0	1.4	-2.6	-64.8	2.7	6.2	0.30	-0.11
2007	1	4585	8.3	6.5	-1.8	-21.5	7.0	9.7	0.34	-0.89
2008	1	5031	9.6	4.6	-5.0	-51.9	7.1	10.7	0.32	-0.23
2009	1	4894	9.6	7.4	-2.3	-23.5	6.2	10.6	0.40	-0.03
2010	1	4068	9.0	14.6	5.6	61.8	9.6	15.7	0.34	-1.99
2011	1	4959	14.6	8.7	-5.9	-40.2	13.8	19.1	0.07	-0.43
2012	1	1426	3.6	4.2	0.7	18.5	3.9	7.3	-0.05	-0.47
2013	1	1952	12.3	27.5	15.2	124.0	23.0	60.5	0.38	-1.24
2014	1	3642	34.9	9.9	-25.0	-71.6	26.0	35.6	0.36	-1.01
2015	1	5028	77.2	21.4	-55.7	-72.2	61.3	77.6	0.20	-1.19
2016	1	4476	76.0	15.8	-60.2	-79.2	60.3	73.2	-0.01	-2.92
Total	1	64319	21.0	9.7	-11.4	-54.1	17.1	33.8	0.30	-0.09

James Creek statistical analysis by warm season months



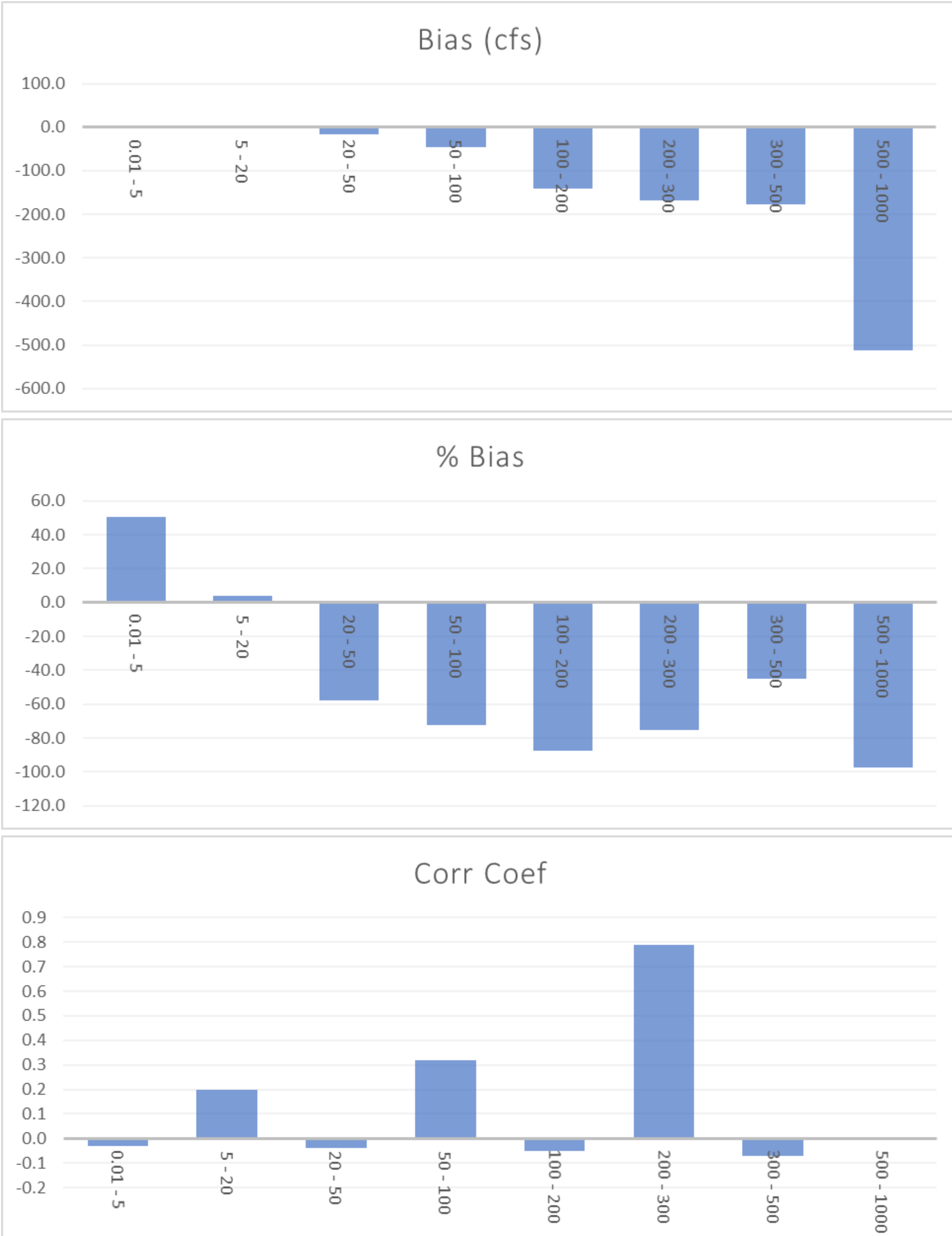


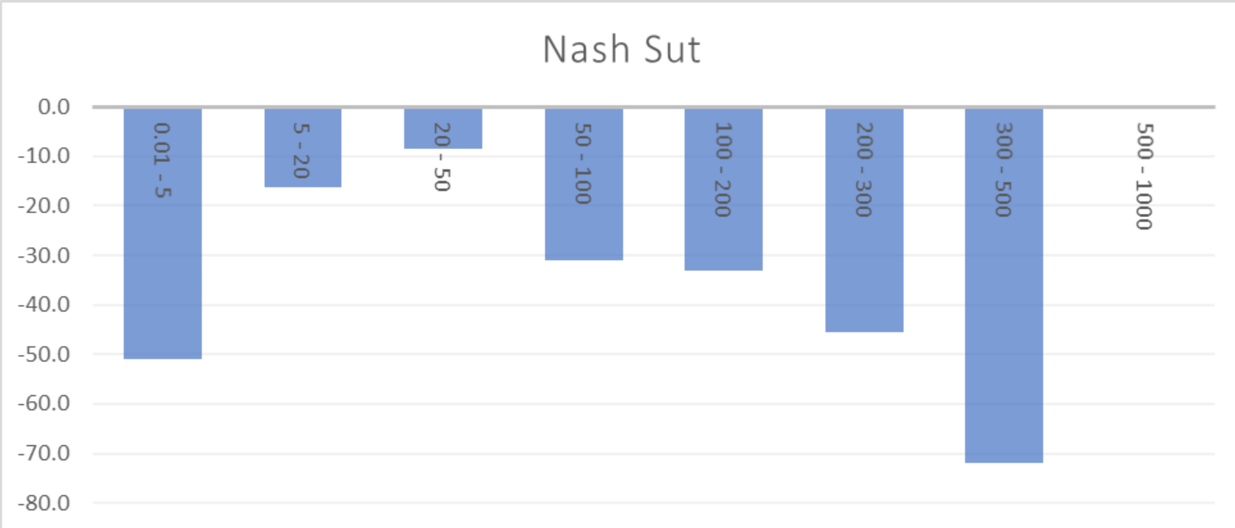




Month	Month#	#obs	Avg QIN (cfs)	Avg SQIN (cfs)	Bias (cfs)	% Bias	MAE (cfs)	RMSE (cfs)	Corr Coef	Nash Sut
Mar	3	768	14.0	4.1	-9.9	-70.6	13.5	25.9	0.17	-0.14
Apr	4	6214	13.2	12.7	-0.5	-3.9	10.5	18.1	0.52	0.25
May	5	8831	24.6	33.3	8.7	35.3	19.5	28.3	0.61	0.29
Jun	6	9485	45.1	12.5	-32.6	-72.3	33.8	58.8	0.30	-0.35
Jul	7	10766	25.4	4.3	-21.0	-82.9	21.5	34.4	0.34	-0.49
Aug	8	11659	13.6	3.2	-10.4	-76.6	11.9	23.2	0.01	-0.69
Sep	9	10678	11.6	3.0	-8.7	-74.5	10.4	30.3	0.28	-0.42
Oct	10	5537	10.1	1.8	-8.3	-82.1	8.6	20.0	-0.02	-0.23

James Creek statistical analysis by flow range

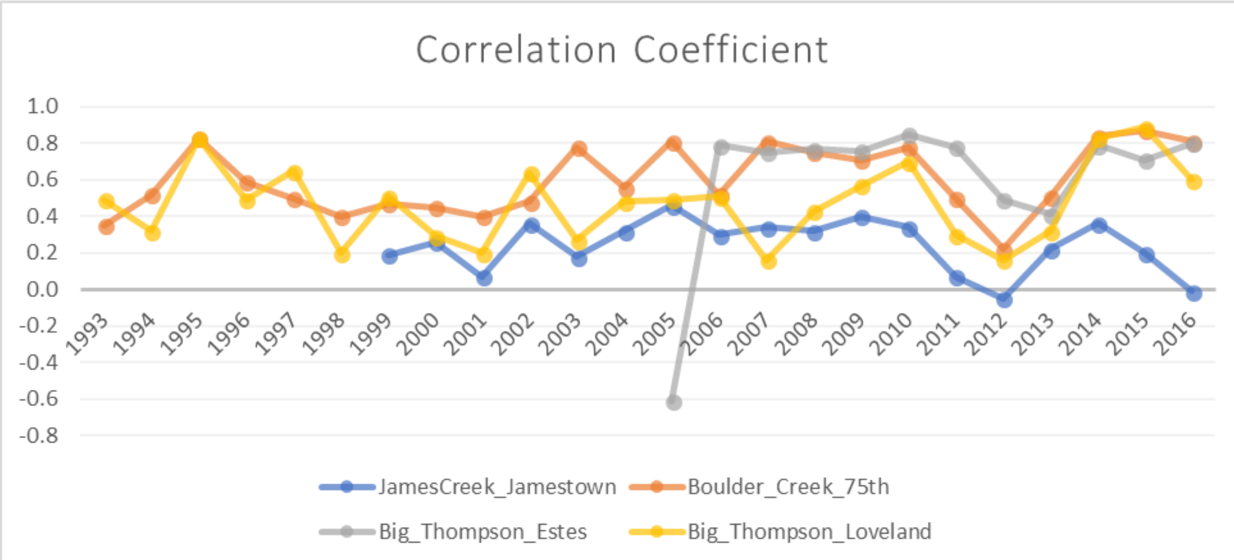


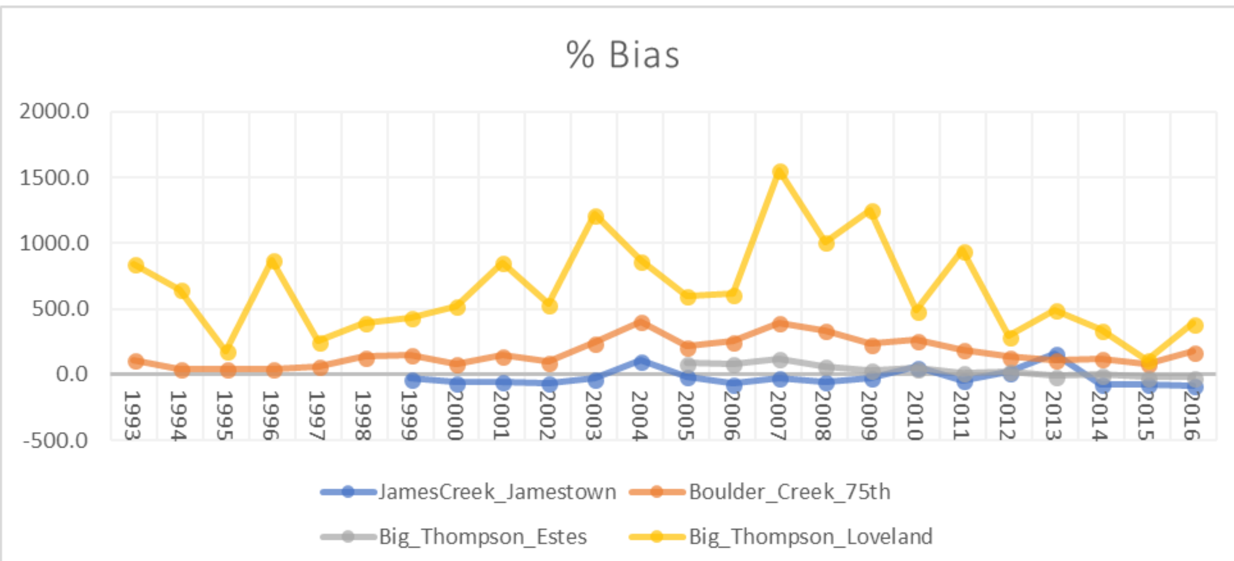


Min Flow (cfs)	Max Flow (cfs)	#obs	Avg QIN (cfs)	Avg SQIN (cfs)	Bias (cfs)	% Bias	MAE (cfs)	RMSE (cfs)	Corr Coef	Nash Sut
0.01	***5***	24417	2.6	3.8	1.3	50.7	2.9	6.5	-0.03	-51.04
5	***20***	20886	10.5	10.9	0.4	3.8	10.3	16.5	0.20	-16.19
20	***50***	8876	29.1	12.3	-16.8	-57.9	19.6	23.7	-0.04	-8.49
50	***100***	8487	62.3	17.4	-45.0	-72.1	46.4	50.3	0.32	-31.04
100	***200***	1468	161.2	19.8	-141.4	-87.7	142.6	147.3	-0.05	-33.11
200	***300***	162	223.9	55.2	-168.7	-75.4	168.7	170.5	0.79	-45.45
300	***500***	22	393.1	216.7	-176.4	-44.9	345.7	396.2	-0.07	-72.00
500	***1000***	1	525.5	12.7	-512.8	-97.6	512.8	512.8	nan	nan
1000	***5000***									
5000	***10000***									

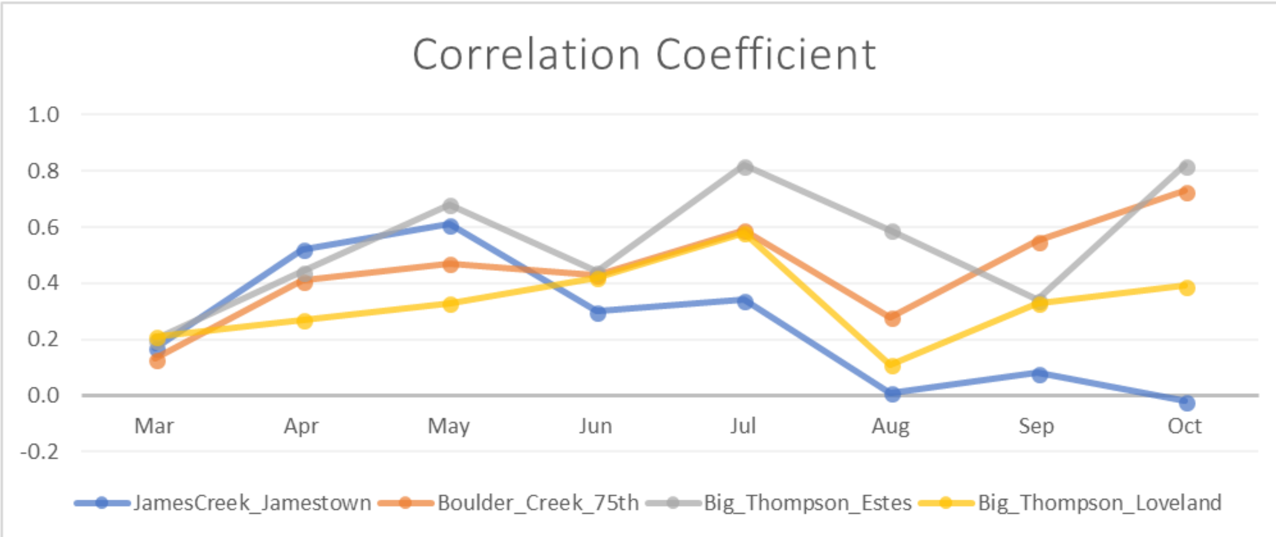
Appendix G: NWM Simulation Performance Statistics – Big Thompson, Boulder Creek, James Creek

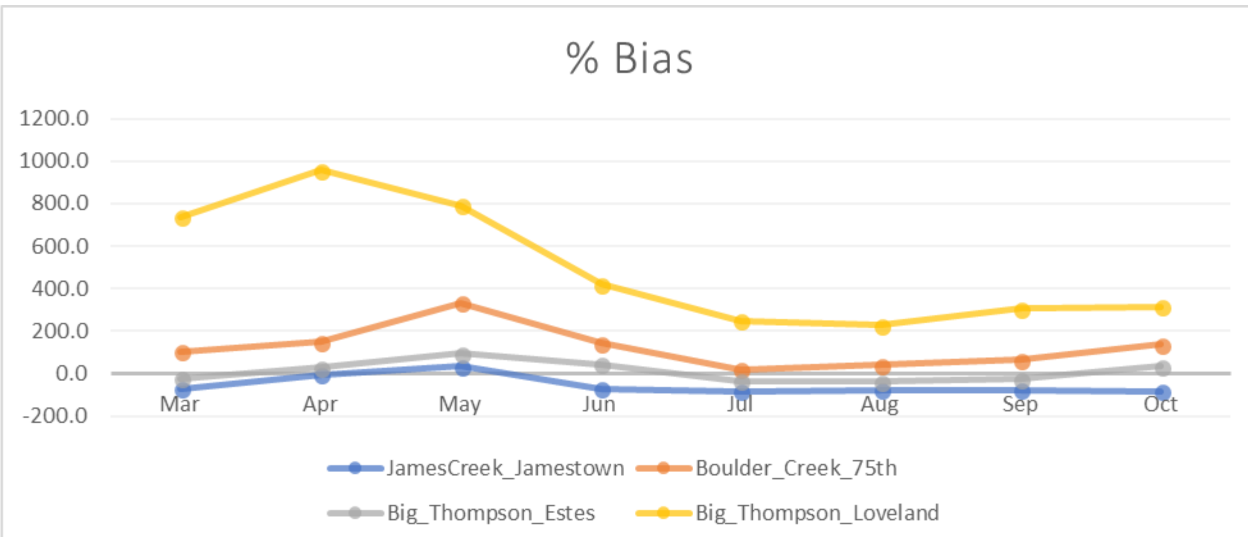
Statistical analysis by calendar year:





Statistical analysis by warm season month:





Statistical analysis by flow range: