Submitted to:

The Town of Jamestown

BOULDER COUNTY

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

Design Development Technical Report

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Summary

In the wake of the September 2013 Jamestown flooding and ensuing damage, the Town of Jamestown has been working to improve early warning systems for the Town. This project is intended to assess the current systems in place to provide early flood and rainfall warnings and propose improvements to that system. The Lynker Team developed a desktop analysis of rainfall and geographic data from the 2013 flood events to evaluate the effectiveness of the existing rain/stream gauge network and flood early warning system near Jamestown. The Lynker Team also conducted site visits to evaluate potential locations for new rain gauges. Lynker teamed with OneRain and WEST Consultants, Inc. to offer Jamestown the full range of capabilities, experience, and expert resources in meeting the diverse needs of this contract.

1 Final Recommendations

Upon completing a thorough evaluation of the existing gauge network for the James Creek watershed and surrounding region along with a background examination of the current flood monitoring and response operations within Boulder County Office of Emergency Management (OEM), the Lynker team recommends the following actions for the next phase of the Jamestown AFWS project:

- **Installation of one new rain gauge site located near Walker Mountain**
    - Walker Mountain is located on the southern border of the basin and can help provide optimal lead time for the dominant storm tracks from the south
    - Funding assured for future maintenance through Boulder County OEM
    - Backup rain gauge installation site: Overland Road

- **Develop and implement a series of optimized rainfall thresholds tailored for the Jamestown Community.**
    - Analyze the complete historical record of rainfall and streamflow data for the James Creek region to develop and evaluate a set of rainfall thresholds.
    - Facilitate further refinement to the flood alert communication system between Boulder County OEM and the Jamestown Emergency Response representatives.
    - Evaluate the alert frequency of new/modified thresholds and optimize final alert values to alert needs of Jamestown emergency response protocols.

- **Develop a James Creek hydrologic runoff model to evaluate the watershed's hydrologic response characteristics**
    - Develop the historical GARR data for the James Creek watershed using the existing rain gauge network.
    - Develop and calibrate James Creek distributed/semi-distributed hydrologic model.
    - Evaluate the hydrologic model with historical/design rainfall scenarios to assist with identifying dynamic storm conditions and watershed response characteristics.

2 Reconnaissance, Inventory, and Planning

The Lynker team worked closely with key local agencies heavily involved with the Boulder County gauge network to assess the best use of flood monitoring and alert efforts for the Town of Jamestown. A summary of our coordination with Boulder County Office of Emergency Management (OEM) and Urban Drainage and Flood Control District (UDFCD) is outlined below.

Boulder County Office of Emergency Management

- Presented initial project results to Mike Chard
- Confirmed budget allocation for ongoing gauge maintenance (resources have been allocated for maintenance of 1 new rain gauge)
- Received an overview of existing flood monitoring and response operations (use of radar projected rainfall)

Urban Drainage Flood Control District

- Presented project goals and logistics to Kevin Stewart
- Received info for existing gauge and equipment locations
- Provided info/background for current alert/threshold values
- Discussed future integration into the UDFCD gauge network monitoring utilities

OneRain provided historical rainfall and streamflow/stage data (2013-2017) for the James Creek region as well as equipment specifications for existing Boulder County gauge network. Jamestown mayor Tara Schoedinger and project committee members Philip Strom, Mark Williams, and Tim Stokes provided project guidance and insight to Jamestown flood warning needs.

2.1 Summary of the September 2013 Rainfall Event

The heavy rainfall and resulting flooding from the September 9-16, 2013 was an extraordinary event for the Town of Jamestown along with much of the Colorado Front Range. A vital component of this project involved a general analysis of the rainfall timing, pattern, and magnitude of that event. NEXRAD radar data from the KFTG site was downloaded from the NCEI portal and displayed using the NCEI Weather and Climate Toolkit (https://www.ncdc.noaa.gov/wct/). The 2013 event was highly unusual in terms of rainfall duration, magnitude, and coverage. The September 9-16 radar loop for the James Creek region shows a general storm track evolution starting with a northeasterly movement and steadily progressing to a northern, northwestern, western, and ending with a slight west/southwestern movement. Some of the individual storm cells also remained relatively stationary throughout the course of the multi-day event. An overview of the NEXRAD Level III Storm Total Precipitation (Dual Pol Algorithm) for the period from 9/9/2013 17:39 GMT to 9/13/2013 14:17 GMT shows a large portion of the James Creek basin receiving rainfall totals greater than 5 inches with the largest rainfall amounts (6+ inches) occurring over the Little James Creek drainage (

Figure 2-1).

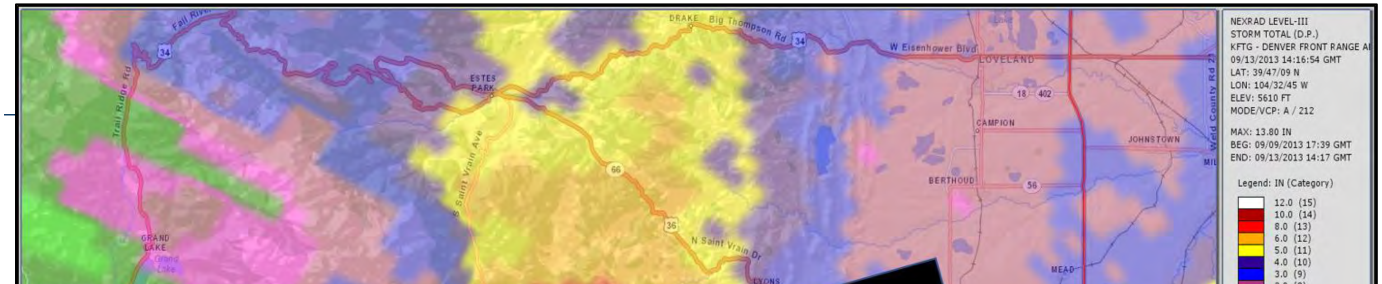


Figure 2-1. NEXRAD Storm Total Precipitation estimates for the James Creek region 9/9/2013 – 9/13/2013

3 Desktop Planning Services

An extensive analysis was developed to evaluate the physical and hydrologic features impacting the James Creek region. Figure 3-1 identifies each of the spatial data products used in the desktop analysis. A geographic information system (ArcGIS version 10.2) was used to process and extract summary characteristics for the data products and results are summarized in the following sections.

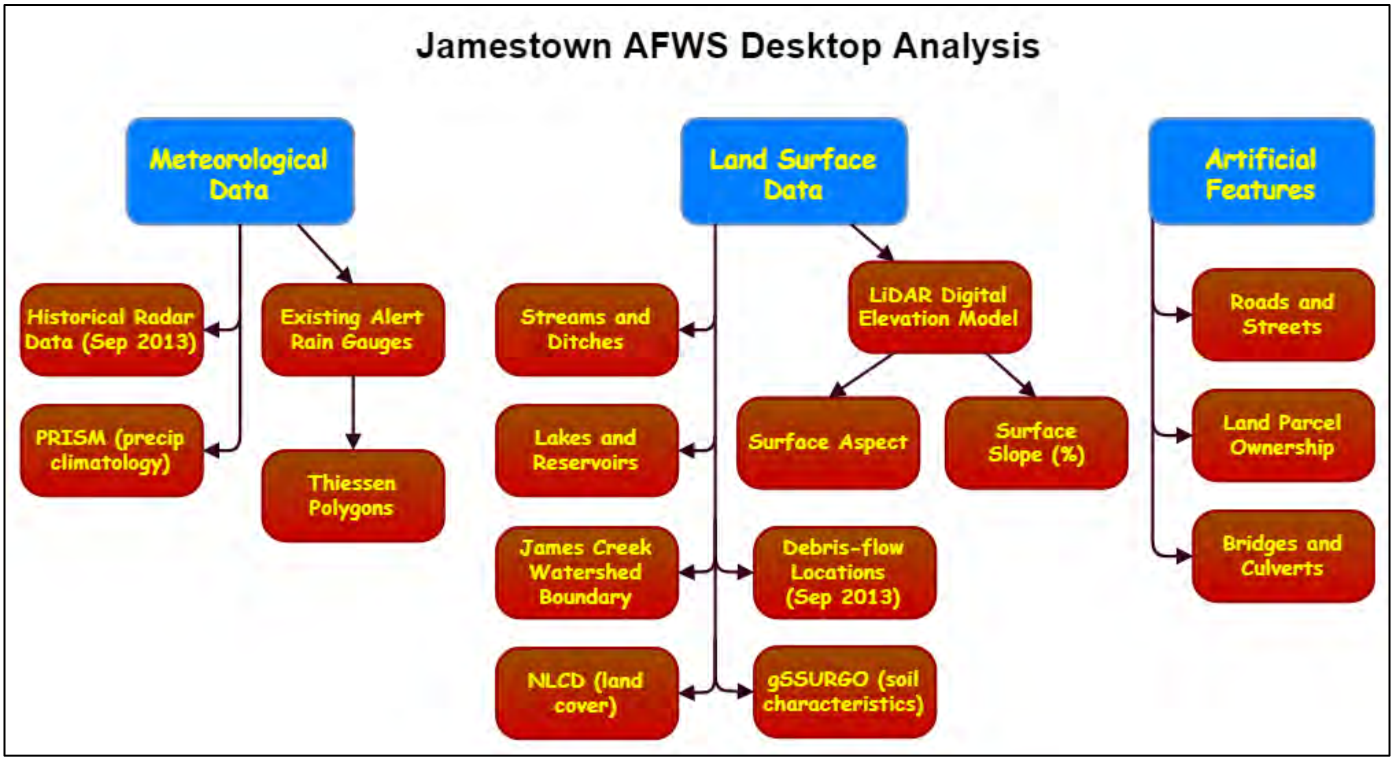


Figure 3-1. Overview of the desktop GIS data evaluation

3.1 Description of Data Sources used in the Desktop Analysis:

James Creek Watershed Delineation

- Polygon shapefile: Boundary of drainage area for James Creek basin
- Generated from USGS StreamStats using the James Creek coordinates immediately upstream of the Left Hand Creek confluence (StreamStats Site)
- Basin area: 48.2 km^2

Municipalities

- Polygon shapefile: Municipal boundaries drawn from recorded annexation documents
- Data hosted by Boulder County Geospatial Open Data Site (download site)

Streams and Ditches

- Multi-line shapefile: conflated from various data sources, including NHD, Colorado Department of Natural Resources Division of Water Resources (CDSS), Boulder County, City of Boulder and individual ditch companies
- Data hosted by Boulder County Geospatial Open Data Site (download site)

County Open Space

- Polygon shapefile: dataset represents all open space properties in which Boulder County Parks and Open Space has an interest
- Data hosted by Boulder County Geospatial Open Data Site (download site)

Street Centerlines

- Multi-line shapefile: data was developed and is maintained by the Boulder Regional Emergency Telephone Authority (BRETSA)
- Data hosted by Boulder County Geospatial Open Data Site (download site)

Building Footprints

- Polygon shapefile: dataset represents the building footprints for unincorporated Boulder County
- Data hosted by Boulder County Geospatial Open Data Site (download site)

Bridges and Culverts

- Point shapefile: data collected by Boulder Road Maintenance using a Trimble GEOXT GPS unit
- Data hosted by Boulder County Geospatial Open Data Site (download site)

Lakes and Reservoirs

- Polygon shapefile: conflated from various data sources, including NHD, Colorado Department of Natural Resources Division of Water Resources (CDSS), Boulder County, City of Boulder and individual ditch companies
- Data hosted by Boulder County Geospatial Open Data Site (download site)

Land Parcels

- Polygon shapefile: data created and maintained by the Boulder County Assessor's Office
- Data hosted by Boulder County Geospatial Open Data Site (download site)
- Assessor's property database available for Boulder County (download site)

Existing Boulder County/UDFCD rain gauges

- Point shapefile
- Lat/Lon coordinates from UDFCD website

Radar Estimated Precipitation

- Archived data available from NOAA National Centers for Environmental Information (NCEI) data portal
- NEXRAD radar derived data from the KFTG (Denver/Boulder) site for the Sep 9-15, 2013 period:
  - Base reflectivity (N0R)
  - 1-hour precipitation accumulation estimate w/ Dual Pol. Algorithm (OHA)
  - Storm total precipitation estimate w/ Dual Pol. Algorithm (PTA)

LiDAR Elevation Data

- "Post-flood LiDAR" data acquired by FEMA after the 2013 flood
- Files provided in DEM format (*.img files)
- Data info: https://data.colorado.gov/Environment/Post-flood-LiDAR/gw6w-cx24
- Horizontal resolution (xy): 0.75 meter
- Elevation data provided as integer values (meters)

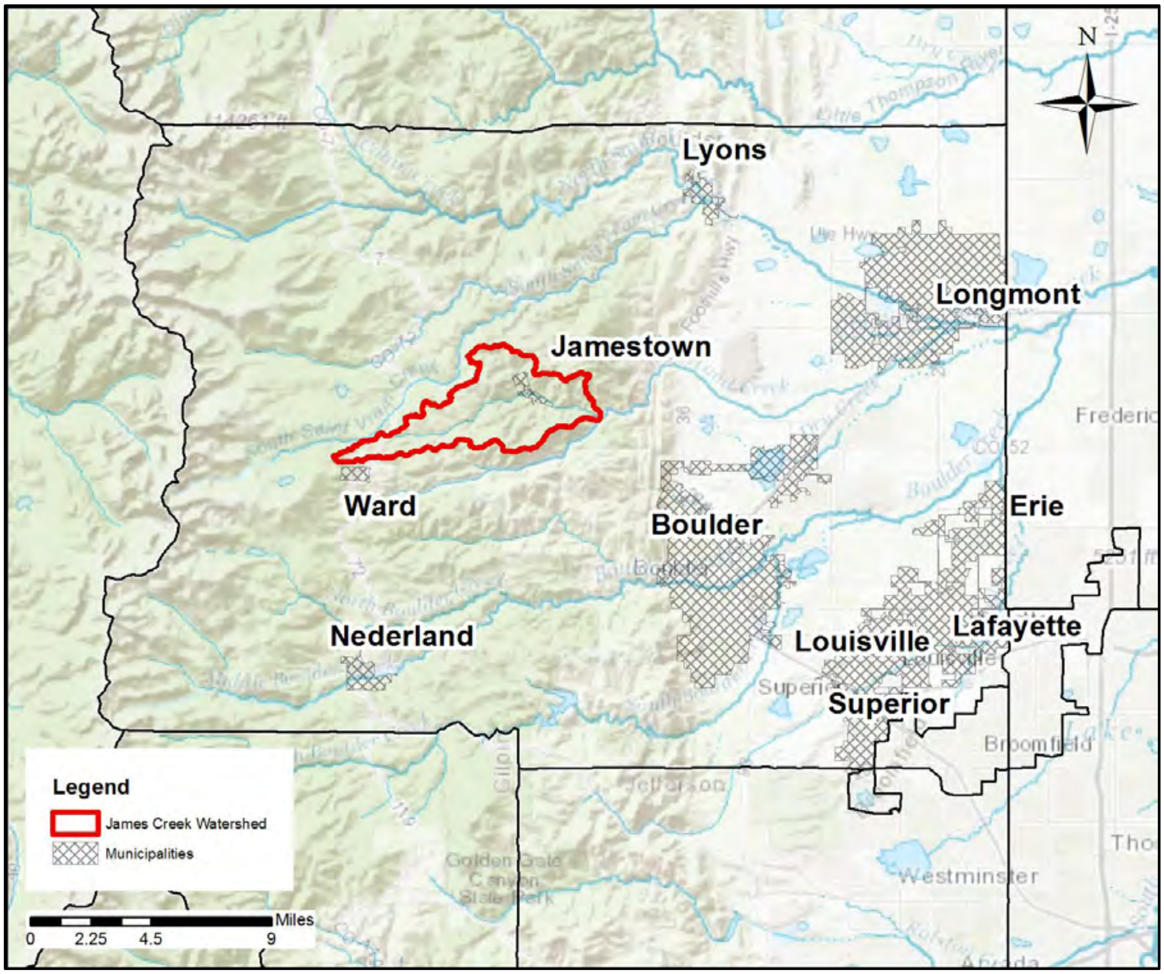


Figure 3-2. Overview of Boulder County and the location of the James Creek watershed

3.2 Elevation, Slope, and Aspect Analysis

A thorough evaluation of the land surface elevation was performed for the region within and around the James Creek watershed. All available Light Detection And Ranging (LiDAR) DEM files (77 tiles) were acquired for the study region. The individual tiles were then mosaiced into a single DEM product. Raster statistics were calculated for the nearly 300 million grid cells.

Additional GIS processing was performed with the LiDAR DEM to generate slope and aspect products. The ArcGIS Spatial Analyst tools Aspect and Slope were applied to calculate the new raster datasets. The combination of the elevation, slope, and aspect datasets provide a comprehensive evaluation of topographic conditions within and surrounding the basin. The histogram analysis (Appendix A) of the elevation data also provided insight into the gauge network coverage with respect to different elevation bands in the region.

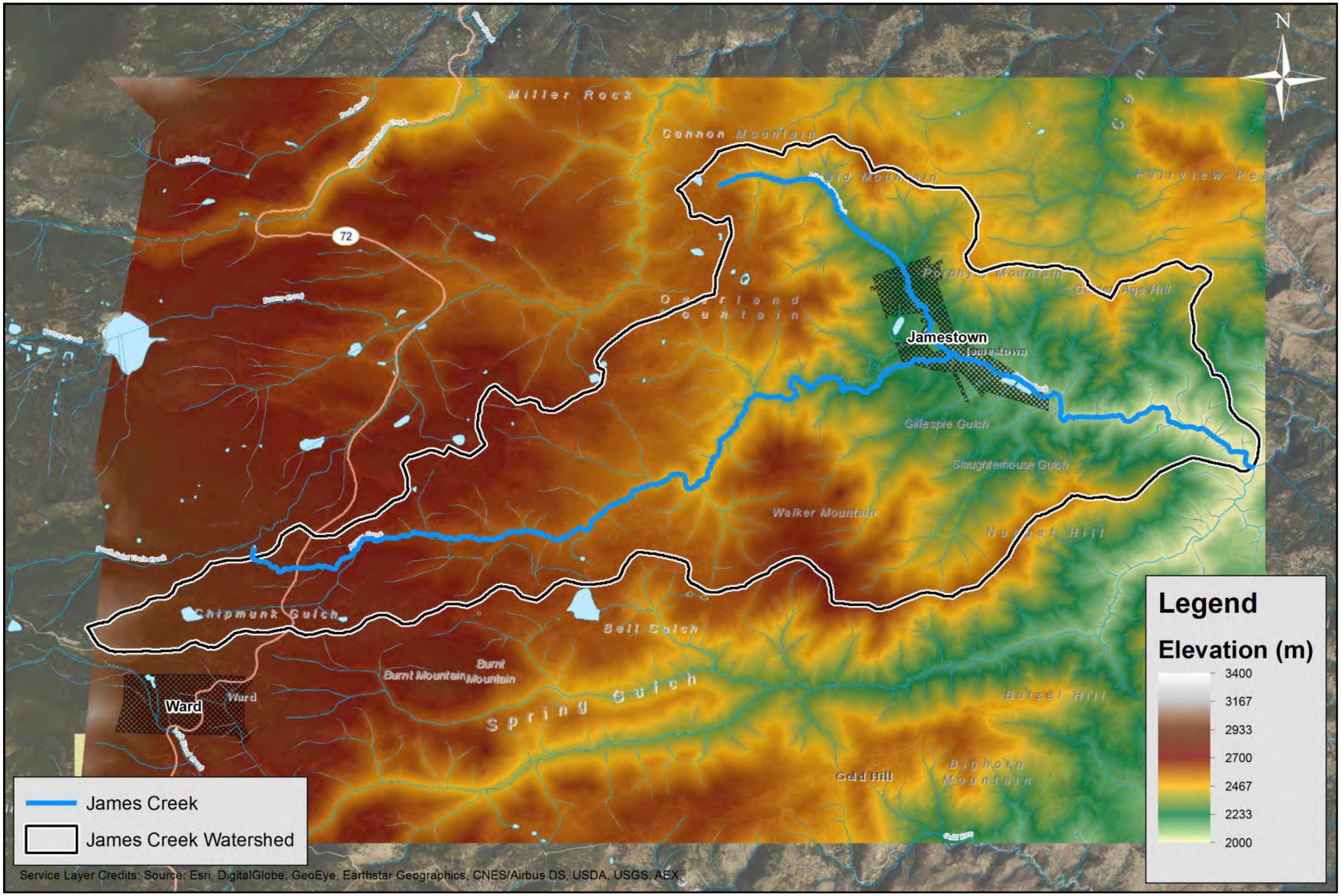


Figure 3-3. LiDAR Digital Elevation Model view of the James Creek watershed

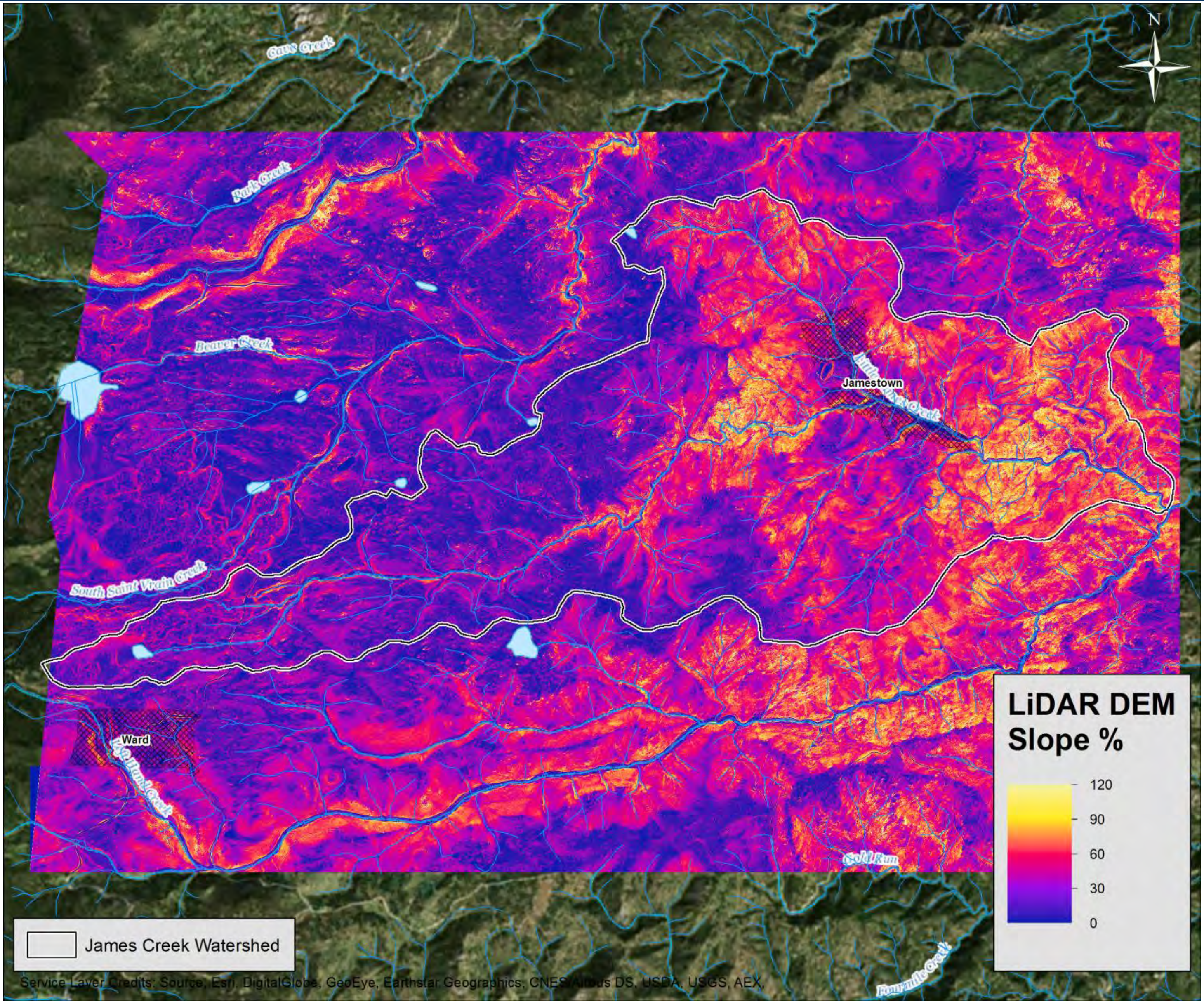
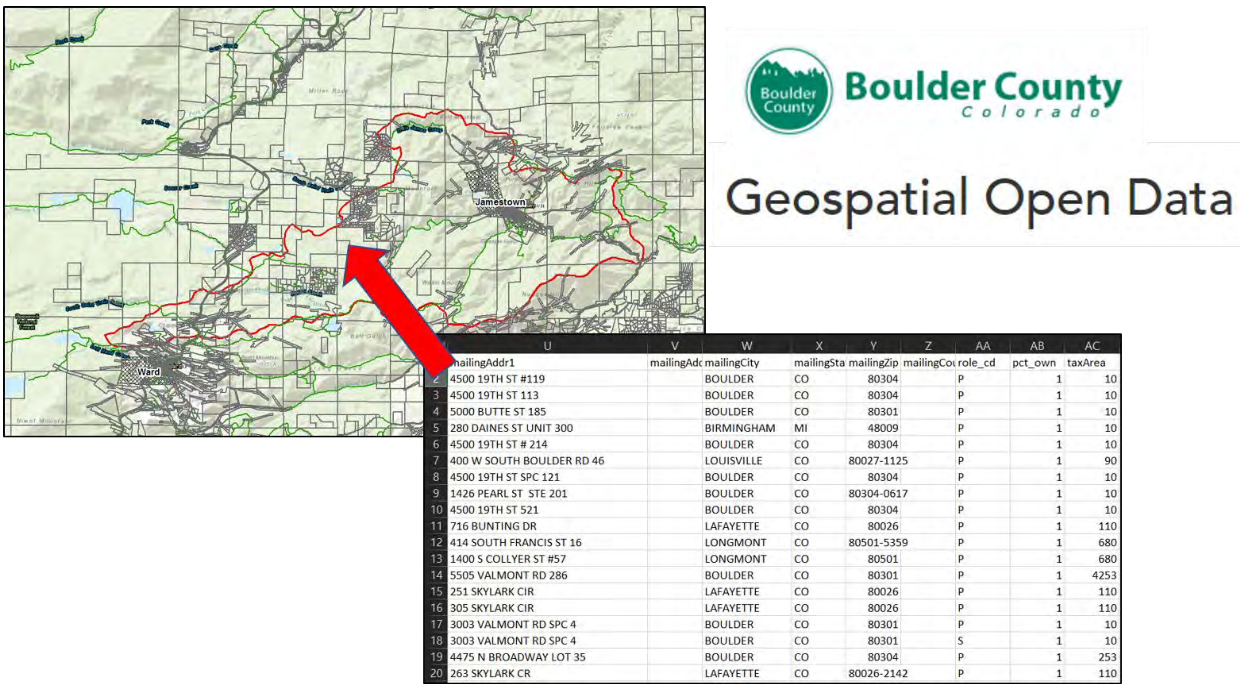


Figure 3-4. LiDAR analysis of the slope grade percentage

3.3 Land Parcel Analysis

The land parcel polygon shapefile data hosted by Boulder County was downloaded and merged with the parcel attribute databases using ArcGIS tools. The parcel attribute data generated by the Boulder County Assessor's office contains detailed information regarding the property type and land owner information for each land parcel. The parcel information is an essential tool for locating and coordinating with land owners for potential gauge placement. Based on previous experience with gauge installations within Boulder County, Government owned land is often a preferred land manager to work with for rain/stream gauge placements. For this reason, our initial efforts focused on locating all parcels owned/managed by the government.



	U	V	W	X	Y	Z	AA	AB	AC
1	mailingAddr1	mailingAdc	mailingCity	mailingSta	mailingZip	mailingCou	role_cd	pct_own	taxArea
2	4500 19TH ST #119		BOULDER	CO	80304		P	1	10
3	4500 19TH ST 113		BOULDER	CO	80304		P	1	10
4	5000 BUTTE ST 185		BOULDER	CO	80301		P	1	10
5	280 DAINES ST UNIT 300		BIRMINGHAM	MI	48009		P	1	10
6	4500 19TH ST # 214		BOULDER	CO	80304		P	1	10
7	400 W SOUTH BOULDER RD 46		LOUISVILLE	CO	80027-1125		P	1	90
8	4500 19TH ST SPC 121		BOULDER	CO	80304		P	1	10
9	1426 PEARL ST STE 201		BOULDER	CO	80304-0617		P	1	10
10	4500 19TH ST 521		BOULDER	CO	80304		P	1	10
11	716 BUNTING DR		LAFAYETTE	CO	80026		P	1	110
12	414 SOUTH FRANCIS ST 16		LONGMONT	CO	80501-5359		P	1	680
13	1400 S COLLYER ST #57		LONGMONT	CO	80501		P	1	680
14	5505 VALMONT RD 286		BOULDER	CO	80301		P	1	4253
15	251 SKYLARK CIR		LAFAYETTE	CO	80026		P	1	110
16	305 SKYLARK CIR		LAFAYETTE	CO	80026		P	1	110
17	3003 VALMONT RD SPC 4		BOULDER	CO	80301		P	1	10
18	3003 VALMONT RD SPC 4		BOULDER	CO	80301		S	1	10
19	4475 N BROADWAY LOT 35		BOULDER	CO	80304		P	1	253
20	263 SKYLARK CR		LAFAYETTE	CO	80026-2142		P	1	110

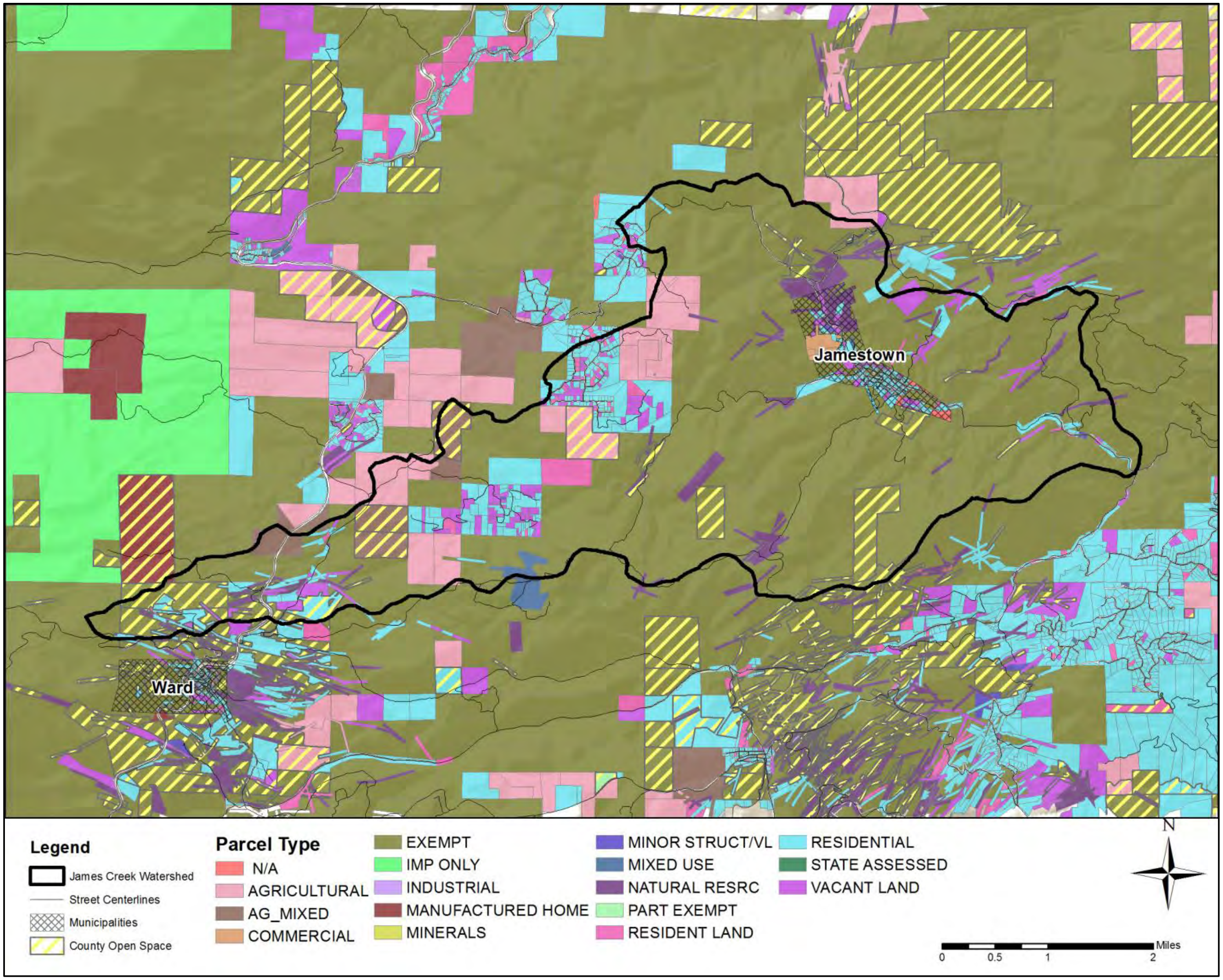


Figure 3-5. Boulder County land parcel classifications for the James Creek watershed region

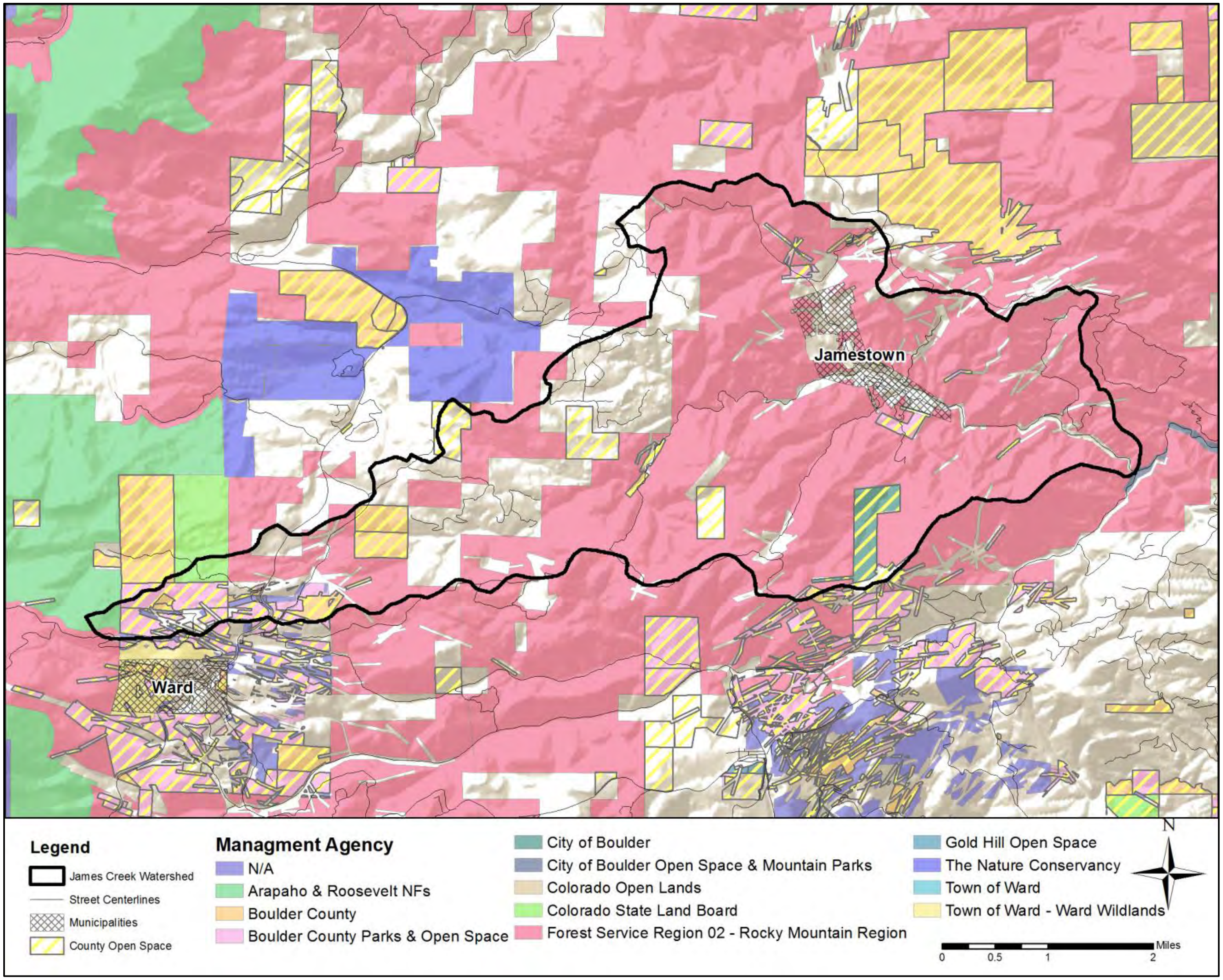


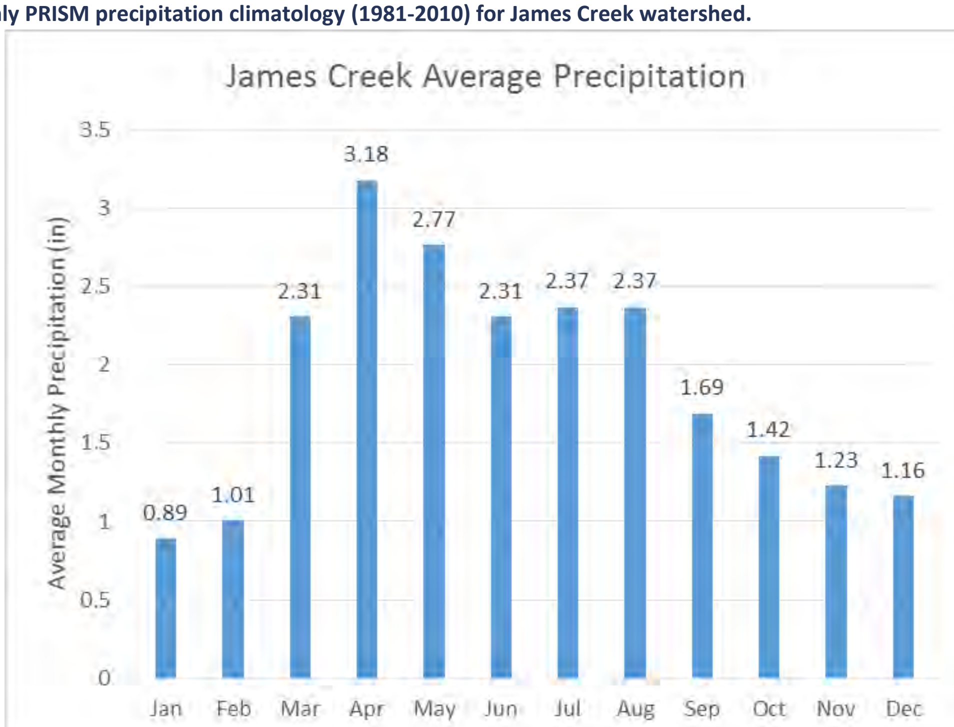
Figure 3-6. Boulder County overview of government managed land parcels for the James Creek region

3.4 Meteorological and Climatological Precipitation

An initial analysis to understand the precipitation climatology analyzed the Parameter-elevation Regressions on Independent Slopes Model (PRISM) 800m gridded dataset (PRISM Climate Group, Oregon State University, 2013). The PRISM precipitation product uses a combination of point measurements of monthly and annual precipitation and applies a statistical analysis to account for orographic precipitation influences. The 30-year (1981-2010) annual climatology grid (Figure 3-7) shows precipitation values within the James Creek basin range from 800 mm (31.5 in) to 530 mm (20.9 in). Basin precipitation values generally increase from east/northeast to west with increasing elevation. The same climatology analysis was also performed on the monthly gridded data to provide an overview of the expected seasonal precipitation pattern (Table 3-1). It's also important to note that snowfall is the dominant form of precipitation during the cold season months, and Boulder County ALERT rain gauges are offline during the winter months. The March through August period stands out as the dominant precipitation months. Note that the September 2013 heavy rainfall event is not included in this OSU climatology analysis.

Table 3-1. Monthly PRISM precipitation climatology (1981-2010) for James Creek watershed.

Month	James Creek Precip (in)
Jan	0.89
Feb	1.01
Mar	2.31
Apr	3.18
May	2.77
Jun	2.31
Jul	2.37
Aug	2.37
Sep	1.69
Oct	1.42
Nov	1.23
Dec	1.16
Annual	22.71



Lynker also generated Thiessen polygons from the existing automated rain gauge network in and around the James Creek watershed. The Thiessen polygon analysis is a graphical approach to providing a high-level evaluation of the current gauge network coverage while also identifying regions of the basin that may benefit from additional gauge placements. Locations along the polygon boundaries highlight regions of the watershed that may not be well represented by the existing gauge network. Four regions of the basin were initially identified in this analysis for further gauge placement evaluations. These regions are identified with yellow circles in Figure 3-8.

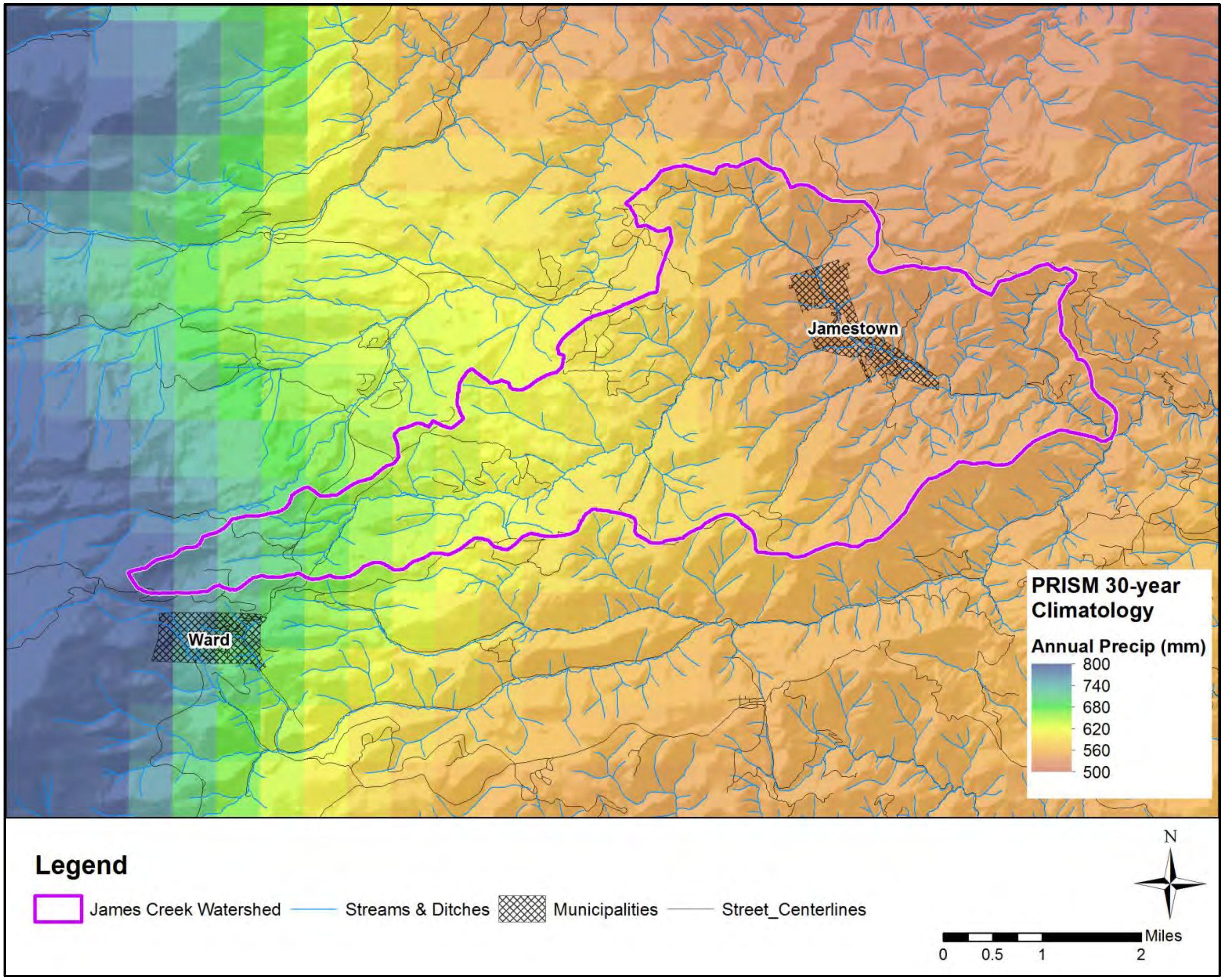


Figure 3-7. PRISM annual precipitation climatology for the 1981-2010 period

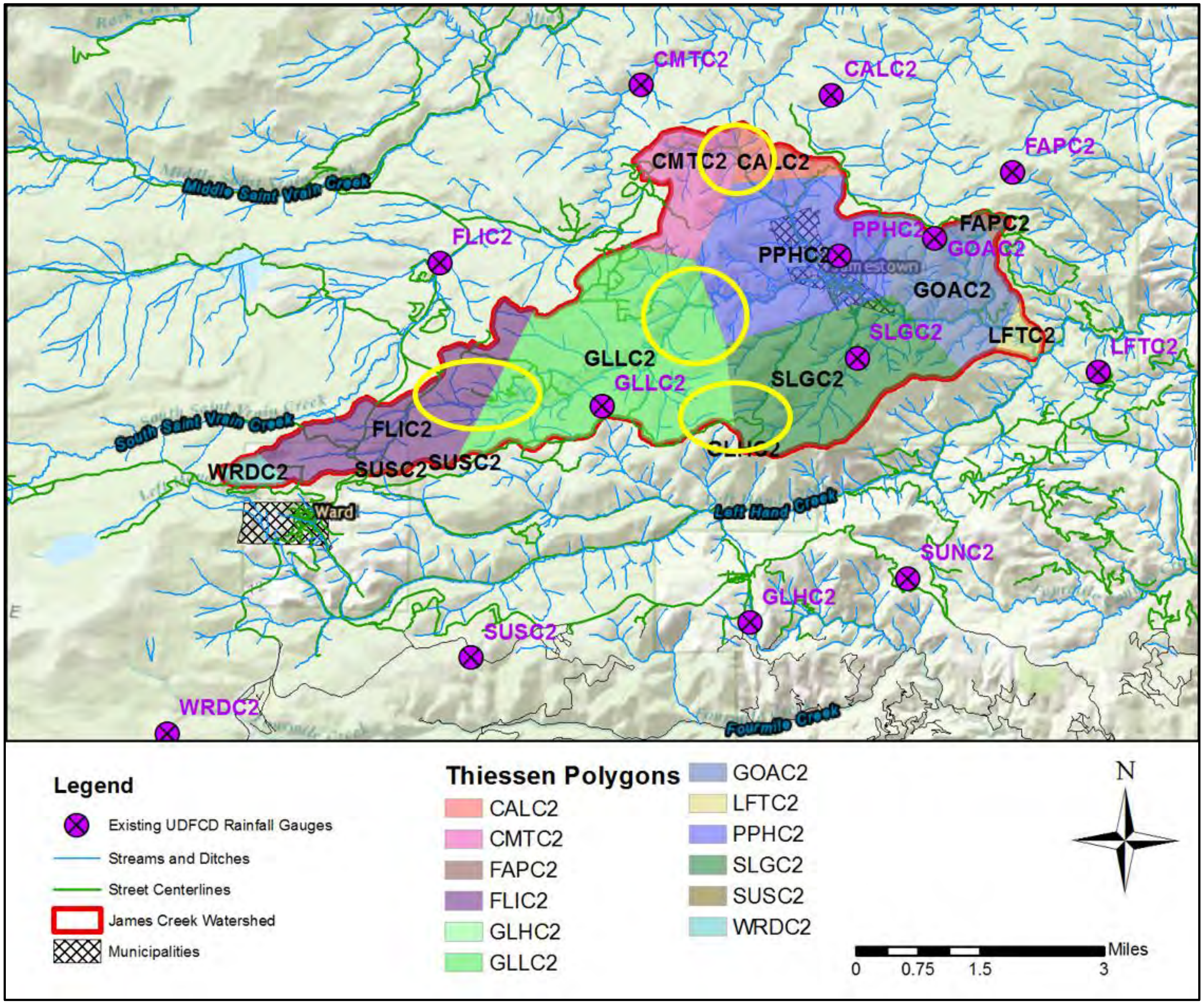


Figure 3-8. Thiessen Polygon analysis of the James Creek basin using the existing rain gauge network

Table 3-2 provides an overview of the 13 automated rainfall sites near the James Creek watershed and Table 3-3 details the three nearest stream gauge locations. Archived data files for all active sites were provided by OneRain for subsequent rainfall threshold analysis.

Table 3-2. Alert rain gauges in the vicinity of the James Creek watershed

NAME	ID	NETWORK	ALERT ID	SHEF ID	Lat	Lon	Elev (ft)
Cal-Wood Ranch	CALC2	CO_DCP	4770	CALC2	40.148	-105.390	7760
Cannon Mountain	CMTC2	CO_DCP	4270	CMTC2	40.149	-105.433	8120
Fairview Peak	FAPC2	CO_DCP	4860	FAPC2	40.134	-105.348	8208
Fling's	FLIC2	CO_DCP	4220	FLIC2	40.118	-105.479	8543
Golden Age	GOAC2	CO_DCP	4230	GOAC2	40.123	-105.366	8160
Gold Hill	GLHC2	CO_DCP	4150	GLHC2	40.055	-105.408	8120
Gold Lake	GLLC2	CO_DCP	4180	GLLC2	40.093	-105.442	8560
Lazy Acres	LFTC2	CO_DCP	4200	LFTC2	40.099	-105.329	7020
Porphyry Mountain	PPHC2	CO_DCP	4850	PPHC2	40.120	-105.388	7347
Slaughterhouse	SLGC2	CO_DCP	4190	SLGC2	40.102	-105.384	7400
Sunset	SUSC2	CO_DCP	4240	SUSC2	40.049	-105.471	8680
Sunshine	SUNC2	CO_DCP	4160	SUNC2	40.063	-105.372	7560
Ward C-1 (Hills Mills)	WRDC2	CO_DCP	4710	WRDC2	40.035	-105.541	9915

Table 3-3. Alert streamflow/stage gauges

Name	ALERT ID	Lat	Lon	Elev (ft)
James Creek at Jamestown	10017	40.115	-105.386	6922
Rowena	4430	40.075	-105.398	7170
Lower Left Hand	10018	40.126	-105.304	6230

3.5 Gauge Placement Desktop Optimization

Initial gauge placement physical considerations were identified based on standard conditions required for preferential access and gauge network distribution. Features used in the initial placement optimization included the following:

- Road/trail access
- Public Land/Open Space preference
- Distance from an existing ALERT gauge
- Proximity to a stream channel (for potential stream gauge)
- Outside the estimated floodplain (unless necessary)
- Within or near the James Creek basin boundary

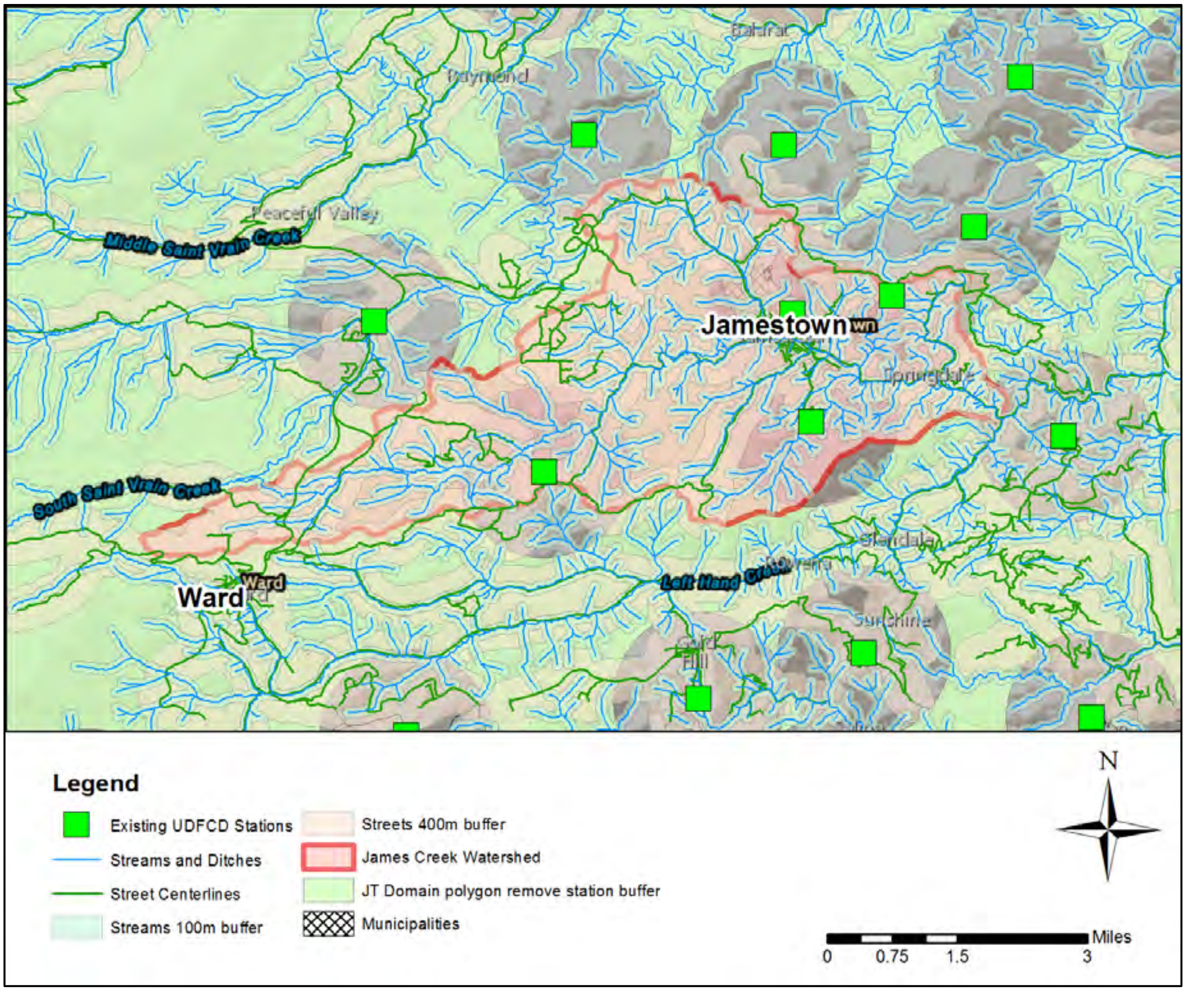


Figure 3-9. Overview of the feature buffer development used in the development of gauge placement heat map

Lynker Technologies has developed an extensive analysis toolset to support the data processing and visualization of geospatial data products used for gauge placement optimization. The output of this toolset is a detailed gridded image termed a "heat map" that quantifies the presence of the preferred physical gauge location characteristics outlined above and enables ready visualization of these locations. The following workflow summarizes the steps to producing the heat maps. The resulting heat map is shown in Figure 3-10.

1. Download/import and prepare road/trail line shapefile, existing gauge point shapefile, stream channel line shapefile, basin boundary shapefile, and any other applicable shapefiles.
2. Apply the desired buffer distance to line and point shapefiles to generate new polygon shapefiles (e.g. 400m road/trail buffer; 1600m existing gauge buffer)
3. Merge all polygon shapefiles to a single polygon shapefile while maintaining the overlap between individual layers. Duplicate polygon shapefiles can be used to assign additional weight to preferred features.
4. Run the "Count Overlapping Polygon" toolkit available for ArcGIS
5. Covert the newly created overlapping polygon to a raster using the "Join_Count" field to define cell values
6. Run the Filter tool on the new raster to smooth the raster display of the image

7. Apply a cold/hot color scheme to illustrate regions of optimal placement (red) vs. less optimal regions (blue).

A combined evaluation of the Thiessen Polygons, land parcel identification, hydrography assessment, and optimized placement heat map was applied to manually identify a set of point locations for continued evaluation. Thirteen initial test locations were identified from this analysis (Figure 3-10).

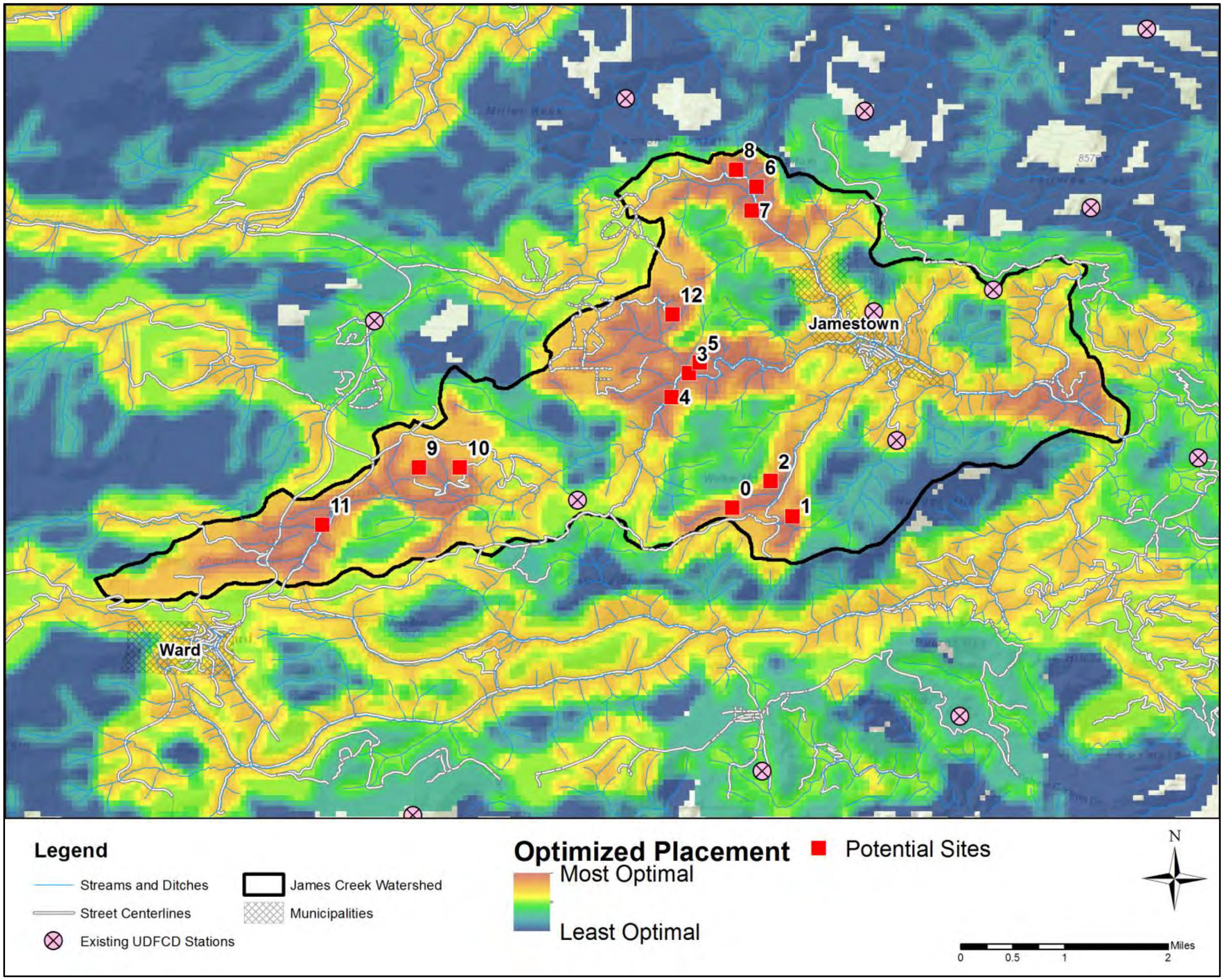


Figure 3-10. Heatmap showing optimal gauge sites, as well as sites selected and final sites visited.

3.6 Theoretical Path Analysis for Communication Signal Strength

Upon completing the initial gauge placement site selections using the results from the GIS analysis, a comprehensive theoretical path analysis calculation was performed by OneRain for the thirteen point locations. Results of the analysis showed an acceptable signal strength (greater than 6 dB) for 12 out of the 13 tested locations. The only location to fail the path test was location #4 situated in the valley along James Creek. Table 3-4 summarizes the results from the theoretical path analysis. This path analysis is used to verify all locations where new gauges are expected to have good communication linkage with the existing Boulder County rain gauge system.

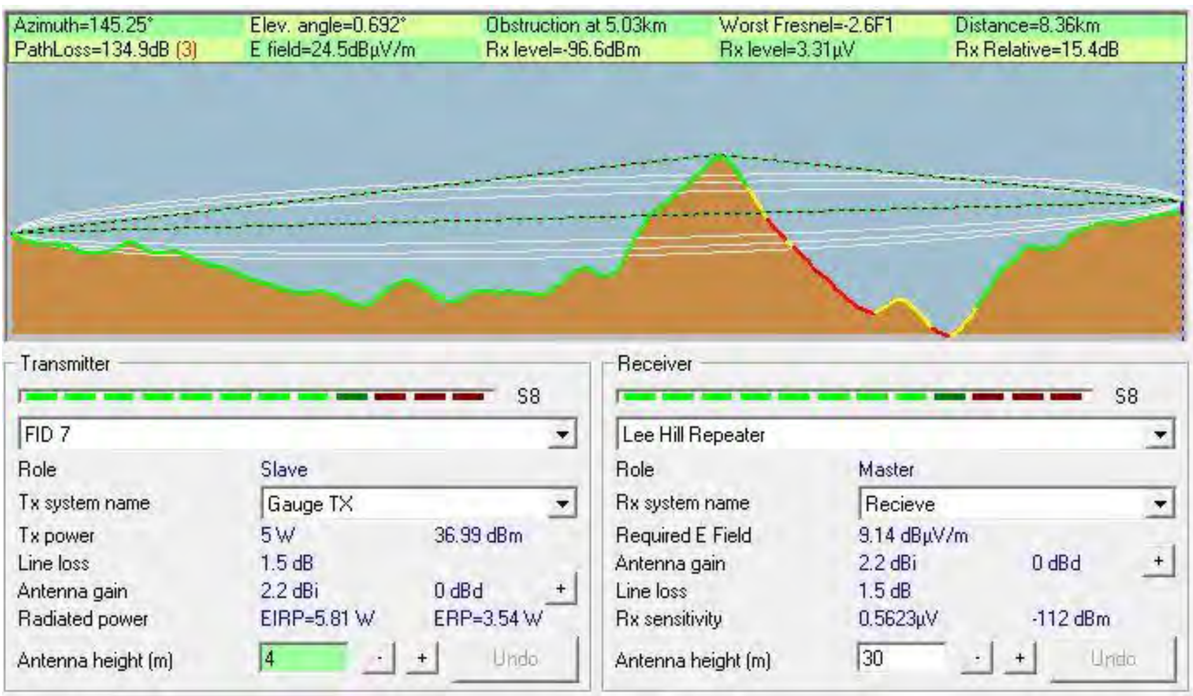


Figure 3-11. Output example from the theoretical path analysis

Table 3-4. Theoretical path analysis results for the 13 test locations

ID #	Gauge Type	Lat	Lon	Receive (dB)
0	rain	40.0922	-105.4140	41.0
1	rain	40.0910	-105.4030	49.4
2	rain	40.0960	-105.4070	26.1
3	rain and stream	40.1110	-105.4220	6.5
4	rain and stream	40.1077	-105.4250	-4.9
5	rain	40.1125	-105.4200	17.9
6	rain	40.1372	-105.4090	18.1
7	rain	40.1338	-105.4100	15.4
8	rain	40.1395	-105.4130	20.0
9	rain	40.0976	-105.4710	22.5
10	rain	40.0976	-105.4630	19.6
11	rain	40.0896	-105.4880	10.7
12	rain	40.1192	-105.4250	23.2

4 Integration of Existing and New Technologies

4.1 Evaluation and Suggestions for Alert Thresholds

A network of well-positioned rain/stream gauges can provide lifesaving data, but the interpretation of that data is critical for converting the data into actionable information required to prevent loss of life and property in the event of a flood. Finely tuned precipitation and stream gauge thresholds are an important piece of a well-designed flood monitoring and alert system. The Lynker Team applied the extensive historical dataset for the existing Boulder County precipitation and stream gauges in and around the James Creek watershed to evaluate rainfall alarm thresholds. The analysis largely focused on the September 2013 flood event, as this was the only significant event within the recent archive of rainfall and stream stage data. The goal for this threshold/alarm evaluation is to provide emergency managers and community members with recommendations for a robust toolset of rainfall alerts while minimizing the false alarm occurrences.

Throughout the Colorado Front Range, the UDFCD implements a set of default rainfall accumulation thresholds (Table 4-1) to alert key personnel of potential flooding via email and SMS messaging services. Rolling window rainfall accumulation calculations are performed every 5-minutes for each gauge. OneRain also provided the current river stage flood impact thresholds configured within the Boulder County Contrail system (Table 4-2). 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 4-1. 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

Table 4-2. Flooding impacts currently configured for the Jamestown stream stage

River Stage Height (feet)	Category Impact
0.88 ft	Bank Full
3.0 ft	Minor Flooding
3.9 ft	Moderate Flooding
5.7 ft	Major Flooding
8.0 ft	Est. Peak Stage – Sep 2013

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

- Format and import and the incremental precipitation QA/QC'd data (non-equidistant time steps) and instantaneous streamflow data
- Bin/Group the precipitation data (5-minute) to allow for simplified processing
- Perform a rolling accumulation calculation using a range of time durations (example provided in Figure 4-1)
    - 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 alarms/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 4-1. Example of the rolling accumulation calculation

The rainfall accumulation threshold analysis was performed using the seven rainfall gauges identified during the Thiessen Polygon analysis. These rainfall gauges provide a representative areal coverage within the James Creek basin upstream of Jamestown (Figure 4-2). While some of these gauges are positioned outside the basin boundary, the relatively close proximity to the basin can provide an added data buffer for heavy precipitation along the fringes of the basin. Examining multiple gauges in the James Creek vicinity as a single alarm can also allow emergency managers to better understand the spatial coverage of a storm event.

The following automated rain gauges are included in the James Creek alert/threshold analysis (red circles in figure below): WRDC2, FLIC2, GLLC2, CMTC2, CALC2, PPHC2, SLGC2. 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 4-3).

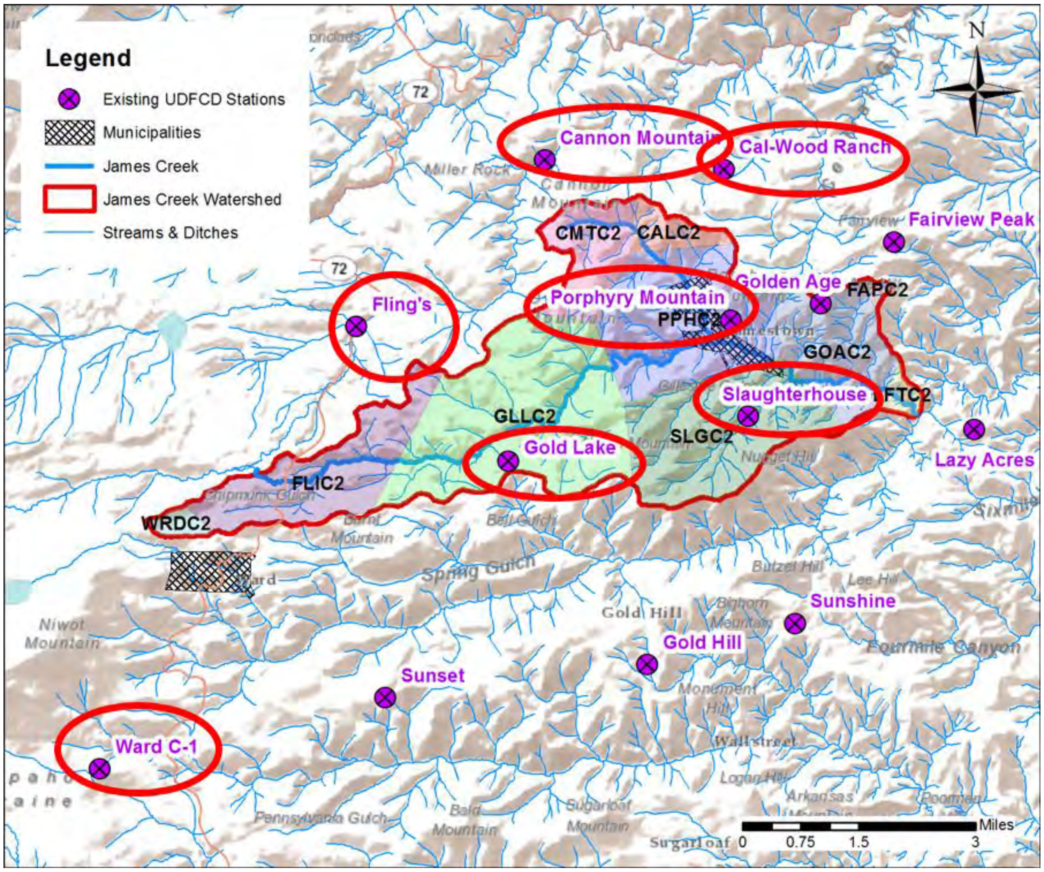


Figure 4-2. Location of existing automated rain gauges in the James Creek basin vicinity

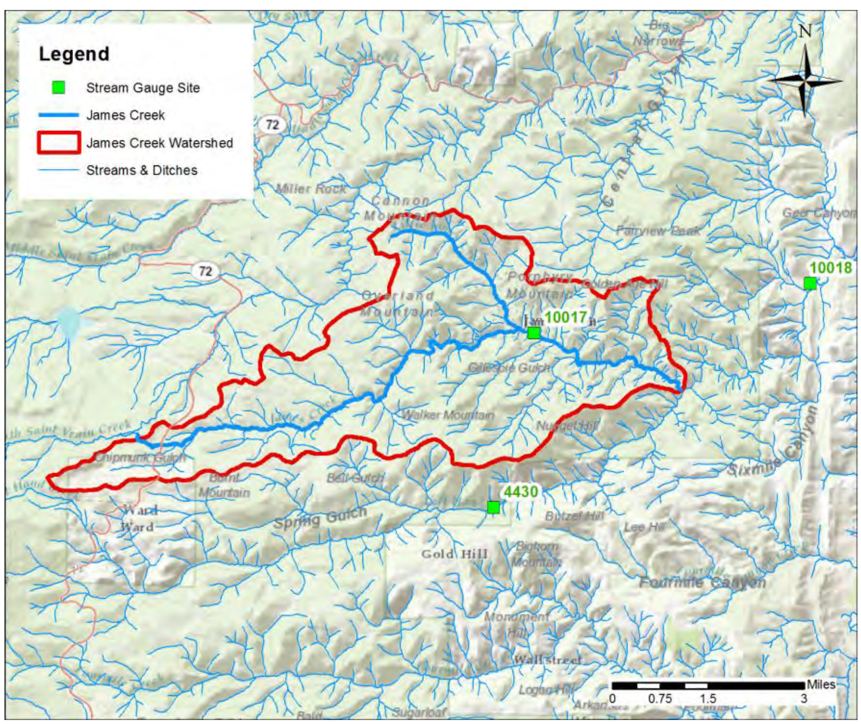


Figure 4-3. Location of three stream gauge sites within the James Creek region.

4.2 Graphical Assessment of Alarming Thresholds

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). An annotated plot of the James Creek river stage timeseries for the Sep 2013 event is provided in Figure 4-4.

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.

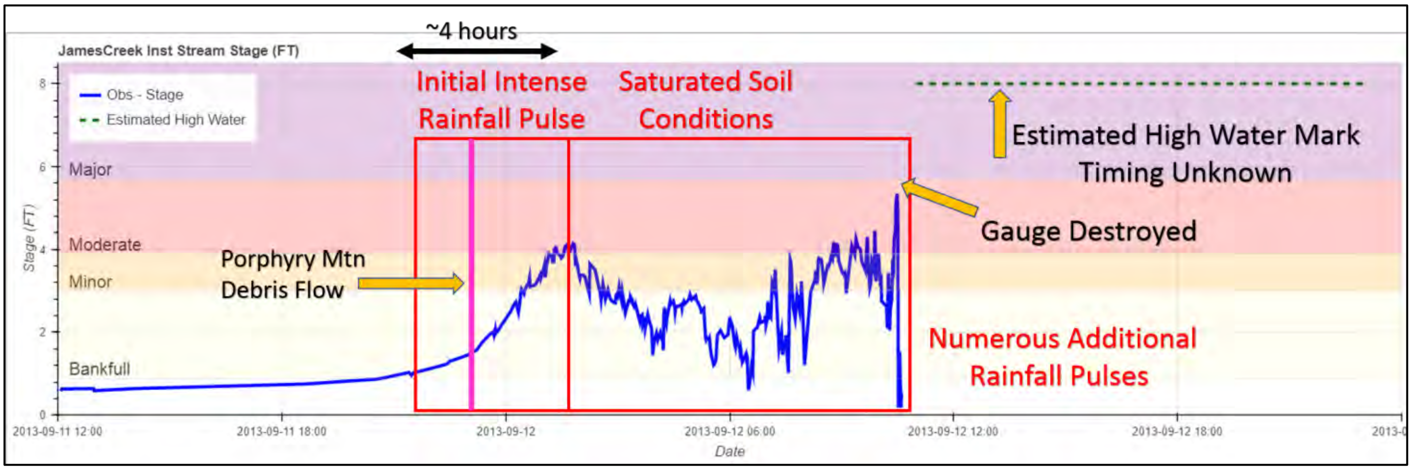


Figure 4-4. James Creek at Jamestown annotated hydrograph overview of the September 2013 flood event

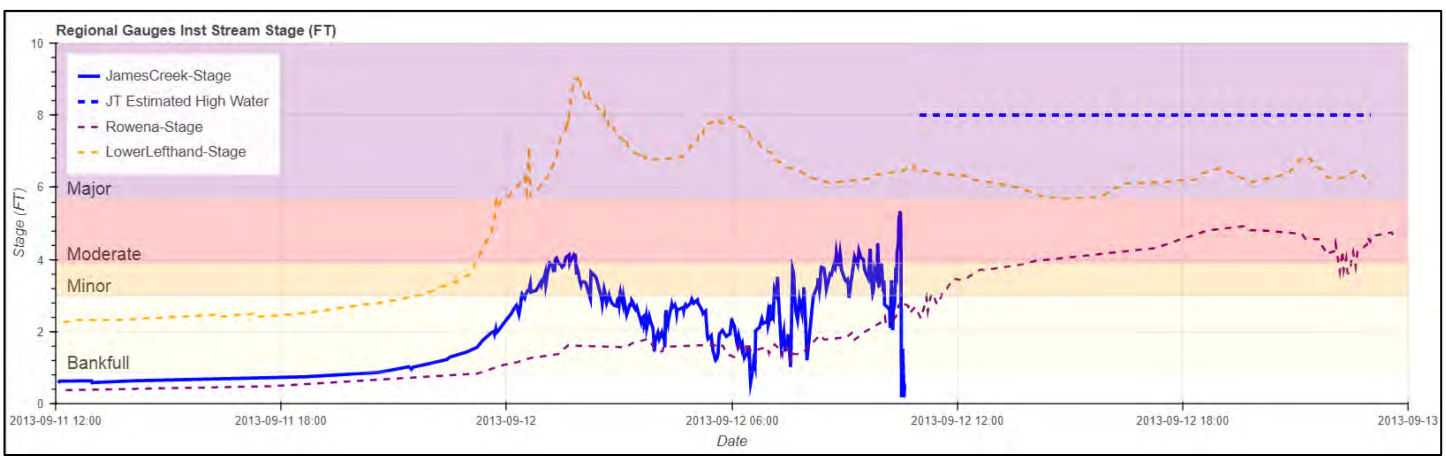


Figure 4-5. Overlay of the James Creek @ Jamestown, Rowena, and Lower Left Hand observed stage 9/11/13 12pm – 9/13/13 12am

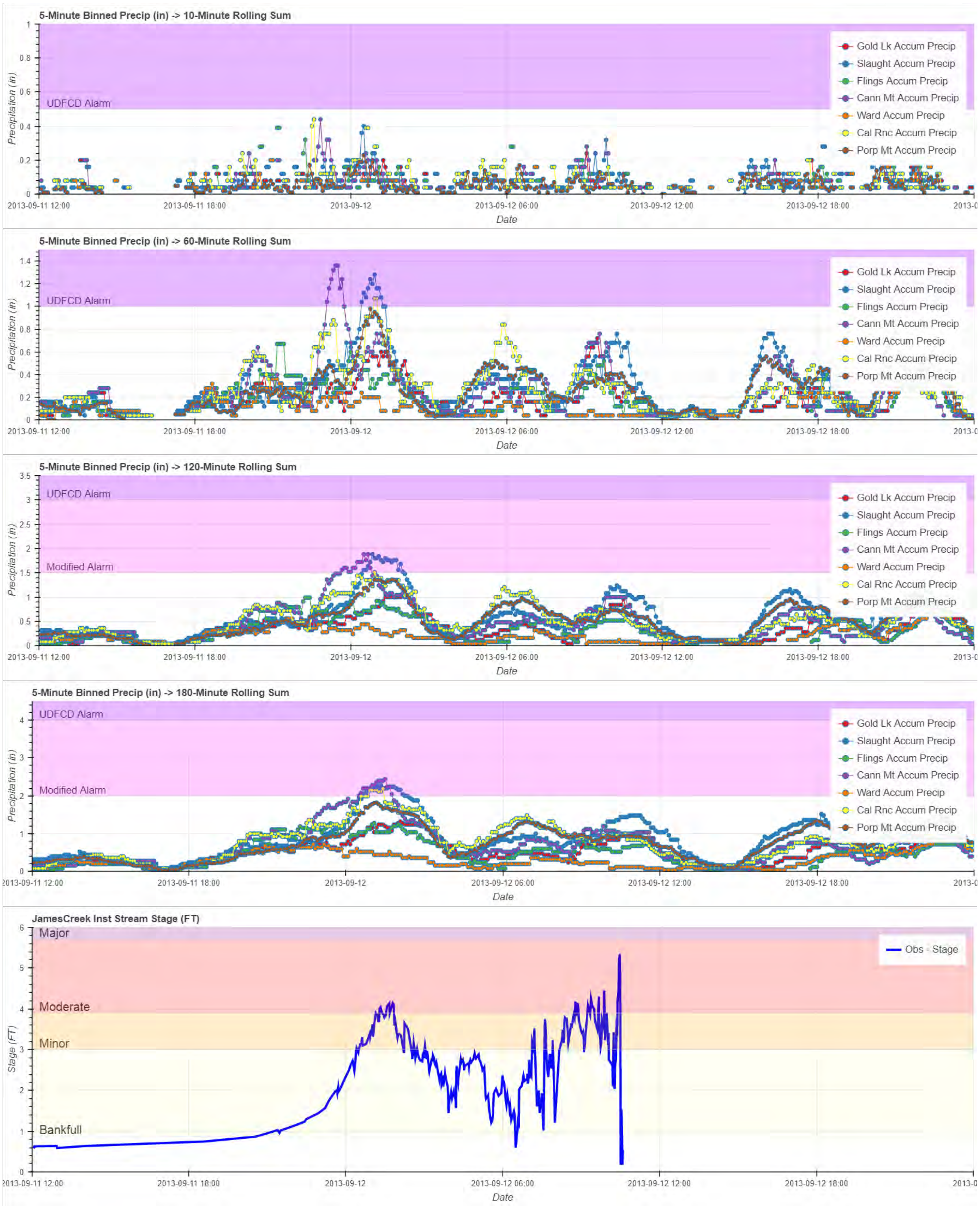


Figure 4-6. 10-min, 60-min, 120-min, and 180-min rolling window rainfall accumulations with the observed river stage at Jamestown

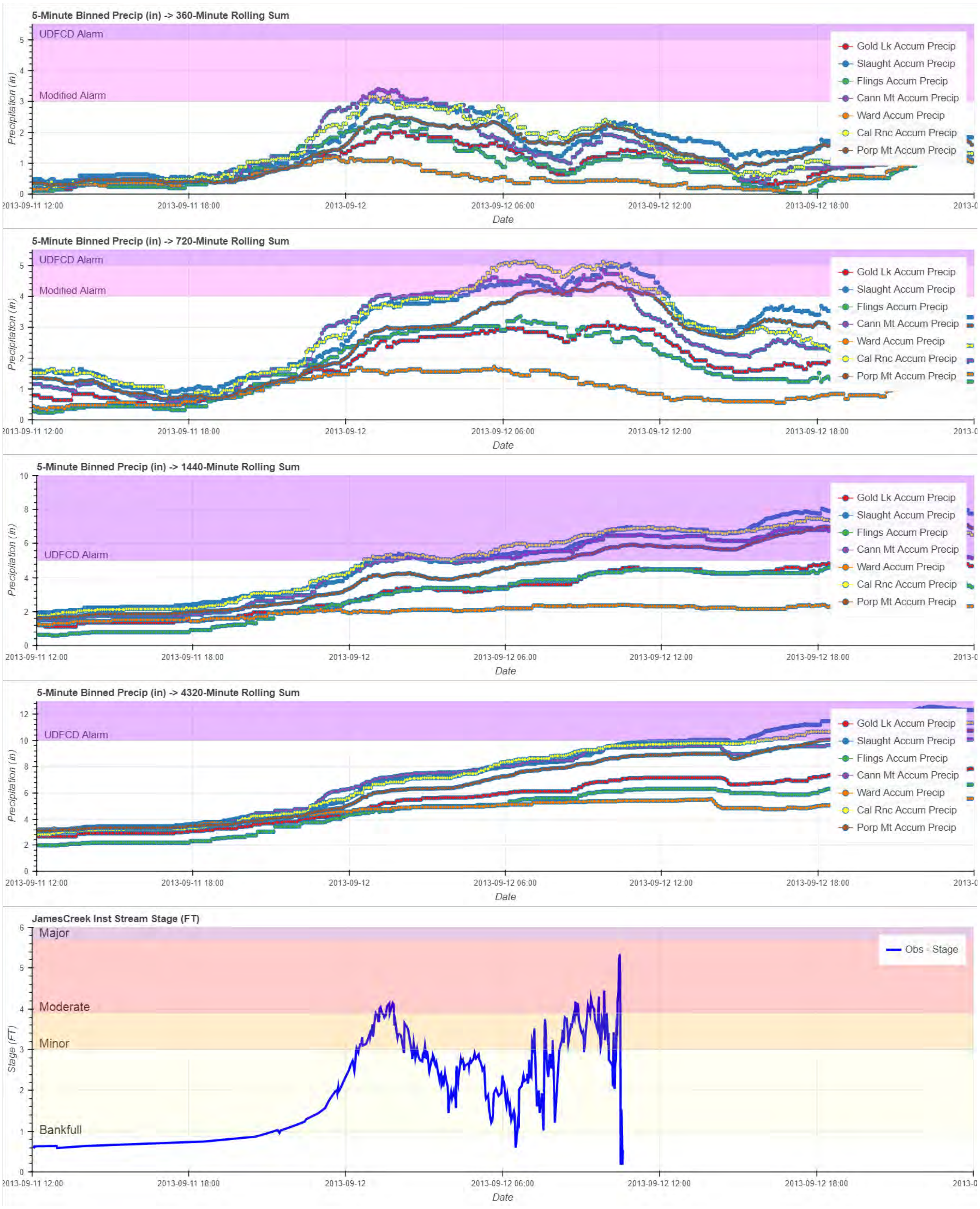


Figure 4-7. 360-min, 720-min, 1440-min, and 4320-min rolling window rainfall accumulations with the observed river stage at Jamestown

After evaluating the default and modified alarm values for the September 2013 event, the Lynker Team also examined the larger historical time series data period (2013-2017) to check the alert frequency of the modified thresholds during other non-threatening rainfall events. This analysis examined eight different rainfall accumulation duration alarm thresholds (**Error! Not a valid bookmark self-reference.**) in preparation for providing emergency managers and Jamestown personnel with insight and recommendations for potential rainfall-flood monitoring in the future.

Table 4-3. Rainfall accumulation exceedance alarm notification thresholds evaluated

Time Duration	Default Rainfall Accumulation Alert (inches)	Modified Rainfall Accumulation Alert (inches)	General Alarm Category
10-minutes	0.5 in	0.5 in	Flash Flooding Potential – minor flooding (curb and gutter full)
1-hour	1.0 in	1.0 in	Flash Flooding Potential
2-hours	3.0 in	1.5 in	Flash Flooding Potential
**3-hours*	--	2.0 in	Short-term Flooding; Saturated Conditions Alert
6-hours	5.0 in	3.0 in	Saturated Conditions Alert; Moderate Flooding Potential;
**12-hours*	--	4.0 in	Large Scale Flooding Potential
24-hours	5.0 in	5.0 in	Large Scale Flooding Potential
72-hours	10.0 in	10.0 in	Large Scale Flooding Potential

* New threshold duration alarms

Red values were modified by Lynker and require additional threshold evaluation before adoption

Eight accumulation duration thresholds were tested using a reanalysis of the September 2013 event. The progression of the time interval alarms focused on provided a robust alert system that can capture a wide range of precipitation events. The shorter 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 as was the case for the September 2013 event. The moderate duration (3-hour and 6-hour) alarms are intended to provide emergency managers with a notice of likely flood 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. The 72-hour alarm in the case of the September 2013 event is largely irrelevant as a warning tool due to the fast hydrologic response of this mountainous basin.

IMPORTANT DISCLAIMER: The new/modified thresholds should be further evaluated to determine the proper alert frequency based on the flood mitigation/ response needs of Jamestown. Any new/modified alerts should also be configured in coordination with Boulder County OEM to ensure all alerts are in sync with existing flood monitoring efforts.

While the newly proposed automated rain gauge will provide a more detailed understanding of precipitation falling directly within the basin boundary, it is important for emergency managers and key Jamestown personnel to monitor the entire nearby rain gauge network – including gauges outside the watershed. When reviewing the rainfall accumulation at individual gauges during the September 2013 event, the only rainfall gauge positioned within the James Creek basin to exceed a default threshold (with a duration less than 12-hours) was the Slaughterhouse gauge.

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 shaded column:

- Green: threshold exceeded for each of the 10-min, 60-min, and 120-min durations
- Orange: threshold exceeded for each of the 180-min and 360-min durations
- Purple: threshold exceeded for each of the 720-min and 1440-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. The following plots illustrate the modified alarm thresholds developed as a test for the September 2013 rainfall event (Figure 4-9). For comparison, the UDFCD default rainfall thresholds were also plotted and are provided in Appendix C.

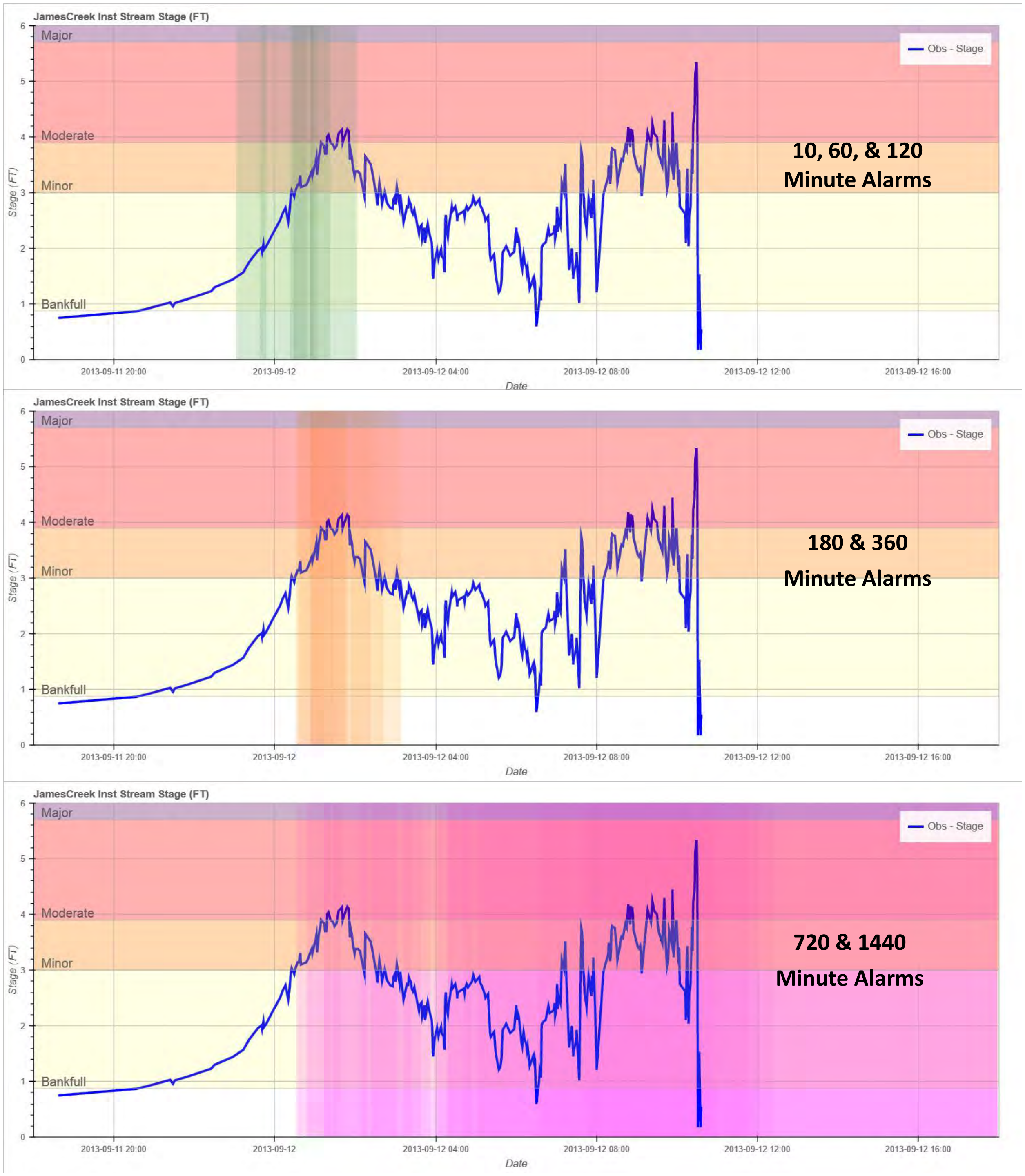


Figure 4-8. September 2013 James Creek stage with categorized alarm counts in green (10-min, 60-min, and 120-min durations), orange (180-min and 360-min durations), and purple (720-min and 1440-min durations)

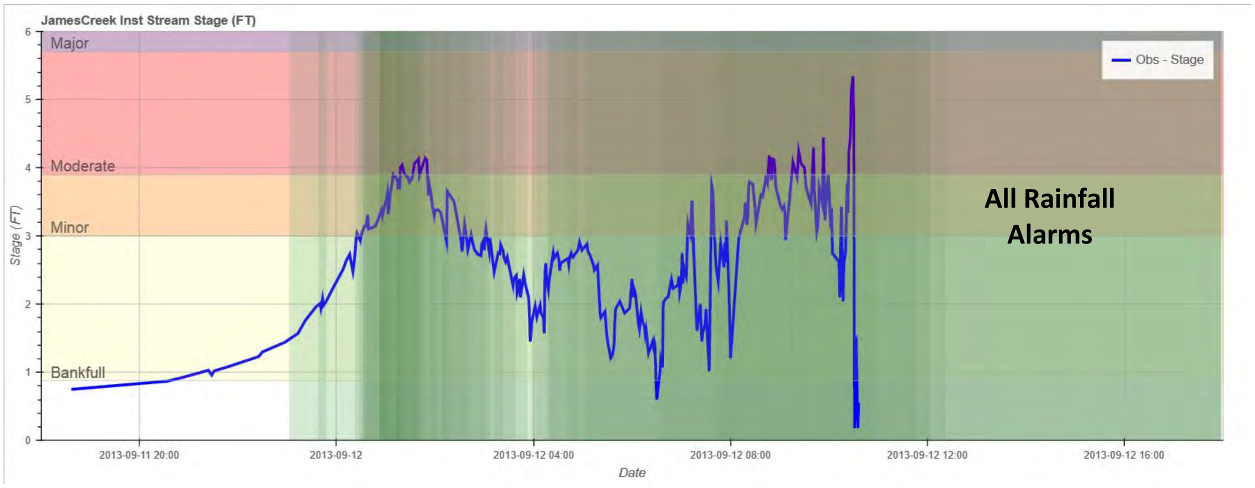


Figure 4-9. September 2013 James Creek observed stage with total binned alarm counts for all accumulation duration periods (green columns)

Results of this initial analysis revealed some clear opportunities for flood alert improvement using the existing rain gauge network; however, to achieve a reliable and adequate flood warning lead time, a more comprehensive evaluation of conditional rainfall alerts is necessary. The conditional alerts would rely on a "if this then that" system of rainfall accumulation data to determine appropriate alert values in real time based on antecedent rainfall data conditions. The mountainous topography and fast hydrologic response nature of James Creek requires a robust system of alert values that can account for different levels of soil saturation while also avoiding frequent false-alarm alerts.

Based on the rain gauge alert analysis, radar derived precipitation estimates and radar storm track estimates are an essential tool to providing adequate warning lead time for Jamestown for a range of storm scenarios. This aligns with the overall approach to flood monitoring performed by the Boulder County OEM team in using early warning storm initiation and subsequent radar storm track/progression tools.

The Lynker team recommends a follow-on task to apply historic radar data to reasonably model rainfall and rainfall-runoff response, and then use this as a foundation to demonstrate how a series of deterministic events can be hydrologically modeled to gain a better understanding of (i) how rainfall-runoff response and high flow timing is influenced by different storms of different magnitude, intensity and direction, and (ii) how a suite of results could be developed using different historical storms or design (possible future) storms, to better understand the timing and threshold scenario response(s) to flooding in the most vulnerable parts of the watershed (i.e. in Jamestown).

If implemented, the above recommendations can produce a tested and refined alert system that the Jamestown community can monitor and be notified ahead of potential flooding conditions during future rainfall events.

5 Site Conditions

5.1 Site Visit Results

On July 21st, personnel from Lynker and OneRain located a single optimal site at each of the four preferential gauge placement clusters identified in the GIS desktop analysis (Overland Road, Walker Mountain, James Creek Headwaters and Basin Centroid). The field team performed field assessments to select gauge sites with acceptable "rainfall catch" (i.e., no trees or structures nearby that would obstruct a view of the sky at a 45-degree angle from vertical). Additionally, radio surveys were conducted to test and validate that any communications equipment installed at each site would function reliably. At all locations, acceptable gauge placement sites were chosen with confirmed radio communication transmissions.

Figure 5-1 shows a map of locations of existing UDFCD gauges, the sites the team selected for assessment, as well as the field sites visited and evaluated for radio communications. Table 5-1 shows final GPS coordinates, elevation, gauge type and comments on communication accessibility. Detailed field notes of GPS coordinates, site photos, parcel information etc. for each of the five site visit locations can be found in Appendix B.

Upon final evaluation of the existing gauge network, site visit analysis, budgetary overview, and communications with emergency management personnel, the Lynker team determined a final recommendation for a new rain gauge location.

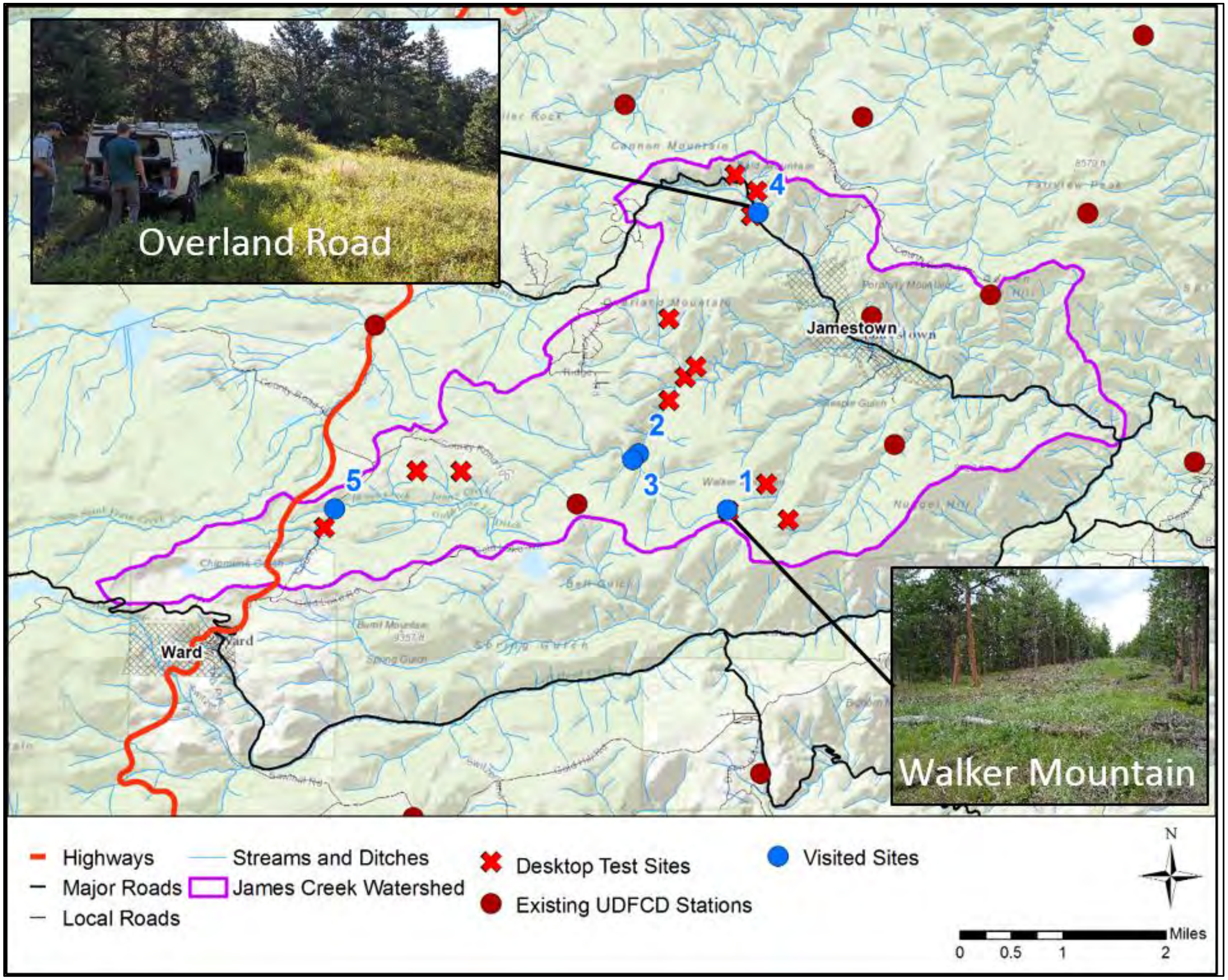


Figure 5-1 Existing Gauges, Proposed Gauges and Sites Visited

Table 5-1. Summary of potential gauge locations identified during the field visits

ID #	Name	Type	UTM E	UTM N	Lat	Long	Elev (ft)	Radio Transmission & Notes
1	Walker Mountain	rain	13T 0464699	4438097	40.092	-105.414	8790	Received all transmissions. Hit 3 repeaters, Lee Hill, Gold Hill, Smoky Hill. Great site location with easy access off of road. Site can be well hidden.
2	Basin Centroid (Lower Site)	rain and stream	13T 0463303	4438974	40.100	-105.431	7976	Received all transmissions. Hit 1 repeater, Lee Hill Site is harder to access. It would be extremely difficult to install a PT at this location. The lack of multiple repeaters is a concern.
3	Basin Centroid (Upper Site)	rain and stream	13T 0463214	4438884	40.099	-105.432	8012	Received all transmissions. Hit 2 repeaters, Lee Hill, Gold Hill Better site for a PT. Still difficult to install, but much easier than lower river section. Site hits 2 repeaters which is a plus. Is a PT needed this far upstream?
4	Overland Road	rain	13T 0465182	4442739	40.134	-105.409	7562	Received all transmissions. Hit 3 repeaters, Lee Hill, Gold Hill, Smoky Hill Great site location with easy access off of road.
5	Chipmunk Gulch	rain	13T 0458561	4438113	40.092	-105.486	8771	Received all transmissions. Hit 2 repeaters, Lee Hill, Gold Hill In small clearing, many houses around. easy access

6 Planning and Design Services

Upon completing a thorough evaluation of the James Creek existing gauge network along with a background examination of the current flood operations monitoring and response within Boulder County OEM, the Lynker team has developed an outline of recommendations for the next phase of this project:

- **Installation of one new rain gauge site located near Walker Mountain**
  - Walker Mountain is located on the southern border of the basin and can help provide optimal lead team for the dominant storm tracks from the south
  - Funding assured for future maintenance through Boulder County OEM
  - Backup rain gauge installation site: Overland Road

- **Develop and implement a series of optimized rainfall thresholds tailored for the Jamestown Community.**
  - Analyze the complete historical record of rainfall and streamflow data for the James Creek region to develop and evaluate a set of rainfall thresholds.
  - Facilitate further refinement to the flood alert communication system between Boulder County OEM and the Jamestown Emergency Response representatives.
  - Evaluate the alert frequency of new/modified thresholds and optimize final alert values to alert needs of Jamestown emergency response protocols.

- **Develop a James Creek hydrologic runoff model to evaluate the watershed's hydrologic response characteristics**
  - Develop the historical GARR data for the James Creek watershed using the existing rain gauge network.
  - Develop and calibrate James Creek distributed/semi-distributed hydrologic model.
  - Evaluate the hydrologic model with historical/design rainfall scenarios to assist with identifying vital storm conditions and watershed response characteristics.

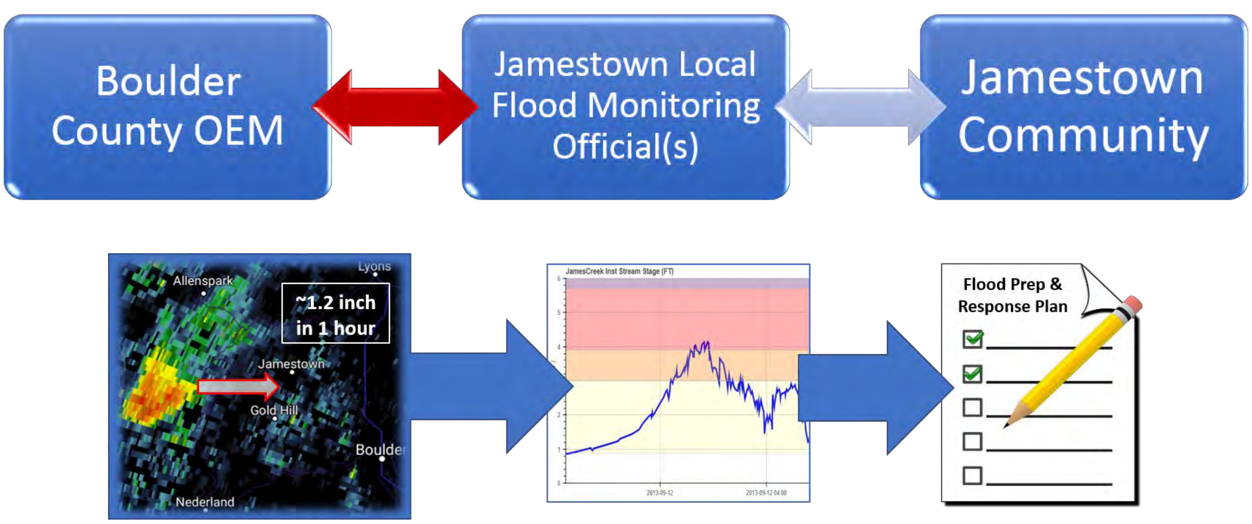


Figure 6-1. Basic overview of the flood alert communication chain (top) and a GARR impact-based threshold tool (bottom).

6.1 Cost estimate for gauge installation

Based on conversations with Boulder County OEM, the current maintenance budget allocation for FY 2017 with regards to this project is $2500. The $2500 annual budget is the current value allocated for a single rain gauge within the county network.

Table 6-1. Gauge equipment, installation, and maintenance cost estimates

Gauge Name	Gauge Type	Priority	Estimated Equipment and Install Cost	Estimated Annual Maintenance Cost	Expected Installation Effort
Walker Mountain	**Rain**	**Moderate**	**$7,500**	**$2,500**	**1 day**
Overland Road	Rain	Moderate	$7,500	$2,500	1 day

6.2 Land ownership for each gauge

Table 6-2 outlines the land parcel information for the primary and backup suggested gauge installation locations. Appendix B also provides a detailed map layout, photographs, and site description from each site visit. The GIS point shapefiles for the gauge installation locations will also be provided with the delivery of the technical report.

Permitting for installation on US Forest Service property will need to be coordinated in cooperation with the Boulder County Office of Emergency Management. Permitting and existing rain gauge land use agreements between Boulder County and USFS are in place; however, permitting information/documentation was not available from Boulder County OEM at the time of this report. Contact information for the appropriate permitting personnel is provided in Appendix E.

Table 6-2. Land ownership parcel summary for the field site visits (data provided by Boulder County)

ID	Name	Parcel Number	Parcel Description	Owner	Sec-Town-Range	Lat	Lon
1	**Walker Mountain**	**132100000023**	**TR, NBR 950 JAMESTOWN AREA**	**U S GOVERNMENT**	**35 - 2N - 72**	**40.092**	**-105.414**
4	Overland Road	132113000119	TR, NBR 950 JAMESTOWN AREA	U S GOVERNMENT	13 - 2N - 72	40.134	-105.409

6.3 General Details and Specifications for Rainfall Gauges

Typical gauge installation pictures and detailed specifications can be found in Appendix F. Note that the expected order, shipment, and delivery timeline for new equipment is typically 1-month.

General specifications for transmission equipment:

- Sensor Input - Analog 0-5 Volt, Pulse Counter, SDI-12
- Data Format - ALERT2 Binary Standard
- Memory - 16GB SD Card for local logging
- Radio Frequency - VHF 136 to 174 Mhz @ 5 watts

- On Board GPS Receiver

General maintenance of Boulder County gauges includes:

- Static and dynamic calibration procedures on tipping buckets.
- Bench testing of transmitters to verify power output and frequency error and deviation.
- Full cyclic charging of all batteries.
- Thorough drying of all desiccant packets used in transmitter enclosures.

Table 6-3, outlines the schedule for traditional preventive maintenance services. This schedule takes into account the required 75-day return cycle as well as the more frequent visits to sites with known power consumption, calibration or clogging issues.

Table 6-3: Preventative Maintenance Schedule (Approximately 75-day Frequency)

Description of Service	2017 Schedule
Round 1 Startup – install sites after winter maintenance	Prior to April 1
Round 2 Weather, stage, and trouble sites	Jun 1-15
Round 3 Supplementary round for rain only sites	July 1-15
Round 4 Weather, stage, and trouble sites	August 1-15
Round 5 Shutdown – sites in for winter maintenance	October 1-15

The Urban Drainage Flood Control District (UDFCD) upgraded their RF ALERT (Automated Local Evaluation in Real Time) backbone to ALERT2 in 2011. This included two repeaters located in Boulder County. ALERT2 is the successor of ALERT and offers 10 times the channel capacity and detects and corrects transmission errors. ALERT2 utilizes TDMA (Time Division Multiple Access) technology where all gauges share the same clock, and only transmit during specific intervals, thus negating all chances of data collisions and corruption.

With the ALERT2 backbone in place, all new gauges installed in Boulder County will utilize this technology to ensure a seamless coupling to the network communication system. Ideally each gauge installed will pass through a minimum of two repeaters providing a redundant data path to the primary receive location. It has been determined that all proposed gauge locations pass through at minimum, two repeaters.

7 References

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Appendix A: Additional Spatial Analysis – Hydrography, Geology, and Geography

An elevation histogram was generated for the study region (Figure 7-1) using the LiDAR data for the James Creek region. This histogram provides an overview of the elevation characteristics for the James Creek watershed region and the data can be used to identify elevation zones that should be represented in the gauge network coverage.

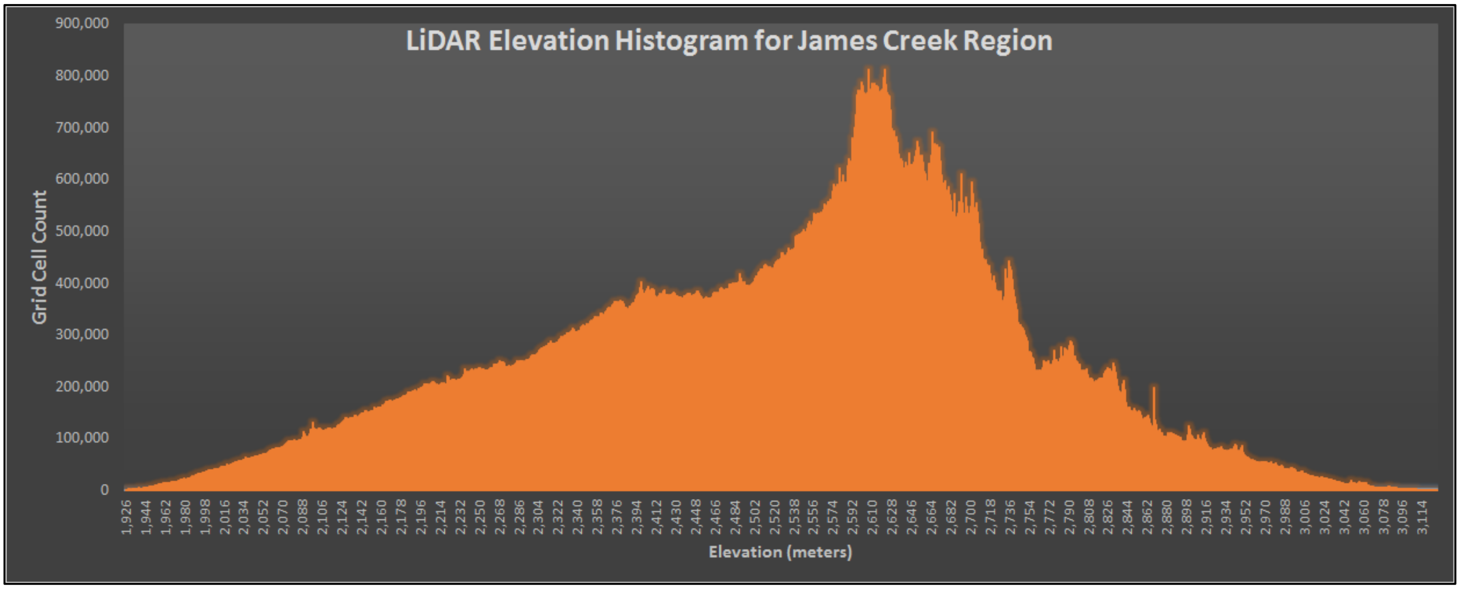


Figure 7-1. LiDAR DEM histogram analysis of the study region

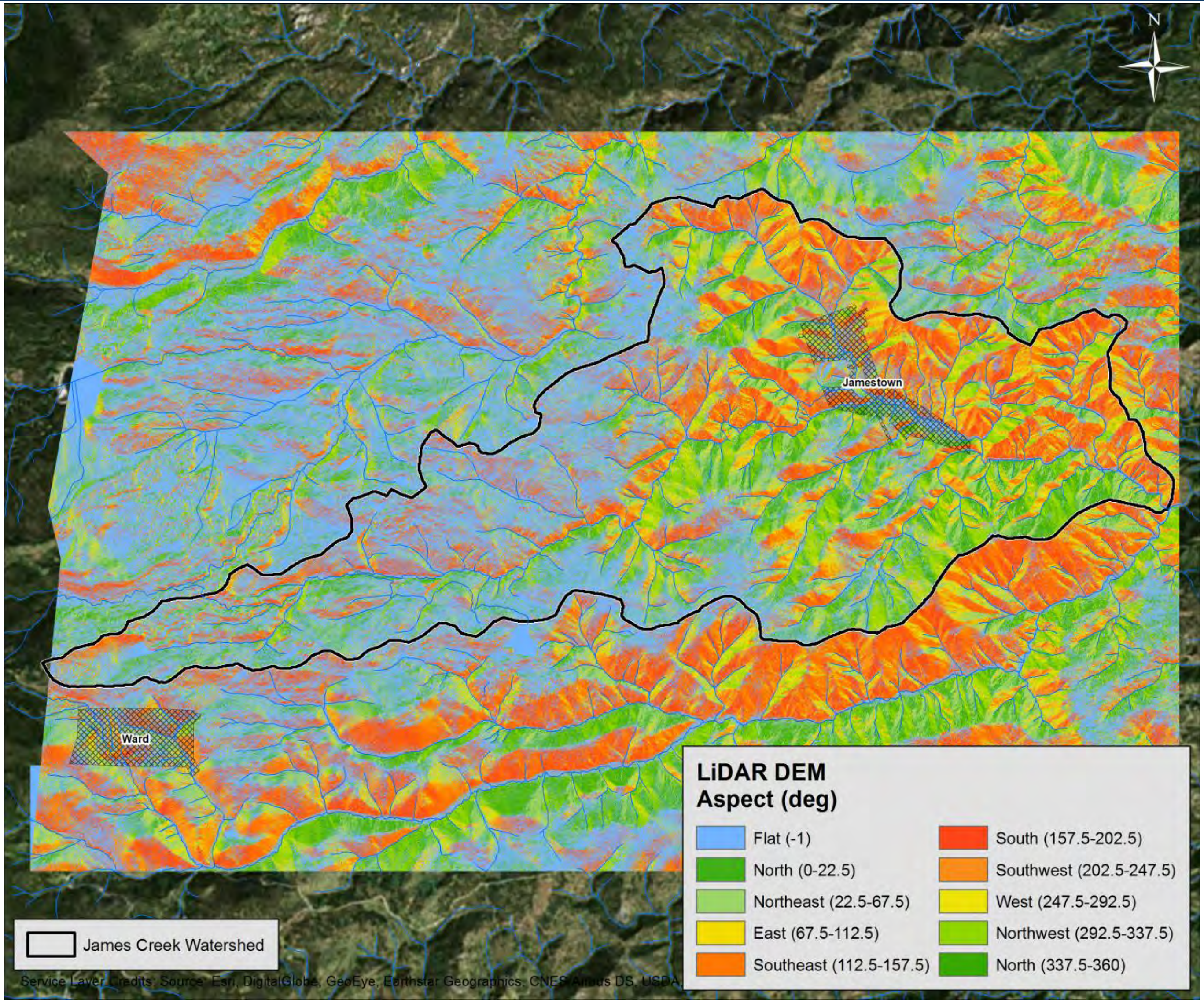


Figure 7-2. LiDAR analysis of the calculated slope aspect

Soil Type Analysis

The Gridded Soil Survey Geographic (gSSURGO) Database (Soil Survey Staff, accessed 2017) was downloaded and processed to examine the soil characteristics within the James Creek watershed. The following table summarizes the "Hydrologic Group – Dominant Conditions" which categorizes the soil coverage based on the runoff potential under similar storm and cover conditions. The James Creek watershed is primarily made up of a combination of the soil types B and D which corresponds to a moderate to very high relative runoff potential throughout the basin (Table 7-1).

Table 7-1. James Creek watershed hydrologic soil type coverage, description, and relative runoff potential.

Soil Type	Basin Coverage (%)	Description	Relative Runoff Potential
A	0.0	sand, loamy sand, or sandy loam	Low
B	47.2	silt loam or loam	Moderate
C	8.6	sandy clay loam	High
D	44.2	clay loam, silty clay loam, sandy clay, silty clay, or clay	Very High

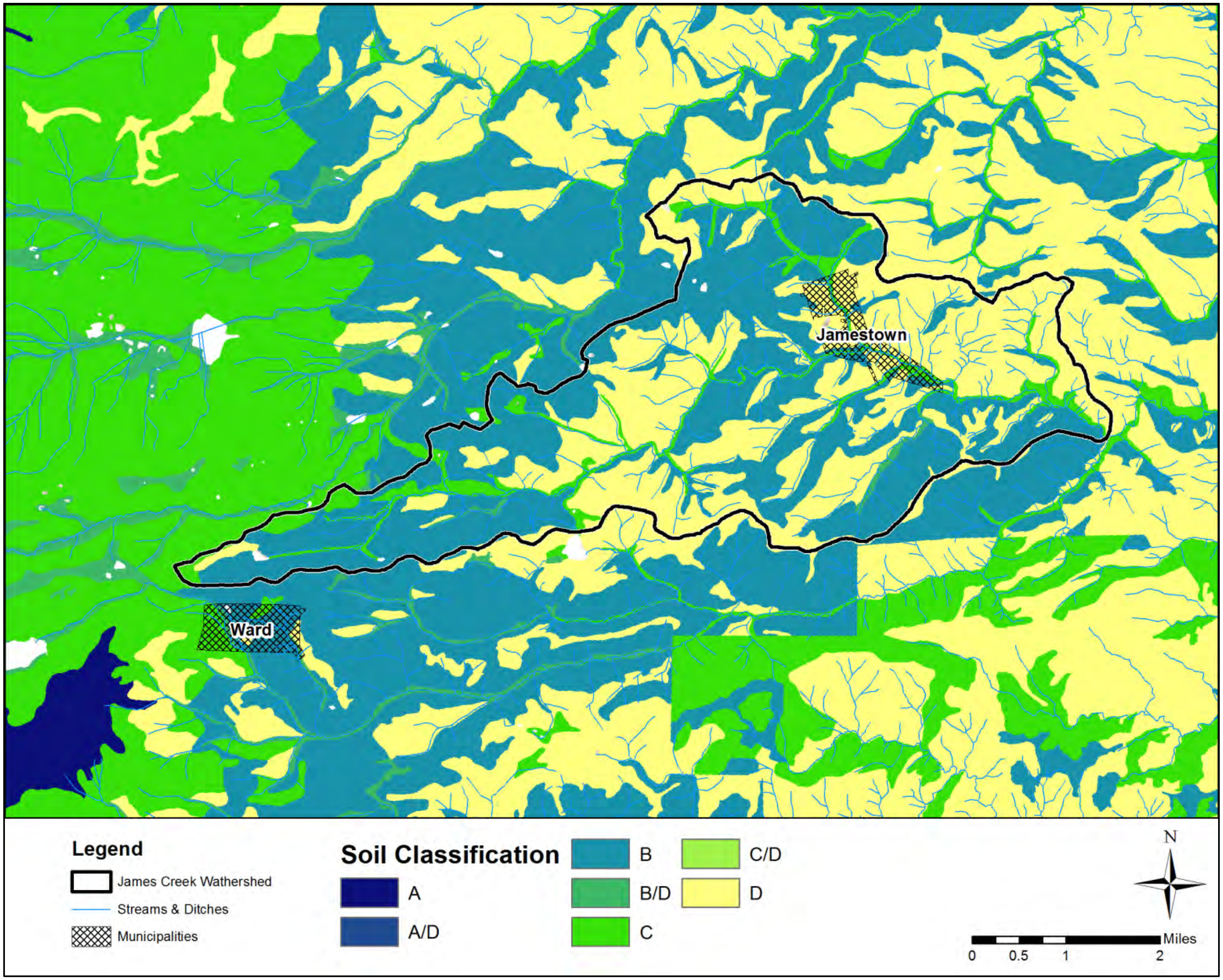


Figure 7-3. gSSURGO overview of the hydrologic soil classifications for the James Creek watershed

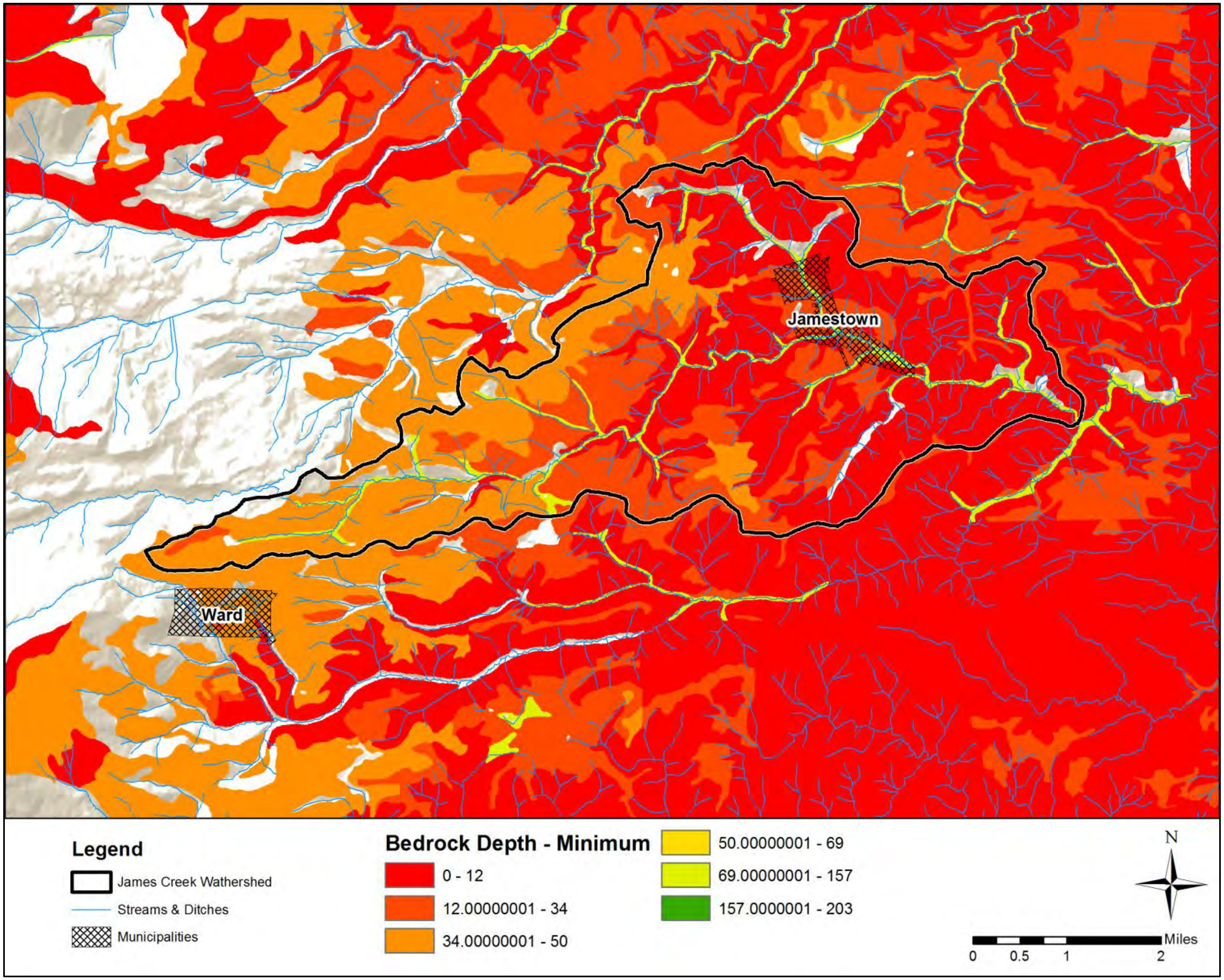


Figure 7-4. gSSURGO overview of the depth to bedrock (depth in cm) for the James Creek watershed

Land Cover Analysis

The 2011 National Land Cover Database (2011 NLCD) provides a 30-meter resolution gridded dataset that classifies land cover into 16 categories for the United States. To better understand the primary land cover features within the James Creek basin, a watershed summary analysis (Table 7-2) was performed using Python/ArcGIS tools developed by Lynker. This analysis provides useful insight to the potential for evaporation, infiltration, and surface runoff over the landscape. Evergreen forest coverage (77%) makes up the clear majority of the total basin land cover with shrub/scrub coverage (14%) the next largest land cover type.

Table 7-2. NLCD 2011 land cover statistical summary for the James Creek watershed

Land Cover Category	James Creek Watershed Coverage (%)
Open Water	0.08
Perennial Snow/Ice	0.00
Developed Open Space	0.37
Developed Low Intensity	0.10
Developed Medium Intensity	0.00
Developed High Intensity	0.00
Barren Land	0.00
Deciduous Forest	4.16
Evergreen Forest	76.89
Mixed Forest	0.24
Shrub/Scrub	13.80
Herbaceous	2.52
Hay/Pasture	0.02
Cultivated Crops	0.00
Woody Wetlands	1.70
Emergent Herbaceous Wetlands	0.10
Total Developed	0.48
Total Forest	81.29

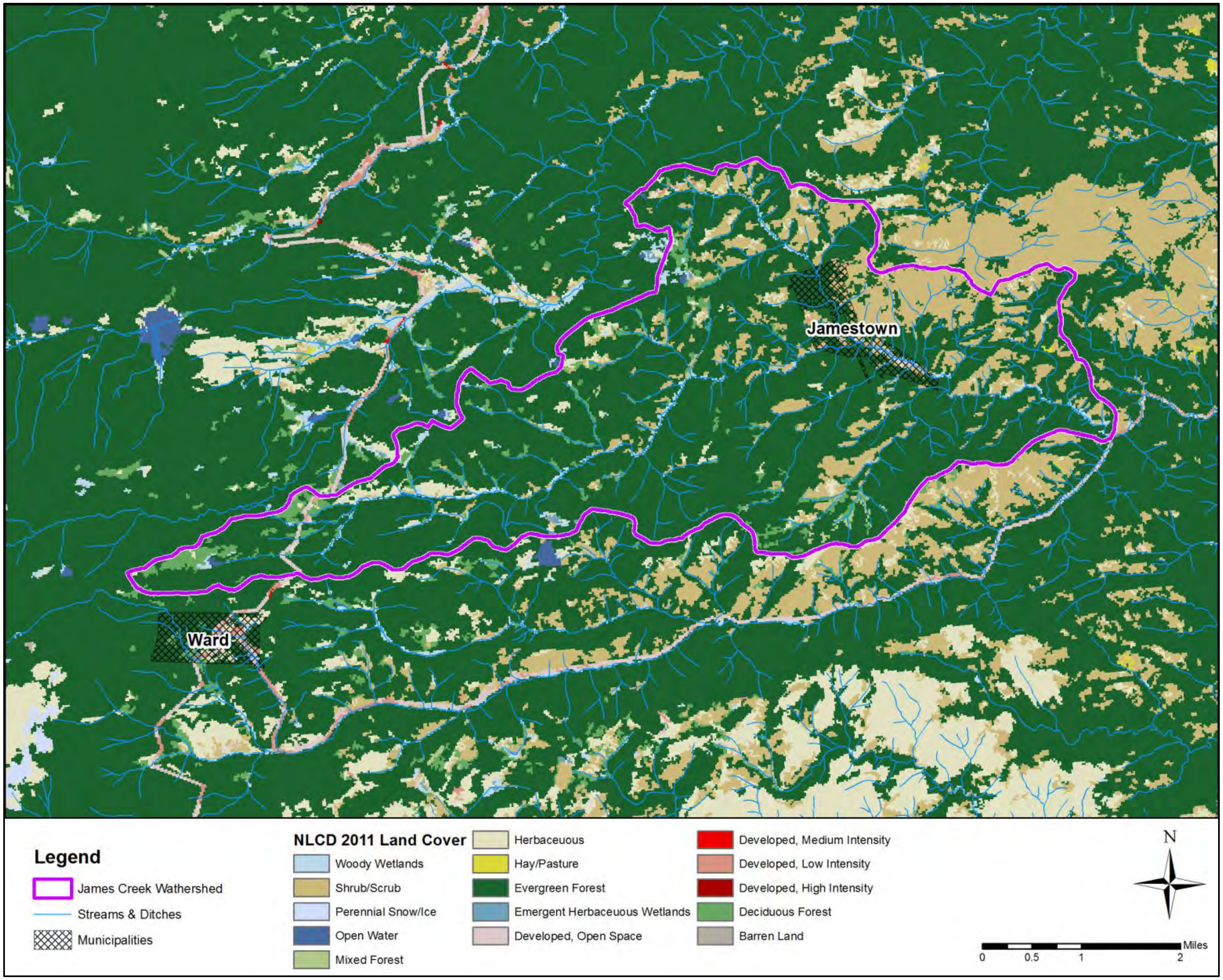
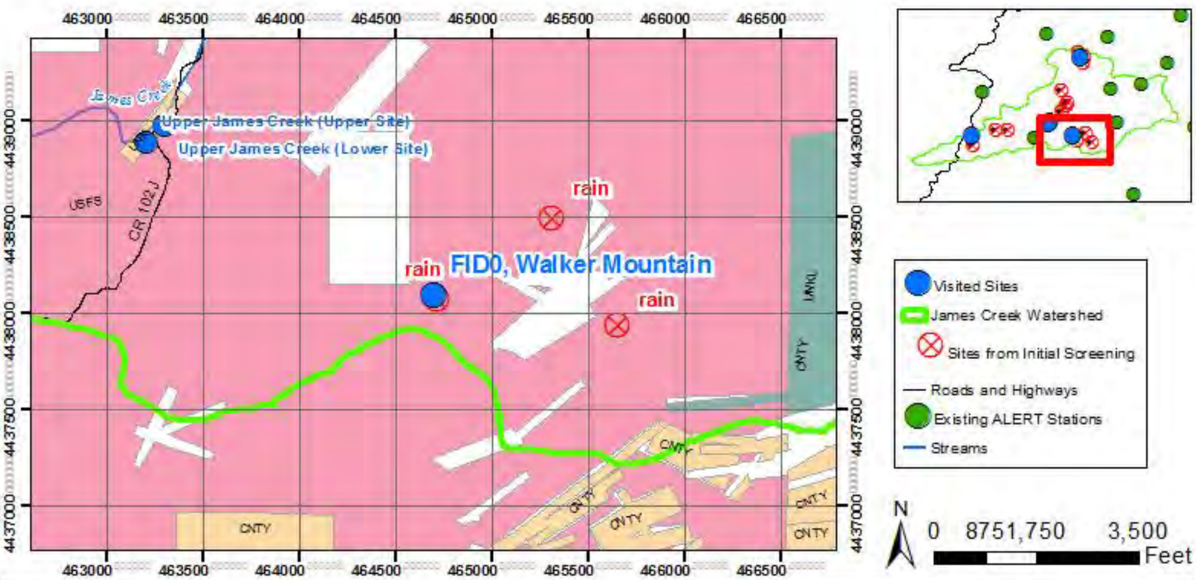


Figure 7-5. NLCD land cover view of the James Creek watershed region

Appendix B: Site Assessment Field Notes



Station FID0
Proposed name:Walker Mountain, type: rain
Lat: 40.094297, Long: -105.414704, Elevation: 8790 ft

Visit Date: 7/21/2017

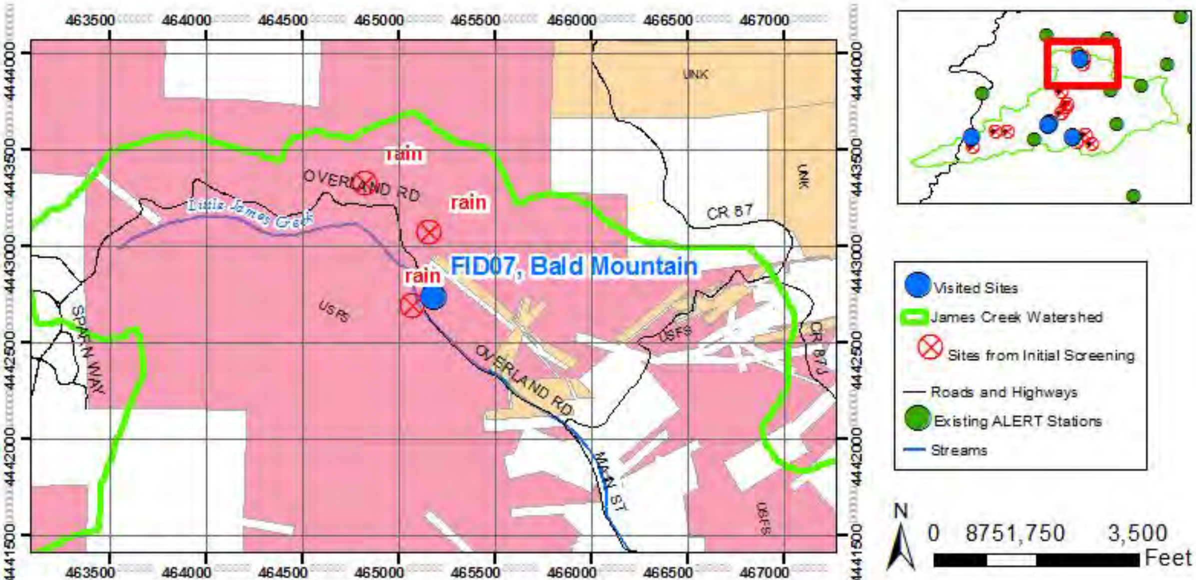
Visited By:Page Weil, Ryan Spies, Scott Bores

Radio Signal Notes:
Received all transmissions. Hit 3 repeaters, Lee Hill, Gold Hill, Smoky Hill. Great site location with easy access off of road. Site can be well hidden.

Other Site Notes:
Ample clearing (possible fire line clearing). Good road access off CR509 (East of Gold Lake). Not visible from road

Looking south at rain gage site

Looking north from rain gage site



Station FID07
Proposed name:Bald Mountain, type: rain
Lat: 40.136139, Long: -105.409288, Elevation: 7562 ft

Visit Date: 7/21/2017

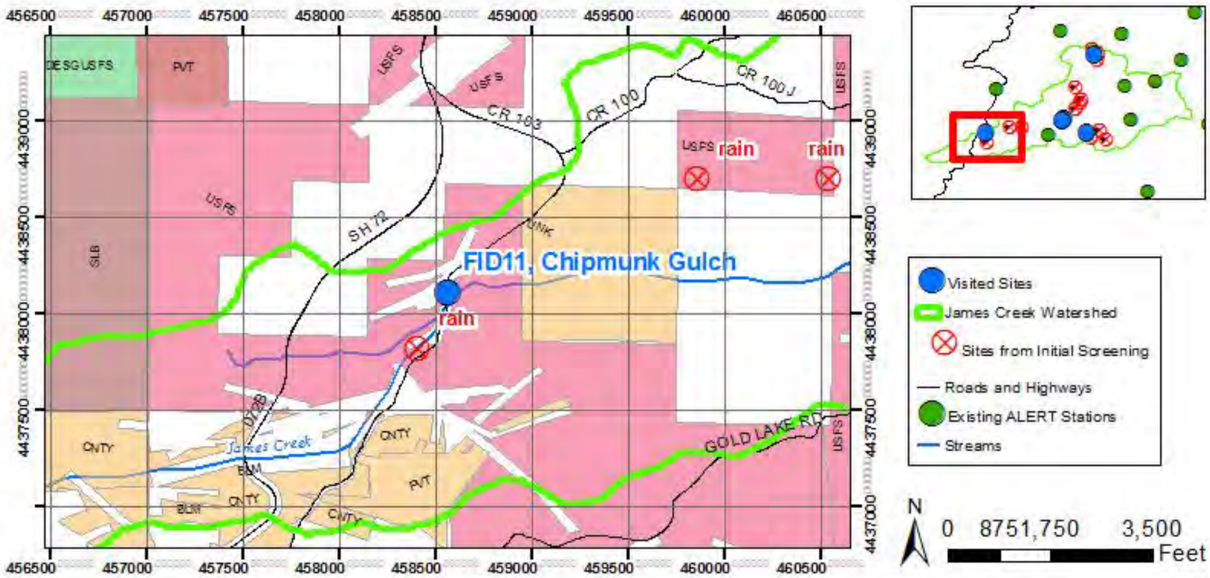
Visited By:Page Weil,
Ryan Spies, Scott Bores

Radio Signal Notes:
Received all transmissions. Hit 3 repeaters, Lee Hill, Gold Hill, Smoky Hill Great site location with easy access off of road.

Other Site Notes:
Approximately 50m east of road, mining road access directly to site, ample clearing (20m radius)

View of site from East

Looking northwest down access road



Station FID11
Proposed name:Chipmunk Gulch, type: rain
Lat: 40.094161, Long: -105.486709, Elevation: 8771 ft

Visit Date: 7/21/2017

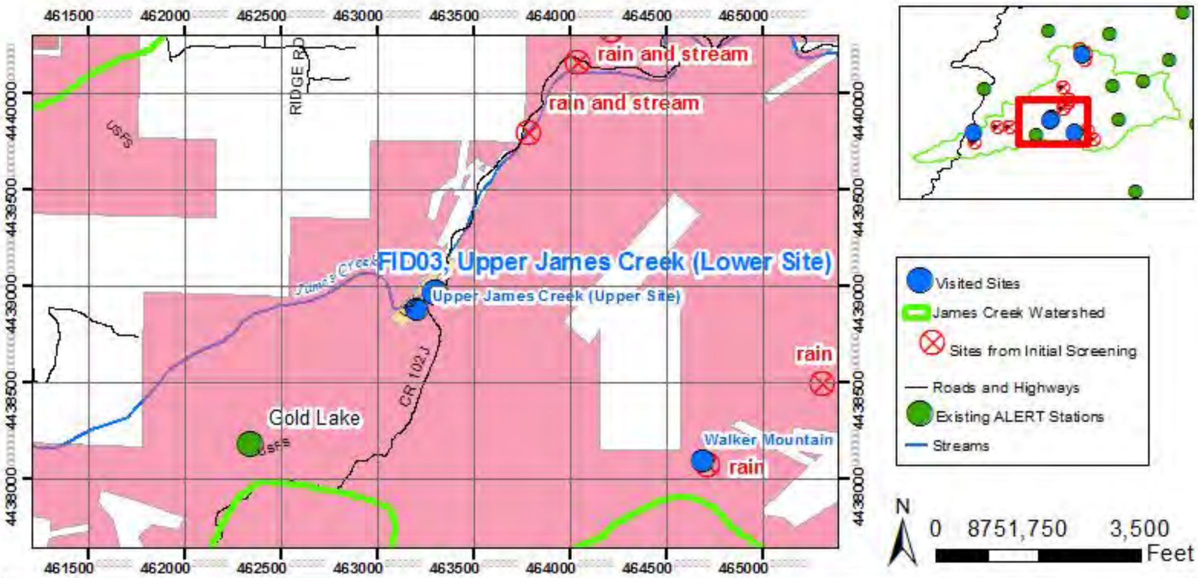
Visited By:Page Weil, Ryan Spies, Scott Bores

Radio Signal Notes:
Received all transmissions. Hit 2 repeaters, Lee Hill, Gold Hill In small clearing, many houses around. easy access

Other Site Notes:
Easy road access (CR100), Grove of aspen trees to prevent visibility from road, private land and houses nearby, check parcel ownership, located directly north of James Creek Channel

Looking west at rain gage site

Looking east at rain gage site



Station FID03
Proposed name:Upper James Creek (Lower Site), type: rain and stream
Lat: 40.102139, Long: -105.43113, Elevation: 7976 ft

Visit Date: 7/21/2017

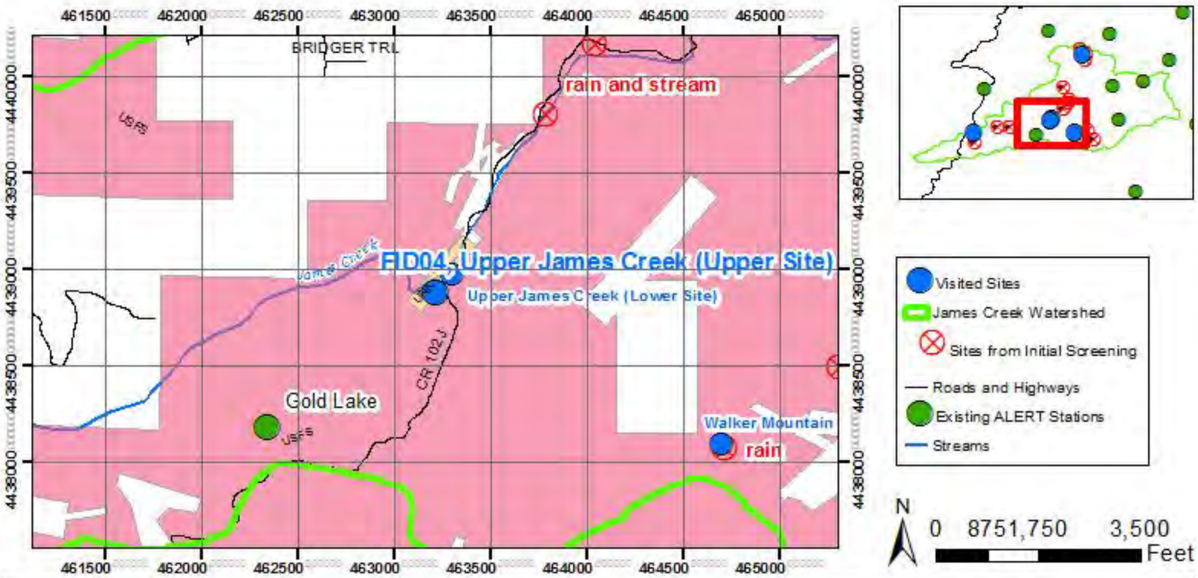
Visited By:Page Weil, Ryan Spies, Scott Bores

Radio Signal Notes:
Received all transmissions. Hit 1 repeater, Lee Hill Site is harder to access. It would be extremely difficult to install a PT at this location. The lack of multiple repeaters is a concern.

Other Site Notes:
Least accessible road location on CR102J, potential for stream gage, Ample clearing next to road for rain catchment, relatively active mining site 20m upslope on the north side of channel, Need to confirm land ownership

Stream channel at stream gage site

Looking east at rain gage site



Station FID04
Proposed name:Upper James Creek (Upper Site), type: rain and stream
Lat: 40.101324, Long: -105.432169, Elevation: 8012 ft

Visit Date: 7/21/2017

Visited By:Page Weil, Ryan Spies, Scott Bores

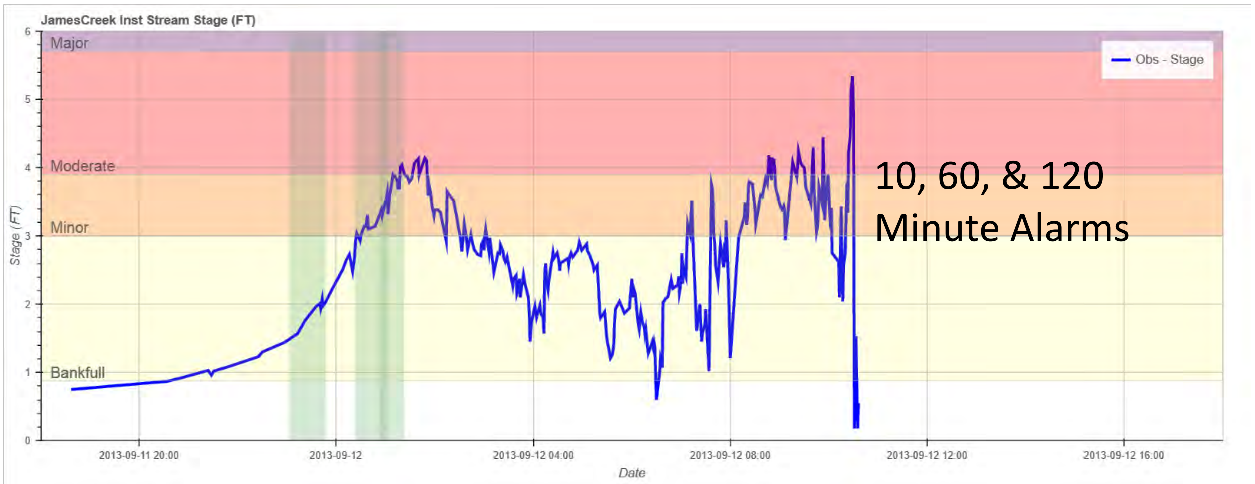
Radio Signal Notes:
Received all transmissions. Hit 2 repeaters, Lee Hill, Gold Hill Better site for a PT. Still dicicult to install, but much easier than lower river section. Site hits 2 repeaters which is a plus. Is a PT needed this far upstream?

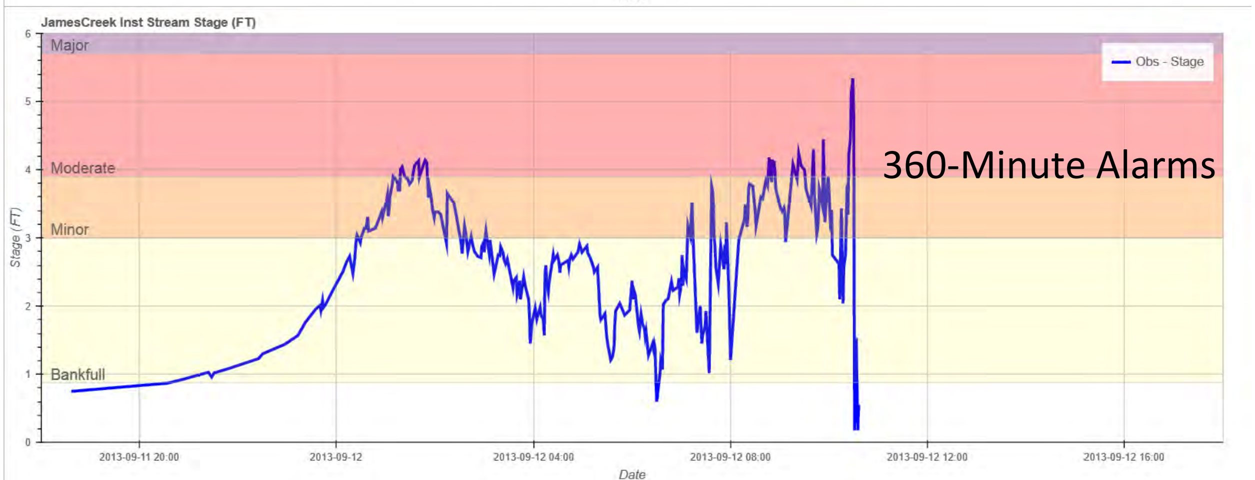
Other Site Notes:
CR102J road access (Forest Service gate key needed), Aple clearing for rain catchment, better location than FID03 for stream gage, stream banks less steep (installation is easier), lower gradient stream (easier rating)

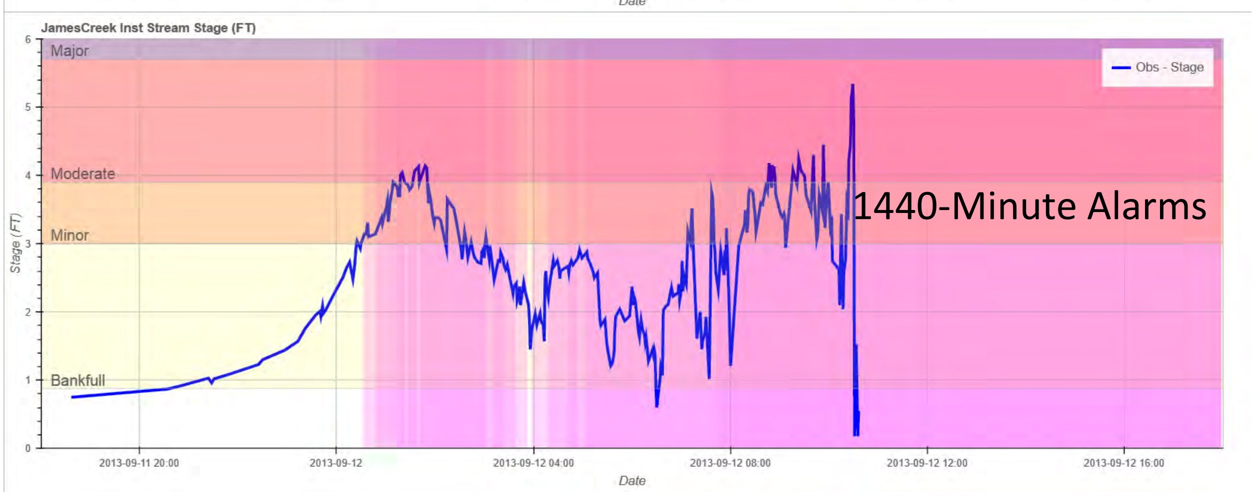
Looking west towards rain gage site

Stream channel near stream gage site

Appendix C: UDFCD Default Rainfall Duration Threshold Exceedance Plots







Appendix D: Debris Flow Triggering Review

Lynker Technologies examined the latest literature on debris flow initiation in the James Creek basin. A recent USGS study reveals that “rainfall on 9–13 September 2013 triggered at least 1,138 debris flows in a 3430 km^2 area of the Colorado Front Range.” These debris flows caused significant property damage and loss of life in the James Creek basin specifically. The project team reviewed the various triggering mechanisms for these debris flows to provide insight into how to prepare for and potentially mitigate this hazard. Figure 7-8 shows an elevation map of the James Creek basin overlaid with the locations of all documented debris flows that occurred during the September 2013 floods.

In the USGS paper (Coe 2014), the authors examined 27 debris flows that were documented in terms of exact time and location. Figure 7-6 shows the amount of rainfall at the station closest to the debris flow and at what time the debris flow was triggered. In all cases, debris flows did not trigger until the cumulative rainfall exceeded 120 mm starting from 9/11/13. Cumulative gauged precipitation prior to debris flow triggering ranged from 120mm to almost 350mm. This highlights how condition-dependent debris flows can be.

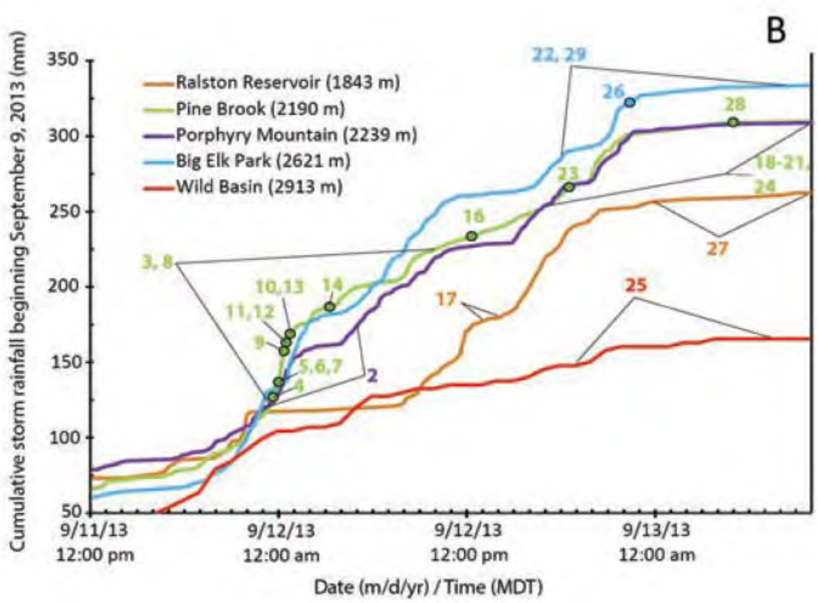


Figure 7-6. Debris Flows shown with Cumulative Rainfall at Adjacent Gauge

Debris flows are a complicated phenomenon with many factors contributing to the risk of occurrence including soil saturation, precipitation intensity, local geology and soils characteristics, slope angle, slope aspect and elevation to name a few. Using data obtained in Coe, 2014, Lynker conducted an analysis of slope and aspect of landslides triggered during the 2013 flood event. Figure 7-7 shows the occurrence of all recorded landslides during the 2013 flood event based on slope angle and aspect. The top plot shows all 1,350 landslides recorded by the USGS; darker blue represents more landslides at a particular slope angle and aspect. Darker red on the Y-axis represents more landslides in a particular range of slope aspects only. Darker orange on the X-axis represents more landslides in a particular range of slope angles. The bottom plot is presented in the same format, but it only uses the 86 landslides that were recorded within the James Creek Watershed.

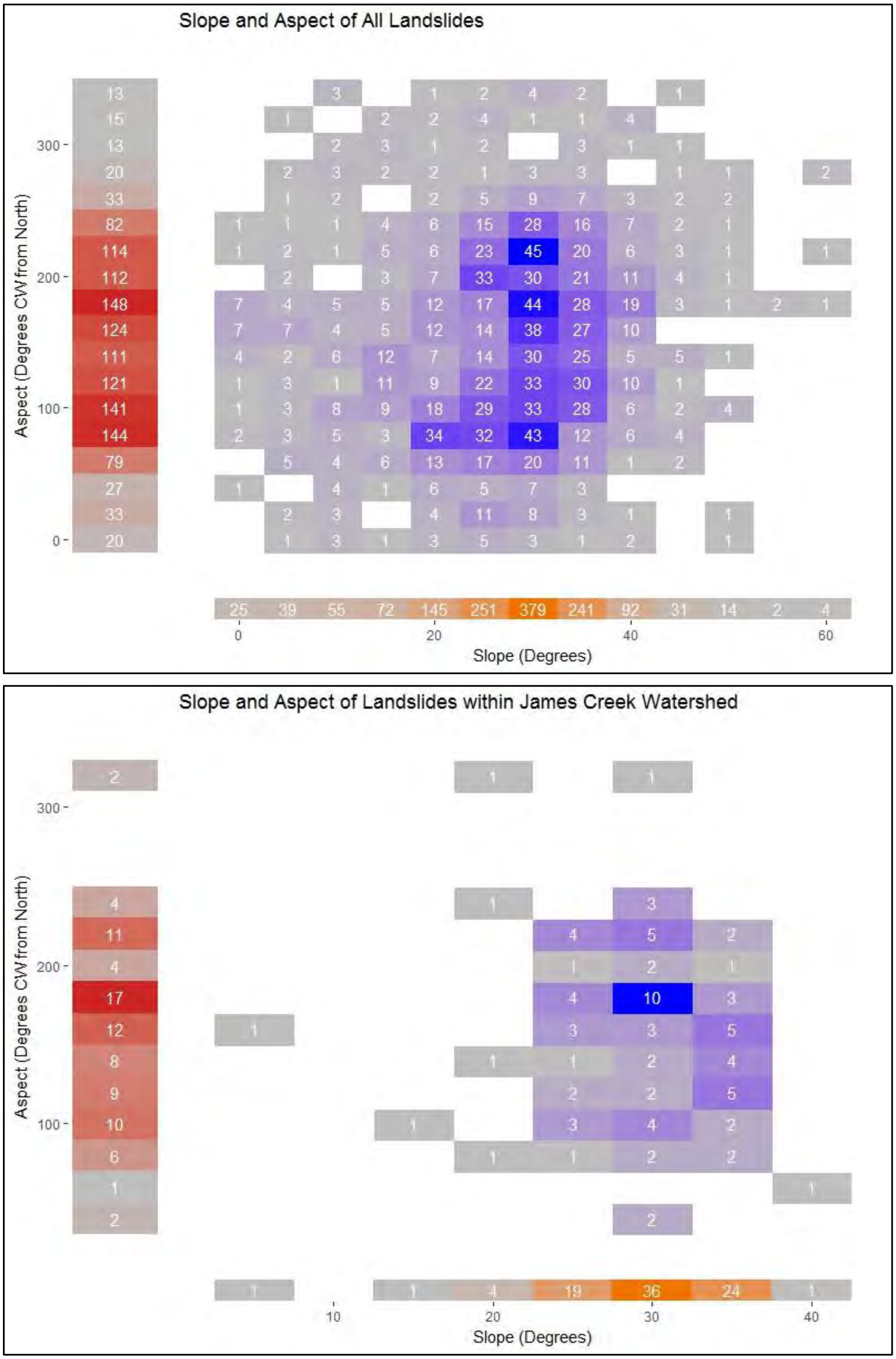


Figure 7-7 Prevalence of Landslides by Slope Angle and Aspect for all September 2013 events (top) and within the James Creek Basin (bottom).

Based on a statistical analysis of the landslides within the Jamestown watershed, we found that 90% of the slides occurred between a range of 22.2 and 39 degrees slope angle and between 86.3 (East) and 246 (Southwest). Figure 7-9 shows the location of all recorded debris flows in and around the James Creek watershed with slopes and aspects highlighted where 90% of all slides occurred. While there are many other aspects that trigger debris flows, it is worth noting that the majority of slopes immediately north of the Town of Jamestown fall within the highlighted range.

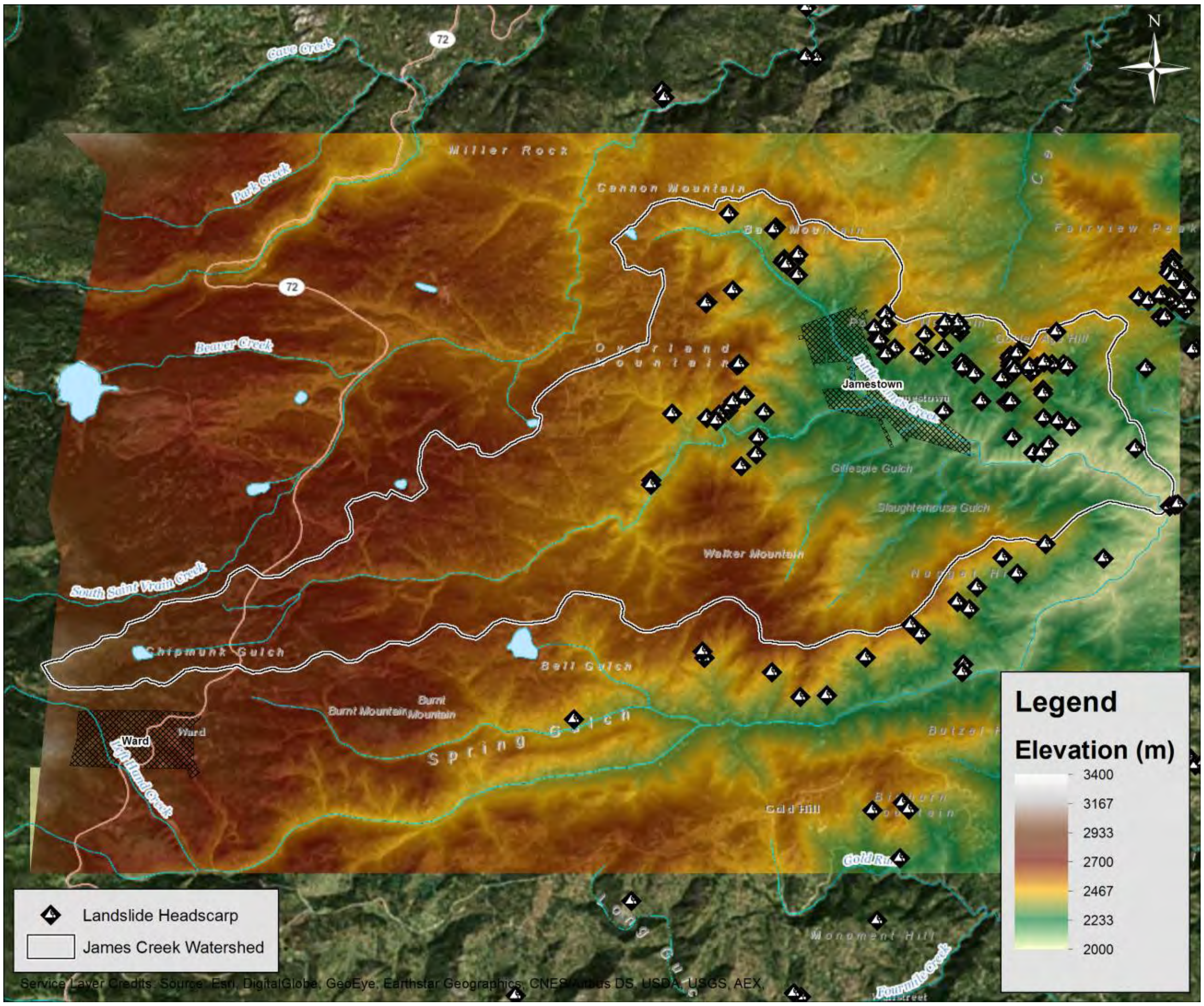


Figure 7-8. Debris flow locations identified within the James Creek basin region (Coe et al, 2014)

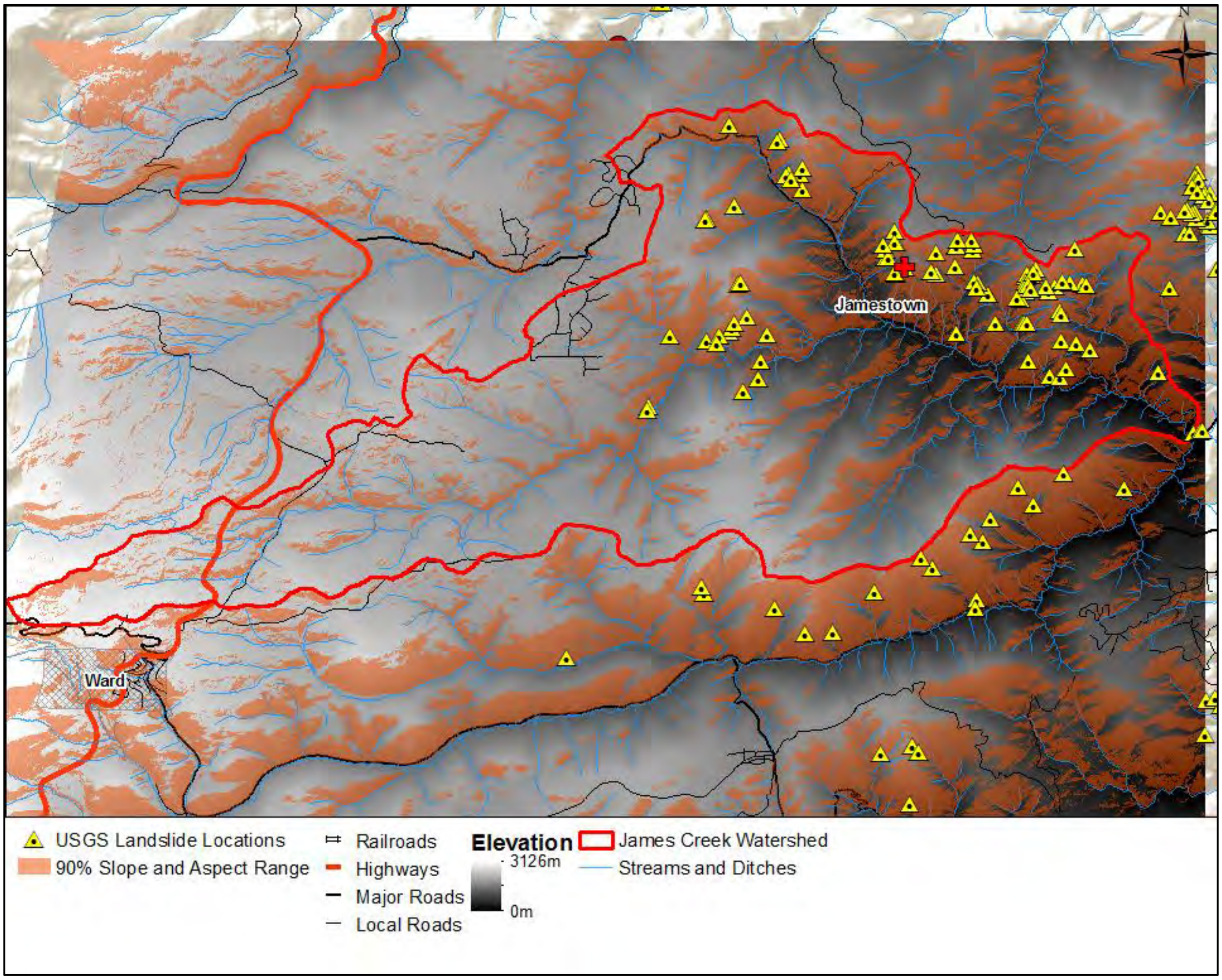


Figure 7-9. Debris Flow Locations and Slopes and Aspects Highlighted where 90% of Debris Flows Occurred

Appendix E: Permits and Approvals

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USFS Special Use Permitting Forms Website:
https://www.fs.fed.us/r2/recreation/special-use/forms/index.shtml
Special Use Permit Form (Noncommercial Group Use):
https://www.fs.fed.us/r2/recreation/special-use/forms/new-forms/fs-2700-4.pdf

Appendix F: Detailed Transmitter Specifications – Recommendations

Sensor Inputs	6 analog, 2 precipitation, 2 shaft encoder, and 2 SDI-12, wind. Battery Voltage and Wind Gust (if wind sensor is enabled) are internal sensors which use one of the available analog inputs)
Total Number of Sensors	Up to 20
Analog Resolution	12 bits (0.0012 V)
Sampling Interval	0 seconds to 18 hrs, programmable
Reporting Modes	Timed-defined and/or event
Reporting Interval	0 seconds to 596523 hrs, programmable
Event Change to Report	0 to 65535 counts
Reporting Override Value	0 to 65535 counts
Data Logging Modes	Timed-defined and/or on transmission
Data Logging Interval	0 seconds to 596523 hrs, programmable
Data Format	ALERT2 Binary Standard
Recorded Data	Integer or floating point
Record size	9 bytes/record (integer sensor type) or 11 bytes/record (float sensor type), 1 file per month containing all sensors
Memory	16GB SD Card
Real Time Clock	Clock/Calendar with on-board Battery Back Up with Leap Year Correction, Syncs with GPS
Transmission Baud Rate	4800
TDMA	
Slot Size	Selectable: 0.5, 1, 1.5, 2.5, 3, and 5 Seconds
Frame Size	Selectable: 15, 30, 45, 60, 90, and 120 Seconds
On-Board GPS Receiver	
Sensitivity	< -163 dBm
Channels	48
GPS Connector	Reverse SMA Female
Radio Frequency Range	VHF 136 to 174 Mhz @ 5W, UHF and other bands available
Operating Voltage	12 to 18 VDC
Current Draw	
Battery	12 VDC, 12 AHr
Lightning Protection	Standard on all inputs
Input Connector	MS
Antenna Connector	BNC
Solar Panel Connector	Standard 3-PIN MS
Enclosure	Aluminum Canister
Operating Temperature Range	-40° to 140° F (-40° to 60° C)
Storage Temperature Range	-58° to 158° F (-50° to 70° C)
Dimensions	7x17 inch (17.8x43.2 cm) Dia.xL
Weight	9 lbs (4.1 kg)
Shipping Weight	10 lbs (4.5 kg)
Warranty	3 Years from date of shipment

Photo of the Slaughterhouse rain gauge instrument located within the James Creek watershed.