Final Report

Little Thompson River Hydrologic Analysis

Phase 2: Little Thompson River above

Big Thompson River

Prepared for

Colorado Department of Transportation

June 10, 2015

CH2MHILL®

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Acronyms and Abbreviations

AMC	Antecedent Moisture Condition
AWA	Applied Weather Associates
CDOT	Colorado Department of Transportation
CDWR	Colorado Division of Water Resources
cfs	cubic feet per second
CN	curve number
CWCB	Colorado Water Conservation Board
DARF	depth-Area reduction factor
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GIS	geographic information system
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
I-25	Interstate 25
LiDAR	Light Detection and Ranging
LULC	Land Use and Land Cover
NED	National Elevation Dataset
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
PMR	Physical Map Revision
QC	quality control
SCS	Soil Conservation Service
SH	State Highway
SPAS	Storm Precipitation Analysis System
US 36	U.S. Route 36
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

I hereby affirm that this report and hydrologic analysis for the Little Thompson River was prepared by me, or under my direct supervision, for the owners thereof, in accordance with the current provisions of the *Colorado Floodplain and Stormwater Criteria Manual*, and approved variances and exceptions thereto.

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Executive Summary

In late summer 2013, the Colorado Front Range experienced an extensive rainstorm event spanning approximately 10 days from September 8 to September 18. The event generated widespread flooding as the long-duration storm saturated soils and increased runoff potential. Flooding resulted in substantial erosion, bank widening, and realigning of stream channels; transport of mud, rock, and debris; failures of dams; landslides; damage to roads, bridges, utilities, and other public infrastructures; and flood impacts to many residential and commercial structures. Ten fatalities were attributed to the floods.

During and immediately following the rainstorm event, the Colorado Department of Transportation (CDOT) engaged in a massive flood response effort to protect the traveling public, rebuild damaged roadways and bridges to get critical travel corridors open again, and engage in assessments and analyses to guide longer-term rebuilding efforts. As part of this effort, CDOT partnered with the Colorado Water Conservation Board (CWCB) to initiate hydrologic analyses in several key river systems impacted by the floods. The work was contracted to three consultant teams led by the following firms:

Boulder Creek, Little Thompson River	CH2M HILL
Big Thompson River, St. Vrain Creek, Lefthand Creek	Jacobs
Coal Creek, South Platte River	URS

The purpose of the analyses is to ascertain the approximate magnitude of the September flood event in key locations throughout the watershed and to prepare estimates of peak discharge that can serve to guide the design of permanent roadway and other infrastructure improvements along the impacted streams. These estimates of peak discharges for various return periods will be shared with local floodplain administrators for their consideration in revising or updating any current regulatory discharges.

The primary tasks of the hydrologic analyses include:

1. Estimate peak discharges that were believed to have occurred during the flood event at key locations along the study streams. Summarize these discharges along with estimates provided by others in comparison to existing regulatory discharges. Document the approximate return period associated with the September flood event based on current regulatory discharges.
2. Prepare rainfall-runoff models of the study watersheds, input available rainfall data representing the September rainstorm, and calibrate results to provide correlation to estimated peak discharges.
3. Prepare updated flood frequency analyses using available gage data and incorporate the estimated peak discharges from the September event.
4. Use rainfall-runoff models to estimate predictive peak discharges for a number of return periods based on rainfall information published by the National Oceanic and Atmospheric Administration (NOAA) (NOAA Atlas 14, Volume 8, Updated 2013; NOAA, 2013a). Compare results to updated flood frequency analyses and unit discharge information, and calibrate as appropriate.

The hydrologic analyses were divided into two phases of work. Phase 1 focused on the mountainous areas in the upper portion of the watersheds, extending from the upper divides of the Big Thompson River, Little Thompson River, St. Vrain Creek, Lefthand Creek, Coal Creek, and Boulder Creek watersheds to the mouth of their respective canyons. The Phase 1 analyses have been documented in six reports with the following titles and dates:

1. Hydrologic Evaluation of the Big Thompson Watershed, August 2014
2. Little Thompson River Hydrologic Analysis Final Report, August 2014
3. Hydrologic Evaluation of the St. Vrain Watershed, August 2014
4. Hydrologic Evaluation of the Lefthand Creek Watershed, August 2014, revised December 2014

5. Coal Creek Hydrology Evaluation, August 2014
6. Boulder Creek Hydrologic Evaluation Final Report, August 2014

Copies of these Phase 1 reports can be downloaded from the CWCB website at the following link:

http://cwcb.state.co.us/water-management/flood/pages/2013floodresponse.aspx

Phase 2 of the hydrologic analyses focused on the plains region of the Big Thompson River, Boulder Creek, Little Thompson River, and St. Vrain Creek from the downstream limit of the Phase 1 studies at the mouth of the canyons to the downstream confluences of the watersheds with their respective receiving streams. The hydrologic analyses were contracted to two consultant teams led by the following firms:

Boulder Creek, Little Thompson River	CH2M HILL
Big Thompson River, St. Vrain Creek	Jacobs

Phase 2 hydrologic analyses for each of the watersheds included flows from the original Phase 1 watersheds, as appropriate: the downstream reach of the Big Thompson River was modeled to include flows from the Little Thompson River. Likewise, the downstream reach of St. Vrain Creek included flows from Lefthand Creek and Boulder Creek, with Boulder Creek in turn receiving flows from Coal Creek.

This report documents the Phase 2 hydrologic evaluation for the Little Thompson River.

As part of the evaluation, CH2M HILL developed a rainfall-runoff model to transform the recorded rainfall to stream discharge using the U.S. Army Corps of Engineers' (USACE's) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) hydrologic model. The hydrologic model was calibrated through adjustment sof model input values that represent land cover and soil conditions. The calibration of these parameters is common because they take into account vegetative cover, soil structure, topography, land use history, and other considerations that are not easily accessible using aerial imagery. The extent of the Little Thompson River Watershed study area and physical-based observation locations is presented in **Figure ES-1**. A comparison of observed discharges and the discharges of the calibrated model is presented in **Table ES-1**.

TABLE ES-1
Little Thompson River Comparison of Modeled Discharges to Observed Discharges

Site Number	HMS Node	Location	Drainage Area (square miles)	Observed Peak Discharge (cfs)	Modeled Peak Discharge (cfs)	% Difference
N/A	LT-J6	Little Thompson River at X Bar 7 Ranch	81.8	15,731	14,300	-9%
LT-2	LT-J10	Little Thompson River at South County Line Road	132.1	13,400	15,500	16%
LT-3	LT-J12	Little Thompson River at Interstate 25	165.9	15,700	15,200	-3%
LT-4	LT-J13	Little Thompson River at County Road 17	186.5	18,000[a]	14,900	-17%

[a] Bridge overtopped (URS, 2015).

The calibrated model was modified to estimate the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges (10-, 25-, 50-, 100-, and 500-year events, respectively, for purposes of this Executive Summary[1])

[1] While the term "100-year event" and similar terminology are used in this Executive Summary to better relate the magnitude of the September 2013 event to the general public, it is not an event that occurs explicitly once every 100 years, but rather an event that has a 1 percent chance of occurring in any given year. Thus, a 100-year event could happen in back-to-back years, or not at all for 200 years. For this reason, the current FEMA standard is to refer to the "100-year event" as the "1-percent annual chance event" and it is important for the reader to note that the labeling of the September 2013 event as a 50-year event, or other recurrence interval, does not preclude the future occurrence of a similar, or greater, flood in the that corresponding timeframe.

based on a 24-hour Soil Conservation Service (SCS, now the Natural Resources Conservation Service [NRCS]) Type II Storm and recently released 2014 NOAA Atlas 14 rainfall values (NOAA, 2014). The modeled discharges were then compared to previous and concurrent alternative estimates of annual chance peak discharges. The assumptions and limitations of the various methodologies were closely reviewed, compared, and contrasted. The predictive model developed as part of the current study is proposed as the appropriate model to revise high-flow hydrology along the Little Thompson River downstream of U.S. Route 36 (US 36) to the confluence with the Big Thompson River. These recommended values are shown in **Table ES-2** and provided graphically in **Figure ES-2**. With this recommendation, the peak discharges observed along the Little Thompson River during the September 2013 storm event had an estimated recurrence intervals between the 2 percent annual chance peak discharge, or a 50-year storm event, and the 0.2 percent annual chance peak discharge, or a 500-year storm event.

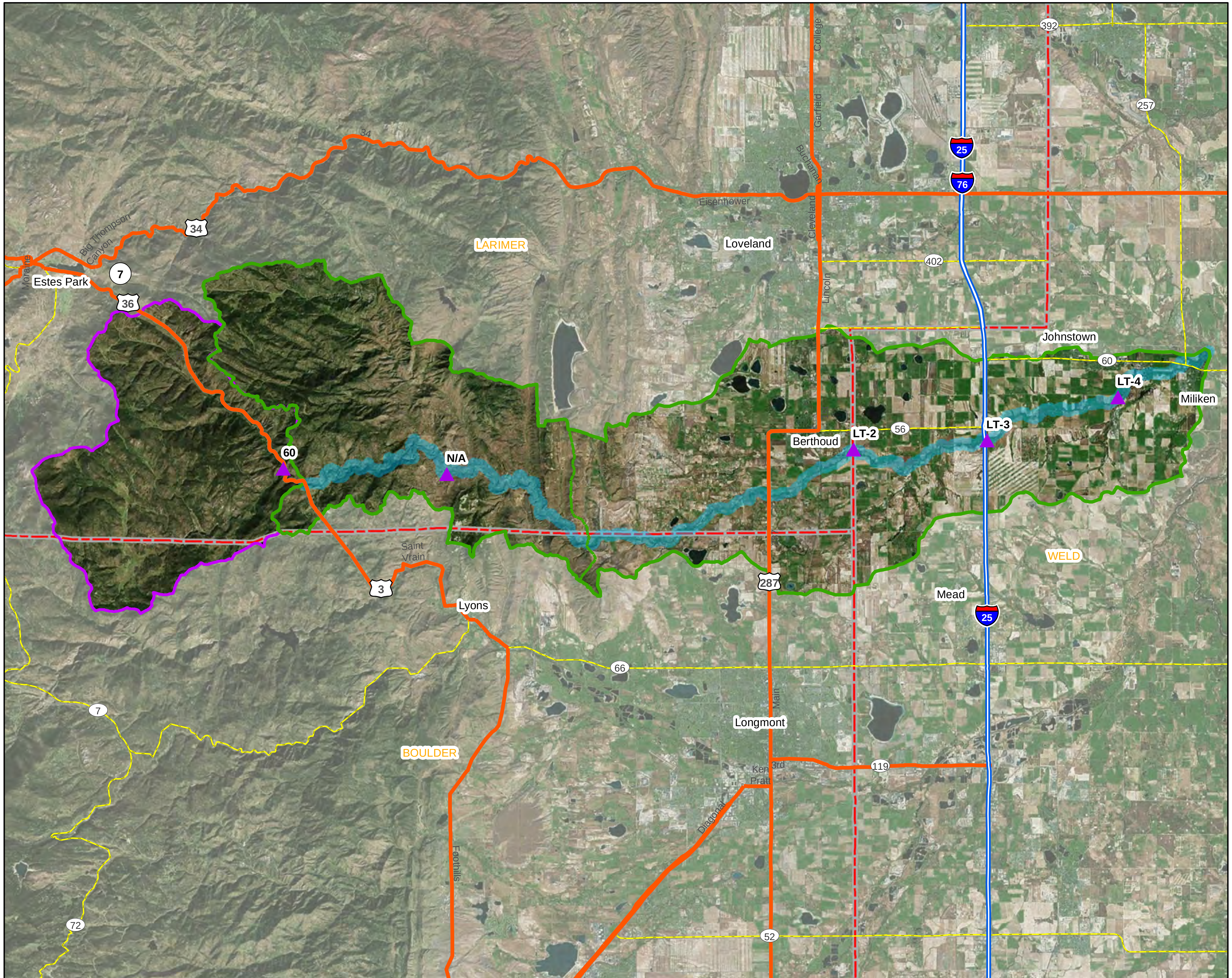
TABLE ES-2
Estimate of the Recurrence Interval of the September 2013 Event

		Predictive Annual Chance Peak Discharge (cfs)					
Location	**Observed Discharge (cfs)**	**10 percent**	**4 percent**	**2 percent**	**1 percent**	**0.2 percent**	**Estimated Recurrence Interval (yr)**
Little Thompson River at X Bar 7 Ranch	15,731[a]	2,310	4,500	6,970	10,200	20,700	100 to 500
Little Thompson River at LTCANYO Gage	15,500[b]	2,760	5,380	8,330	12,100	24,700	100 to 500
Little Thompson River at South County Line Road	13,400[c]	3,650	6,940	10,600	15,300	30,800	50 to 100
Little Thompson River at Interstate 25	15,700[c]	4,140	7,090	10,900	16,000	33,500	100
Little Thompson River at County Road 17	18,000[c]	4,480	7,150	10,700	15,700	32,100	100 to 500
Little Thompson River Upstream of Confluence with Big Thompson	14,700[b]	4,450	7,130	10,500	15,400	31,400	100

[a] Per CDWR, 2014.

[b] Per Calibrated Hydrologic Model.

[c] Per URS, 2015.



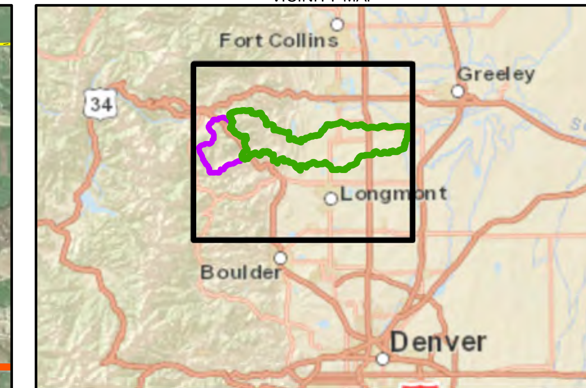


FIGURE ES-1
Little Thompson Overview Map

CDOT Flood Recovery Hydrologic Evaluation

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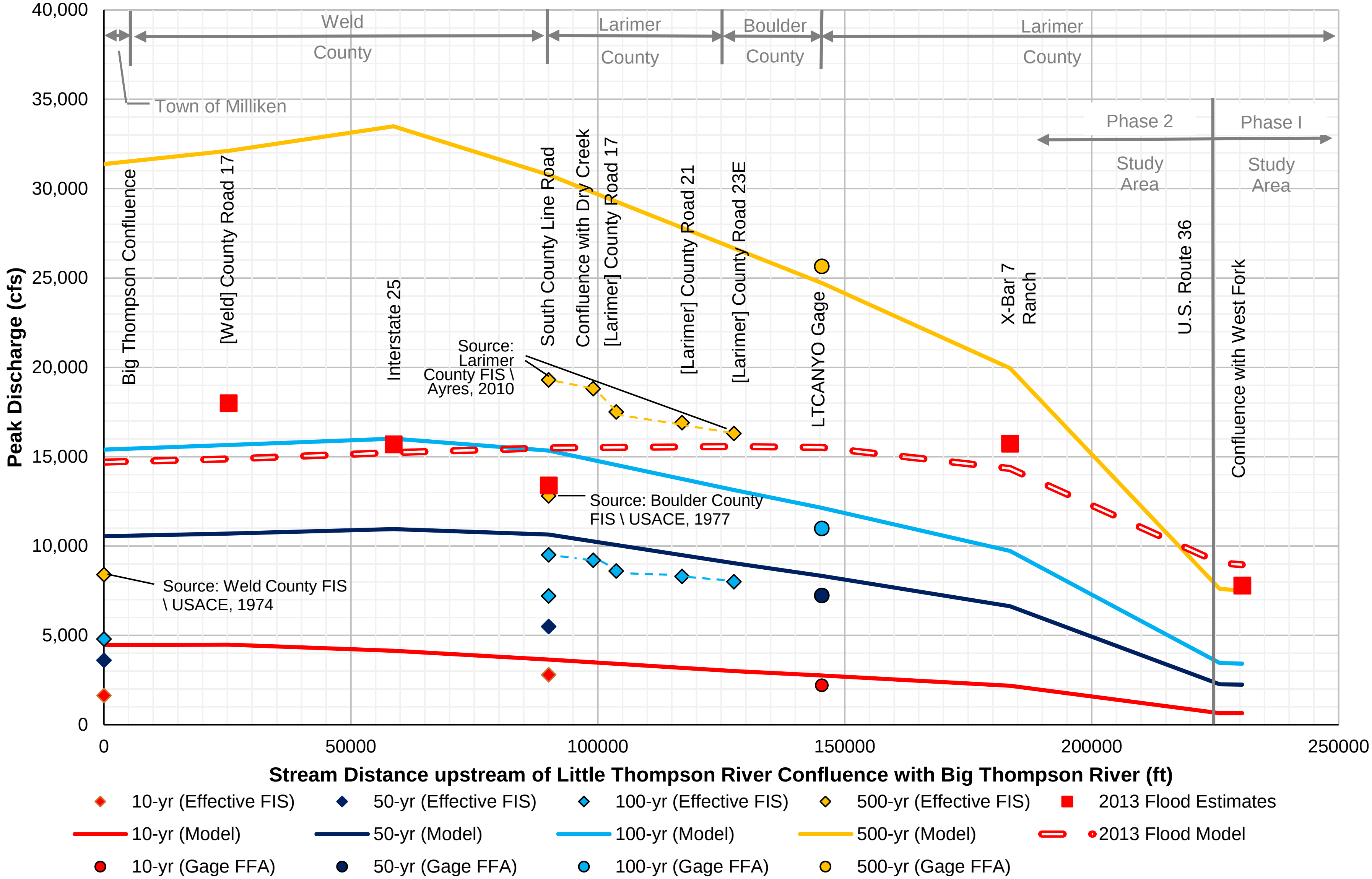
Figure ES-2 - Little Thompson River Peak Discharge Profiles



1.0 Purpose and Objective

1.1 Background

In September 2013, the Colorado Front Range experienced an intense, widespread rainfall event that resulted in damaged infrastructure and property loss in multiple watersheds. CH2M HILL was retained by the Colorado Department of Transportation (CDOT) and Colorado Water Conservation Board (CWCB), the project sponsors, to evaluate the hydrology of two watersheds, the Little Thompson River and Boulder Creek, that experienced flooding and damage as a part of this storm event. The purpose of this report is to evaluate and document the hydrologic conditions within the Little Thompson River downstream of U.S. Route 36 (US 36) to the confluence of the Big Thompson River, calibrate the timing and magnitude of modeled peak discharges to the real-time data collected during September 2013, and determine the recurrence interval for the September 2013 event.

1.2 Project Area Description

Phase 1 of the Little Thompson River watershed was completed in August 2014. The Phase 1 study portion of the Little Thompson River watershed is located predominately in Larimer County in north-central Colorado (see **Figure 1** for a vicinity map of the watershed). The watershed is adjacent to the towns of Estes Park and Lyons along US 36. The Phase 1 study reach extends from the uppermost limits of the watershed near the Town of Estes Park to the Little Thompson River at US 36, and has a total area of approximately of 43.8 square miles. The Phase 2 study portion of the Little Thompson River extends downstream of this confluence, approximately 43 miles into Boulder and Weld counties, where it joins the Big Thompson River. The Phase 2 study area adds 150.8 square miles for a total watershed study area of 196.4 square miles upstream of the confluence of the Big Thompson River. Just downstream of the Phase 1 study reach and US 36 is the residential community of Pinewood Springs. Near the confluence of the North Fork Little Thompson River and the Little Thompson River is a residential community called X Bar 7 Ranch. There is increased urbanization lower in the watershed. Phase 2 of the model includes portions of the towns of Berthoud, Johnstown, and Milliken.

1.3 Effective Flood Insurance Studies

The Little Thompson River watershed extends across portions of three counties: Larimer, Boulder, and Weld. Each county has its own Flood Insurance Study (FIS). The publication date of the most recent revision of the FIS for the other three counties are as follows: Larimer County, February 6, 2013 (FEMA, 2013c); Boulder County, December 18, 2012 (FEMA, 2012); and Weld County, September 22, 1999 (FEMA, 1999). Relevant FIS cover pages and associated summaries of discharge along Little Thompson River and tributaries are provided in **Appendix A**. The effective Weld County FIS does not include the Town of Milliken, which has its own FIS, dated February 1979 (FEMA, 1979). The Town of Milliken FIS (FEMA, 1979) will be integrated with the remainder of Weld County as indicated in the preliminary Weld County, FIS (FEMA, Preliminary). The cover pages for these FISs are also provided in **Appendix A**.

Portions of Little Thompson River are a Federal Emergency Management Agency (FEMA)-designated Zone A floodplain (special flood hazard area corresponding to the zone inundated by the 1 percent annual chance discharge, as determined by approximate methods; no base flood elevations), including the section approximately 4 miles downstream the confluence with North Fork Little Thompson River to the Larimer/Boulder County line and the section downstream of the Larimer/Weld County line to the confluence with the Big Thompson River. The Little Thompson River is a FEMA-designated Zone AE floodplain (special flood hazard area corresponding to the zone inundated by the 1 percent annual chance discharge, as determined by detailed methods) from the Larimer/Boulder County line to the Larimer/Weld County line. The Little Thompson River flood hazard areas are delineated on several Flood Insurance Rate Maps (FIRMs) of which there are 11 panels within Larimer County, one panel within Boulder County, and three panels within Weld County. FEMA FIRM documentation for Little Thompson River is presented in **Appendix A**.

1.4 Mapping

Elevation data for the Study Area were derived from the U.S. Geological Survey (USGS) National Elevation Dataset (NED), which provides 1/3 arc-second (approximately 30 feet) coverage across the Little Thompson River watershed (USGS, 2013a). In addition to the NED dataset, 2013 Light Detection and Ranging (LiDAR) data, in LAS format, were provided by the project sponsors for use on this project. The LiDAR survey was sponsored by FEMA and collected after the September 2013 event; thus, it includes any horizontal channel or floodplain changes that may have occurred during the September 2013 event (FEMA, 2013b). Both the NED and LiDAR data were converted to the NAVD 88 US Survey Foot vertical datum and the NAD 83 Colorado State Plane Central (FIPS 0502) US Survey Foot horizontal datum used in the study. Aerial photography (2011) from the ESRI ArcGIS online data catalog was used for the background imagery (ESRI, 2011).

1.5 Data Collection

For this analysis, CH2M HILL collected a range of data covering the watershed, including recent hydrologic studies, geographic information system (GIS) data, and hydrologic parameters. Detailed explanations of how the data were used during this analysis are provided in subsequent sections of this report. The primary references used for this study are documented in **Table 1**.

TABLE 1
Data Collected for the Little Thompson River

Document Type	Source	Description
Aerial Imagery	ESRI, 2011	Aerial Raster
GIS Raster	U.S. Geological Survey, 2013	Elevation data for approximately 30’ by 30’ grid.
LiDAR LAS	FEMA (sponsor), 2013b	Raw LiDAR survey data
GIS Shapefile	U.S. Department of Agriculture, 2013	Soil Classification
GIS Shapefile	U.S. Geological Survey, 2013	Land Use Cover
Hydrologic Study	Colorado Department of Transportation, 2011	*Little Thompson River Hydrology Analysis – I-25 Frontage Road Mile Marker 249.847, Weld County, Colorado*
Hydrologic Study	Colorado Division of Water Resources Dam Safety Branch, 2014	*Little Thompson River Hydrology Analysis – Report of September 2013 Little Thompson River Flooding*
Hydrologic Study	CH2M HILL, 2014 (prepared for CDOT)	*Little Thompson River Hydrologic Analysis.*
Hydrologic Study	Ayres and Associates, 2010	*Summary of Hydrologic Analysis, Little Thompson River, Larimer County Colorado, Flood Insurance Study/Map Revision. Technical Support Data Notebook*
Hydrologic Study	U.S. Army Corps of Engineers, 1974	*Hydrology Studies for the Big Thompson River and Little Thompson River*

TABLE 1
Data Collected for the Little Thompson River

Document Type	Source	Description
Peak Discharge Estimates	Jarrett, In press	*Estimates of September 2013 peak discharges using indirect methods*
Peak Discharge Estimates	URS, 2015	*Estimated Peak Discharges – Phase 2* (Memorandum)
Rainfall Data (Frequency tables)	National Oceanic and Atmospheric Administration, 2014	*NOAA Atlas 14 Point Precipitation Frequency Estimates*
Rainfall Data (September 2013)	Applied Weather Associates, 2014	5-minute rainfall data at subbasin centroids from September 8, 2013 to September 18, 2013
Rainfall Data (site-specific DARF)	Applied Weather Associates, 2015	*Colorado Front Range 24-hr Rainfall Areal Reduction Factors*

1.6 Flood History

1.6.1 Historic Flood Events

While the Little Thompson has caused flooding prior to September 2013, documentation of historical floods and damage estimates prior to September 2013 along the Little Thompson are sparse. Per the Town of Milliken FIS and preliminary Weld County FIS, the primary cause of floods along the Little Thompson River in Milliken is cloudbursts that usually occur from May through August (FEMA, 1979; FEMA, Preliminary). The flood of record in the systematic gage record was 4,000 cfs recorded in May of 1957.

1.6.2 September 2013

The days preceding the high-flow event in September 2013 saw record-breaking heat and high humidity throughout the Front Range of Colorado. The heat and influx of tropical moisture from the Gulf of Mexico combined over the Front Range of Colorado to saturate the atmosphere and develop conditions ideal for heavy sustained rainfall over the Front Range. The Little Thompson River watershed experienced rainfall from September 8, 2013, to September 16, 2013. The heaviest rain occurred on September 12, 2013, with a maximum rainfall of 1.41 inches per hour in the Phase 1 portion of the Little Thompson River watershed. Less rainfall occurred in the Phase 2 portion of the Little Thompson River watershed, with a maximum rainfall of 1.11 inches per hour. During the September 2013 storm event, Interstate 25 (I-25) suffered substantial damage, including a significant headcut on the north bank upstream and widespread channel degradation downstream. Northwest of Milliken, the Little Thompson River overtopped State Highways (SHs) 60 and 257, resulting in bridge damage. Additional damage and severe flooding occurred in towns along in the Little Thompson River, including the towns of Berthoud and Milliken and the X Bar 7 Ranch communities.

2.0 Hydrologic Analyses

When determining an appropriate method to develop watershed hydrology, it is common to compare several statistical-, physical-, and model-based estimates. Statistical-based estimates include the regression analysis of historical peak flow measurements to estimate the magnitude of infrequent high-flow events using statistical distributions; *Bulletin 17B: Guidelines for Determining Flood Flow Frequency* recommends a minimum of 10 years of data to perform such an analysis (USGS, 1982). Physical-based estimates estimate peak discharges based on watershed characteristics, high-water marks, hydraulic parameters, or other physically relevant parameters. Model-based estimates are based on conceptual or theoretical hydrologic models that estimate discharges based on watershed characteristics and meteorological conditions.

For this analysis, it was concluded that a rainfall-runoff model would be used to determine peak discharges for the 10, 4, 2, 1, and 0.2 percent annual chance events due to the availability of calibration data, general acceptance of calibrated rainfall-runoff models to predict infrequent discharges, inability of physical-based estimates to predict future flood hydrology, and limitations in statistical-based estimates, discussed in subsequent sections. Physical- and statistical-based methods discussed in the following sections of this report were used for calibration or comparison purposes to validate the rainfall-runoff model.

2.1 Previous Studies

As described below, several studies have been published to date documenting the hydrology of the Little Thompson River within the study reach: *Hydrology Studies for the Big Thompson River and Little Thompson River* (USACE, 1974); *Floodplain Information Report. Little Thompson River. Boulder and Larimer Counties* (USACE, 1977a); *Summary of Hydrologic Analysis, Little Thompson River, Larimer County Colorado, Flood Insurance Study/Map Revision. Technical Support Data Notebook (Ayres, 2010); Little Thompson River Hydrology Analysis – I-25 Frontage Road Mile marker 249.847, Weld County, Colorado* (CDOT, 2011); *Little Thompson River Hydrology Analysis – Report of September 2013 Little Thompson River Flooding* (CDWR Dam Safety, 2014); and *Little Thompson River Hydrologic Analysis [Phase I]* (CH2M HILL, 2014). Portions of the Little Thompson River are documented in the effective Boulder, Larimer, and Weld County FIS. The remaining publications include the current FIS, previous FIS, and hydraulic modeling reports, none of which is discussed in detail because each references one of the hydrologic studies cited above.

2.1.1 Hydrology Studies for the Big Thompson River and Little Thompson River (USACE, 1974)

The preliminary and existing effective discharge within Weld County includes a study completed in 1974 by the U.S. Army Corps of Engineers (USACE) for the Town of Milliken. The study was based on a log-Pearson Type III analysis on 17 years of data prior to 1974 at the Berthoud gaging station LTCANYO. The discharge was routed to the Town of Milliken through three reaches using HEC-2 modeling program. The FEMA effective discharge location at the Town of Milliken corresponds to the model location Little Thompson River Upstream of Confluence with Big Thompson. A comparison at this location is made between the effective hydrology and the predictive model in Section 3.2 of this report. **The FEMA effective 1 percent annual chance peak flow at location Little Thompson River Upstream of Confluence with Big Thompson was 4,800 cubic feet per second (cfs)**.

2.1.2 Floodplain Information Report. Little Thompson River. Boulder and Larimer Counties (USACE, 1977a)

The effective discharges within Boulder County were documented in this 1977 study by USACE. The method of study is unknown as the original report was not available. **The FEMA effective 1 percent annual chance discharge is provided as 7,200 cfs at the Larimer-Weld County Line** which, while reported in the Boulder County FIS, is not in Boulder County itself.

2.1.3 Summary of Hydrologic Analysis, Little Thompson River, Larimer County Colorado, Flood Insurance Study/Map Revision. Technical Support Data Notebook (Ayres, 2010)

The Larimer County FIS was updated in February 6, 2013, to incorporate a Physical Map Revision (PMR) for the Little Thompson River. In support of the revision, Ayres Associates, Inc. performed the hydrologic and hydraulic analyses and floodplain mapping for the Little Thompson River within Larimer County. The study reach was for approximately 138 square miles of the Little Thompson watershed upstream of the Larimer-Weld County line. The study area was divided into six subbasins, and USGS regression equations were used to calculate discharge values at five locations within the study reach. USACE's HEC-RAS version 4.0 step-backwater computer program and cross sections from a Floodplain Information Report for the Big and Little Thompson (USACE, 1977c) were used, assuming unobstructed flow conditions.

One of the FEMA effective discharge locations, Little Thompson River at South County Line Road, corresponds to a location of observed discharges in the current study. A comparison at this location is made between the effective hydrology and the predictive model in Section 3.2 of this report. **The FEMA effective 1 percent annual chance peak flow on Little Thompson River at South County Line Road was 9,500 cfs**.

2.1.4 *Little Thompson River Hydrology Analysis – I-25 Frontage Road Mile Marker 249.847, Weld County, Colorado* (CDOT, 2011)

To support the design of Bridge C-17-FS, which replaces C-17-BN and will carry the I-25 Frontage Road downstream of I-25 across the Little Thompson River, CDOT performed a hydrologic analysis in 2011 to develop peak discharge rates for the Little Thompson River at this location. This analysis was based on the development of a Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) model. The CDOT model was composed of 14 subbasins that cover approximately 172 square miles of the Little Thompson River watershed. No calibration efforts were done as part of this analysis. While several locations in the CDOT model correspond to locations of observed discharge in the current study (Little Thompson Downstream of Confluence with West Fork Little Thompson River, Little Thompson River at LTCANYO Gage, Little Thompson River at South County Line Road, and Little Thompson River at I-25), the purpose of the study was to determine the peak discharge at I-25. CDOT's 2011 model used the following parameters:

- **Precipitation:** The model included 24-hour Soil Conservation Service (SCS) (now Natural Resources Conservation Service [NRCS]) Type II design storms with depth-area adjustment of 0.958. Precipitation depths were taken from the National Oceanic and Atmospheric Administration (NOAA) *Precipitation-Frequency Atlas of the Western United States*, "Volume III, Colorado isopluvial maps" (NOAA, 1973).
- **Infiltration losses:** The SCS curve number (CN) method was employed using NRCS data for soils coverage and USGS Land Use and Land Cover (LULC) data. CN values were then obtained from NRCS's *Urban Hydrology for Small Watersheds Technical Release 55 (TR-55) Manual* (NRCS, 1986). "Fair" hydrologic soil conditions were used except for areas where severe degradation of vegetation cover was observed. In those areas, a hydrologic soil condition of "poor" was used.
- **Rainfall Runoff Transformation:** The SCS unit hydrograph method was used for transformation. Lag time was computed with TR-55 equations for sheet flow and shallow concentrated flow, and Manning's equation for open channel flow.
- **Channel Routing:** The Muskingum-Cunge channel routing method was used to route the storm runoff through the reaches. A trapezoidal channel section was utilized with Manning's values ranging from 0.042 to 0.075.

As a check for the HEC-HMS model, a regression analysis using USGS *Scientific Investigation Report 2009-5126,* "Regional Regression Equations for Estimation of Natural Stream-flow Statistics in Colorado" (USGS, 2009), was performed for the full model size of 172 square miles. The 1 percent annual chance peak flow rate using the regression analysis of 3,996 cfs is significantly lower as compared to **HEC-HMS model results**

of 14,728 cfs for the entire 172-square-mile watershed at the I-25 Frontage Road. CDOT determined that the peak runoff values from the HEC-HMS model were most representative of the watershed and will be used for the bridge replacement projects.

2.1.5 Little Thompson River Hydrology Analysis – Report of September 2013 Little Thompson River Flooding (CDWR Dam Safety, 2014)

The Colorado Division of Water Resources' (CDWR) Dam Safety Branch concurrently studied the failure of the five water supply dams in the Big Elk Meadows area during the September 2013 flood event. This report was published in June 2014 and revised December 2014. In order to evaluate the effect of the dam failure, the Dam Safety Branch constructed a HEC-HMS rainfall-runoff model and ran scenarios with and without the dam failure. The 83-square-mile study area extends from the Little Thompson Headwaters 17.8 miles downstream to the X Bar 7 Ranch Area, and was delineated into seven subbasins ranging in size from 4.28 to 27.86 square miles. The Dam Safety model was calibrated at eight locations where peak flow estimates were made from indirect methodology. Two of these locations, Little Thompson River at Pinewood Springs and Little Thompson River at X Bar 7 Ranch, correspond to locations of observed discharges in the current study. A comparison at these two locations is made between the Dam Safety model and the calibrated model in Section 3.2 of this report; the modeled peak flow discharge is within 15 percent of each at both locations. The Dam Safety model used the following parameters:

- **Precipitation:** Applied Weather Associates (AWA) provided rainfall data for the September 2013 storm event from September 8 to September 18, 2013, using the same analysis as described in Section 2.4.5, Model Development, of this report.
- **Infiltration losses:** The Initial and Uniform Loss Rate Method (Sabol, 2008) was used to estimate infiltration losses. The method is a simplified alternative of the Green-Ampt Loss Rate Method.
- **Rainfall Runoff Transformation:** The Synthetic Unit Hydrograph Procedure (Cudworth, 1989) method was used for transformation. The Rocky Mountain Thunderstorm dimensionless Unit Hydrograph was selected and the lumped resistance parameter value was calibrated to 0.2.
- **Channel Routing:** The Kinematic Wave channel routing method was used to route the storm runoff through the reaches. A trapezoidal channel section was utilized with Manning's values calibrated to 0.05.

The study was able to confirm eye witness accounts of the dam failures and timing of surge flow reported by X Bar 7 Ranch residents.

2.1.6 Little Thompson River Hydrologic Analysis [Phase I] (CH2M HILL, 2014)

In September 2013, the Colorado Front Range experienced an intense, widespread rainfall event that resulted in damaged infrastructure and property loss in multiple watersheds. CH2M HILL was retained by the CDOT and the CWCB to evaluate high-flow hydrology of Little Thompson River above US 36. As part of the hydrologic evaluation, CH2M HILL developed a hydrologic model of the watershed using USACE's HEC-HMS, version 3.5 (USACE, 2010a). The HEC-HMS model was calibrated to estimates of the magnitude and timing of September 2013 peak discharges and accounted for variations in rainfall and hydrologic response across the watershed. The calibrated hydrologic model was then used to develop a predictive hydrologic model to predict the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges along Little Thompson River and assess the recurrence interval of the September 2013 flood event. Based on implementation of the predictive hydrologic model, the **1 percent annual chance flow at US 36 in the Phase 1 model was estimated as 3,460 cfs.**

2.2 Stream Gage Analysis

The only recording stream gage on the Little Thompson River is located near the Town of Berthoud as shown on **Figure 2**. The gage (Little Thompson River at Canyon Mouth near Berthoud – LTCANYO) is currently owned and operated by CDWR at a location adjacent to Rabbit Mountain Open Space. CDWR has collected daily data seasonally at this site from 1993 until the gage failed during the September 2013 storm event. Prior to that time, USGS operated the gage (USGS # 06742000) and compiled 17 non-consecutive years of data from 1929 to 1961; in total, 36 years of data were available for this gage.

Ayres Associates performed flood frequency analyses to supplement the hydrologic evaluation of the Little Thompson River. The analyses followed the methods described in the document *Guidelines for Determining Flood Flow Frequency* published by USGS on behalf of the Interagency Advisory Committee on Water Data, dated September 1981 (USGS, 1982). This document is commonly known as *Bulletin 17B*. Following the *Bulletin 17B* methods using the computer program HEC-SSP (USACE, 2010b), Ayres Associates conducted the flood frequency analyses using the annual peak flow records at CDWR Gage LTCANYO. Summarizing their stream gage analyses for the report, Ayres Associates stated:

> *Stream gage analysis by Bulletin 17B methods requires as input the highest peak discharge for every available year of record. The engineer must also decide how to treat the skew coefficient. The possible options include the following:*
>
> 1. ***Using a weighted skew coefficient in which the station skew is weighted with a regional skew determined from the map included in Bulletin 17B.*** *A drawback to this method is that the stream flow data used to develop that map were from the 1960s.*
> 2. ***Weighting the skew coefficient with a regional coefficient developed from a current regional regression analysis.*** *The initial attempts to use this approach had the drawback that very few gages were available for the regression analysis that had measured or approximated peak values for the September 2013 flood. Furthermore, many of the available gages were missing peak flows from other known large flood events. The results from this approach appeared unreliable at several gages, in that the resulting 100-year flow values were lower than two or three of the observed peaks in periods of record no more than 120 years.*
> 3. ***Use the station skew coefficient, without any regional skew weighting.*** *This approach yielded the most reasonable results and was adopted for this study.*

The detailed input to and output from HEC-SSP is included as part of **Appendix C**. The results of the flood frequency analysis is summarized in **Table 2** below. Comparison of the flood frequency result to September 2013 discharge is provided in Section 3.2.

TABLE 2
Discharge-Frequency Based on Flood Frequency Analysis of Gage Record

Exceedance Recurrence Interval (years)	Little Thompson River at LT CANYO Gage	
	Discharge (cfs)	Unit Discharge (cfs/square miles)
2	306	3.1
5	1,119	11.2
10	2,204	22.0
50	7,229	72.1
100	10,992	109.7
500	25,656	256.0

2.3 Peak Discharge Estimates

No direct observations of peak discharge were available within the Little Thompson watershed as the only stream gage in the Little Thompson watershed, CDWR's LTCANYO gage, was damaged during the September

2013 event and did not record peak discharge, peak discharges that occurred during the September 2013 event were quantified using indirect methods to provide calibration data for the rainfall-runoff model discussed in detail in Section 2.4. Time-of-peak discharge, or the recorded time that the peak discharge was observed, was assumed from CDOT observation at the I-25 Bridge during the September 2013 event. The following indirect methods were used to estimate peak discharges during the September 2013 event:

1. **Indirect Observation from Critical-Depth Method Application**: cross-sections and high-water marks were surveyed at select locations and peak discharge was estimated by assuming critical depth occurred at the surveyed cross-sections.
2. **Indirect Observation from Bridge Hydraulic Modeling**: cross-sections and high-water marks were surveyed at select bridge crossings and a hydraulic model developed to iterate peak discharges until observed high water marks were reproduced using the hydraulic model.
3. **Indirect Observation from Other Studies**: peak discharge estimates developed as part of independent studies were compared to results of the developed rainfall-runoff model.

Detailed discussion of the critical-depth method is provided in *Little Thompson Hydrologic Analysis [Phase 1]* (CH2M, 2014). Detailed discussion of the bridge hydraulic modeling peak discharge estimate method and peak discharge estimates from other studies are provided in the following paragraphs.

CDOT and CWCB contracted URS to obtain peak flow estimates in the Phase 2 portion of the Little Thompson River watershed following the September 2013 storm event (URS, 2015). For the analysis, URS surveyed at least four cross sections, collected bridge information, and obtained a high water estimate at each peak flow estimate location. A USACE River Analysis System, HEC-RAS Version 4.1 (USACE, 2010c) model was constructed for each location using the cross sections and calibrated to the high water marks under subcritical and supercritical flow regimes. Generally, the subcritical flow regime had more consistent values where channel slope is milder. Flow estimates were less certain where bridge structures were overtopped due to greater uncertainty in assessing high water marks and more complex hydraulic conditions at locations where flow overtopped the approach roadway, rather than the bridge itself. The locations used for evaluation are shown in **Figure 2** for Little Thompson. Some of the peak flow estimates, including evaluations performed by others after the September 2013 storm event, are shown on **Table 3**.

TABLE 3
Little Thompson Physical-Based Peak Discharge Observations

Site Number	Site Description	Calibration Source	Drainage Area (square miles)	Peak Discharge (cfs)
#60	Little Thompson River Downstream of Confluence with West Fork Little Thompson River	Jarrett, In Press	43.2	7,800[a]
N/A	Little Thompson River at X Bar 7 Ranch	CDWR, 2014	81.8	15,731
LT-2	Little Thompson River at South County Line Road	URS, 2015	132.1	13,400
LT-3	Little Thompson River at Interstate 25	URS, 2015	165.9	15,700
LT-4	Little Thompson River at County Road 17	URS, 2015	186.5	18,000[b]

[a] This flow was estimated to be the peak discharge based on observations along similar, adjacent watersheds.

[b] Split flow condition occurred, (URS, 2015).

The peak discharge at site # 60 at the Little Thompson River Downstream of Confluence with West Fork Little Thompson River was obtained during the Phase 1 portion of the Little Thompson River watershed study (CH2M HILL, 2014) and the Phase 2 model was recalibrated at that point. The peak discharge at the Little Thompson River at X Bar 7 Ranch was calculated using indirect flow measurements by the Dam Safety

Branch (CDWR, 2014). In addition to the peak discharge estimates, the Little Thompson River at I-25 was observed by CDOT to peak in the afternoon of September 12 during the September 2013 flood event (CDOT, In Press).

2.4 Rainfall-Runoff Modeling

2.4.1 Overall Modeling Approach

In general, hydrologic modeling of the Little Thompson River entailed the development and calibration of a hydrologic model to the September 2013 high-flow event that was then used to estimate the magnitude of the 10, 4, 2, 1, and 0.2 percent annual chance (10-, 25-, 50-, 100-, and 500-year storm event) hydrograph. Given that the September 2013 high-flow event prompting this study was driven by substantial rainfall, a rainfall-runoff model was used to evaluate hydrologic conditions within the Little Thompson River. USACE's HEC-HMS version 3.5 (USACE, 2010a) was selected to model the hydrologic conditions within the Little Thompson River as a result of FEMA's approval of HEC-HMS to model single-event flood hydrographs (FEMA, 2013a) and the ability to incorporate complex calibration data and modeling parameters into the program. The hydrologic modeling process entailed the development of two separate hydrologic models to evaluate hydrologic conditions in the Little Thompson River:

- A *calibrated hydrologic model* was developed to model the September 2013 event. Hydrologic conditions unique to the September 2013 event (such as measured rainfall) were used to calibrate remaining model parameters to match modeled peak discharges to observed peak discharges observed following the September 2013 event by indirect measurements.
- Following development of the calibrated hydrologic model, a *predictive hydrologic model* was developed to estimate discharge-frequency relationships based on calibrated model parameters, rainfall-frequency relationships, and adjusted hydrologic conditions that reflected anticipated flood conditions, rather than the unique conditions preceding the September 2013 event.

Detailed discussion of the difference between the two hydrologic models is provided in following sections.

Beyond the selection of the hydrologic model itself, selection of modeling methodologies would control the subsequent calibration and implementation of the hydrologic model: selection of an infiltration loss method, which controls the conversion of rainfall to runoff; selection of a transformation method, which controls the transformation of runoff volume to an outflow hydrograph; and selection of a routing method, which controls the routing of hydrographs from various watersheds to the downstream outlet.

The SCS CN method was selected to model infiltration losses due to its relative simplicity, acceptance in the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008), and its ability to reflect varying land use conditions and infiltration properties of underlying soils. The Snyder's unit hydrograph was used due to its acceptance in the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008) and its ability to calibrate the transformation method to observed data. The Muskingum-Cunge routing methodology was selected to route flow hydrographs due to the method's ability to attenuate flows based on a specified hydraulic roughness and channel-floodplain cross section.

At a detailed level, the hydrologic model was calibrated to the peak 24-hour rainfall measured during the September 2013 event to replicate the assumptions used to originally develop the SCS infiltration loss model. The peak 24-hour rainfall associated with the peak discharge observed on the Little Thompson River was determined to occur from 7:40 p.m. on September 11 to 7:40 p.m. on September 12.

2.4.2 Summary of Modeling Approaches Considered

During Phase 1, several modeling methodologies were considered, applied, evaluated, and subsequently discarded over the course of hydrologic model development to assess the performance of alternative modeling methodologies or to synchronize model development efforts with other consultants. The following alternative modeling methodologies are documented in the Little Thompson River Phase 1 report

(CH2M HILL, 2014): Calibration of Model to Entirety of September 2013 Event, and Calibration of Model using Green-Ampt Loss Method. The scope of Phase 2 was to follow the modelling approach of Phase 1. This approach is described in the following sections. During the process of predictive hydrologic modeling, it was suggested during regular Hydrology Coordination meetings that the peak discharge at a study location may not be the result of a general storm distributed over the entire watershed area but rather a more-intense storm concentrated over a smaller portion of the watershed. Spatially varied storms were evaluated for the *Boulder Creek Hydrologic Analysis Phase 2: Boulder Creek above St. Vrain Creek* (CH2M HILL, In press):

> *Evaluation of the results of hydrologic modeling of spatially-concentrated storms yielded that in all cases, peak discharges along Boulder Creek estimated using a general storm spread over the entire watershed were greater than peak discharges estimates developed through modeling of spatially-concentrated storms. To further consider differences in spatially-concentrated storms over general storms, spatially-concentrated storms were also modeled as shorter duration events with theoretically higher rainfall intensities. When the spatially-concentrated storms were modeled using a 6-hour NRCS Type II unit rainfall hyetograph and conservative approximations of the 6-hour rainfall depths, modeled peak discharges using the 6-hour spatially-concentrated storms were less than the modeled peak discharge for the co-located 24-hour spatially-concentrated storm. Considering these hydrologic modeling results of spatially-concentrated storms, it was determined that the 24-hour general storm was the critical event for high-flow hydrology along Boulder Creek.*

The effect of spatially concentrated storms was not evaluated further for the Little Thompson River because the depth-area reduction factor (DARF; see Section 2.5 for further discussion) did not vary considerably throughout the watershed and varied less than for the Boulder Creek watershed. Given the results of Boulder Creek modeling that indicated short-duration storms do not control peak discharges on Boulder Creek, shorter-duration storms were not considered further for the Little Thompson River.

2.4.3 Basin Delineation

The Little Thompson River watershed was modeled in two phases. Phase 1 in the uppermost portion of the Little Thompson River watershed has a total of 18 subbasins totaling 43.8 square miles. This portion of the model was completed in August 2014 (CH2M HILL, 2014). Phase 2 extends to the confluence with Big Thompson River. Phase 2 consists of 13 additional subbasins totaling 152.6 square miles for a total watershed study area of 196.4 square miles. The increase in scale of the project and the changes in topography and land use allowed the average size of subbasin to increase as the model was extended from Phase 1 and Phase 2. Phase 1 area consists entirely of mountain topography while Phase 2 consists of mountain and plains topography (Phase 2 Mountains and Phase 2 Plains). Subbasins were developed using 40-foot USGS topographic map (NGS, 2013). **Table B-1** in **Appendix B** summarizes the basin ID and areas for all 31 subbasins. Resulting delineated subbasins are superimposed on aerial imagery as part of **Figure 3**. In regard to naming convention, subbasins were named in accordance with abbreviations of the FEMA-studied feature to which they first drained,[2] e.g., "NF" for North Fork Little Thompson River.

2.4.4 Basin Characterization

Phase 2 of the study area transitions from Mountains to Plains topography. The Phase 2 Mountains portion of the model includes the North Fork Little Thompson River, which is primarily mountainous terrain. Just downstream of Phase 1 and US 36 is the residential community of Pinewood Springs. Near the confluence of the North Fork Little Thompson River and the Little Thompson River is a residential community called X Bar 7 Ranch. There is increased urbanization lower in the watershed. The Phase 2 Plains portion of the model includes portions of the towns of Berthoud, Johnstown, and Milliken. The increase in the scale of the project and the changes in topography and land use allowed the average size of the subbasin to increase as the

[2] LT = Little Thompson River; DC = Dry Creek; NF = North Fork Little Thompson River; WF = West Fork Little Thompson River.

model was extended from Phase 1 to Phase 2. As discussed in subsequent sections, hydrologic modeling results agree well with the general runoff concepts described above.

2.4.5 Model Development

The developed HEC-HMS hydrologic models used “hydrologic elements” in the form of subbasins, junctions, and reaches to convert input rainfall to output hydrographs. Subbasin elements contain parameters to estimate infiltration losses and convert the resultant runoff to an outflow hydrograph. Reach elements route inflows based on the hydraulic characteristics of the conveying element, such as the Little Thompson River. Junction elements have no hydrologic function other than congregating multiple inflows to a single outflow. A description of input parameters, presented by hydrologic elements and then hydrologic order, is provided below.

Rainfall Analysis

The Storm Precipitation Analysis System (SPAS) was used to analyze the rainfall for the September 2013 event. SPAS uses a combination of climatological base maps and NEXRAD weather radar data that is calibrated and bias corrected to rain gage observations (considered ground truth) to spatially distribute the rainfall accumulation each hour over the entire domain of the storm. Therefore, through the use of climatological base maps and weather radar data, SPAS accounts for topography and locations of rain gages. For quality control (QC), SPAS storm analyses have withheld some rain gages observations and run the rainfall analysis to see how well the magnitude and timing fit at the withheld rain gage locations. In nearly all cases, the analyzed rainfall has been within 5 percent of the rain gage observations and usually within 2 percent. In data-sparse regions where a limited number of rain gages are present, there can be increased uncertainty in traditional rainfall analyses, especially in topographically significant regions. For the September 2013 storm, this was not the case. Excellent weather radar coverage existed as well as many rainfall observations with excellent overall spatial distributions at both low- and high-elevation locations (AWA, 2014).

Rainfall Hyetographs

AWA provided rainfall data for the September 2013 storm event through the methodology described in the preceding section (AWA, 2014). Incremental rainfall was provided in 5-minute intervals from 1 a.m. on September 8, 2013, to 1 a.m. on September 18, 2013. Individualized rainfall hyetographs were generated for each modeled subbasin using weighting techniques to transfer precipitation gage measurements collected during the event to the centroid of each subbasin. The total rainfall for each subbasin in Phase 2 is depicted in **Figure 4**.

The 24-hour rainfall depths for the 10, 4, 2, 1, and 0.2 percent annual chance precipitation were developed for each subbasin from *NOAA Atlas 14* point precipitation frequency estimates by inputting the centroid of each basin into NOAA’s online, GIS-based database (NOAA, 2014). The reported NOAA rainfall estimates used in the hydrologic model are the 50th percentile rainfall depths estimated from a population frequency curve of expected rainfall depths at each of the subbasin centroids. Therefore, in addition to providing the 50th percentile rainfall depths, the NOAA tables also provide the bounding 90 percent confidence intervals for expected rainfall depth at each of the subbasin centroids, thereby providing an estimate of uncertainty in the rainfall-frequency estimates. In general, the 90 percent confidence intervals vary ± 25 percent from the 50th percentile rainfall depth. Rainfall depths for each subbasin for these recurrence intervals are provided in **Table B-2** in **Appendix B**. The 24-hour total rainfall for the September 2013 event is included in this table for comparison. In all but 14 of the basins, the 24-hour rainfall depths from September 2013 met or exceeded the depths of the 0.2 percent chance precipitation. Five of the basins (LT-1B, LT-6, NF-1, NF-2, and NF-3) had rainfall depths greater than the 1 percent annual chance but just less than the 0.2 percent chance precipitation total. One of the basins (LT-7) had rainfall depths greater than the 2 percent annual chance but less than the 1 percent chance precipitation total. One of the basins (LT-8) had rainfall depths greater than the 10 percent annual chance but less than the 4 percent chance precipitation total, while the seven subbasins in the plains (DC-3, LT-9, LT-10, LT-11, LT-12, LT-13, and LT-14) had rainfall depths less than the 10 percent annual chance. The standard SCS 24-hour Type II rainfall distribution was used as the design hyetograph to distribute the 24-hour rainfall depths to generate hydrographs for the 10, 4, 2, 1, and 0.2 percent annual chance discharge as recommended by *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008). While the NRCS has developed new Atlas 14 temporal distributions for the Ohio River Basin and neighboring states, the NRCS Type II temporal distribution is still recommended in the Volume 8 area of Atlas 14 (Midwestern States), where the Little Thompson River is located. The hyetograph is provided in **Figure 5** and the dimensionless values are presented in **Table B-3** in **Appendix B.**

Depth-Area Reduction Factor

Prior to generating runoff hydrographs for the 10, 4, 2, 1, and 0.2 percent annual chance events, DARFs were applied to NOAA 50th percentile point precipitation estimates. The DARF accounts for the gradual decrease in rainfall intensity with increasing distance from the storm centroid, and corrects the NOAA point precipitation estimate to the average rainfall that would occur over the spatial extent of the storm. While DARF curves provided in NOAA Atlas 2 were used in the Phase 1 hydrologic analysis of studied watersheds, those curves only covered drainage areas up to 400 square miles. Because total drainage areas of the Big Thompson River, Boulder Creek, and St. Vrain Creek each exceeded 400 square miles, CDOT and CWCB contracted AWA to derive a site-specific 24-hour DARF curve for use in the hydrologic analysis of these large watersheds. A memorandum documenting AWA's work is provided as **Appendix F**. In a summary of its "Colorado Front Range 24-Hr Rainfall Areal Reduction Factors Memorandum for Record" (AWA, 2015) for inclusion in this report, AWA stated the following of the analysis:

> *Applied Weather Associates analyzed nine storm events along the Front Range of the Rocky Mountains extending from northern New Mexico through southern Canada, including the September 2013 event. Each storm event utilized in this analysis represented meteorological and topographical characteristics that were similar to each other and to the September 2013 event. These storms were selected to derive storm-specific areal reduction factors (DARF). The individual storm DARFs were then utilized to derive a site-specific set of 24-hour DARF values to be used in the Phase 2 hydrologic analyses along the northern Front Range of Colorado (Big Thompson River, Boulder Creek, and St. Vrain Creek). These site-specific storm based 24-hour DARF values were used to extend those provided in NOAA Atlas 2 for area sizes greater than 400 square miles. This analysis resulted in 24-hour DARF values that varied significantly from NOAA Atlas 2 values* [**Figure 6**] *demonstrating the need for the updated analysis to capture the unique storm characteristics along the Front Range and to more accurately capture the DARFs for larger basins in the region.*

To avoid significant reductions in the predicted 10, 4, 2, 1, and 0.2 percent annual chance peak discharges at the interfaces between the Phase 1 and Phase 2 study areas that would occur if the site-specific AWA DARF curve was strictly adopted for the Phase 2 hydrology analysis, a transition curve between the higher NOAA Atlas 2 DARF curve and the AWA site-specific DARF curve was developed by the Jacobs consultant team. The transition curve started at 315 square miles, which allowed for a consistent approach to be used between the two study phases and all the watersheds, as a DARF of 0.92 was utilized to estimate predictive hydrology for a drainage area of 315 square miles in the Phase 1 hydrologic analysis of the Big Thompson River. The transition curve then dropped down and tied into the AWA curve at 500 square miles, providing a smooth transition between the two curves. This transition curve was tested at several design points with areas between 315 and 500 square miles, and it produced reasonable results when compared against current regulatory values and expected unit discharges. For modeling purposes, a step function was developed to break the combined DARF curve into about a dozen area increments. The stepped area increments reasonably represent the actual DARF value for all of the modeled design points (within 1 percent) and significantly reduces the number of model runs necessary to produce results at each design point. **Figure 6** provides the various DARF curves, the design point areas for each watershed, and the stepped area increments used to represent the design points. **Table 4** also provides the area increments and resulting DARF values used in the Phase 2 hydrologic analysis.

TABLE 4
Depth-Area Reduction Factors

Area Range (mi^2)			Area Range (mi^2)		
Low	**High**	**DARF**	**Low**	**High**	**DARF**
0	10	1.00	400	425	0.80
10	30	0.98	425	450	0.78
30	50	0.96	450	500	0.75
50	100	0.94	500	570	0.70
100	315	0.92	570	800	0.68
315	350	0.90	800	1000	0.66
350	400	0.86			

As recommended in **Table 4**, DARF values of 0.92 and 0.94 were applied to the NOAA point precipitation estimates for the Little Thompson River watershed.

Subbasin Parameters (Infiltration Losses and Hydrograph Transformation)

As discussed in previous sections, the NRCS (formerly SCS) method was selected to convert input rainfall to infiltration losses and runoff. The key parameter in the NRCS method is the CN, which defines the runoff potential of a particular land cover, land condition, and underlying soil substrate. For example, a completely impervious surface would be represented by a CN of 100, whereas a forest in good condition with permeable substrate would have a lower CN, e.g., 30. The CN also considers saturation as the more saturated a soil becomes, the less interstitial space is available for the storage of rainfall and thus a greater proportion of rainfall will runoff. A saturated soil by definition cannot store additional water and will have a CN of or close to 100. The NRCS method accounts for soil saturation by assigning an antecedent moisture condition (AMC) based on the rainfall during the preceding 5 days. AMCII is considered “normal” conditions and is generally assumed. AMCIII conditions represent a saturated condition, such as occurs immediately after a moderate to high rainfall, with higher resultant CNs as compared to AMCII. AMCI is a dry condition, such as occurs when no rainfall has occurred for several days, weeks, or months, with a lower resultant CN as compared to AMCII. For initial model development, it was assumed that all subbasins were “fair” condition for selection of CN values.

Two GIS-based data sources, *Technical Release 55: Urban Hydrology for Small Watersheds* (“TR-55,” NRCS, 1986) and engineering judgment were used to develop CNs for each subbasin. TR-55 provides CNs for a given land cover description and hydrologic soil group (a measure of the infiltration capacity of the underlying soil alone). Land cover was delineated using the National Land Cover Dataset (USGS, 2006) to identify forests, barren ground, urbanized areas, wetland, etc., across the subbasins on a 100-foot by 100-foot scale. Residential development since 2006 was delineated using recent aerials and reassigned the appropriate classification. Delineation of hydrologic soil groups was accomplished using the U.S. Department of Agriculture’s (USDA’s) Web Soil Survey (USDA, 2013). The two overlapping datasets were then joined by intersecting the two datasets such that each land cover unit was further subdivided by hydrologic soil group. These results were then exported to Microsoft® Excel® where a CN was applied for each unique land cover condition and hydrologic soil group using engineering judgment to correlate observed land cover conditions with a representative land cover description provided in TR-55. Microsoft® Excel® was then used to area-weight these results, per TR-55 methodology, to estimate a single, representative CN for each subbasin. The land cover for Phase 2 of the watershed is provided in **Figure 7**. The soil data for Phase 2 of the Little Thompson River watershed are presented in **Figure 8**.

The transformation of runoff volume to an outflow hydrograph was accomplished using the Snyder’s unit hydrograph. The shape of the Snyder’s unit hydrograph is controlled by two factors: a peaking factor, C_p, and a lag time representative of the time elapsed between the centroid of a hyetograph and the peak of the resultant hydrograph. Snyder's C_p can range from 0.4 to 0.8. Lag time was estimated using the following equation (Equation CH9-511) provided in the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008):

$$TLAG = 22.1\ K_n * \left(\frac{L * L_c}{\sqrt{S}}\right)^{0.33}$$

Where K_n is the roughness factor for the basin channels, L is the length of longest watercourse, in miles, L_c is the length along longest watercourse measured upstream to a point opposite the centroid of the basin, in miles, and S is the representative slope of the longest watercourse, in feet per mile. Physical parameters were estimated using ArcHydro tools in ArcGIS to analyze the NED digital elevation model (USGS, 2013a). The K_n parameter was assigned to values between 0.08 and 0.15 depending on the land use along the flow path (Table CH9-T505, CWCB, 2008). The parameter C_p was varied during the calibration process. Lag times for each individual subbasins are provided in **Table B-4** in **Appendix B**. The subbasins with plains topography had longer lag times as compared to subbasins with mountain topography. Phase 2 Plains subbasins had an average lag time of 3.5 hours, and Phase 1 and Phase 2 Mountain subbasins had an average lag time of 2.4 hours.

Reach Parameters (Hydrograph Routing)

The Muskingum-Cunge routing methodology was selected to route inflow hydrographs along basin streams because of its solution of the continuity and momentum equations to estimate lag time and flow attenuation; thus, the Muskingum-Cunge method is based on channel hydraulics including channel roughness, cross section, and slope. Eight-point cross sections were used to model the channel cross section shape because the 8-point cross section allowed for the incorporation of channel floodplains that convey a significant portion of high-flows. Eight-point cross sections were derived using GIS and manually transposed to the hydrologic model. LiDAR (NOAA, 2013b) was used to develop cross sections along the Little Thompson River. A single cross section was selected for each reach based on visual identification of a representative cross section, erring slightly towards flatter, wider reaches that are likely to provide the majority of floodplain storage and flow attenuation. The model reach locations for Phase 2 of the model are provided in **Figure 3** and the cross sections for each reach in Phase 2 of the model are provided in **Figure 9**.

For Phase 1 subbasins, a Manning's roughness value of 0.045 was selected for the main channel to represent a clean, winding natural channel with some pools, shoals, weeds, and stones. A Manning's roughness value of 0.08 was selected for overbank areas to represent light brush (willows) during the growing season (Chow, 1959). For Phase 2 Plains subbasins, Manning's roughness value of 0.1 was used for the main channel and overbank due to heavier amounts of brush along the waterway as indicated by review of aerial photographs (Chow, 1959). The subbasin in Phase 2 with mountain topography (Phase 2 Mountains) was assigned an intermediate value of 0.08, which was used for the main channel and overbank as a transitional value between the mountains subbasins in Phase 1 and Phase 2 Plains subsections of the model. During selection of the Manning's roughness values, it was noted that the model had mild sensitivity to this parameter as it relates to timing. The selection of Manning's roughness values was justified by the timing of the calibrated model time-of-peak at LT-J12 (Little Thompson River at I-25). The model reach parameters are provided in **Table B-5**.

2.4.6 Model Calibration

Model calibration is the iterative process of adjusting model parameters so that simulated results match real-world observations (measurements). Model calibration provides a degree of certainty beyond that which is achieved through the use of parameters reported in literature because calibrated parameters ideally account for unique attributes of a particular watershed. The following sections describe the calibration of the Little Thompson River HEC-HMS hydrologic model.

Calibration Event

As discussed previously, the hydrologic model was calibrated to a 24-hour period of the September 2013 event to better align the hydrologic modeling effort with the assumptions correlated with development of the SCS infiltration loss equations. The 24-hour period of rainfall associated with the peak rainfall volume, which occurred between 7:40 p.m. on September 11 and 7:40 p.m. on September 12, was selected for model calibration. This window also contains the observed time-of-peak of the afternoon of September 12 at I-25. **Figure 10** shows the incremental rainfall for the 24-hour calibration event in relation to the 10-day September 2013 event.

Calibration Process

The calibration process requires careful consideration of which modeling parameters are most appropriate to adjust to avoid the manipulation of parameters beyond physical reality to achieve desired results. For example, modeled discharges may be "calibrated" to observed discharges by increasing roughness parameters to an unreasonably high value that results in an excessive attenuation of flow in routing elements. While the model may be "calibrated" computationally, it would not be calibrated realistically because careful review of the calibrated parameters would suggest that an excessive roughness is not supported by other physical observations. Considering such situations, available data, and past experience, it was decided that the CN of subbasins and Snyder's peaking coefficient were the most logical calibration parameters and that parameters such as Manning's roughness of routing elements, and lag time would not be adjusted for calibration (as described in preceding sections) (See Table B-2).

Initial estimates of CNs based on interpretation of aerial imagery and land cover classifications yielded modeled discharges that were significantly less than observed flows and indicated a need to drastically increase CNs to calibrate the model. Given that significant rainfall was measured in the days preceding the selected 24-hour period, there was a reasonable probability that basin soils were saturated and had a significantly reduced infiltration capacity not represented by standard CNs, which assume a 5-day antecedent rainfall of less than 2.1 inches (Novotny, 2011). AMCs were considered by estimating the total rainfall in the 5 days prior to the selected 24-hour period. The antecedent rainfall for each subbasin is provided in **Table B-2 in Appendix B**. Subbasins that received more than approximately 2.1 inches of rainfall were classified AMCIII; those that received less were classified as AMCII (Novotny, 2011). CNs for AMCIII were estimated from AMCII CNs in literature using the following equation (Novotny, 2011):

$$CN_{AMCIII} = \frac{23CN_{AMCII}}{10 + 0.13CN_{AMCII}}$$

To limit the possibility of unrealistic estimates of CNs, calibration of CNs relied on the reassignment of land cover descriptions to delineated land covers. The reassignment of land cover description was mostly limited to assigning a "poor condition" instead of a "fair condition" originally assigned. Such a modification is not uncommon because a "poor" or "fair" condition considers vegetative cover, soil structure, topography, land use history, and other considerations not easily accessible using aerial imagery. In general, CNs were reassigned at subbasin scale if the unique reassignment could be justified. For example, "forest" land cover in North Fork Little Thompson River was reassigned as "poor condition" in several of the subbasins, in contrast to "fair condition" in the other sub-watershed, due to knowledge of the potential for landslides during heavy storm events. Land use conditions for the Little Thompson River are provided in **Table B-6** in **Appendix B**.

The Snyder peaking coefficient, C_p, was varied from 0.4 to 0.8 in groups according to the three sub-watersheds in the model: Phase 1, Phase 2 Mountains, and Phase 2 Plains.

Calibration Results

The final calibrated model used "fair condition" CNs for all of subbasins in the Little Thompson River Phase 2 sub-watershed except for the three in North Fork: NF-1, NF-2, and NF-3. The three subbasins in North Fork were assigned "poor condition" due to the conditions that likely led to landslides during the September

2013 storm event (USGS, 2013b). All of the subbasins in the Little Thompson River Phase 2 Plains sub-watershed used "fair" conditions as aerial review of the subbasins did not indicate reasons to change to another condition. Calibrated CNs by subbasin are provided in **Table B-1** in **Appendix B**.

The final calibrated model used a Snyder peaking coefficient of 0.6 for subbasins in Phase 1 and Phase 2 Mountain sub-watershed and 0.7 for subbasins in Phase 2 Plains sub-watershed. Comparison of modeled discharge to observed discharges in provided in **Table 5**.

TABLE 5
Little Thompson River Comparison of Modeled Discharges to Observed Discharges

HMS Node	Location	Observed Peak Discharge (cfs)	Modeled Peak Discharge (cfs)	% Difference	Runoff Volume (in)
LT-J6	Little Thompson River at X Bar 7 Ranch	15,731[a]	14,300	-9%	4.54
LT-J10	Little Thompson River at South County Line Road	13,400	15,500	16%	3.23
LT-J12	Little Thompson River at Interstate 25	15,700	15,200	-3%	2.69
LT-J13	Little Thompson River at County Road 17	18,000[b]	14,900	-17%	2.45

[a] Per CDWR, 2014.

[b] Split flow condition occurred, (URS, 2015).

As shown in **Table 6**, the calibrated model time-of-peak at LT-J12 (Little Thompson River at I-25) of 2:20 p.m. on September 12, 2013, compares favorably to CDOT's estimate of the afternoon of September 12, 2013.

TABLE 6
Comparison of Modeled Time-to-Peak to Observed Time-to-Peak

Location	Calibration Data Source	Observed Time of Peak Discharge	Modeled Time of Peak Discharge
Little Thompson River at Interstate 25	CDOT, In Press	9/12/2013 afternoon	9/12/2013 2:20 p.m.

2.4.7 Predictive Model Implementation

Development of the predictive hydrologic model required a slight modification of the calibrated model to account for differences between the September 2013 event and a theoretical design event. The calibrated AMCIII CNs were converted back to AMCII to maintain consistency with procedures detailed in the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008) for the estimation of peak discharges using the SCS method. With the revision described above, the predictive model was used to estimate peak discharges throughout the watershed for the 10, 4, 2, 1, and 0.2 percent annual chance events assuming a standard 24-hour SCS Type II rainfall distribution.

3.0 Hydrologic Model Results

3.1 Estimate of Design Flow Magnitudes

The peak discharges in **Table 7** were estimated in order to implement the predictive model to estimate the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges based on the respective percent annual chance rainfall and model parameters described in Section 2.4. Hydrographs at key design points in the model are provided in **Figure 11**. The peak flow profile for Little Thompson River is provided in **Figure 12** and detailed model results are provided in **Table B-7** in **Appendix B**. A comparison of the 1 percent chance discharge estimates for the Little Thompson River predictive model, effective FIS, and FFA is provided in **Figure 13**.

TABLE 7
Little Thompson River Modeled 10, 4, 2, 1, and 0.2 Percent Chance Peak Discharge

			Predictive Annual Chance Peak Discharge (cfs)				
Location	**DARF**	**Observed Discharge (cfs)**	**10 percent**	**4 percent**	**2 percent**	**1 percent**	**0.2 percent**
Little Thompson River at X Bar 7 Ranch	0.94	15,731	2,310	4,500	6,970	10,200	20,700
Little Thompson River at LTCANYO Gage	0.92	N/E	2,760	5,380	8,330	12,100	24,700
Little Thompson River at South County Line Road	0.92	13,400	3,650	6,940	10,600	15,300	30,800
Little Thompson River at Interstate 25	0.92	15,700	4,140	7,090	10,900	16,000	33,500
Little Thompson River at County Road 17	0.92	18,000	4,480	7,150	10,700	15,700	32,100
Little Thompson River Upstream of Confluence with Big Thompson	0.92	N/E	4,450	7,130	10,500	15,400	31,400

N/E: No Estimate

Modeled peak unit discharges, defined as peak discharge per square mile of contributing area, are provided in **Table 8**. A comparison of the 1 percent chance unit peak discharge versus subbasin area for Little Thompson River Phase 1, Phase 2 Mountains and Phase 2 Plains sub-watersheds is provided in **Figure 14**. The sub-watersheds range in size from 0.5 to 20 square miles in area and the 1 percent chance unit peak discharges range from 25 to 300 cfs per square mile. Little Thompson River Phase 2 Mountains and Plains have higher unit discharges than Little Thompson River Phase 1 due to higher peaking coefficients and higher CNs due to increased urbanization.

TABLE 8
Little Thompson River Modeled 10-,4,-2,-1, and 0.2-Percent Chance Unit Peak Discharge

Location	Observed Discharge (cfs)	Predictive Annual Chance Peak Unit Discharge (cfs/sq mile)				
		10 percent	4 percent	2 percent	1 percent	0.2 percent
Little Thompson River at X Bar 7 Ranch	15,731	28.2	55.0	85.2	124.6	252.9
Little Thompson River at LTCANYO Gage	N/E	27.6	53.7	83.2	120.8	246.6
Little Thompson River at South County Line Road	13,400	27.6	52.5	80.2	115.8	233.1
Little Thompson River at Interstate 25	15,700	25.0	42.7	65.7	96.5	202.0
Little Thompson River at County Road 17	18,000	24.0	38.3	57.4	84.2	172.1
Little Thompson River Upstream of Confluence with Big Thompson	N/E	22.7	36.3	53.5	78.4	159.9

N/E: No Estimate

3.2 Comparison to Previous Hydrologic Studies

3.2.1 Previous Hydrologic Studies Calibrated to September 2013 Event

Comparisons of the calibrated model peak discharge to the Dam Safety model (CDWR, 2014) peak discharge estimates are provided in **Table 9**.

TABLE 9
Calibrated Model Comparison

Location	Observed Peak Flow (cfs)	CH2M HILL Modeled Peak Flow (cfs)	CDWR Dam Safety Modeled Peak Flow (cfs)
Little Thompson River at Pinewood Springs	14,600[a]	9,400	10,190
Little Thompson River at X Bar 7 Ranch	15,731[b]	14,300	15,997

[a] NRCS, 2013.
[b] CDWR, 2014.

Review of **Table 9** indicates less than a 15 percent difference in the modeled peak flow at the two comparison locations, providing a degree of verification that both models were accurately calibrated. The two models use different infiltration loss, rainfall runoff transformation, and channel routing methods. The models were also different in scale, with an average subbasin size of 12.4 square mile in the Dam Safety model compared to 6.1 square miles in the calibrated model. The models used similar rainfall data and indirect peak flow estimate methods to calibrate the model.

3.2.2 Previous Predictive Hydrologic Studies

Comparisons of the modeled 10, 4, 2, 1, and 0.2 percent annual chance peak discharge estimates to estimates cited in the previous study are provided in **Table 10**.

TABLE 10
Comparison of Modeled 1 Percent Annual Chance Flow to Other Estimates

Location	Drainage Area (square miles)	Estimated 1 Percent Annual Chance Peak Discharge (cfs)			
		Predictive Model	FEMA Effective Hydrology	CDOT, 2011	Gage Analysis
Little Thompson River at LTCANYO Gage	100.2	12,100	N/E	6,962 [a]	10,992
Little Thompson River at South County Line Road	132.1	15,300	9,500 [b]	11,305 [a]	N/E
	132.1		7,200 [c]		
Little Thompson River at Interstate 25	165.9	16,000	N/E	14,728	N/E
Little Thompson River Upstream of Confluence with Big Thompson	196.4	15,400	4,800 [d]	N/E	N/E

N/E: No Estimate

[a] While part of the hydrologic model, peak discharge estimates at this location were not a focus of the study.

[b] Larimer County FIS (2013c).

[c] Boulder County FIS (2012).

[d] Town of Milliken FIS (1979) and Weld County FIS (preliminary).

Review of **Table 10** indicates that estimates of 1 percent annual chance peak discharges in the Little Thompson River watershed are greater than those of previous estimates, including FEMA effective hydrology and the gage analysis. The primary difference between the CDOT 2011 and predictive hydrologic models is that the predictive model was based on calibration to the September 2013 event, whereas the CDOT hydrologic model was not calibrated and was completed prior to the September 2013 event that could have been used as a verification check. Additionally, the predictive model is more detailed in scale with an average subbasin size of 6.1 square miles compared to an average 12.3 square miles subbasin size in the CDOT 2011 model. Both models used the SCS curve number method to estimate infiltration losses. The CDOT 2011 model used the SCS unit hydrograph method and TR-55 equations to develop Lag Time for each of the subbasins. The predictive model used the Snyder unit hydrograph method and Lag Time was developed using length of centroid and watershed slopes. There is likely higher confidence in the predictive model as compared to the CDOT 2011 model primarily because the predictive model has been calibrated to the September 2013 event and secondarily because the predictive model is more detailed. Additionally, the CDOT model, while encompassing the majority of the watershed, was developed to estimate peak discharge solely at one location (I-25) whereas the current predictive model was calibrated and developed to accurately predict peak discharges at a number of discrete locations.

The Larimer County FEMA peak discharge estimates along the Little Thompson River were developed by “approximate methods” using USGS regression equations. The Town of Milliken FEMA value at the Little Thompson River Upstream of Confluence with Big Thompson was based on flood frequency analysis using only data prior to 1974. These methods are not as robust as the methods used to construct the current predictive model. In addition, while not documented for the Little Thompson River, USACE used unsteady models to route flood hydrographs for several other Front Range streams (USACE, 1977b). If such a method was used for the 1970s studies as well, peak discharges would have been attenuated as a result of floodplain storage that is typically disregarded in current flood studies as it cannot be relied upon to exist in perpetuity. It is unknown what the Boulder County FEMA estimate is based on; therefore, no assessments of its accuracy can be made.

Results of the predictive hydrologic model compare favorably with current flood frequency analyses of the LTCANYO gage. In contrast to the majority of other stream gages along the Front Range, there are no major reservoirs or diversions upstream of the stream gage such that flows measured by the LTCANYO gage are fairly representative of unregulated conditions. Also considering that the gage has recorded several events of fairly significant magnitude, flood frequency analysis of the LTCANYO gage is likely representative of expected high-flow hydrology. Therefore, the favorable comparison between the flood frequency analysis at Little Thompson River at LTCANYO Gage and the predictive model provides a high degree of verification of the predictive model.

4.0 Conclusions and Recommendations

The assumptions and limitations of the hydrologic model and previous study were closely reviewed, compared, and contrasted. The predictive hydrologic model was considered more appropriate to estimate Little Thompson peak discharges than previous peak discharge estimates in the effective FISs due to the Larimer County study using approximate methods (regression analysis), the lack of documentation for the Boulder County study, and the availability of additional gage records to conduct a flood frequency analysis at the LTCANYO gage and the non-conservative nature of using an unsteady model to route the resulting discharge to estimate peak discharges downstream. The 2011 CDOT model was concluded less accurate due the larger scale of the model, lack of calibration, and focus on a singular location, I-25, rather than multiple points along the Little Thompson. While flood frequency analysis of the LTCANYO gage may reasonably be used in the estimation of high-flow hydrology, the flood frequency analysis can only be used to estimate high-flows for a short reach of the Little Thompson River before the extrapolation of flood frequency analysis results are outside of typical extrapolation bounds. Therefore, the predictive model developed as part of the current study is proposed as the appropriate model to revise high-flow hydrology along the Little Thompson River upstream of the confluence with the Big Thompson River.

4.1 Design Peak Discharge Magnitudes

Table 11 presents modeled discharge-frequency relationships at physically relevant locations located in close proximity to hydrologic model junctions; comparison of estimated 1 percent chance peak discharges between high-flow prediction methods and previous hydrologic studies were provided previously as part of **Table 10**. Discharge-frequency relationships presented in **Table 11** were rounded to three significant figures to maintain a consistent level of precision as the effective FIS a reasonable level of precision given model uncertainty. Based on the discussion in previous sections, the peak discharges presented in **Table 11** are considered the best estimate of high-flow hydrology for the Little Thompson River study reach between the confluence with West Fork Little Thompson River and the confluence with the Big Thompson River.

TABLE 11
Proposed 10, 4, 2, 1, and 0.2 Percent Chance Peak Discharge

		Annual Chance Peak Discharge (cfs)				
Location	**Drainage Area (mi^2)**	**10 Percent**	**4 Percent**	**2 Percent**	**1 Percent**	**0.2 Percent**
Little Thompson River Downstream of Confluence with West Fork Little Thompson River	*43.2*	*650*	*1,370*	*2,250*	*3,420*	*7,510*
Little Thompson River at US 36	*43.8*	*660*	*1,380*	*2,270*	*3,460*	*7,600*
Little Thompson River at X Bar 7 Ranch	81.8	2,310	4,500	6,970	10,200	20,700
Little Thompson River at LTCANYO Gage	100.2	2,760	5,380	8,330	12,100	24,700
Little Thompson River at South County Line Road	132.1	3,650	6,940	10,600	15,300	30,800
Little Thompson River at Interstate 25	165.9	4,140	7,090	10,900	16,000	33,500
Little Thompson River at County Road 17	186.5	4,480	7,150	10,700	15,700	32,100
Little Thompson River Upstream of Confluence with Big Thompson	196.4	4,450	7,130	10,500	15,400	31,400

4.2 Assessment of September 2013 Event

In accordance with the purpose of the study, the peak discharges observed during the September 2013 event were compared to the modeled 10, 4, 2, 1, and 0.2 percent annual chance peak discharges to assess the recurrence interval of the September 2013 event. **Table 12** provides the comparison and assessment of the September 2013 flood recurrence interval.

TABLE 12
Estimate of the Recurrence Interval of the September 2013 Event

Location	Observed Peak Discharge (cfs)	Predictive Annual Chance Peak Discharge (cfs)					Estimated Recurrence Interval (yr)
		10 percent	4 percent	2 percent	1 percent	0.2 percent	
Little Thompson River Downstream of Confluence with West Fork Little Thompson River	*8,955*[a]	*648*	*1,365*	*2,243*	*3,418*	*7,504*	*> 500*
Little Thompson River at US 36	*9,056*[a]	*651*	*1,376*	*2,264*	*3,455*	*7,600*	*> 500*
Little Thompson River at X Bar 7 Ranch	15,731[b]	2,310	4,500	6,970	10,200	20,700	100 to 500
Little Thompson River at LTCANYO Gage	15,500[a]	2,760	5,380	8,330	12,100	24,700	100 to 500
Little Thompson River at South County Line Road	13,400[c]	3,650	6,940	10,600	15,300	30,800	50 to 100
Little Thompson River at Interstate 25	15,700[c]	4,140	7,090	10,900	16,000	33,500	100
Little Thompson River at County Road 17	18,000[c]	4,480	7,150	10,700	15,700	32,100	100 to 500
Little Thompson River Upstream of Confluence with Big Thompson	14,700[a]	4,450	7,130	10,500	15,400	31,400	100

Note: Italics denote results from the Little Thompson River [Phase 1] Hydrologic Analysis (CH2M HILL, 2014).

[a] Per Calibrated Hydrologic Model.

[b] Per CDWR, 2014.

[c] Per URS, 2015.

Reviewing **Table 12**, the estimated recurrence interval for the September 2013 event is less than 0.2 upstream of US 36, between 1 and 0.2 percent for all locations downstream US 36 to South County Line Road, and between 2 and 1 percent for all locations downstream of South County Line Road. Considering that the 24-hour precipitation totals matched or exceeded a 500-year frequency in all but four of the subbasins upstream of South County Line Road, this conclusion is reasonable. The September 2013 storm event caused extensive damage to the Little Thompson River corridor and the infrastructure downstream, including US 36, SH 60, and SH 257.

5.0 References

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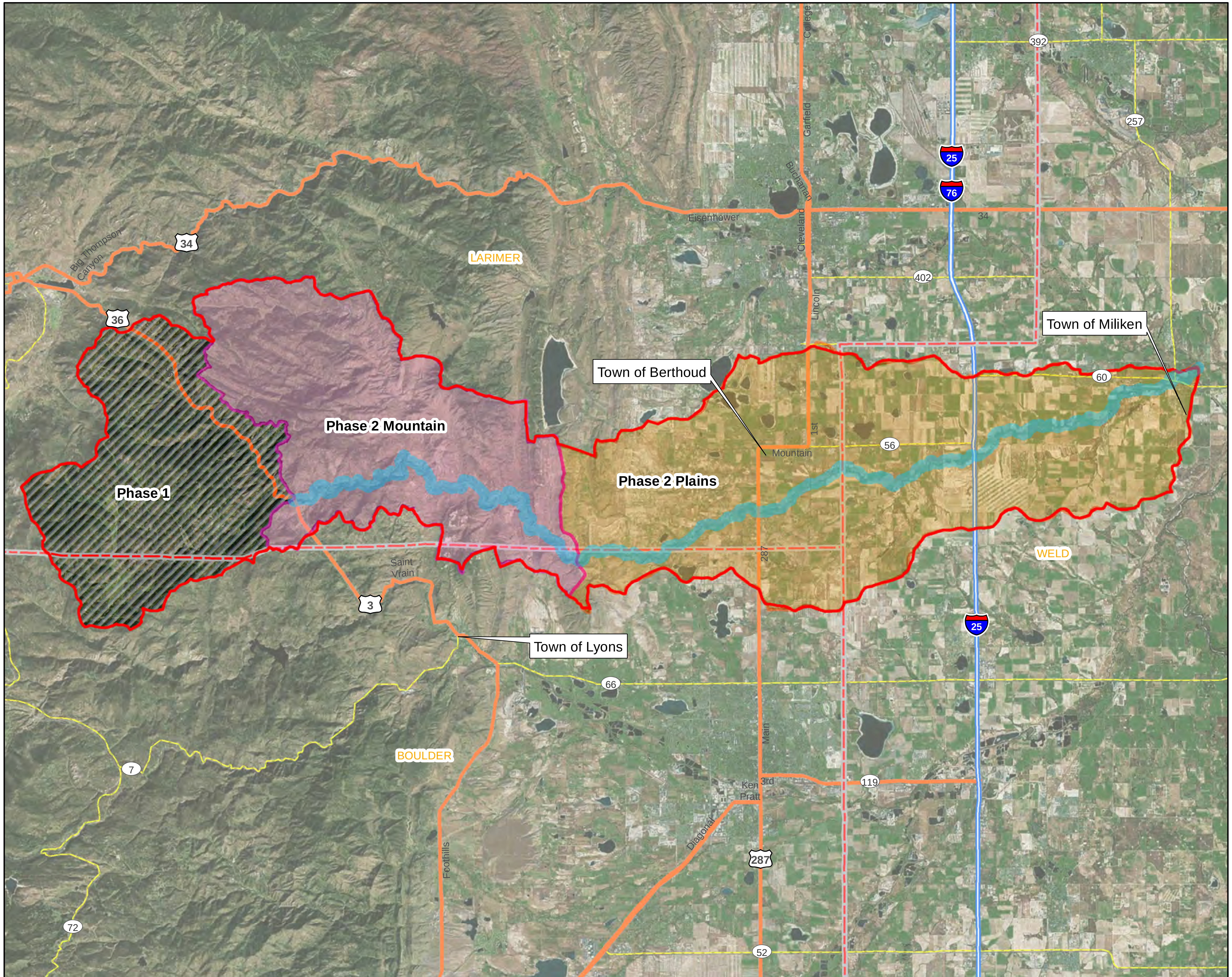
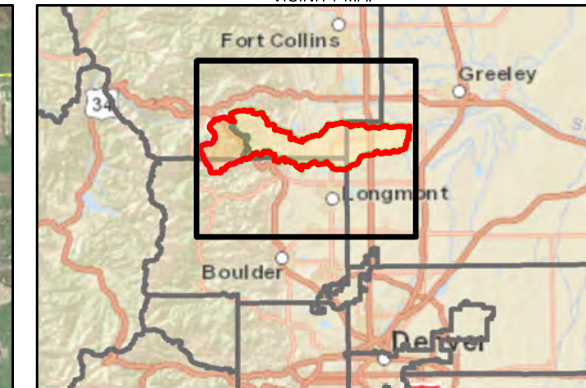
Figures





LEGEND

- Study Reach
- Interstate
- US and State Highway
- Major Road
- Counties
- Little Thompson River Watershed
- Phase 1
- Phase 2 Mountains
- Phase 2 Plains

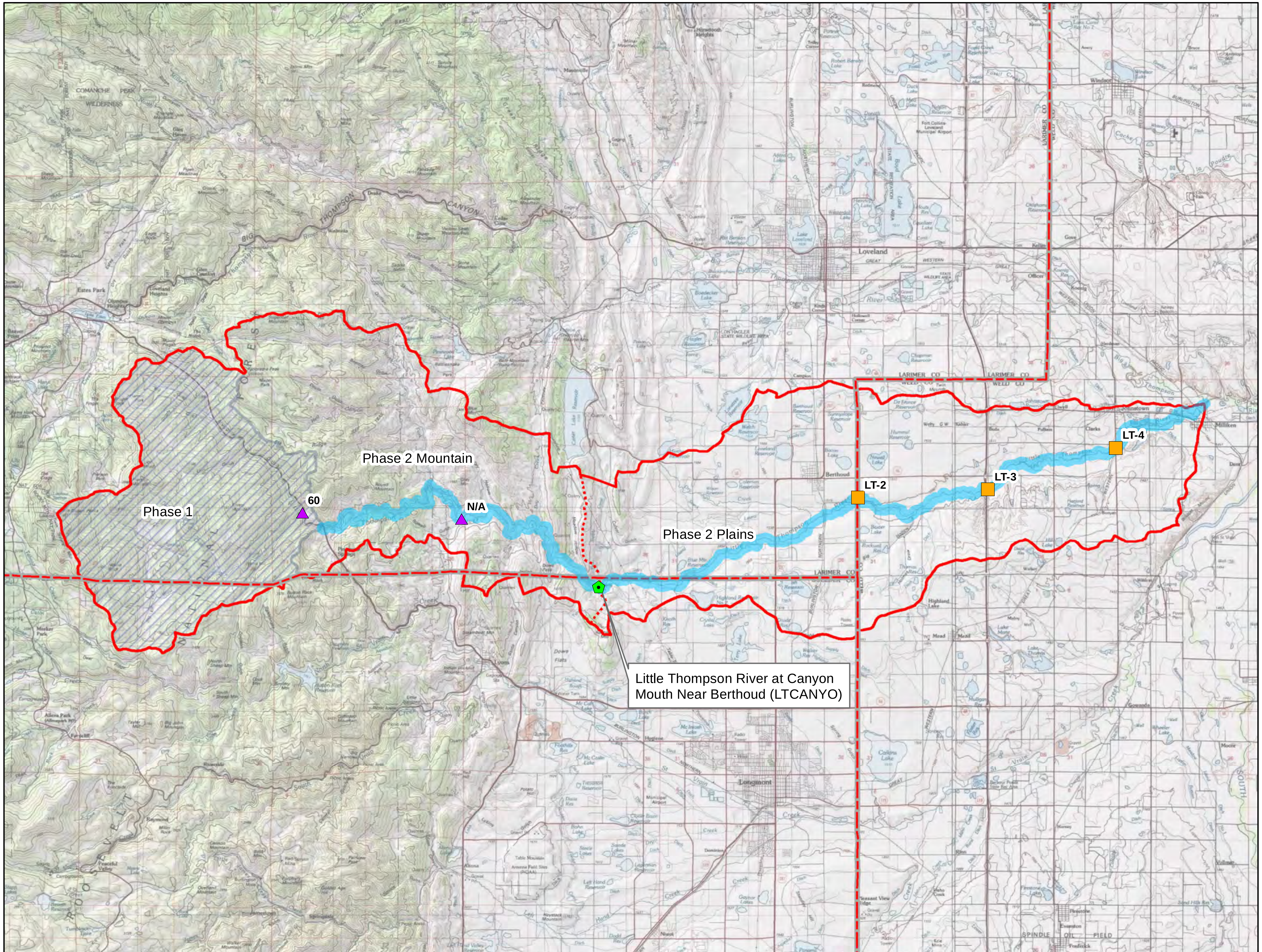
0 0.75 1.5 3 Miles

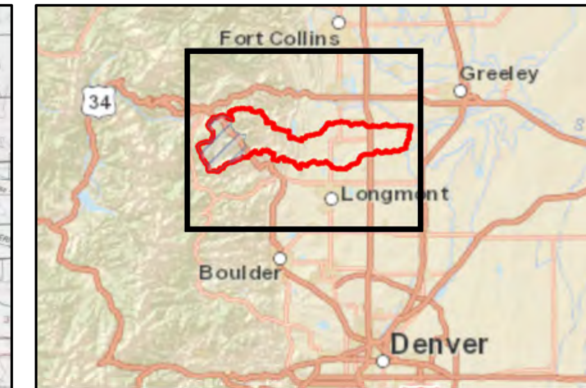
1 in = 3 miles

FIGURE 1
Vicinity and Watershed Map

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.





LEGEND

- Study Reach
- Counties
- Little Thompson River Watershed
- Subwatershed Boundary
- Phase 1 Study Area

Peak Discharge Estimate Locations

- Bridge Hydraulic Estimate
- Critical-Depth Method Estimate
- CDWR Stream Gage

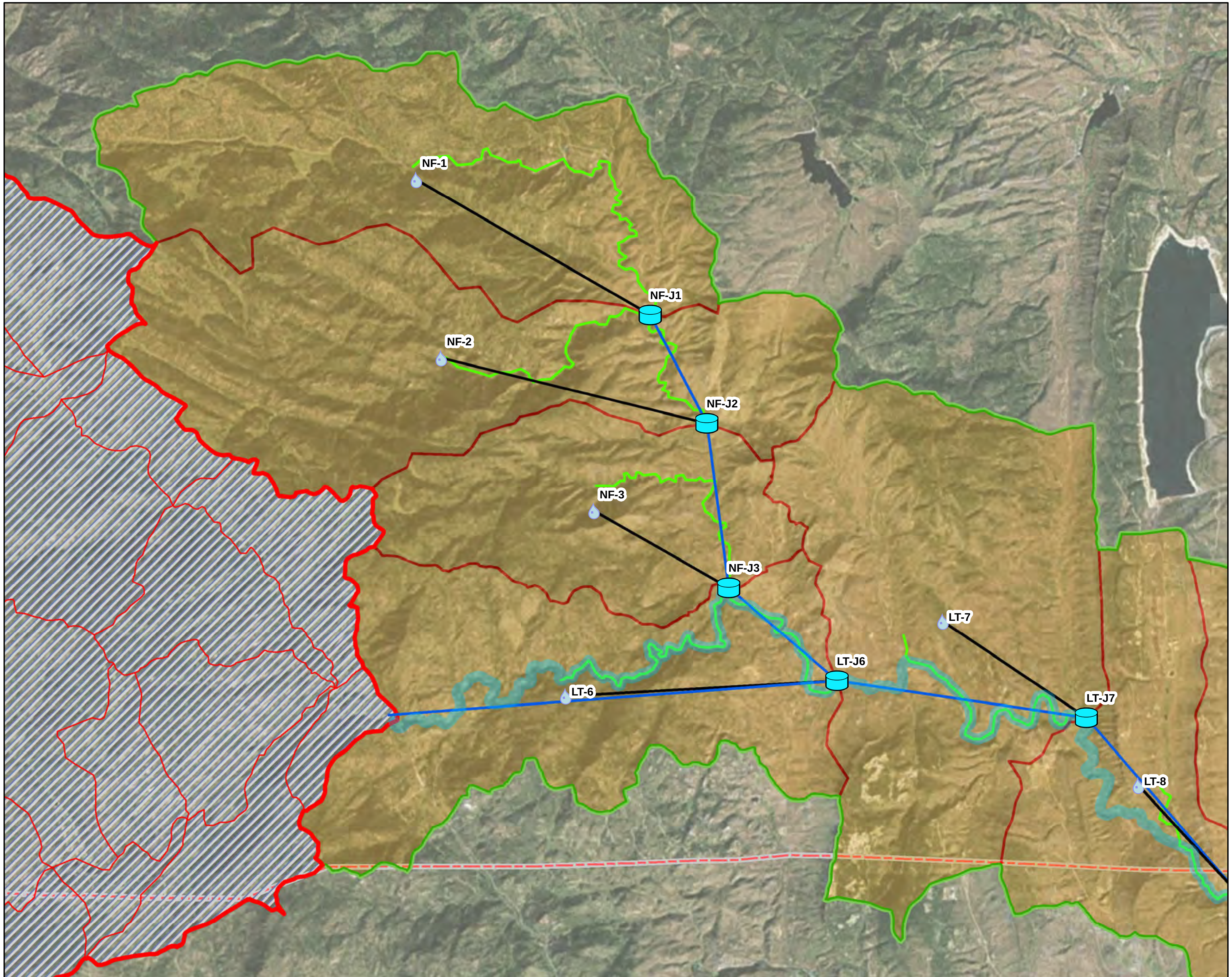
0 1.5 3 4.5 6 Miles

1 inch = 3 miles

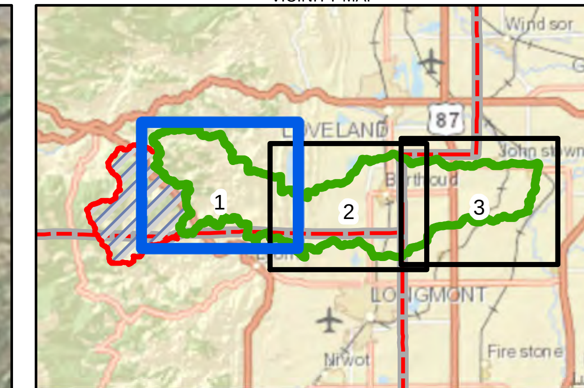
FIGURE 2
Little Thompson River Peak Discharge Estimate and Gage Locations

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.



VICINITY MAP



LEGEND

Model Precipitation Gage

Subbasin Routing

Reach Segment

Basin Connection

Model Junctions

Study Reach

Phase 1 Model Subbasins

Phase 2 Model Subbasins

Flow Paths to Subbasin Centroid

Phase 1 Model Watershed

Phase 2 Model Watershed

Counties

N

0 0.5 1 2 Miles

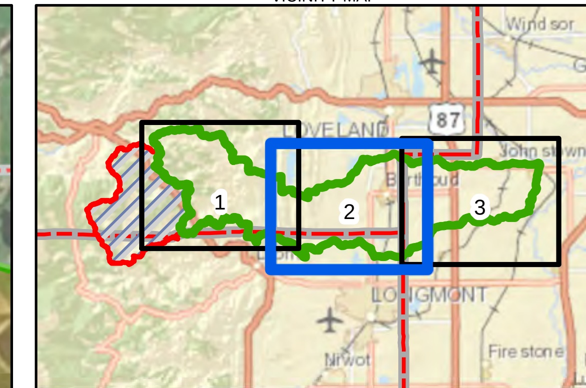
1 inch = 1 miles

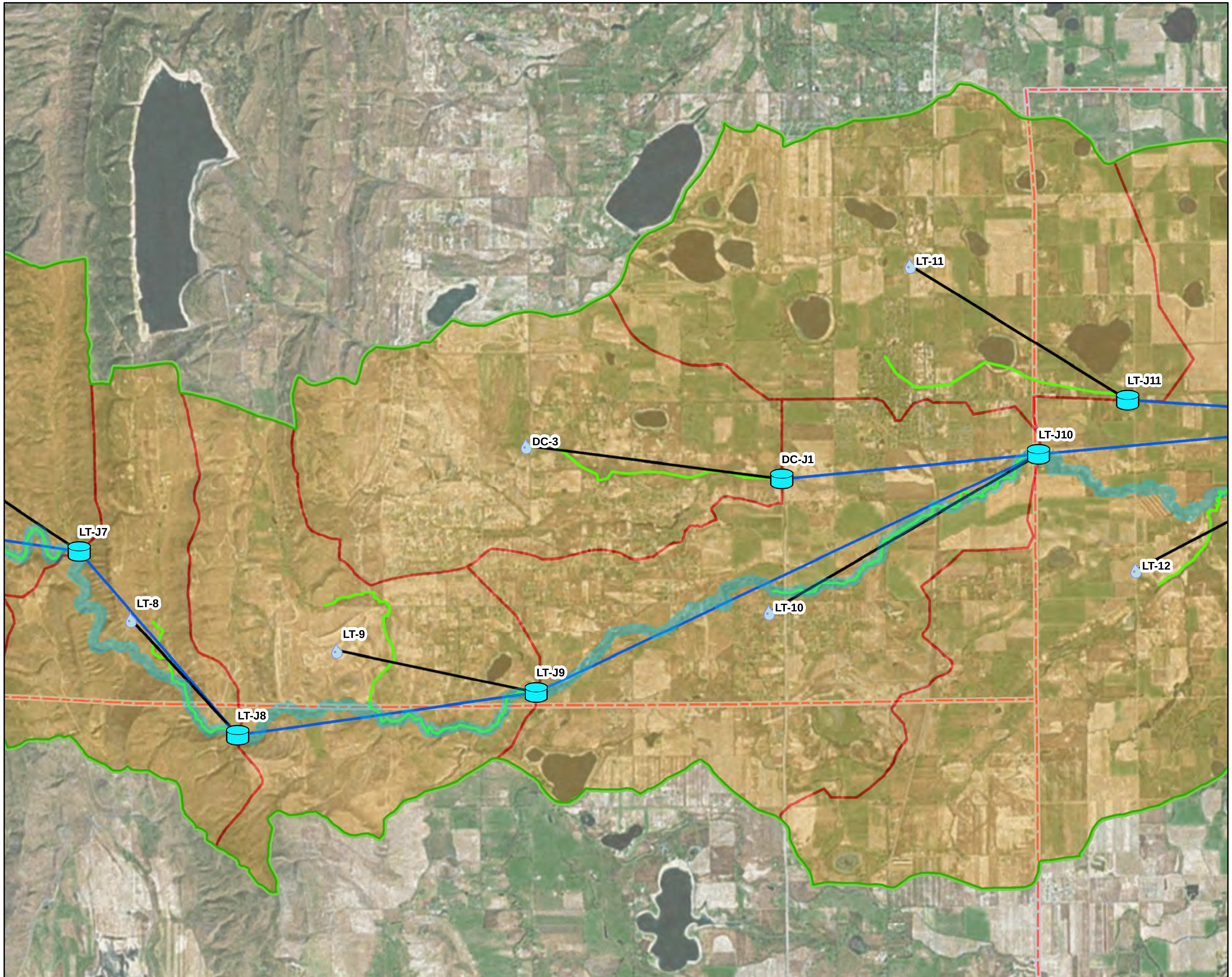
FIGURE B-3a
Phase 2 Connectivity Map - Page 1 of 3

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.

VICINITY MAP





LEGEND

Model Precipitation Gage

Subbasin Routing

Reach Segment

Basin Connection

Model Junctions

Study Reach

Phase 1 Model Subbasins

Phase 2 Model Subbasins

Flow Paths to Subbasin Centroid

Phase 1 Model Watershed

Phase 2 Model Watershed

Counties

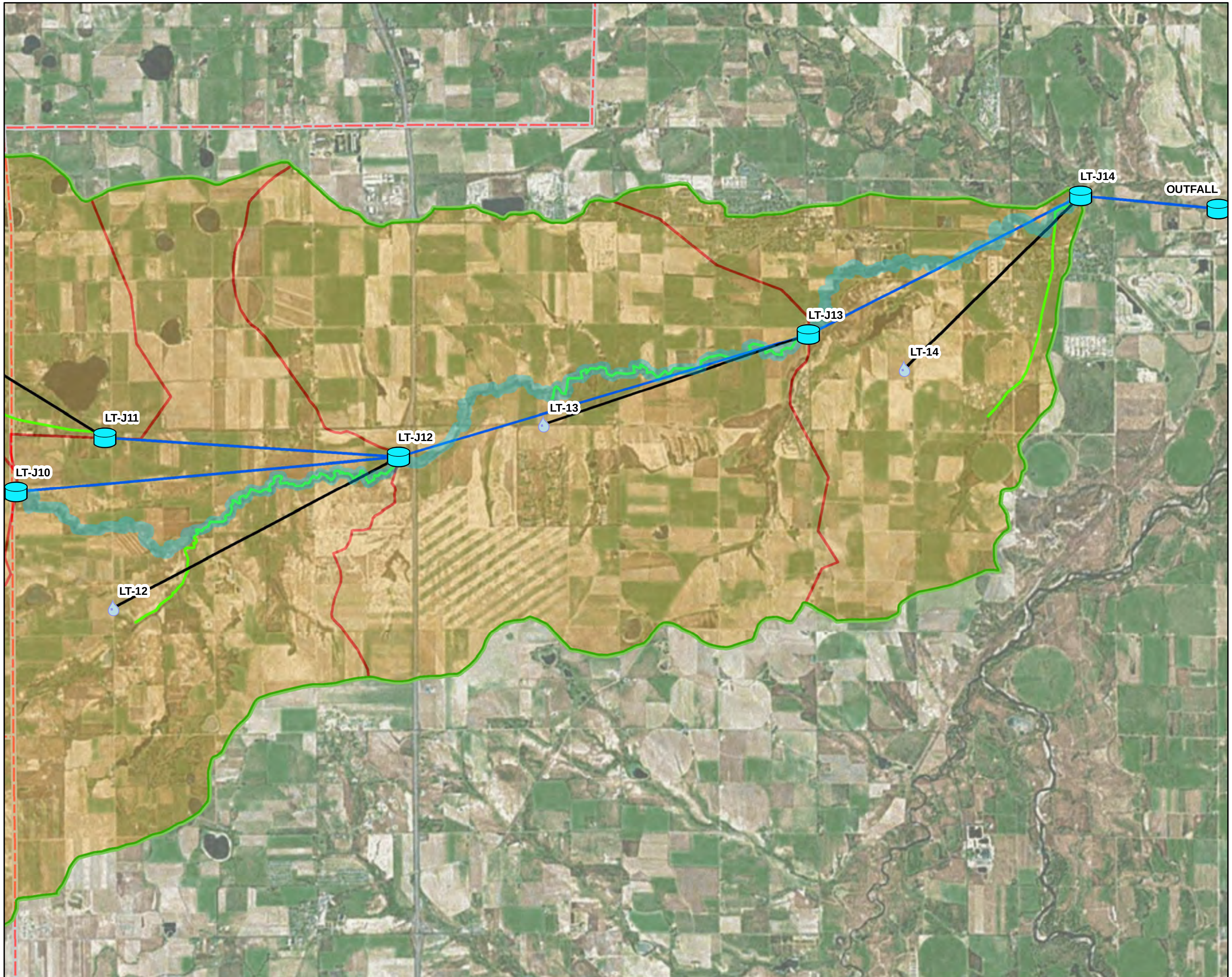
N

0 0.5 1 2 Miles

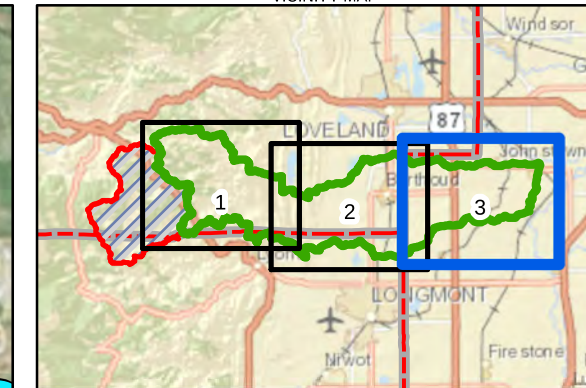
1 inch = 1 miles

FIGURE B-3b
Phase 2 Connectivity Map - Page 2 of 3

CDOT Flood Recovery Hydrologic Evaluation



VICINITY MAP



LEGEND

Model Precipitation Gage

Subbasin Routing

Reach Segment

Basin Connection

Model Junctions

Study Reach

Phase 1 Model Subbasins

Phase 2 Model Subbasins

Flow Paths to Subbasin Centroid

Phase 1 Model Watershed

Phase 2 Model Watershed

Counties

0 0.5 1 2 Miles

1 inch = 1 miles

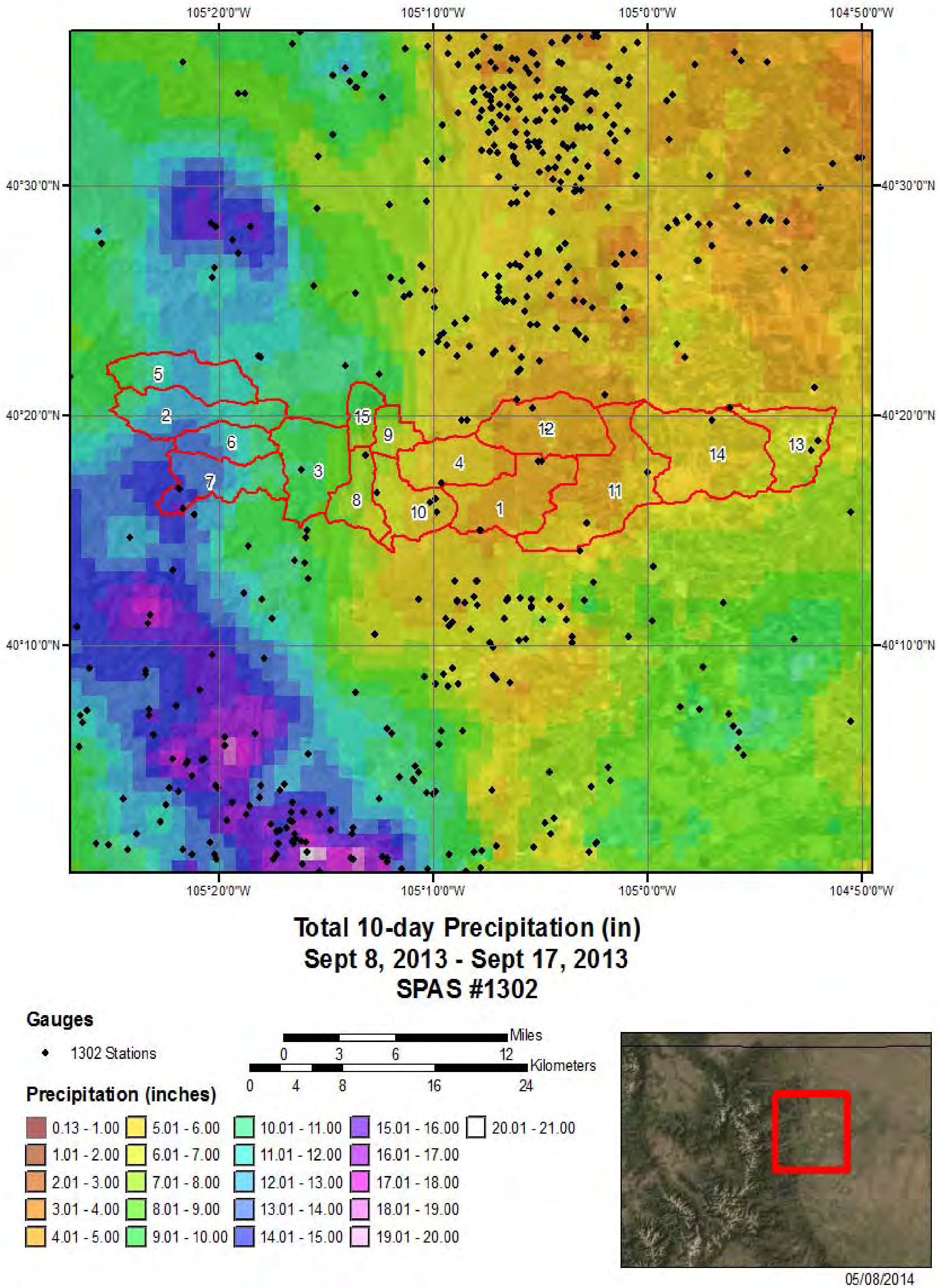
FIGURE B-3c
Phase 2 Connectivity Map - Page 3 of 3

CDOT Flood Recovery Hydrologic Evaluation

UNK T:\481085-482330 CDOT EMERGENCY RESPONSE SERVICES\390_DESIGN_ELEMENTS\DRAINAGE\GIS_PHASE_II\MAPFILES\REPORT\LITTLETHOMPSONCONNECTIVITYMAP_PHASE_II_CBM2.MXD CMCDONOU 3/24/2015 10:40:06 AM

CH2MHILL.

Figure 4 – Phase 2 AWA 10 Day Precipitation



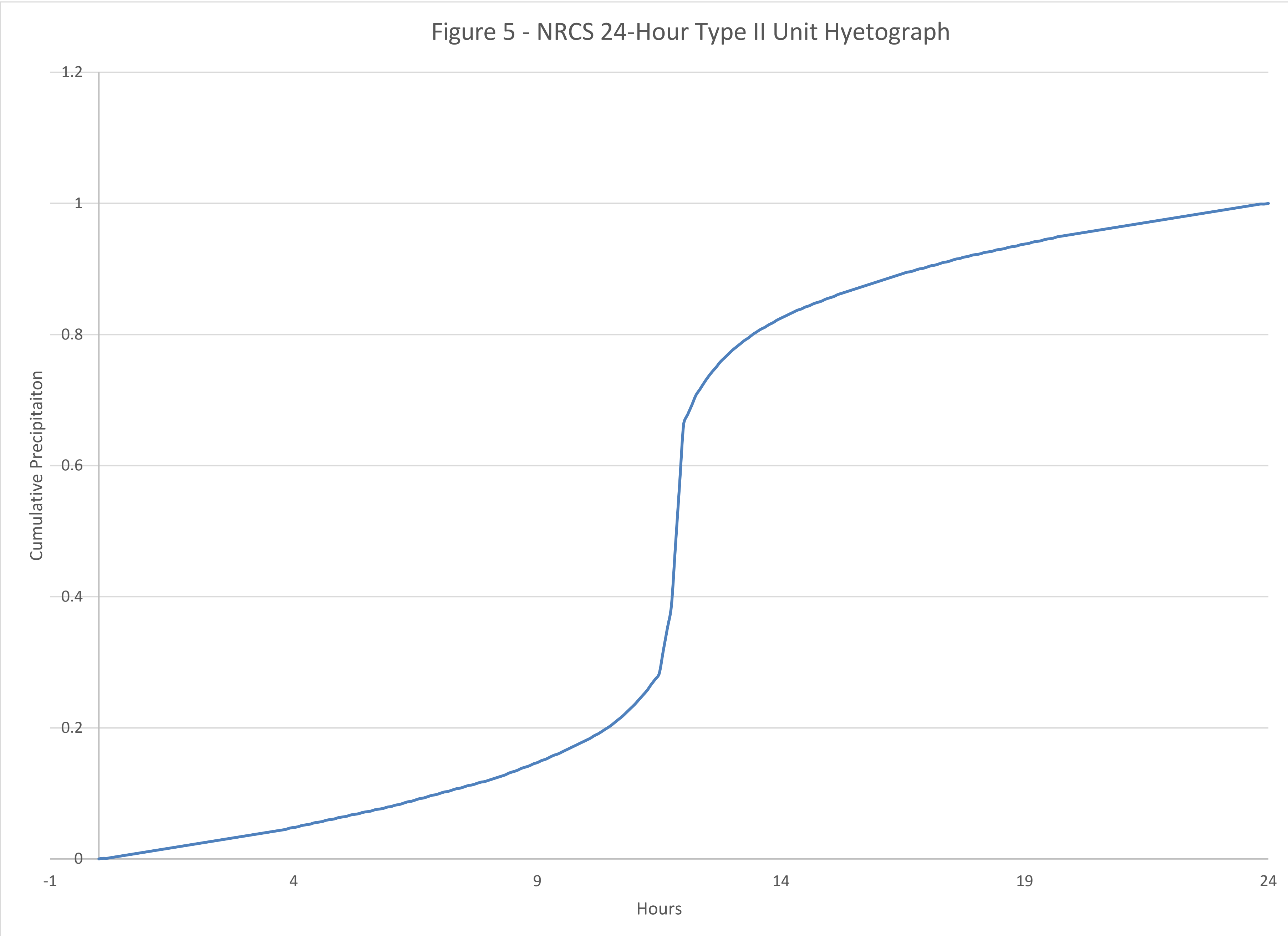
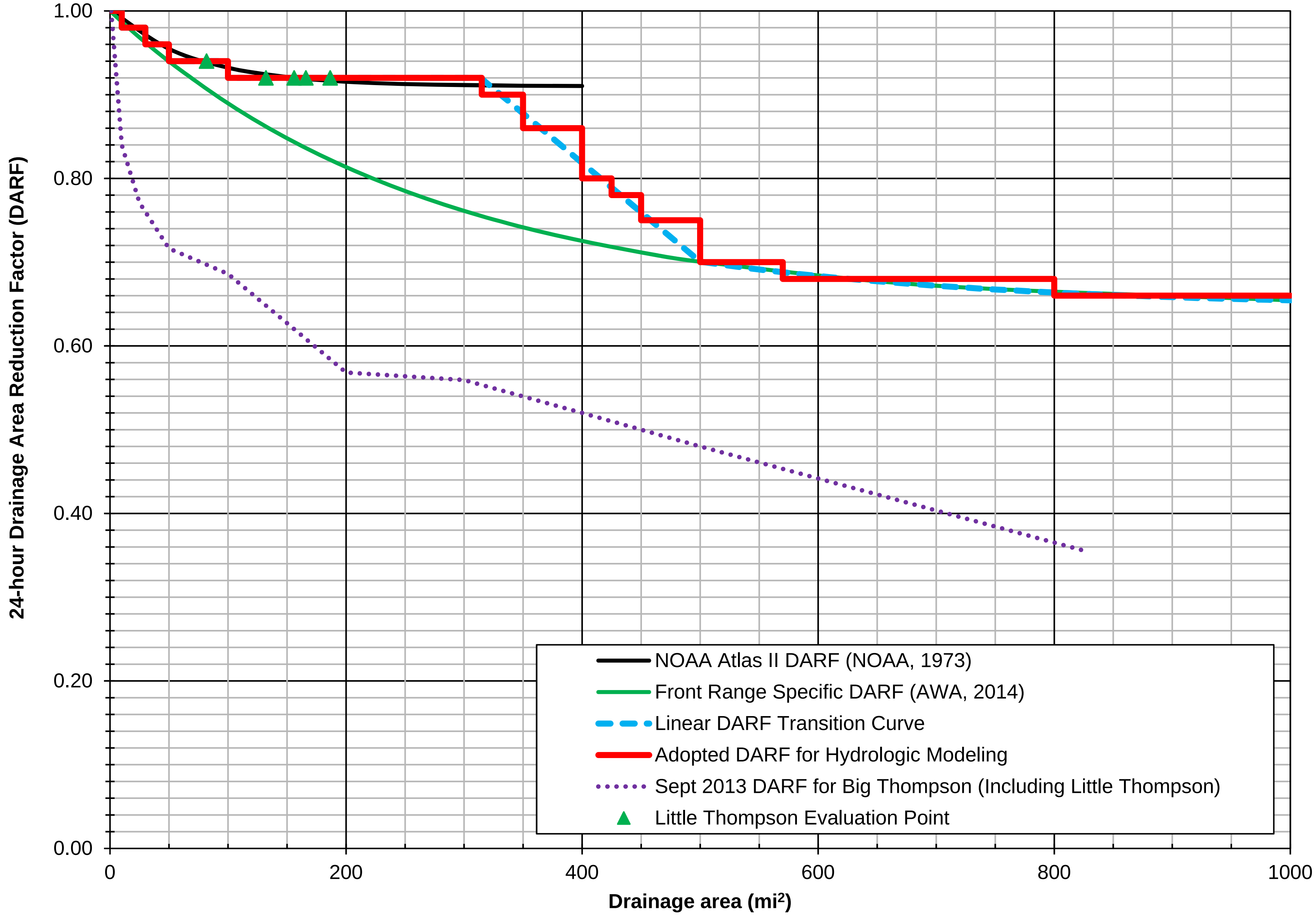
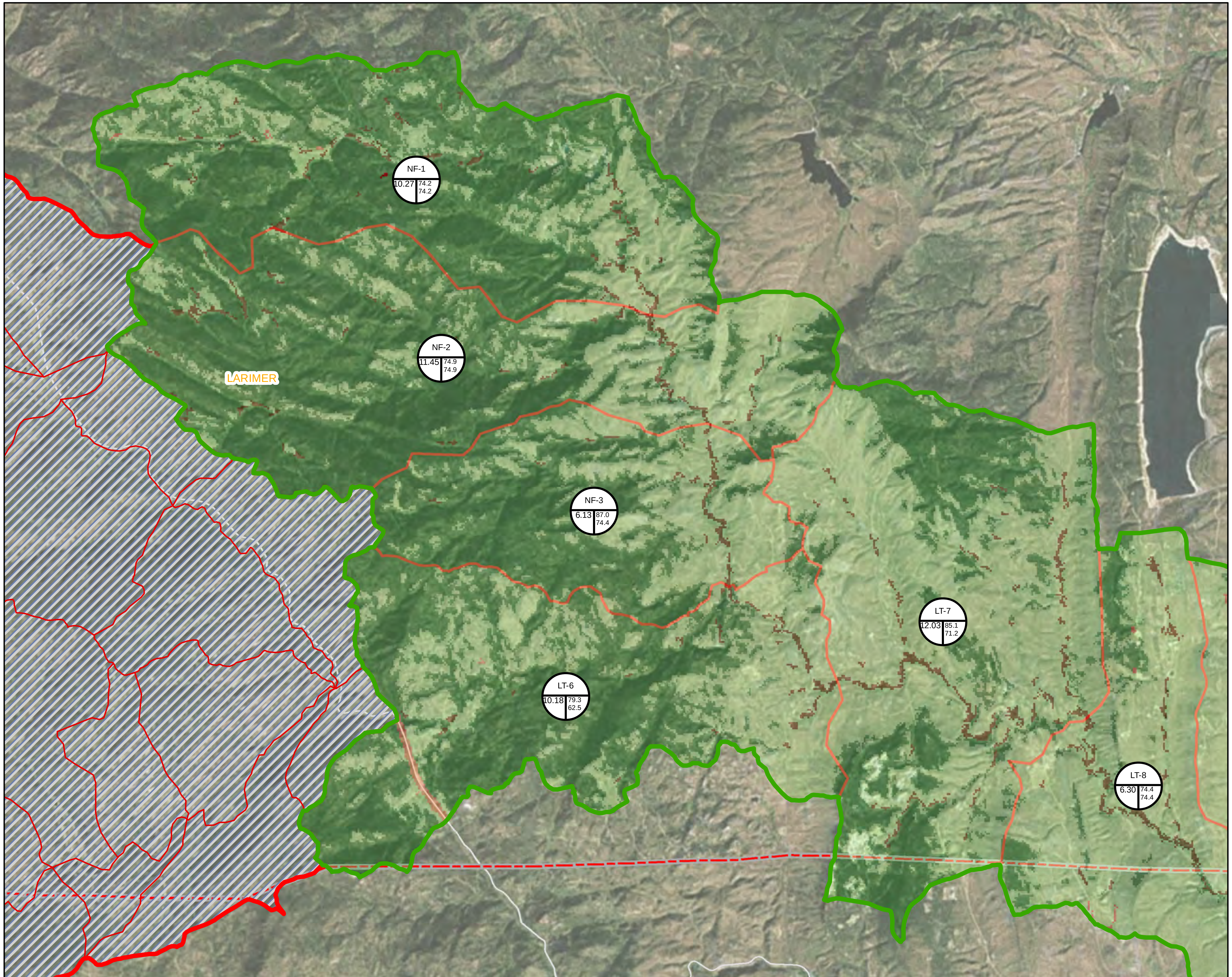


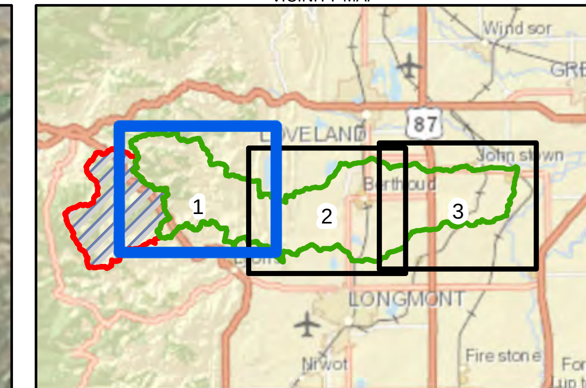
Figure 5 - NRCS 24-Hour Type II Unit Hyetograph
1.2
1
0.8
0.6
0.4
0.2
0
-1
4
9
14
19
24
Hours
Cumulative Precipitaiton

Figure 6 - 24-hour Depth Area Reduction Factor (DARF) Curves





VICINITY MAP



LEGEND

- Phase 1 Model Subbasins
- Phase 2 Model Subbasins
- Phase 1 Model Watershed
- Phase 2 Model Watershed

Land Use

- Open Water
- Developed Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Deciduous Forest - Oak / Aspen
- Shrub/Brush
- Grassland/Pasture
- Row Crops
- Woody Wetlands, Herbaceous
- Counties

Basin # / Area (mi²) / C-CN / D-CN — Landuse Label (C-CN - Calibrated Curve Number) (D-CN - Design Curve Number)

N

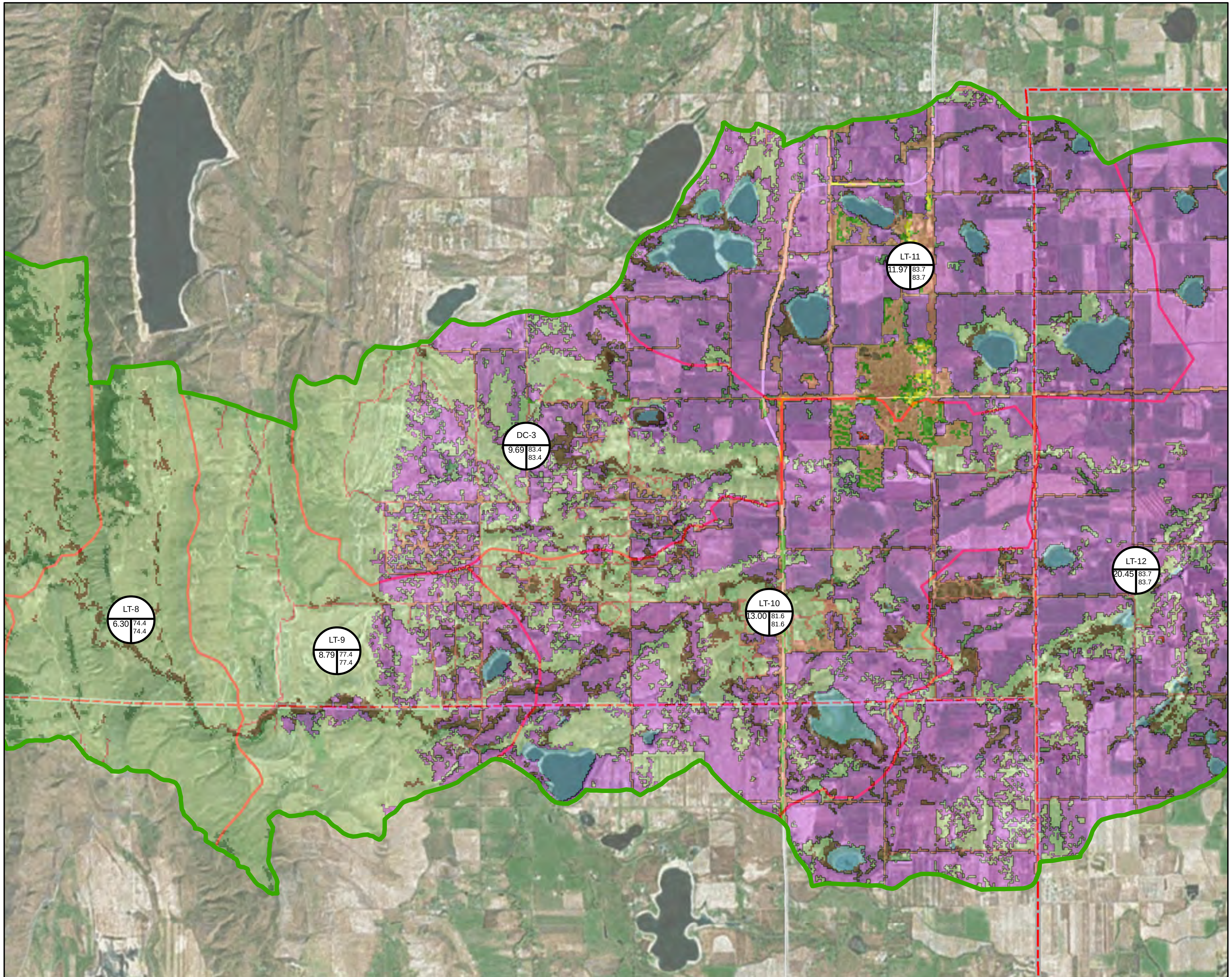
0 0.5 1 2 Miles

1 inch = 1 miles

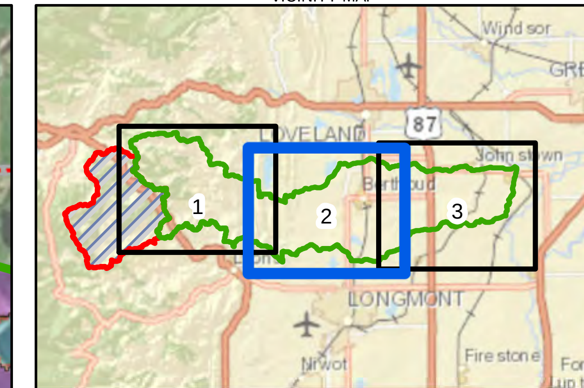
FIGURE 7a

Phase 2 Land Use Map - Page 1 of 3

CDOT Flood Recovery Hydrologic Evaluation



VICINITY MAP



LEGEND

- Phase 1 Model Subbasins
- Phase 2 Model Subbasins
- Phase 1 Model Watershed
- Phase 2 Model Watershed

Land Use

- Open Water
- Developed Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Deciduous Forest - Oak / Aspen
- Shrub/Brush
- Grassland/Pasture
- Row Crops
- Woody Wetlands, Herbaceous
- Counties

Basin # / Area (mi²) / C-CN / D-CN: Landuse Label (C-CN - Calibrated Curve Number) (D-CN - Design Curve Number)

N

0 0.5 1 2 Miles

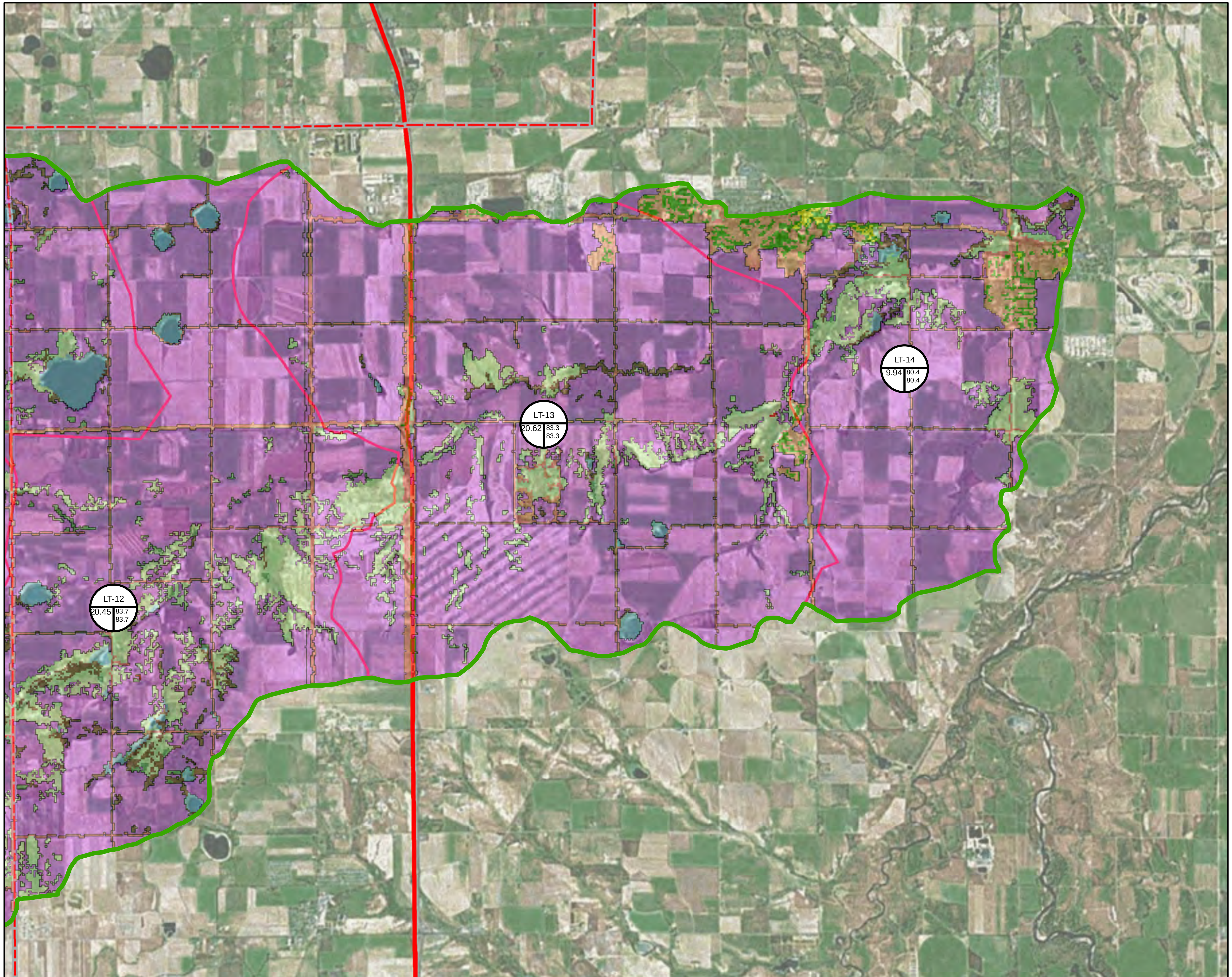
1 inch = 1 miles

FIGURE 7b

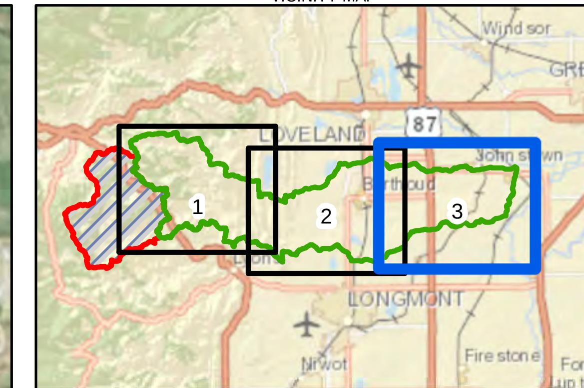
Phase 2 Land Use Map - Page 2 of 3

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.



VICINITY MAP



LEGEND

- Phase 1 Model Subbasins
- Phase 2 Model Subbasins
- Phase 1 Model Watershed
- Phase 2 Model Watershed

Land Use

- Open Water
- Developed Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Deciduous Forest - Oak / Aspen
- Shrub/Brush
- Grassland/Pasture
- Row Crops
- Woody Wetlands, Herbaceous
- Counties

Basin # / Area (mi²) / C-CN / D-CN — Landuse Label (C-CN - Calibrated Curve Number) (D-CN - Design Curve Number)

N

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 7c

Phase 2 Land Use Map - Page 3 of 3

CDOT Flood Recovery Hydrologic Evaluation

UNK \\GECKO\GROUPS\TBG\481085-482330 CDOT EMERGENCY RESPONSE SERVICES\390_DESIGN_ELEMENTS\DRAINAGE\GIS_PHASE_II\MAPFILES\REPORT\PHASEII_LTLANDUSE.MXD BBETTAG 1/8/2015 11:31:56 AM

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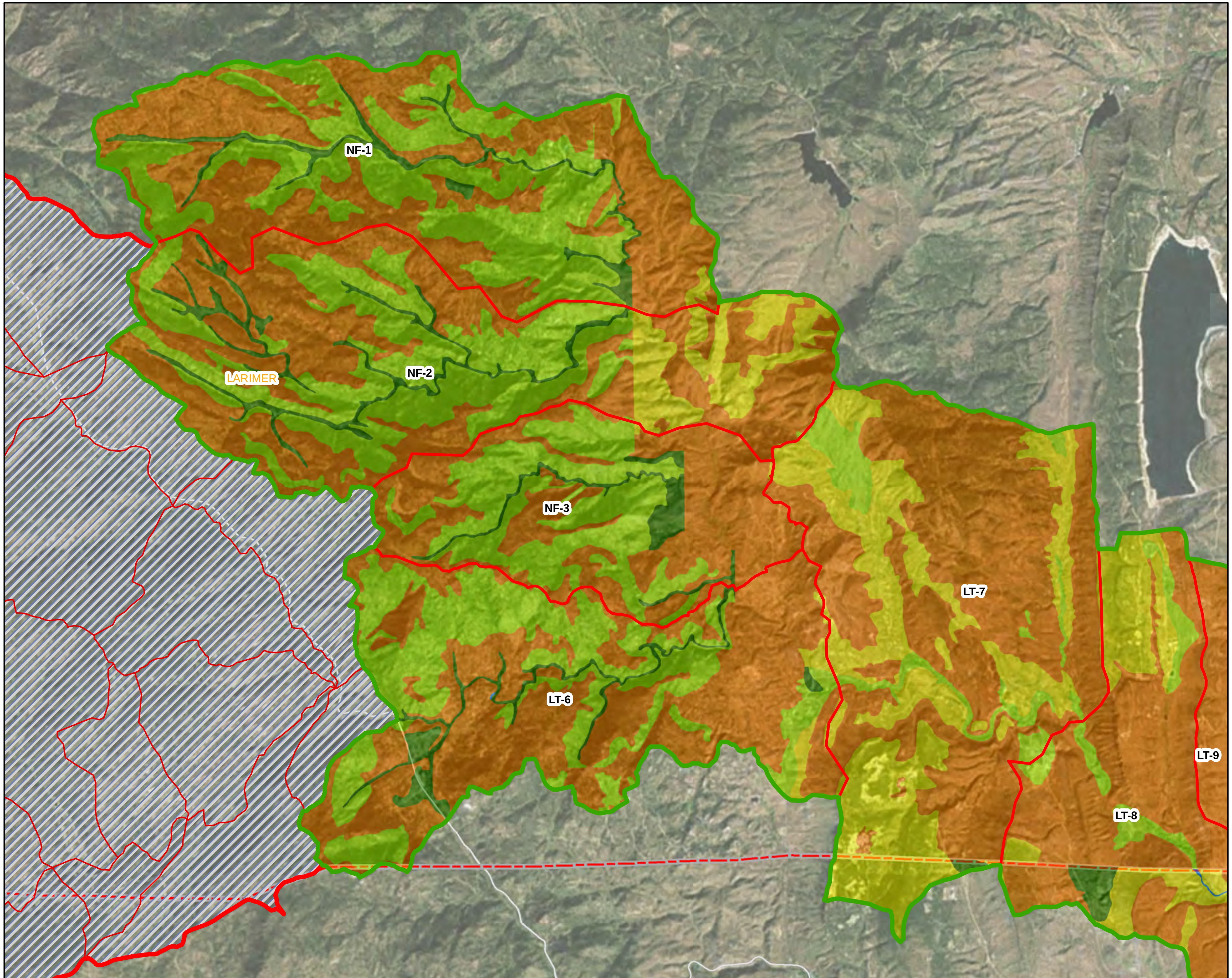

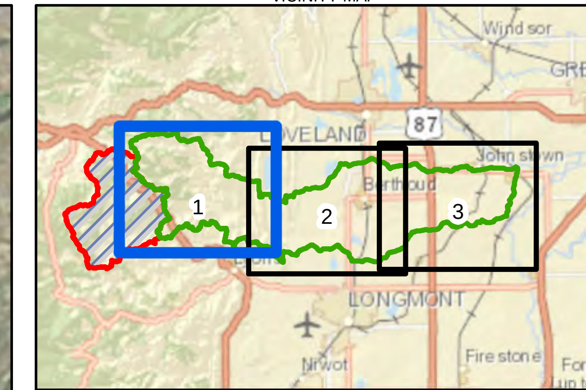

LEGEND

- Phase 1 Model Subbasins
- Phase 2 Model Subbasins
- Phase 1 Model Watershed
- Phase 2 Model Watershed

Hydrologic Soil Group

- A
- B
- C
- D
- Water
- Counties

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 8a

Phase 2 Soils Map - Page 1 of 3

CDOT Flood Recovery Hydrologic Evaluation

UNK \\GECKO\GROUPS\TBG\481085-482330 CDOT EMERGENCY RESPONSE SERVICES\390_DESIGN_ELEMENTS\DRAINAGE\GIS_PHASE_II\MAPFILES\REPORT\PHASEII_LT_SOIL_DATA.MXD BBETTAG 1/5/2015 12:18:58 PM

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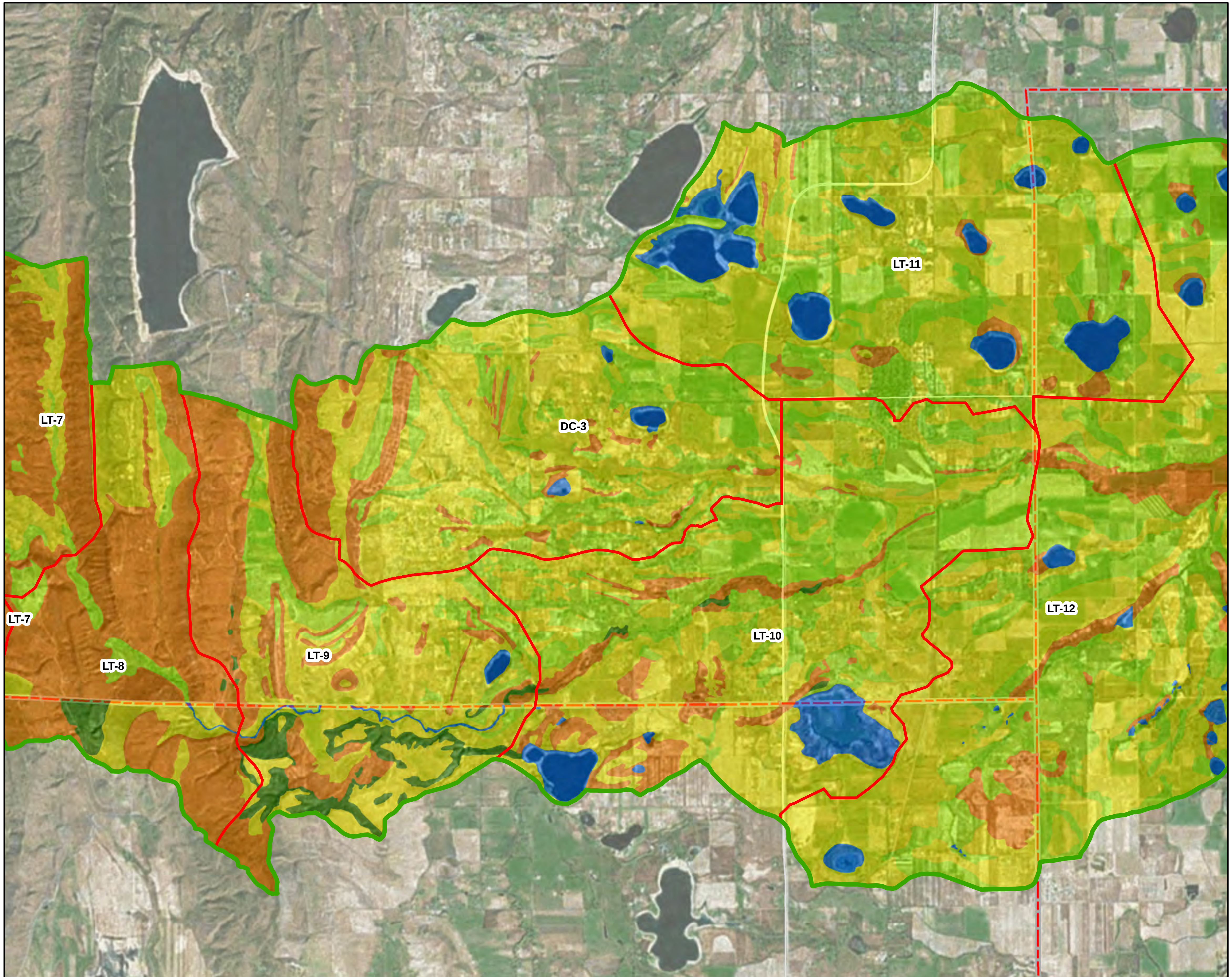
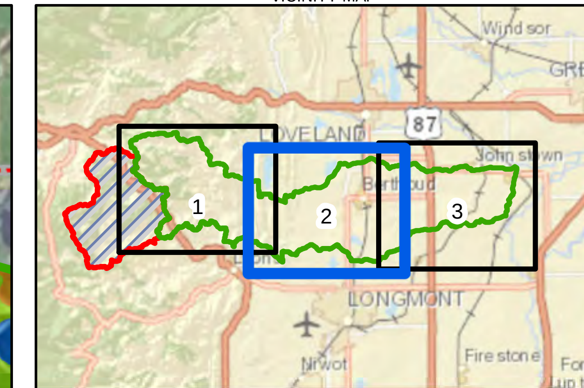


VICINITY MAP



LEGEND

- Phase 1 Model Subbasins
- Phase 2 Model Subbasins
- Phase 1 Model Watershed
- Phase 2 Model Watershed

Hydrologic Soil Group

- A
- B
- C
- D
- Water
- Counties

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 8b

Phase 2 Soils Map - Page 2 of 3

CDOT Flood Recovery Hydrologic Evaluation

UNK \\GECKO\GROUPS\TBG\481085-482330 CDOT EMERGENCY RESPONSE SERVICES\390_DESIGN_ELEMENTS\DRAINAGE\GIS_PHASE_II\MAPFILES\REPORT\PHASEII_LT_SOIL_DATA.MXD BBETTAG 1/5/2015 12:18:58 PM

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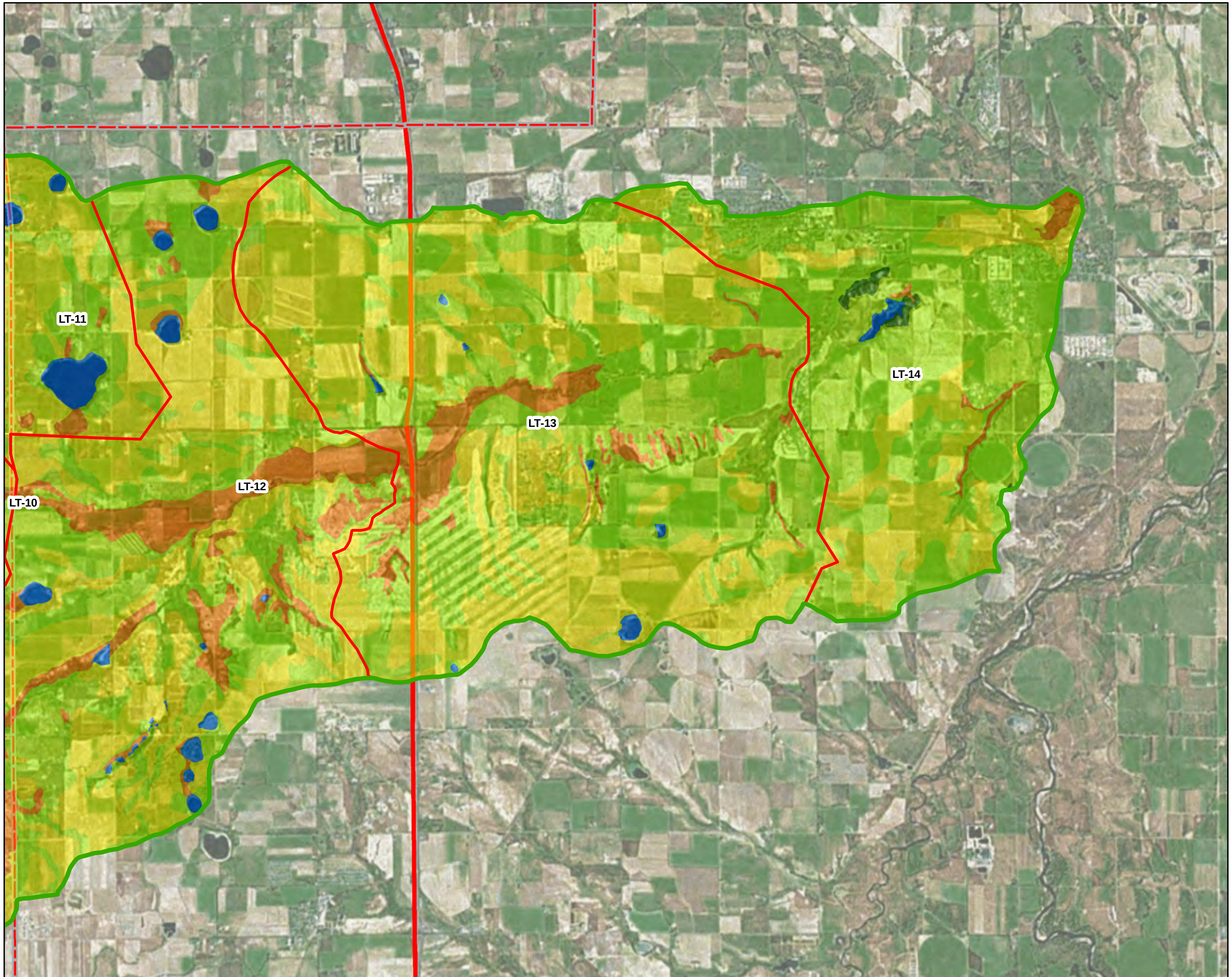
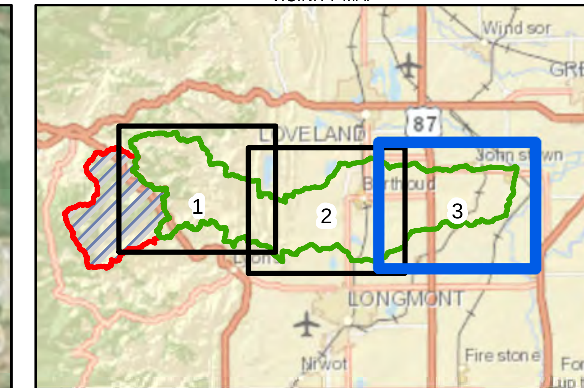


VICINITY MAP



LEGEND

- Phase 1 Model Subbasins
- Phase 2 Model Subbasins
- Phase 1 Model Watershed
- Phase 2 Model Watershed

Hydrologic Soil Group

- A
- B
- C
- D
- Water
- Counties

0 0.5 1 2 Miles

1 inch = 1 miles

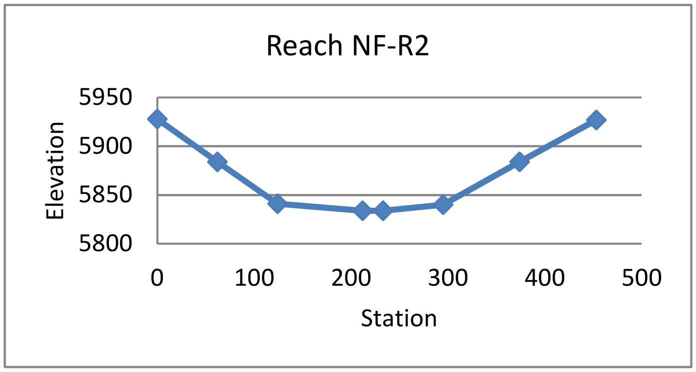
FIGURE 8c

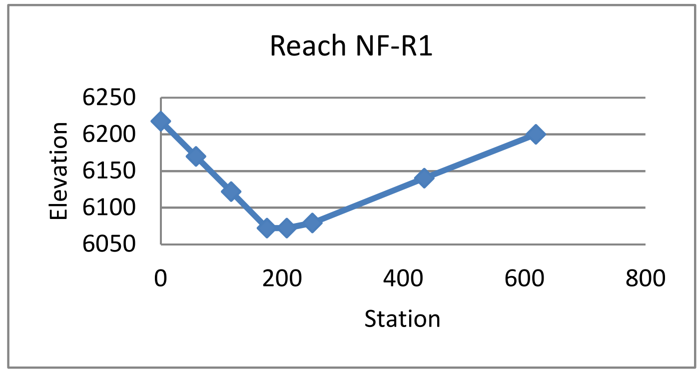
Phase 2 Soils Map - Page 3 of 3

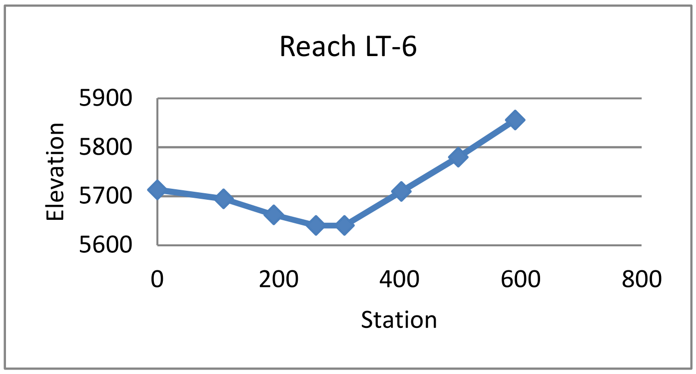
CDOT Flood Recovery Hydrologic Evaluation

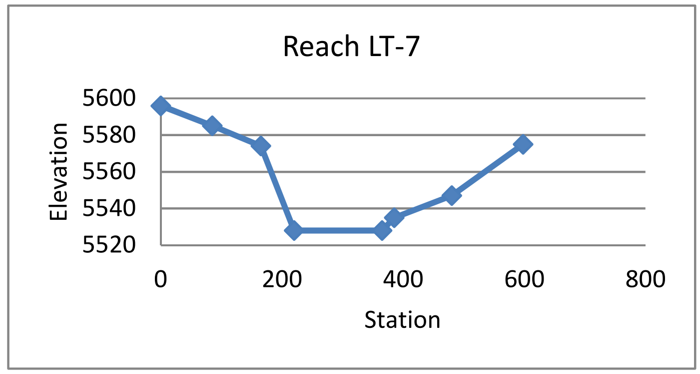
UNK \\GECKO\GROUPS\TBG\481085-482330 CDOT EMERGENCY RESPONSE SERVICES\390_DESIGN_ELEMENTS\DRAINAGE\GIS_PHASE_II\MAPFILES\REPORT\PHASEII_LT_SOIL_DATA.MXD BBETTAG 1/5/2015 12:18:58 PM

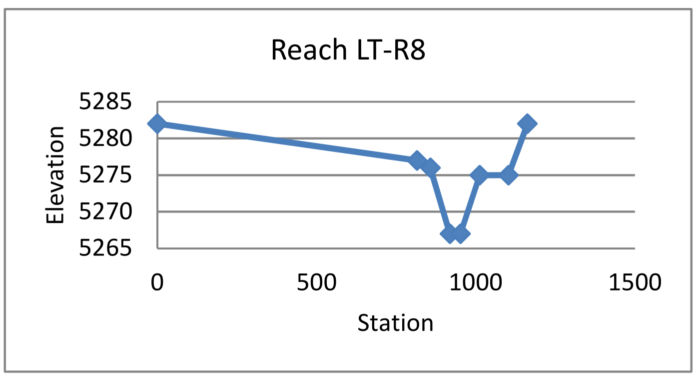
Figure 9a - Phase 2 Muskingum-Cunge Eight-Point Routing Cross Sections

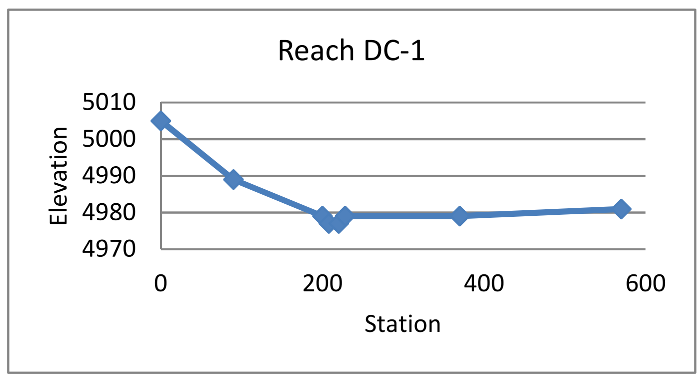


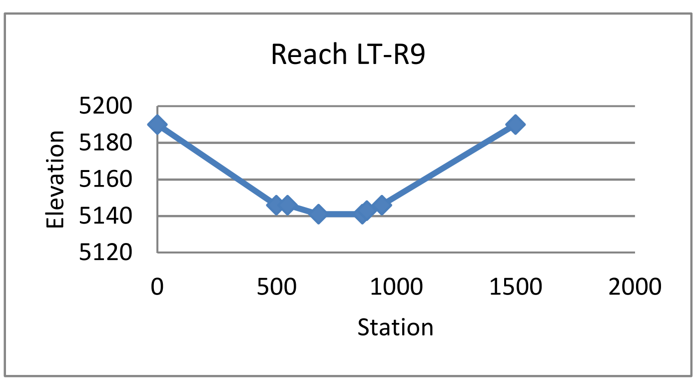












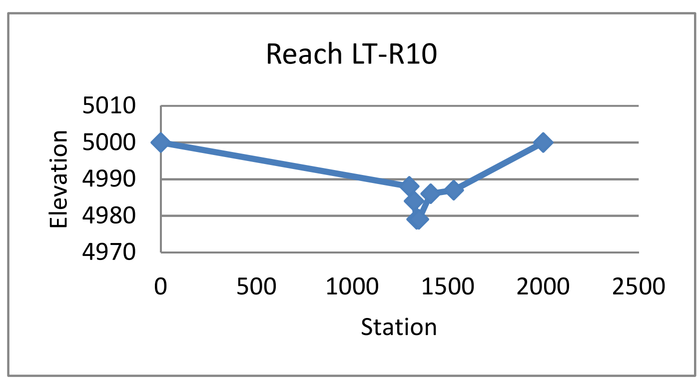
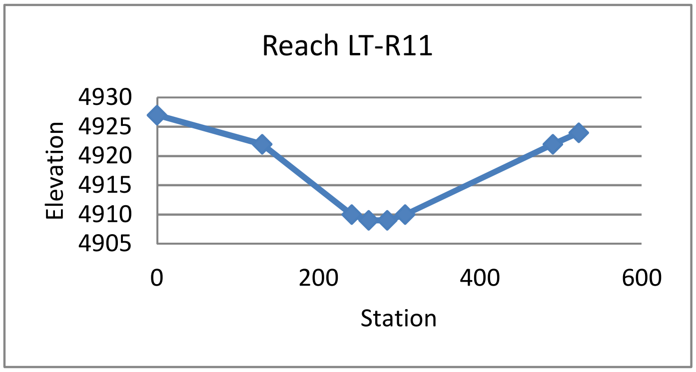
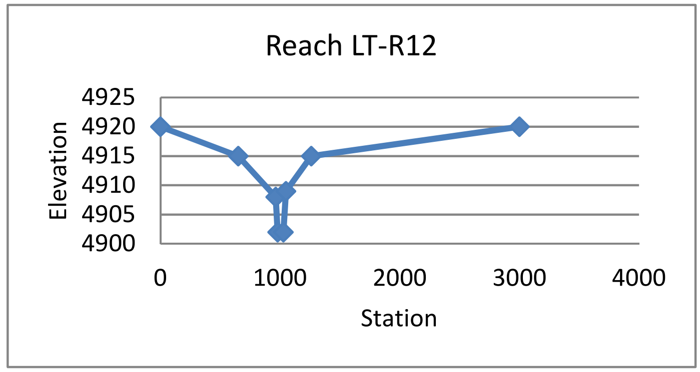
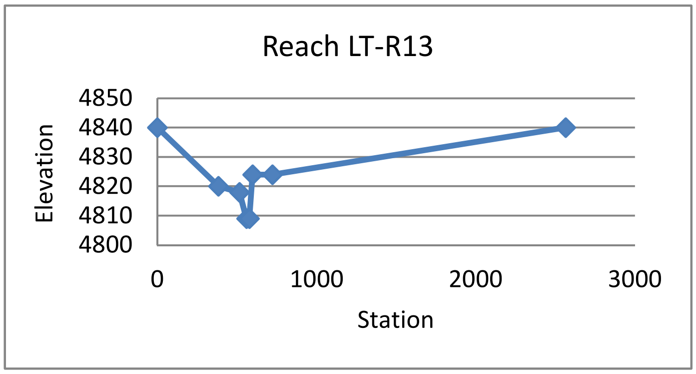
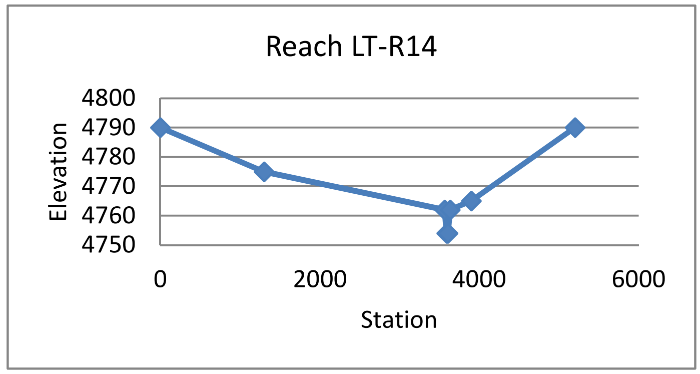


Figure 9b - Phase 2 Muskingum-Cunge Eight-Point Routing Cross Sections (continued)









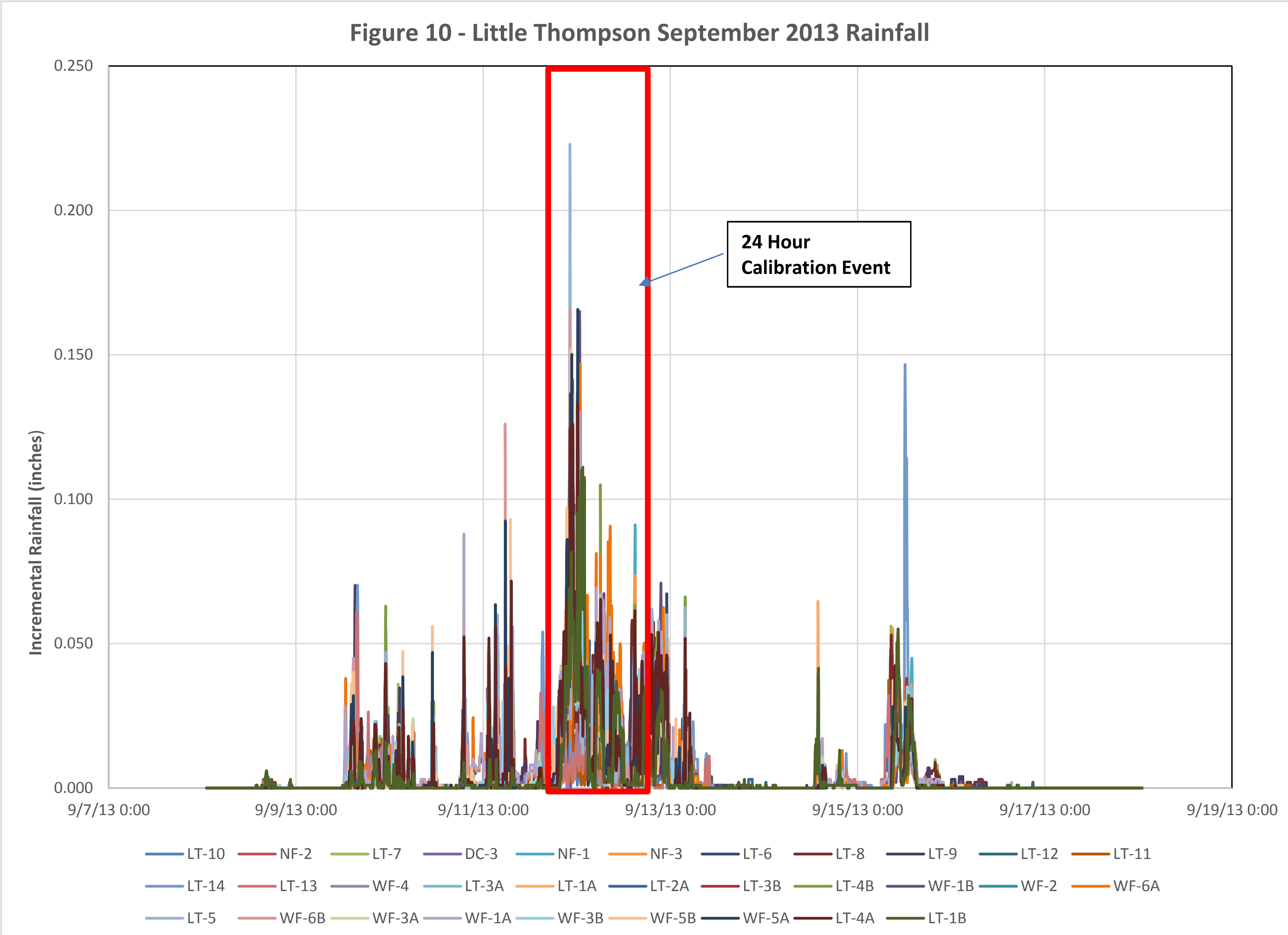
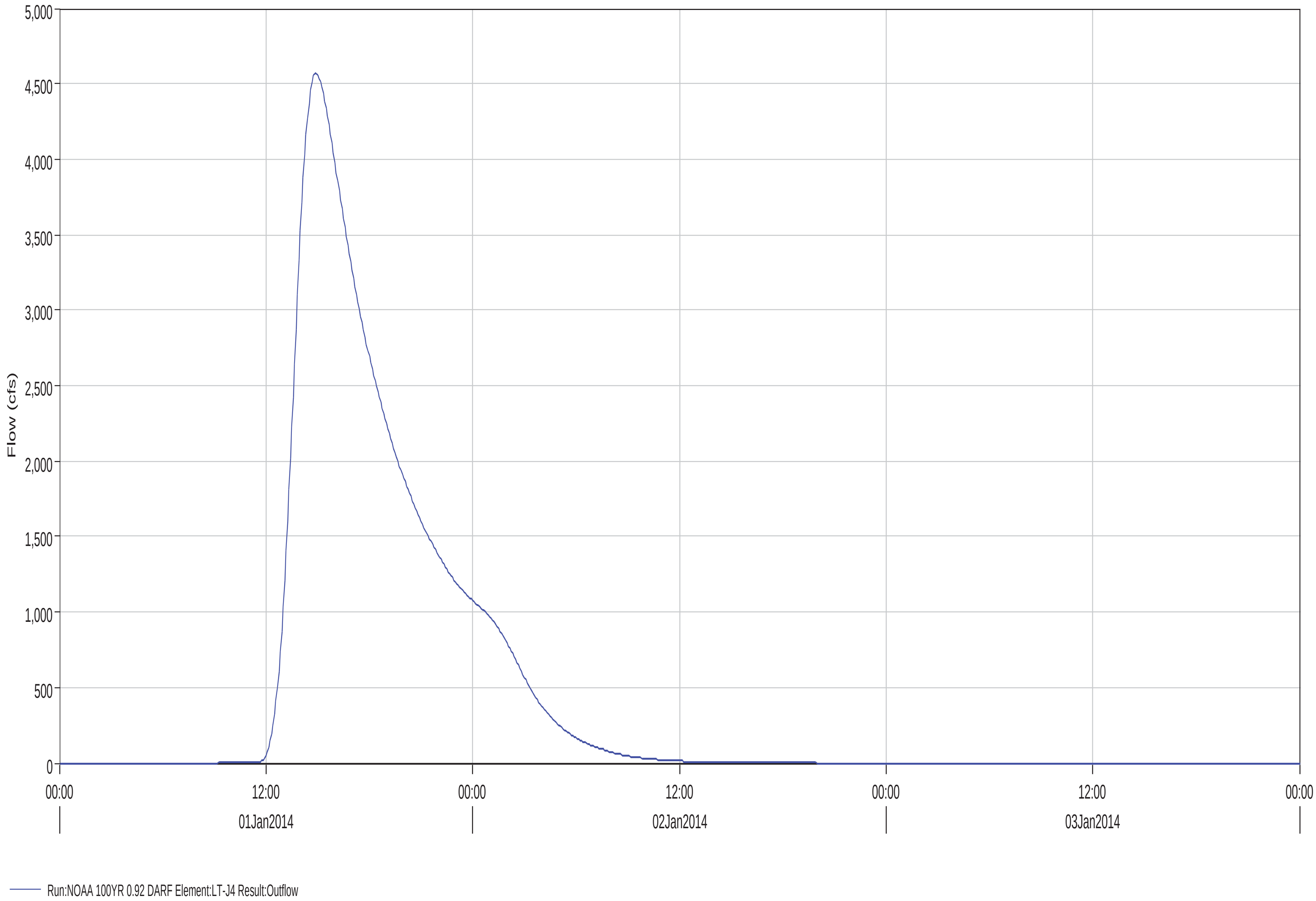


Figure 10 - Little Thompson September 2013 Rainfall
Incremental Rainfall (inches)
0.250
0.200
0.150
0.100
0.050
0.000
9/7/13 0:00
9/9/13 0:00
9/11/13 0:00
9/13/13 0:00
9/15/13 0:00
9/17/13 0:00
9/19/13 0:00
24 Hour Calibration Event
LT-10 NF-2 LT-7 DC-3 NF-1 NF-3 LT-6 LT-8 LT-9 LT-12 LT-11
LT-14 LT-13 WF-4 LT-3A LT-1A LT-2A LT-3B LT-4B WF-1B WF-2 WF-6A
LT-5 WF-6B WF-3A WF-1A WF-3B WF-5B WF-5A LT-4A LT-1B

Figure 11a - Hydrographs at Key Design Locations
Junction "LT-J4" - Little Thompson River Downstream of Confluence with West Fork Results for Run "NRCS 24-HR, DARF=0.92, 100YR"



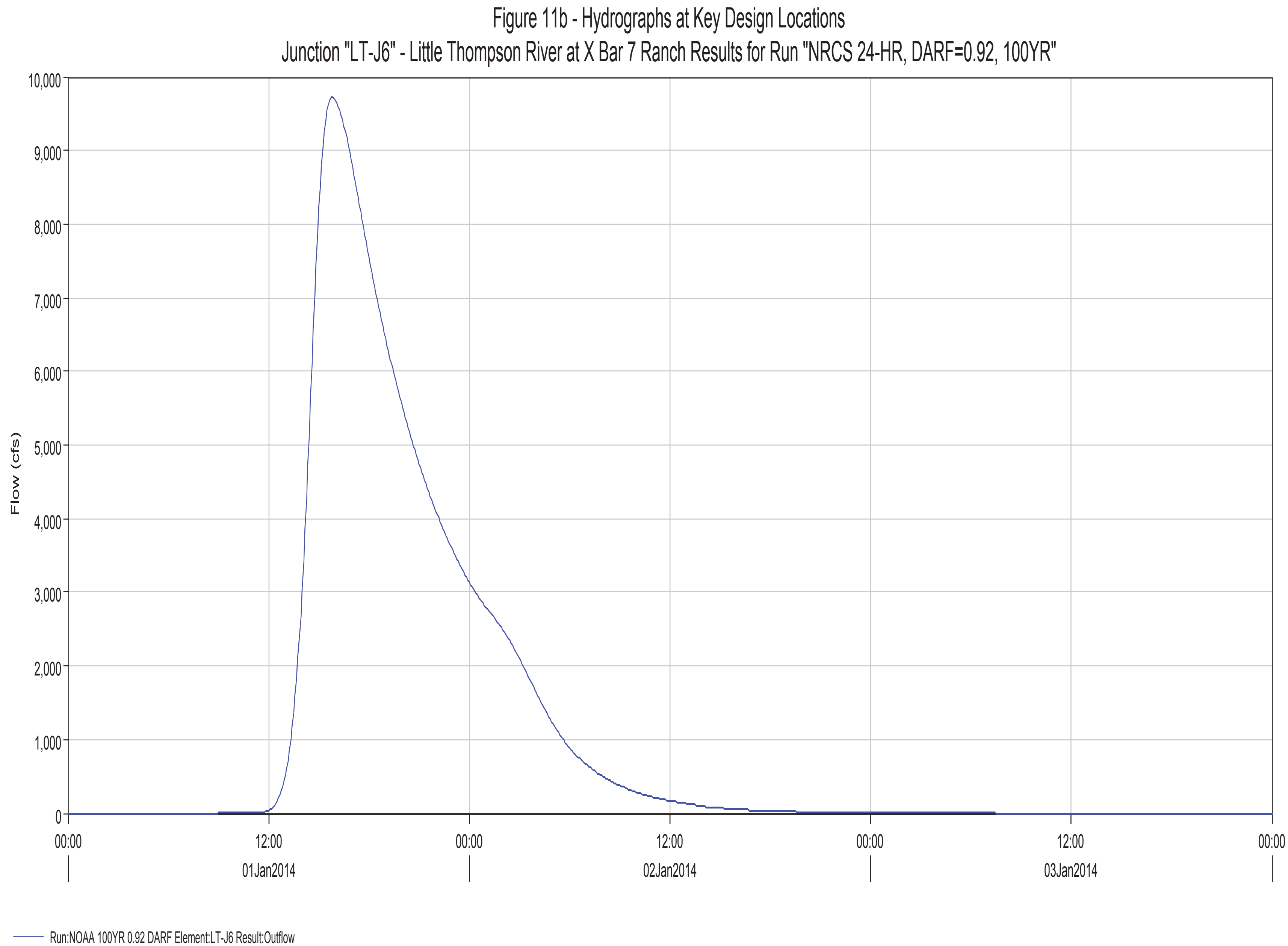


Figure 11b - Hydrographs at Key Design Locations
Junction "LT-J6" - Little Thompson River at X Bar 7 Ranch Results for Run "NRCS 24-HR, DARF=0.92, 100YR"
Flow (cfs)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
00:00
12:00
00:00
12:00
00:00
12:00
00:00
01Jan2014
02Jan2014
03Jan2014
Run:NOAA 100YR 0.92 DARF Element:LT-J6 Result:Outflow

Figure 11c - Hydrographs at Key Design Locations

Junction "LT-J10" - Little Thompson River at South County Line Road Results for Run "NRCS 24-HR, DARF=0.92, 100YR"

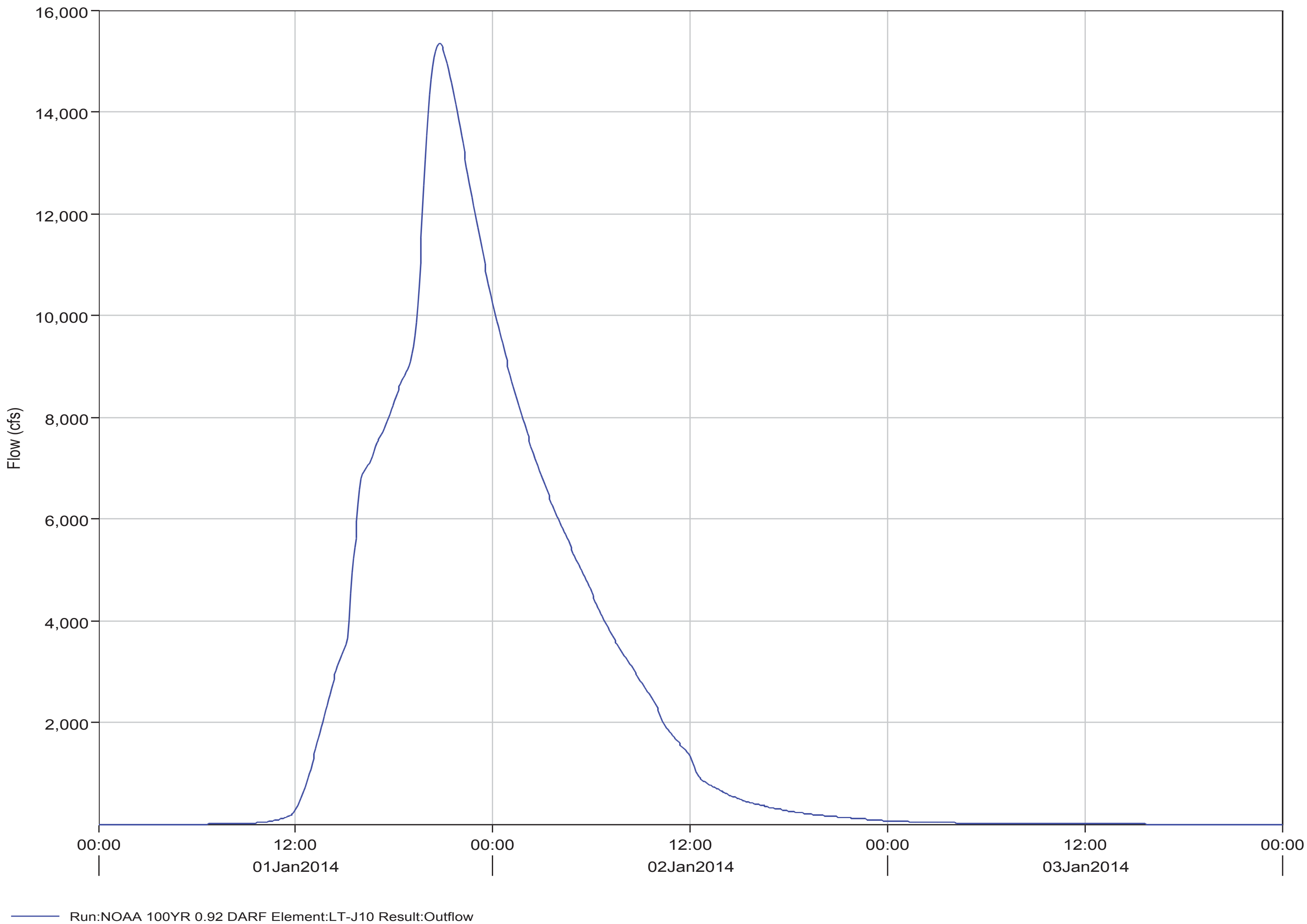


Figure 11d - Hydrographs at Key Design Locations
Junction "LT-J12" - Little Thompson River at Interstate 25 Results for Run "NRCS 24-HR, DARF=0.92, 100YR"

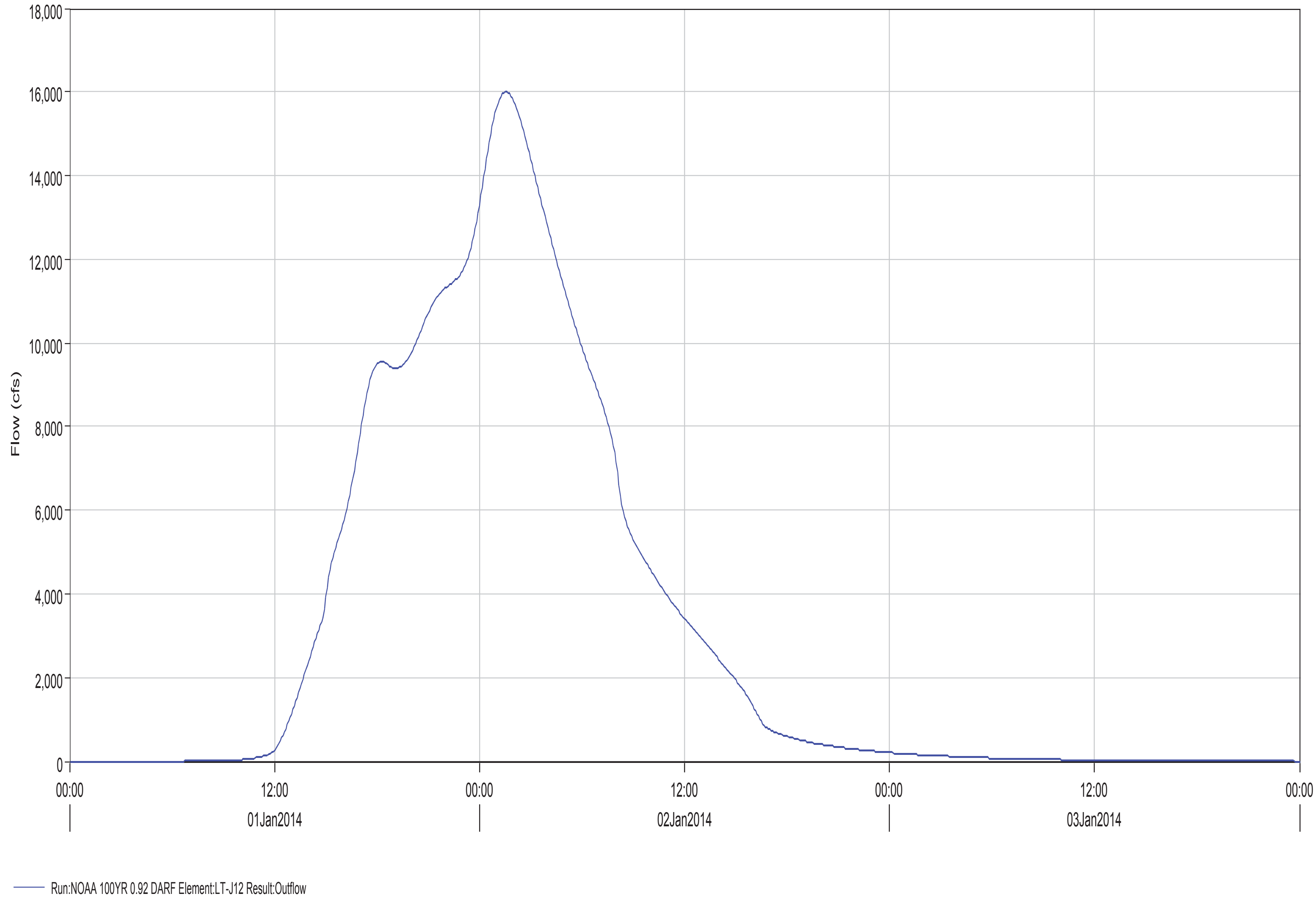


Figure 11e - Hydrographs at Key Design Locations

Junction "LT-J13" - Little Thompson River at County Road 17 Results for Run "NRCS 24-HR, DARF=0.92, 100YR"

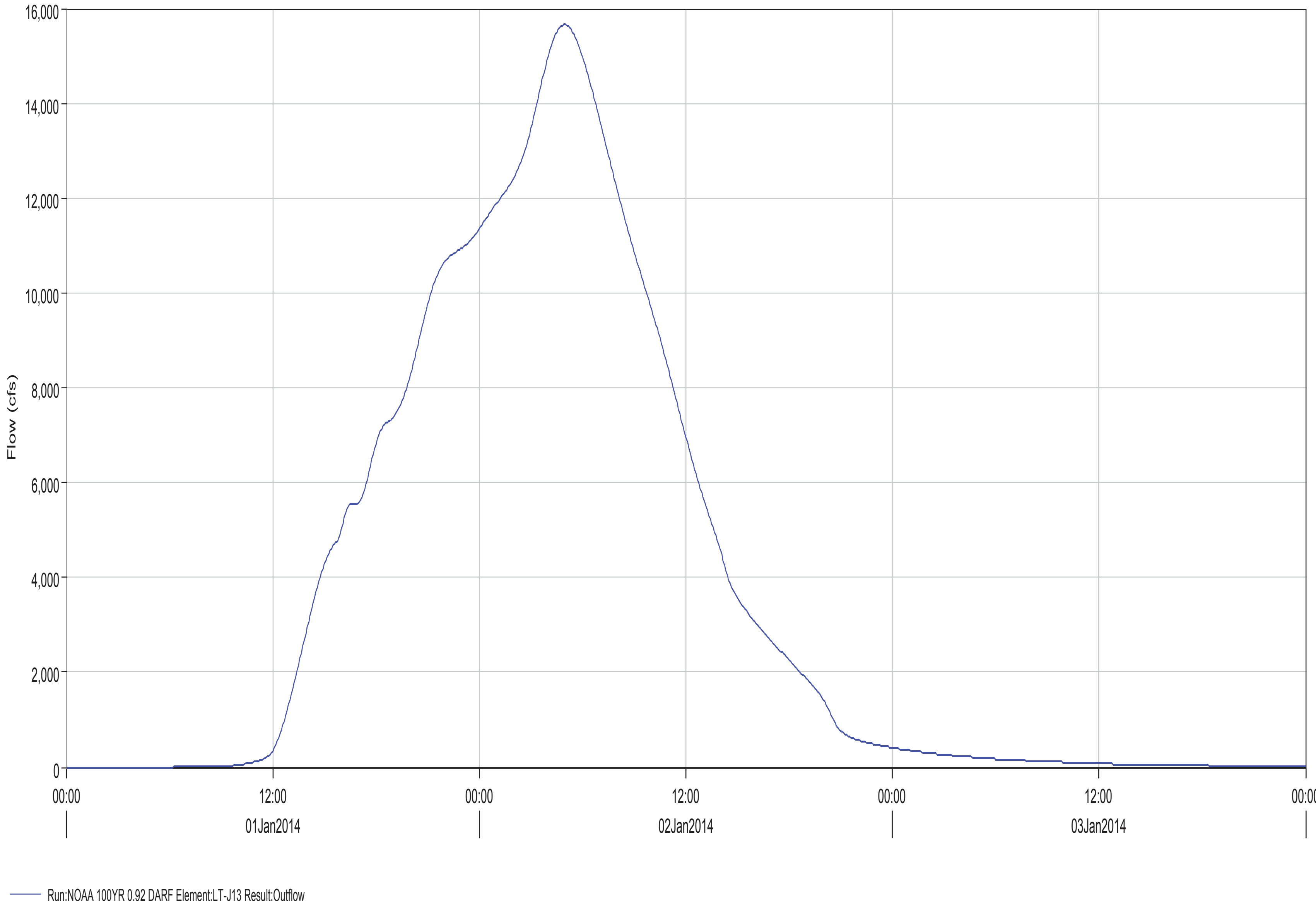


Figure 12 - Little Thompson River Peak Discharge Profiles

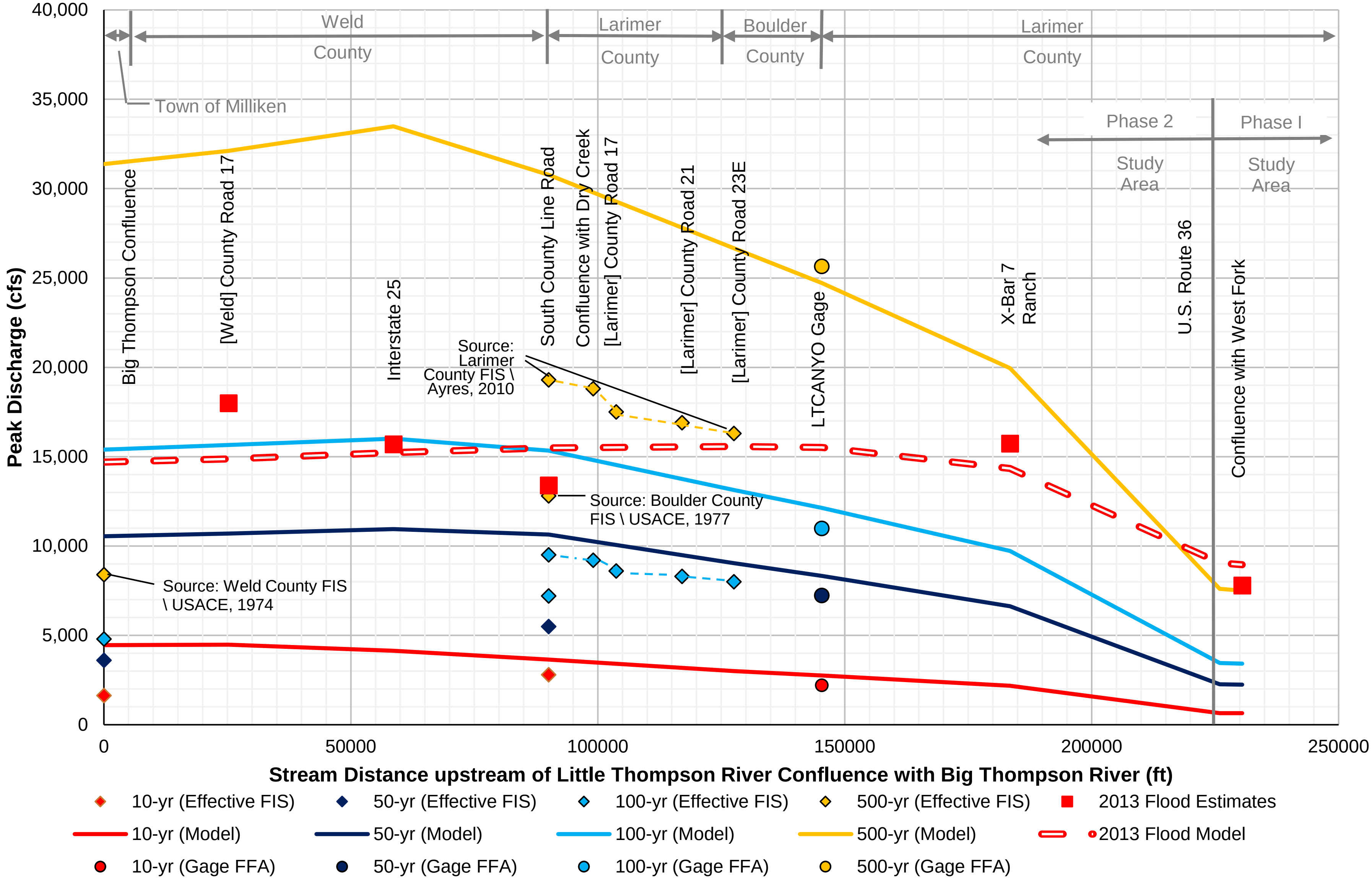
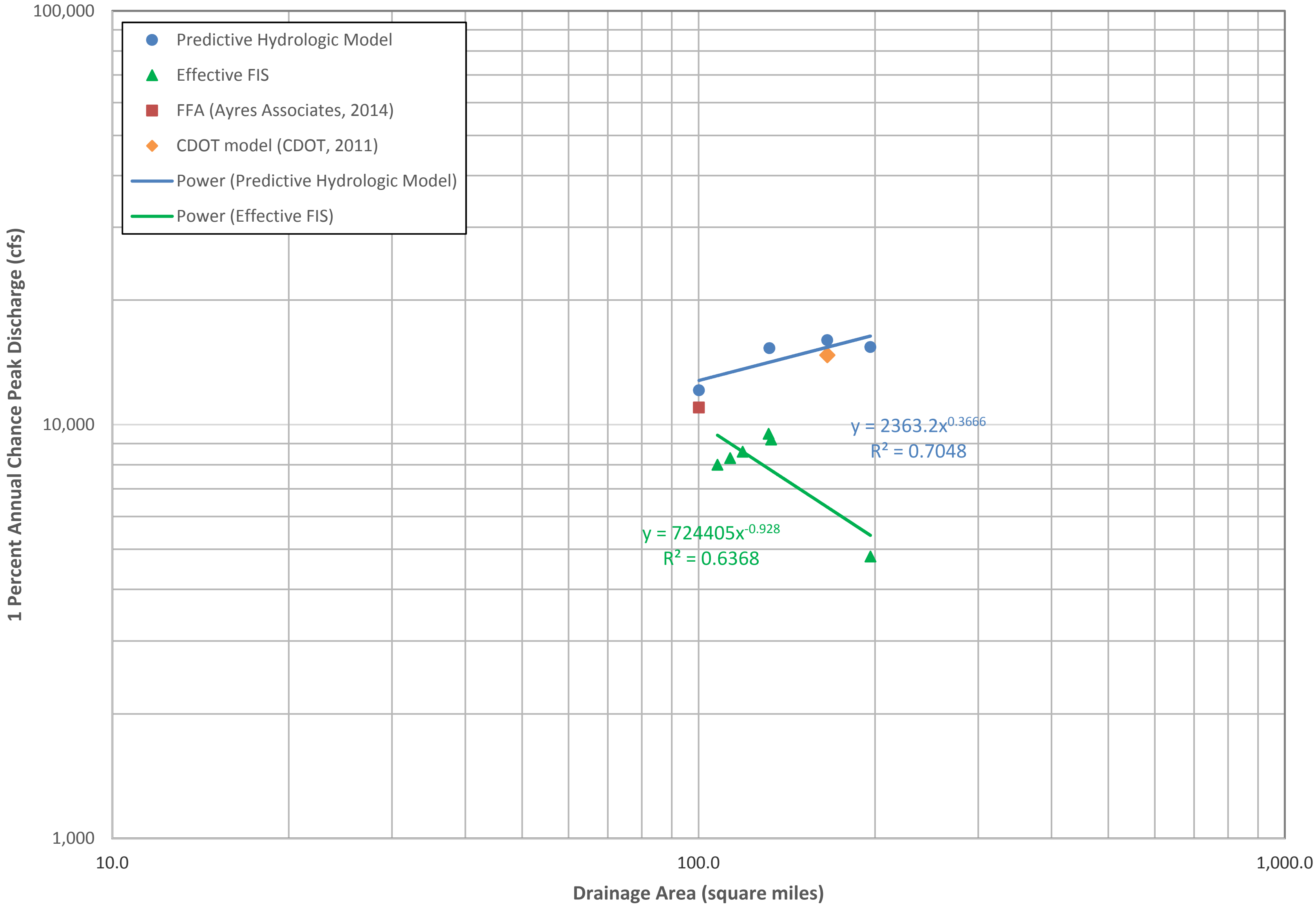


Figure 13 - Comparison of Little Thompson River 1 Percent Chance Discharge Estimates vs. Drainage Area



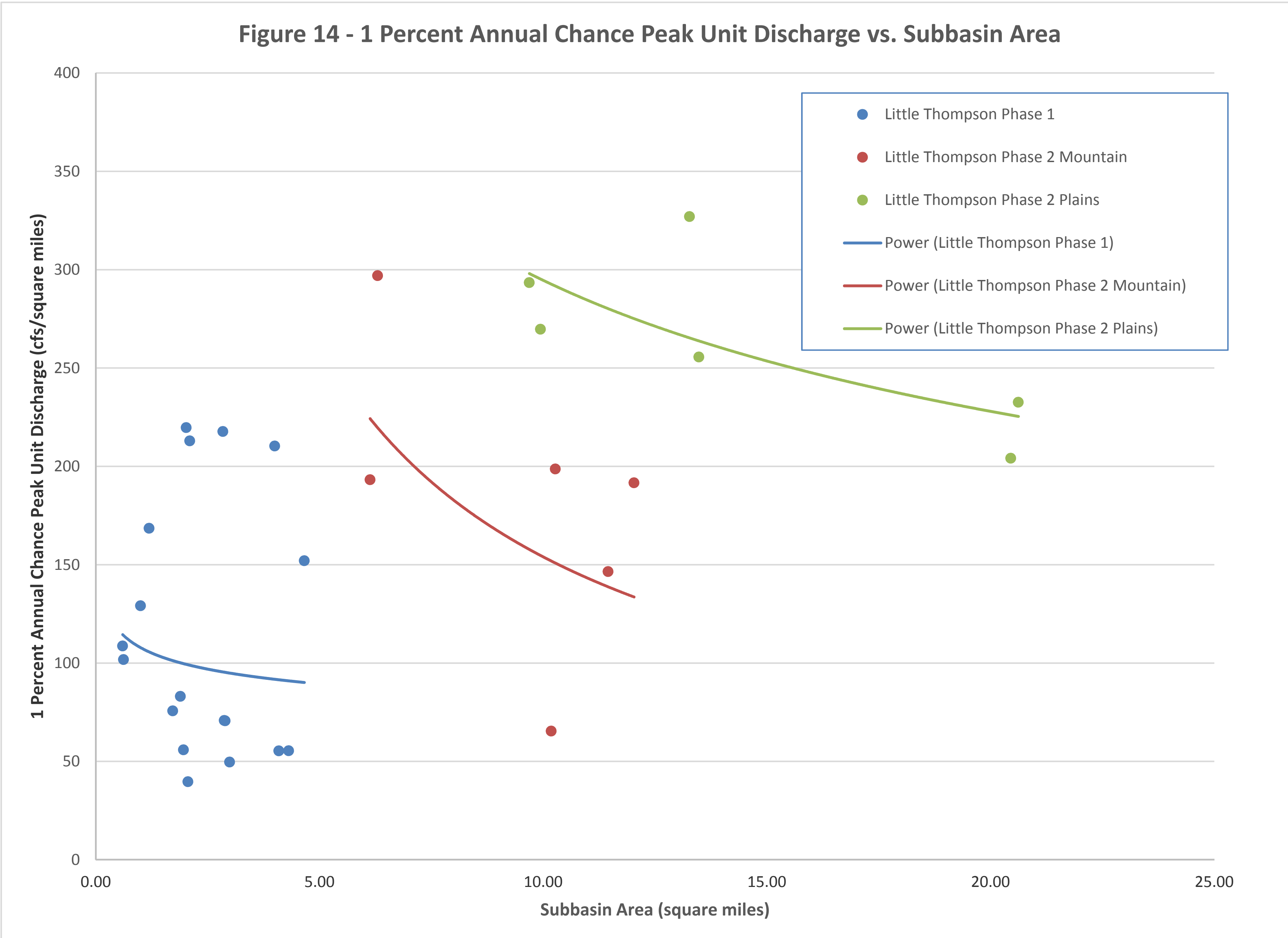


Figure 14 - 1 Percent Annual Chance Peak Unit Discharge vs. Subbasin Area
1 Percent Annual Chance Peak Unit Discharge (cfs/square miles)
400
350
300
250
200
150
100
50
0
0.00
5.00
10.00
15.00
20.00
25.00
Subbasin Area (square miles)
Little Thompson Phase 1
Little Thompson Phase 2 Mountain
Little Thompson Phase 2 Plains
Power (Little Thompson Phase 1)
Power (Little Thompson Phase 2 Mountain)
Power (Little Thompson Phase 2 Plains)

Appendix A
FEMA Information

Larimer County:

Larimer County FIS Volume 1 Cover
Summary of Discharges
FIRM Map Number 08069C1325F_1
FIRM Map Number 08069C1325F_2
FIRM Map Number 08069C1350F
FIRM Map Number 08069C1368G
FIRM Map Number 08069C1369G
FIRM Map Number 08069C1375G
FIRM Map Number 08069C1387G
FIRM Map Number 08069C1388G
FIRM Map Number 08069C1389G
FIRM Map Number 08069C1391G
FIRM Map Number 08069C1410F
FIRM Map Number 08069C1415F

Boulder County:

Boulder County FIS Volume I Cover
Summary of Discharges
FIRM Map Number 08013C0125J

Weld County:

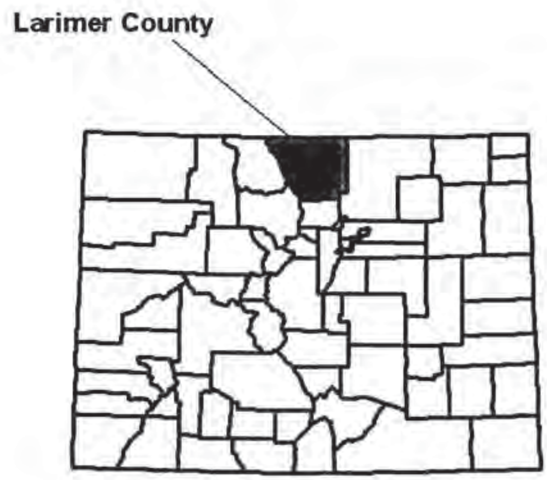
Weld County FIS Cover
Preliminary Weld County FIS Cover
Milliken FIS Cover
Summary of Discharges
FIRM Map Number 0801870001B
FIRM Map Number 0802660725C
FIRM Map Number 0802660750C

FLOOD INSURANCE STUDY

LARIMER COUNTY, COLORADO

AND INCORPORATED AREAS

VOLUME 1 OF 4



Community Name	Community Number
LARIMER COUNTY (UNINCORPORATED AREAS)	080101
BERTHOUD, TOWN OF	080296
ESTES PARK, TOWN OF	080193
FORT COLLINS, CITY OF	080102
JOHNSTOWN, TOWN OF	080250
LOVELAND, CITY OF	080103
TIMNATH, TOWN OF	080005
WELLINGTON, TOWN OF	080104

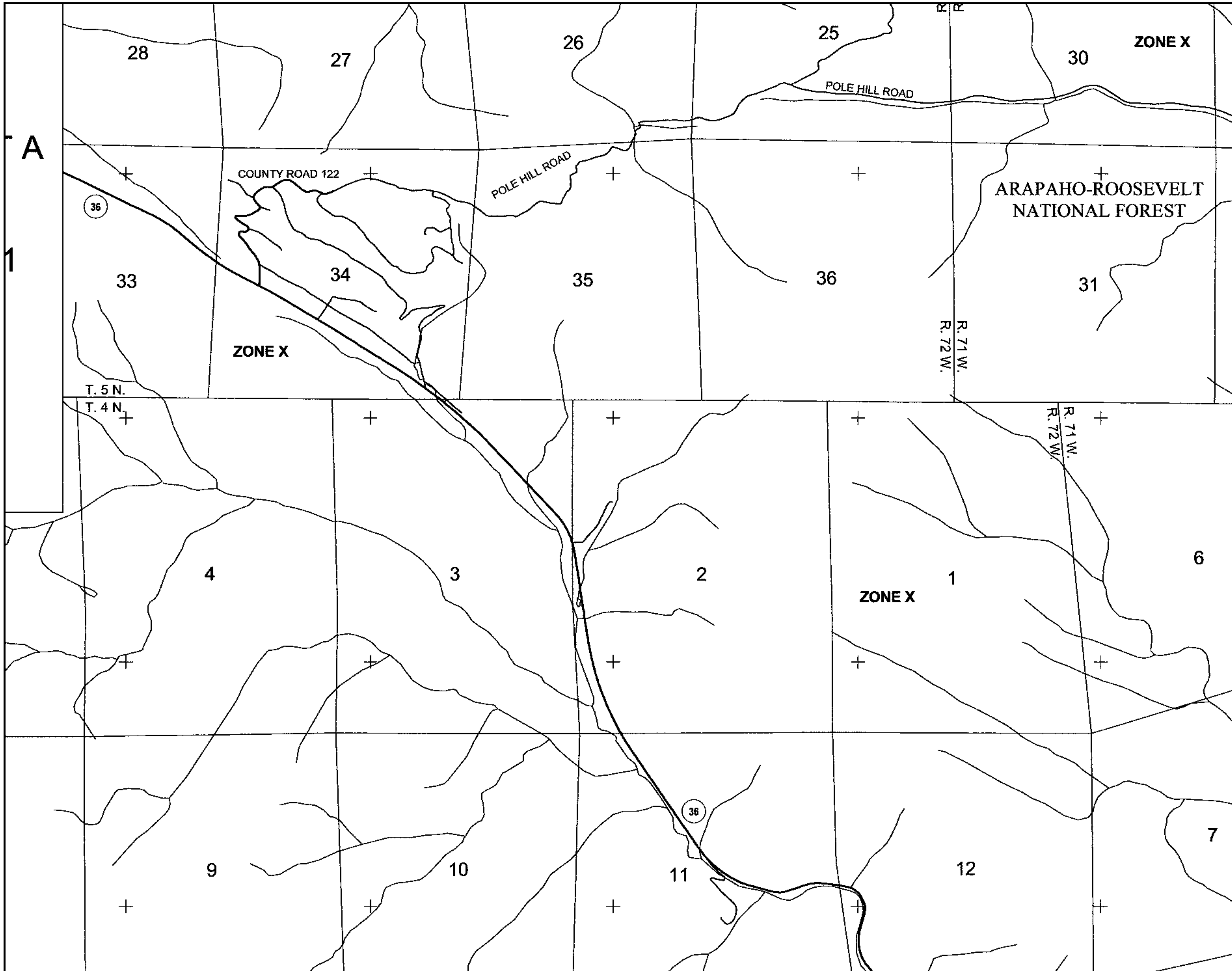
REVISED: FEBRUARY 6, 2013

Federal Emergency Management Agency
FLOOD INSURANCE STUDY NUMBER
08069CV001D

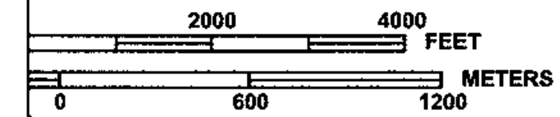
Table 2 – Summary of Discharges (Continued)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance
East Vine Diversion					
At Larimer and Weld Canal	58.6	30	163	330	- -[1]
Dry Gulch					
At Confluence with Big Thompson River	6.25	1,200	2,150	2,600	4,100
Fall River					
At Confluence with Big Thompson River	39.9	450	610	680	830
At Estes Park Corporate Limits	37.3	450	610	680	830
At Upstream Detailed Study Limit	37.3	450	610	680	830
Fish Creek					
At Lake Estes	16.0	105	280	400	840
At Estes Park Corporate Limits	13.4	105	208	400	840
At Upstream Detailed Study Limit	13.4	105	280	400	840
Fox Creek					
At Confluence with North Fork Big Thompson River	7.35	1,200	2,200	2,750	4,800
Little Thompson River					
At Larimer-Weld County Line	138.9	- -[1]	- -[1]	9,500	19,300
At Confluence with Dry Creek	133.0	- -[1]	- -[1]	9,200	18,800
At County Road 17	118.9	- -[1]	- -[1]	8,600	17,500
At County Road 21	113.2	- -[1]	- -[1]	8,300	16,900
At County Road 23E	107.7	- -[1]	- -[1]	8,000	16,300
Little Thompson – Spill Reach					
At Confluence with Little Thompson River	- -[1]	- -[1]	- -[1]	3,827	12,511
Long Gulch					
At Confluence with Big Thompson River	2.00	1,000	1,660	2,000	2,870
Miller Fork					
At Confluence with North Fork Big Thompson River	13.67	1,350	2,650	3,350	6,300

[1] Not Determined



MAP SCALE 1" = 2000'



PANEL 1325F

FIRM

FLOOD INSURANCE RATE MAP

LARIMER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 1325 OF 1420

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
ESTES PARK, TOWN OF	080193	1325	F
LARIMER COUNTY	080101	1325	F

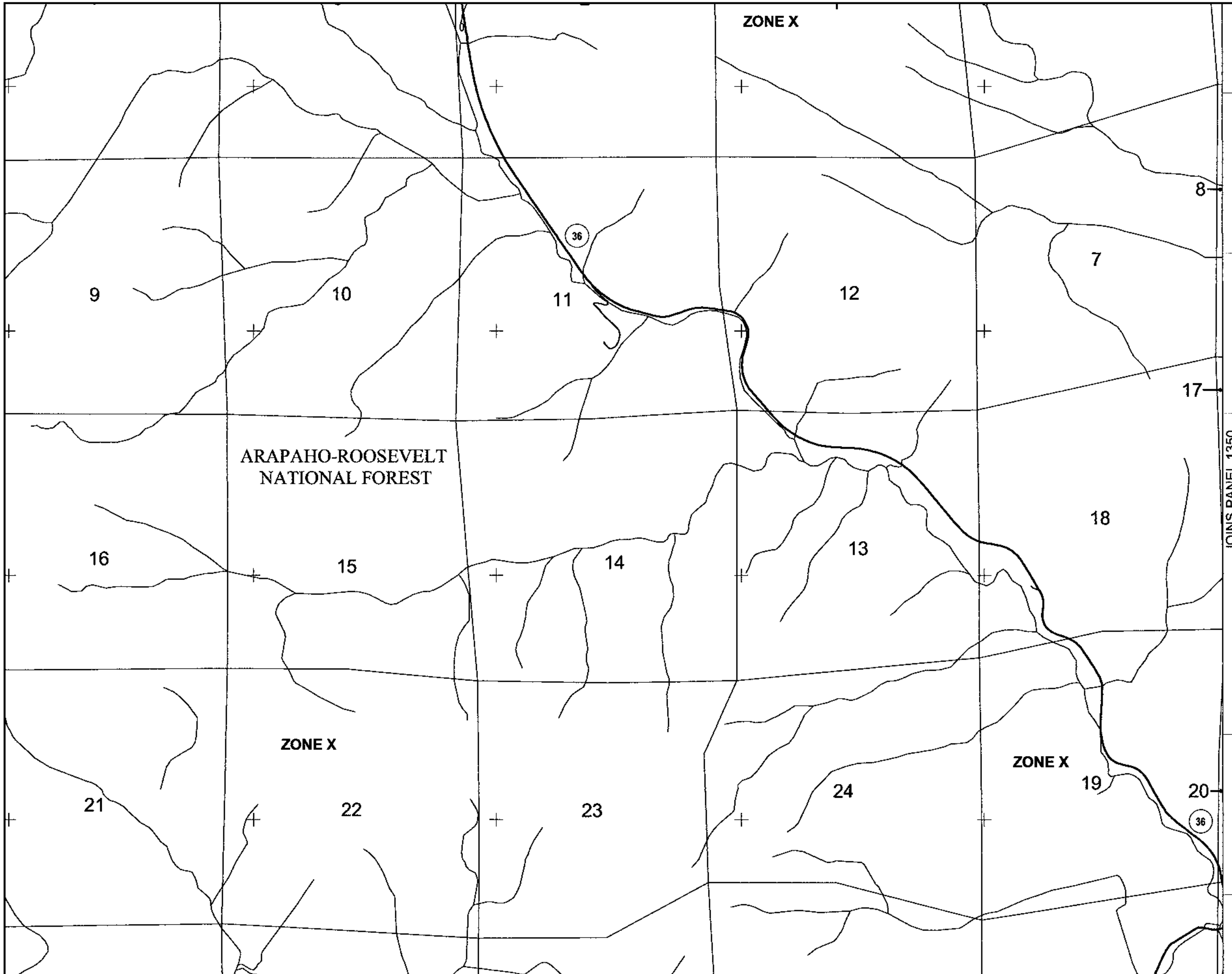
Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08069C1325F

EFFECTIVE DATE
DECEMBER 19, 2006

Federal Emergency Management Agency

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov



MAP SCALE 1" = 2000'

2000 4000 FEET

0 600 1200 METERS

PANEL 1325F

FIRM

FLOOD INSURANCE RATE MAP

LARIMER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 1325 OF 1420

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
ESTES PARK, TOWN OF	080193	1325	F
LARIMER COUNTY	080101	1325	F

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MAP NUMBER
08069C1325F

EFFECTIVE DATE
DECEMBER 19, 2006

Federal Emergency Management Agency

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Floodway Data table shown on this FIRM.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

FEMA recommends that a Flood Insurance Policy be purchased for structures in areas where **levees** are shown as providing protection from the 1% annual chance flood. Flooding is not covered by standard property/fire/dwelling insurance policies nor is it covered by Homeowners Insurance, Renters Insurance, Condominium Owners Insurance, or Commercial Property Insurance. Contact your insurance agent and local floodplain administrator for further information.

Visit http://www.fema.gov/pdf/fhm/frm_gsah.pdf for information on levees and the risk of flooding in areas shown as being protected by levees.

The **projection** used in the preparation of this map was State Plane Colorado North (feet). The **horizontal datum** was NAD 83, GRS80 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

Spatial Reference System Division
National Geodetic Survey, NOAA
Silver Spring Metro Center
1315 East-West Highway
Silver Spring, Maryland 20910
(301) 713-3191

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242**, or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was provided by the Larimer County GIS and Mapping Department. Additional input was provided by the City of Fort Collins Geographic Information Service Division. These data are current as of 2005.

The **profile baselines** depicted on this map represent the hydraulic modeling baselines that match the flood profiles in the Flood Insurance Study report. As a result of improved topographic data, the profile baseline, in some cases, may deviate significantly from the channel centerline or appear outside the Special Flood Hazard Area.

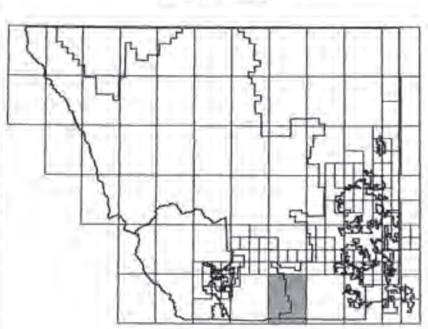
Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

Contact the **FEMA Map Service Center** at 1-800-358-9616 for information on available products associated with this FIRM. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. The FEMA Map Service Center may also be reached by Fax at 1-800-358-9620 and its website at http://www.msc.fema.gov.

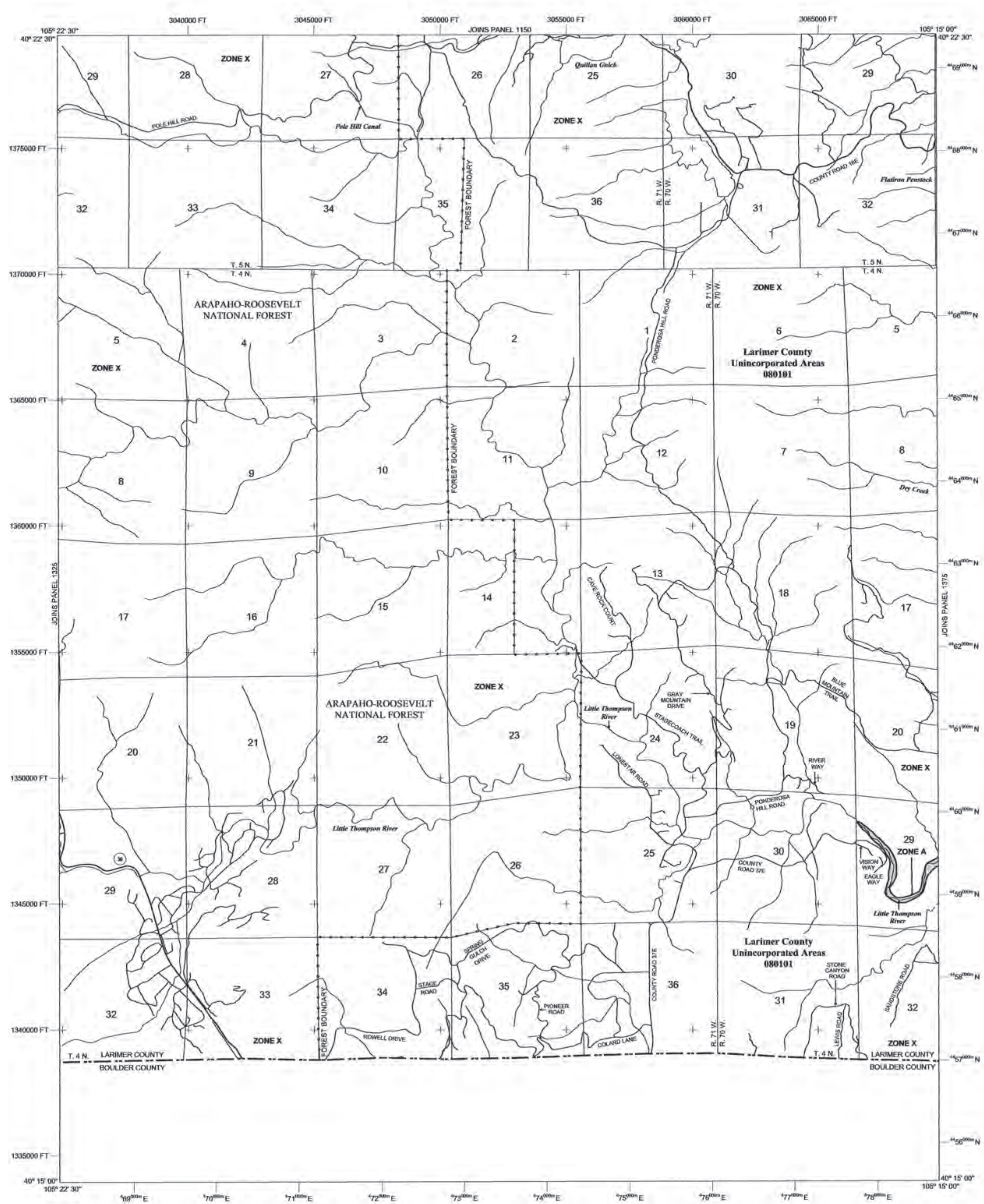
If you have **questions about this map** or questions concerning the National Flood Insurance Program in general, please call **1- 877- FEMA MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov.

Panel Location Map



This Digital Flood Insurance Rate Map (DFIRM) was produced through a Cooperating Technical Partner (CTP) agreement between the State of Colorado Water Conservation Board and the Federal Emergency Management Agency (FEMA).

Additional Flood Hazard Information and resources are available from local communities and the Colorado Water Conservation Board.



LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X — Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X — Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D — Areas in which flood hazards are undetermined, but possible.

Floodplain boundary
Floodway boundary
Zone D boundary

Boundary dividing Special Flood Hazard Area zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.

~~~ 513 ~~~ Base Flood Elevation line and value; elevation in feet*

(EL 987) Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

(A)——(A) Cross section line

104° 50' 37.5", 39° 30' 00" Geographic coordinates referenced to the North American Datum of 1983 (NAD 83), Western Hemisphere

3180000 FT 5000-foot ticks: Colorado State Plane coordinate system, North zone, Lambert Conformal Conic projection

$^{42}76^{000m}$N 1000-meter Universal Transverse Mercator grid ticks, zone 13

KK8400 × National Geodetic Survey bench mark (see explanation in Notes to Users section of this FIRM panel)

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
DECEMBER 19, 2006

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 2000'

1000 0 2000 4000 FEET
600 0 600 1200 METERS

NFIP
NATIONAL FLOOD INSURANCE PROGRAM

PANEL 1350F

FIRM
FLOOD INSURANCE RATE MAP
LARIMER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 1350 OF 1420

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
LARIMER COUNTY	080101	1350	F

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08069C1350F

EFFECTIVE DATE
DECEMBER 19, 2006

Federal Emergency Management Agency
~~~

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0 North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures.** Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Colorado State Plane north zone (FIPSZONE 0501). The **horizontal datum** was NAD83, GRS1980 spheroid. Differences in datum, spheroid, projection or State Plane zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of the FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum.** For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov/ or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, MD 20910-3282

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713-3242,** or visit its website at http://www.ngs.noaa.gov/.

Base map information on this FIRM was provided by the Larimer County GIS and Mapping Department. Additional input was provided by the City of Fort Collins Geographic Information Services Division. These Data are current as of 2010. Additional base map information provided by the Town of Berthoud 2011.

This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables *in the Flood Insurance Study report (which contains authoritative hydraulic data)* may reflect stream channel distances that differ from what is shown on this map.

Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

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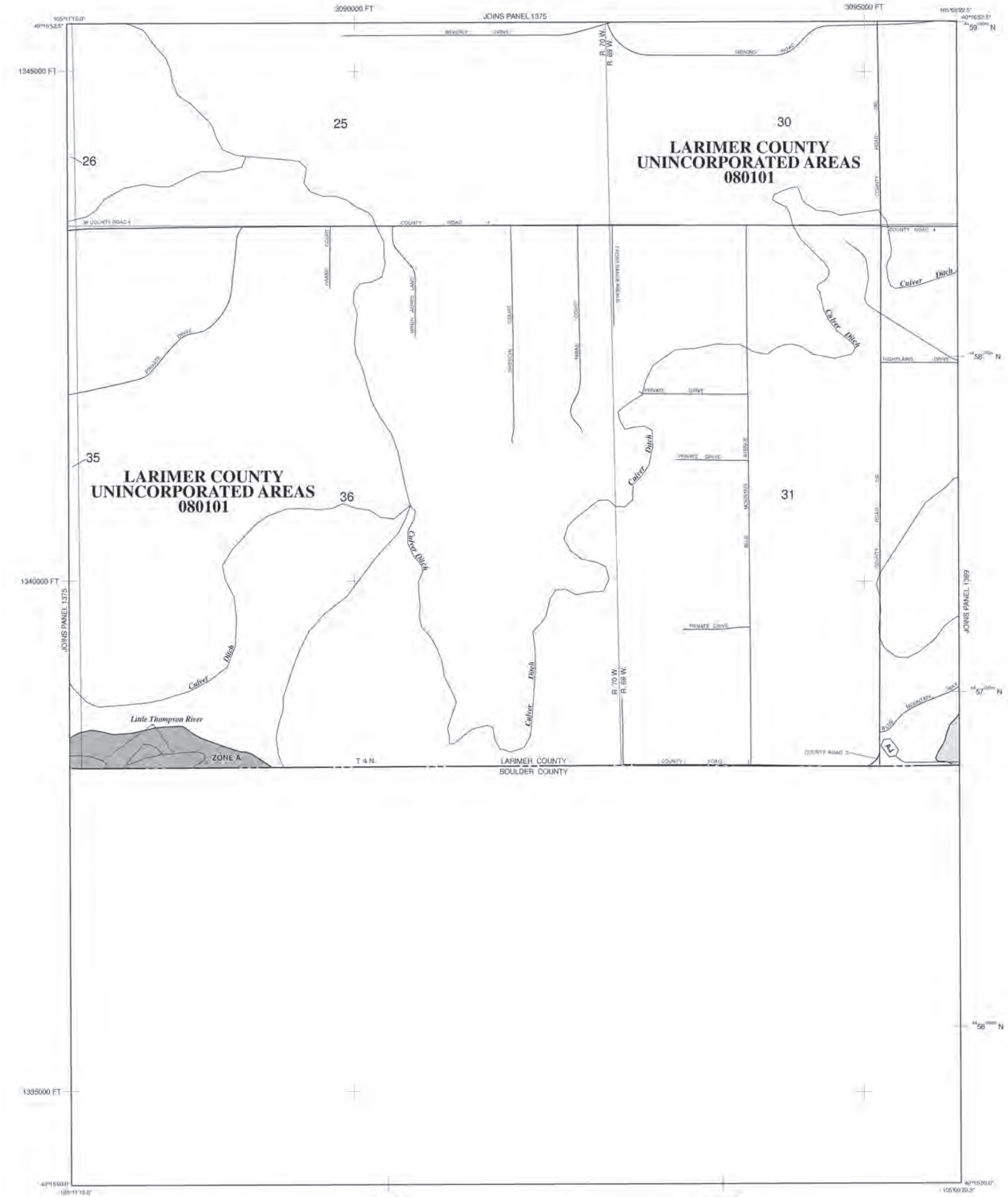

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

	Floodplain boundary
	Floodway boundary
	Zone D boundary
	CBRS and OPA boundary
	Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
~~ 513 ~~~~	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988 (NAVD 88)

(A)——(A)	Cross section line
(23)- - - -(23)	Transect line
97°07'30", 32°22'30"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83)
4275000mN	1000-meter Universal Transverse Mercator grid ticks, zone 13
6000000 FT	5000-foot grid ticks: Colorado State Plane coordinate system, north zone (FIPSZONE 0501), Lambert Conformal Conic
DX5510	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5	River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
December 19, 2006
EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
February 6, 2013 - to change Special Flood Hazard Areas, to add floodway, to add roads and road names, and to add Base Flood Elevations.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

250 0 500 1000 FEET

150 0 150 300 METERS

NFIP

PANEL 1368G

FIRM
FLOOD INSURANCE RATE MAP
LARIMER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 1368 OF 1420
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
LARIMER COUNTY	080101	1368	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

NATIONAL FLOOD INSURANCE PROGRAM

MAP NUMBER 08069C1368G

MAP REVISED FEBRUARY 6, 2013

Federal Emergency Management Agency

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Coastal Base Flood Elevations shown on this map apply only landward of 0.0 North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

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The **projection** used in the preparation of this map was Colorado State Plane north zone (FIPSZONE 0501). The **horizontal datum** was NAD83, GRS1980 spheroid. Differences in datum, spheroid, projection or State Plane zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of the FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum.** For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov/ or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, MD 20910-3282

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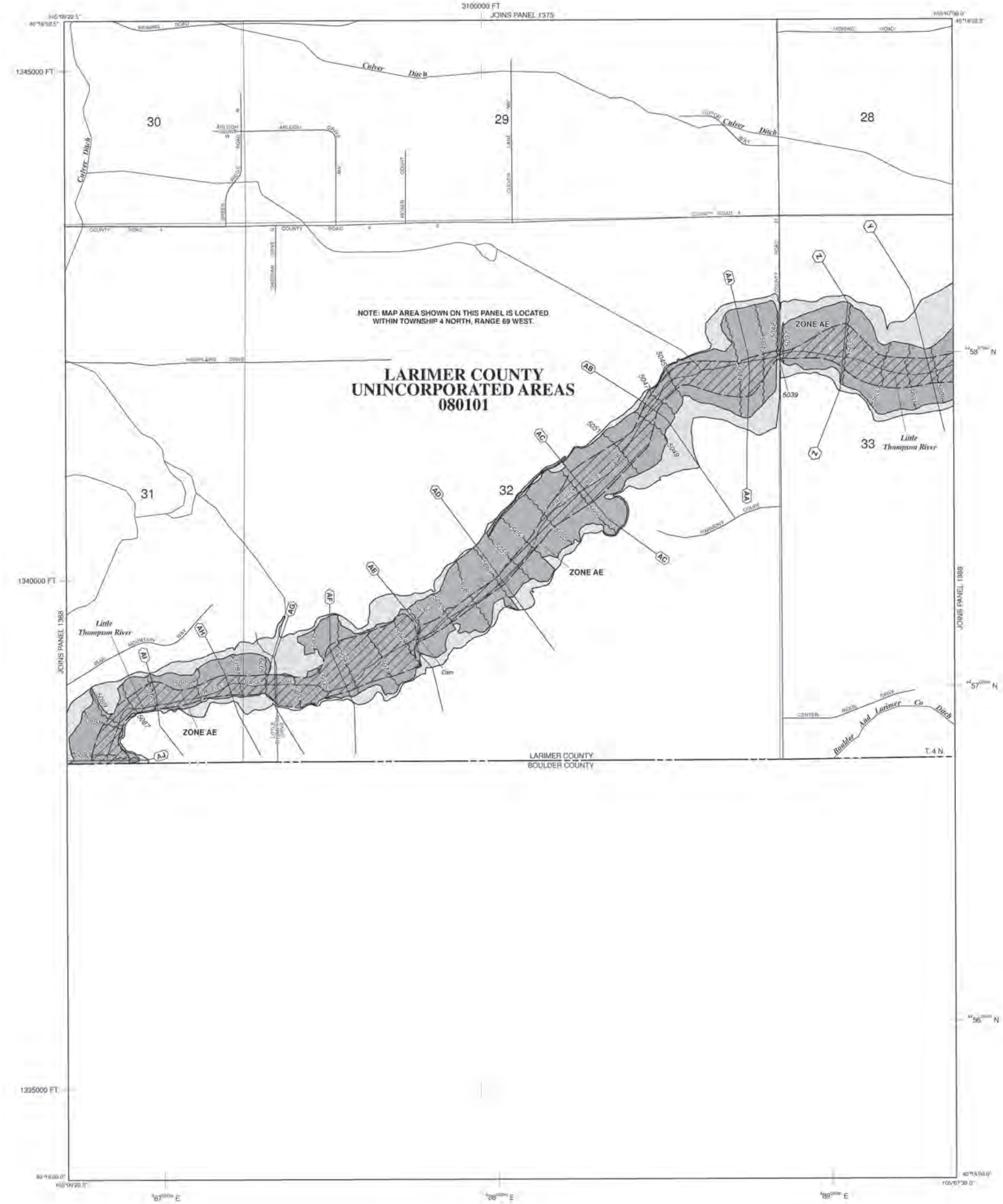

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

- ZONE A — No Base Flood Elevations determined.
- ZONE AE — Base Flood Elevations determined.
- ZONE AH — Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
- ZONE AO — Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
- ZONE AR — Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
- ZONE A99 — Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
- ZONE V — Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
- ZONE VE — Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

- ZONE X — Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

- ZONE X — Areas determined to be outside the 0.2% annual chance floodplain.
- ZONE D — Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

- Floodplain boundary
- Floodway boundary
- Zone D boundary
- CBRS and OPA boundary
- Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
- 513 — Base Flood Elevation line and value; elevation in feet*
- (EL 987) — Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988 (NAVD 88)

- (A)—(A) — Cross section line
- (23)- - -(23) — Transect line
- 97°07'30", 32°22'30" — Geographic coordinates referenced to the North American Datum of 1983 (NAD 83)
- 4275000mN — 1000-meter Universal Transverse Mercator grid ticks, zone 13
- 6000000 FT — 5000-foot grid ticks: Colorado State Plane coordinate system, north zone (FIPSZONE 0501), Lambert Conformal Conic
- DX5510 — Bench mark (see explanation in Notes to Users section of this FIRM panel)
- M1.5 — River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
December 19, 2006
EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
February 6, 2013 - to change Special Flood Hazard Areas, to add floodway, to add roads and road names, and to add Base Flood Elevations

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

250 0 500 1000 FEET
150 0 150 300 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 1369G

FIRM
FLOOD INSURANCE RATE MAP

LARIMER COUNTY, COLORADO AND INCORPORATED AREAS

PANEL 1369 OF 1420
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
LARIMER COUNTY	080101	1369	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08069C1369G

MAP REVISED
FEBRUARY 6, 2013

Federal Emergency Management Agency

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures.** Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Colorado State Plane north zone (FIPSZONE 0501). The **horizontal datum** was NAD83, GRS1980 spheroid. Differences in datum, spheroid, projection or State Plane zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of the FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum.** For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov/ or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, MD 20910-3282

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713-3242,** or visit its website at http://www.ngs.noaa.gov/.

Base map information on this FIRM was provided by the Larimer County GIS and Mapping Department. Additional input was provided by the City of Fort Collins Geographic Information Services Division. These Data are current as of 2010. Additional base map information provided by the Town of Berthoud, 2011.

This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables *in the Flood Insurance Study report (which contains authoritative hydraulic data)* may reflect stream channel distances that differ from what is shown on this map.

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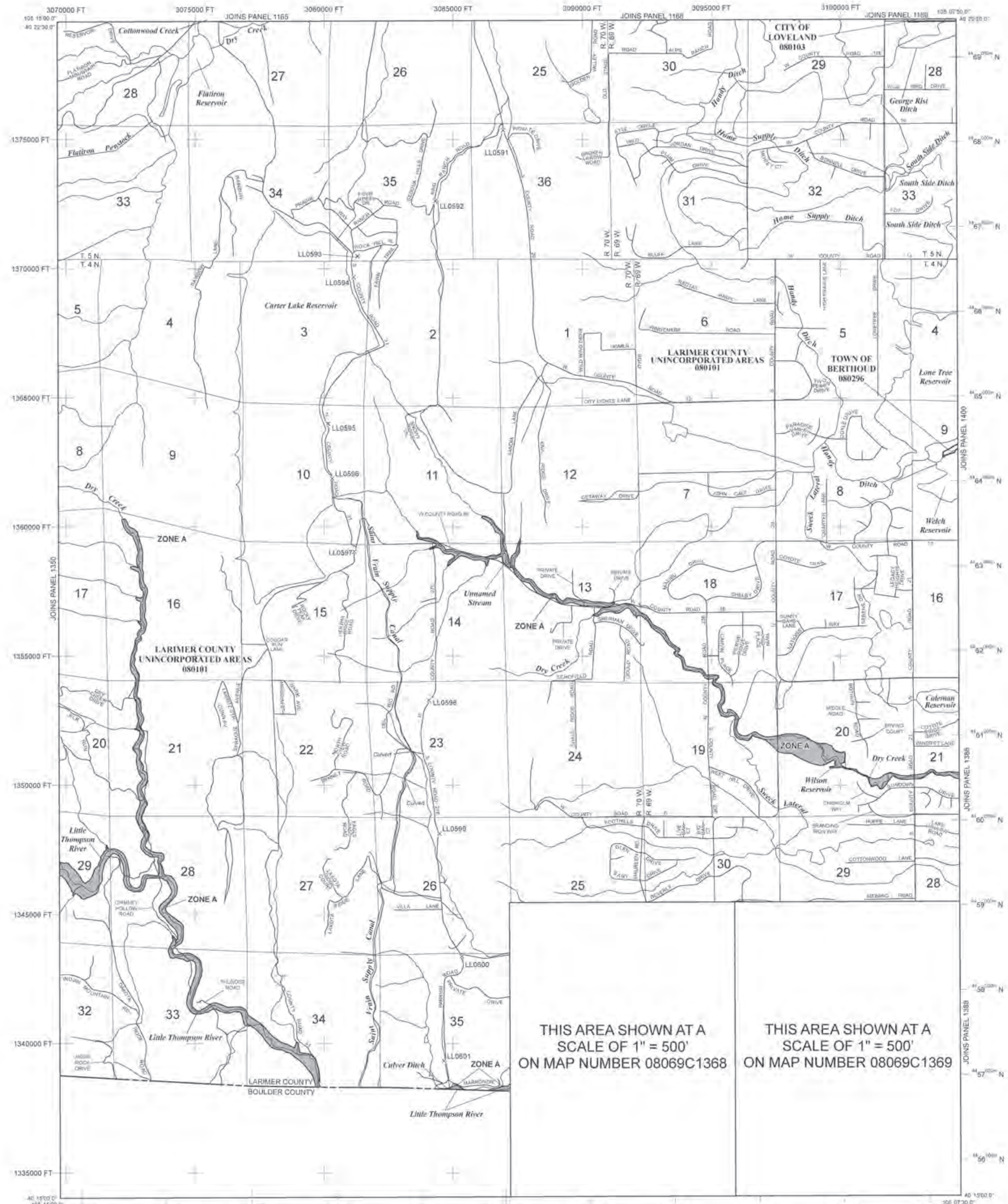

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

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ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

- Floodplain boundary
- Floodway boundary
- Zone D boundary
- CBRS and OPA boundary
- Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.

~~ 513 ~~~	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988 (NAVD 88)

(A)——(A)	Cross section line
(23)- - - -(23)	Transect line
97°07'30", 32°22'30"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83)
$^{42}75^{000m}$N	1000-meter Universal Transverse Mercator grid ticks, zone 13
6000000 FT	5000-foot grid ticks: Colorado State Plane coordinate system, north zone (FIPSZONE 0501), Lambert Conformal Conic
DX5510	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5	River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
December 19, 2006
EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
February 6, 2013 - to change Special Flood Hazard Areas, to add floodway, to add roads and road names, and to add Base Flood Elevations.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 2000'
1000 0 2000 4000 FEET
600 0 600 1200 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 1375G

FIRM
FLOOD INSURANCE RATE MAP
LARIMER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 1375 OF 1420
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
LARIMER COUNTY	[illegible]	1375	G
BERTHOUD, TOWN OF	[illegible]	1375	G
LOVELAND, CITY OF	[illegible]	1375	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08069C1375G

MAP REVISED
FEBRUARY 6, 2013

Federal Emergency Management Agency

NOTES TO USERS

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Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures.** Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Colorado State Plane north zone (FIPSZONE 0501). The **horizontal datum** was NAD83, GRS1980 spheroid. Differences in datum, spheroid, projection or State Plane zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of the FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum.** For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov/ or contact the National Geodetic Survey at the following address:

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SSMC-3, #9202
1315 East-West Highway
Silver Spring, MD 20910-3282

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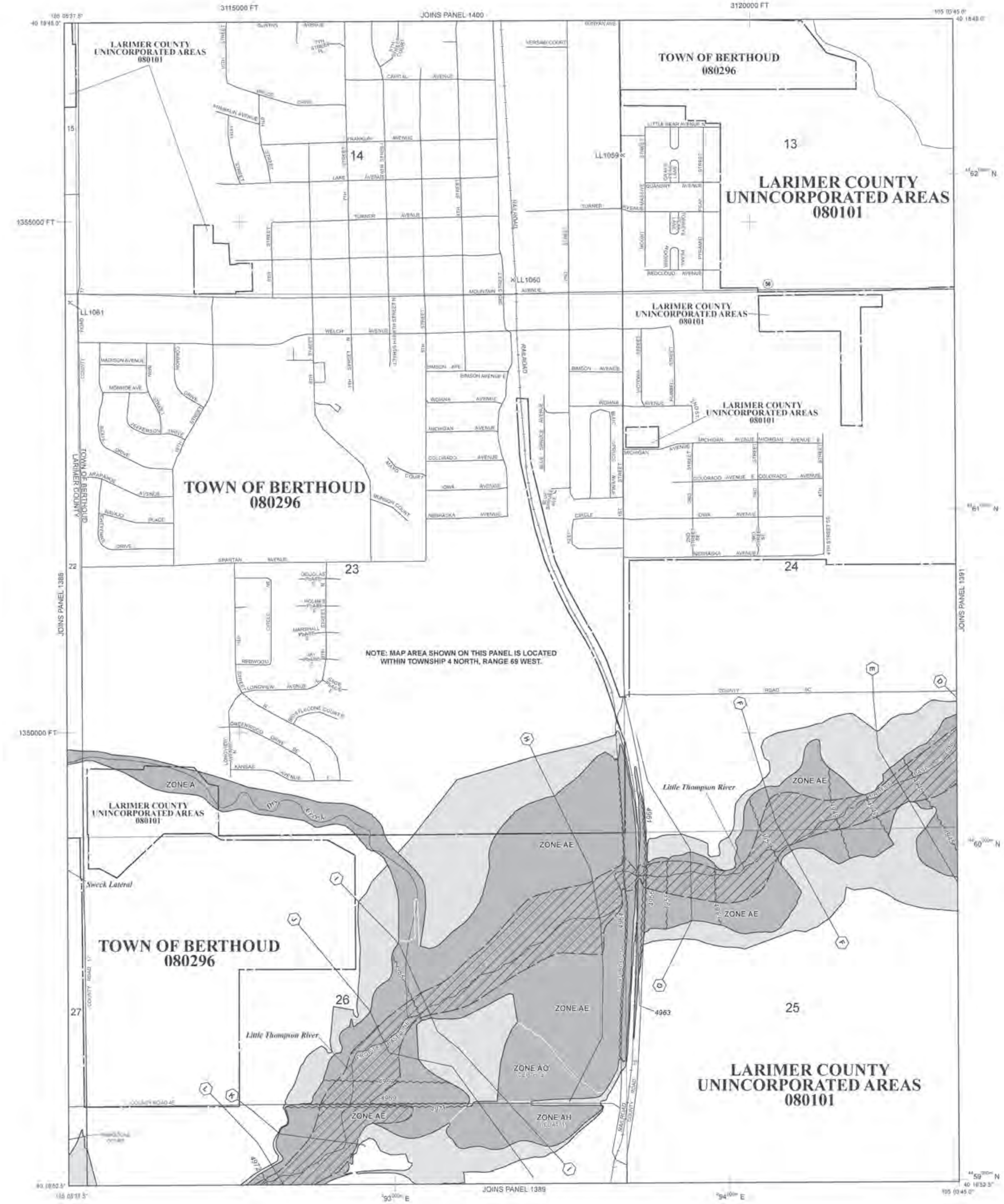

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

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ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

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COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

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	Floodplain boundary
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	Zone D boundary
	CBRS and OPA boundary
	Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
~~ 513 ~~~	Base Flood Elevation line and value; elevation in feet*
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MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
December 19, 2006

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
February 6, 2013 - to change Special Flood Hazard Areas, to add floodway, to add roads and road names, and to add Base Flood Elevations.

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MAP SCALE 1" = 500'

250 0 500 1000 FEET
150 0 150 300 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 1387G

FIRM
FLOOD INSURANCE RATE MAP
LARIMER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 1387 OF 1420
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
LARIMER COUNTY	080101	1387	G
BERTHOUD, TOWN OF	080296	1387	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08069C1387G

MAP REVISED
FEBRUARY 6, 2013

Federal Emergency Management Agency

NOTES TO USERS

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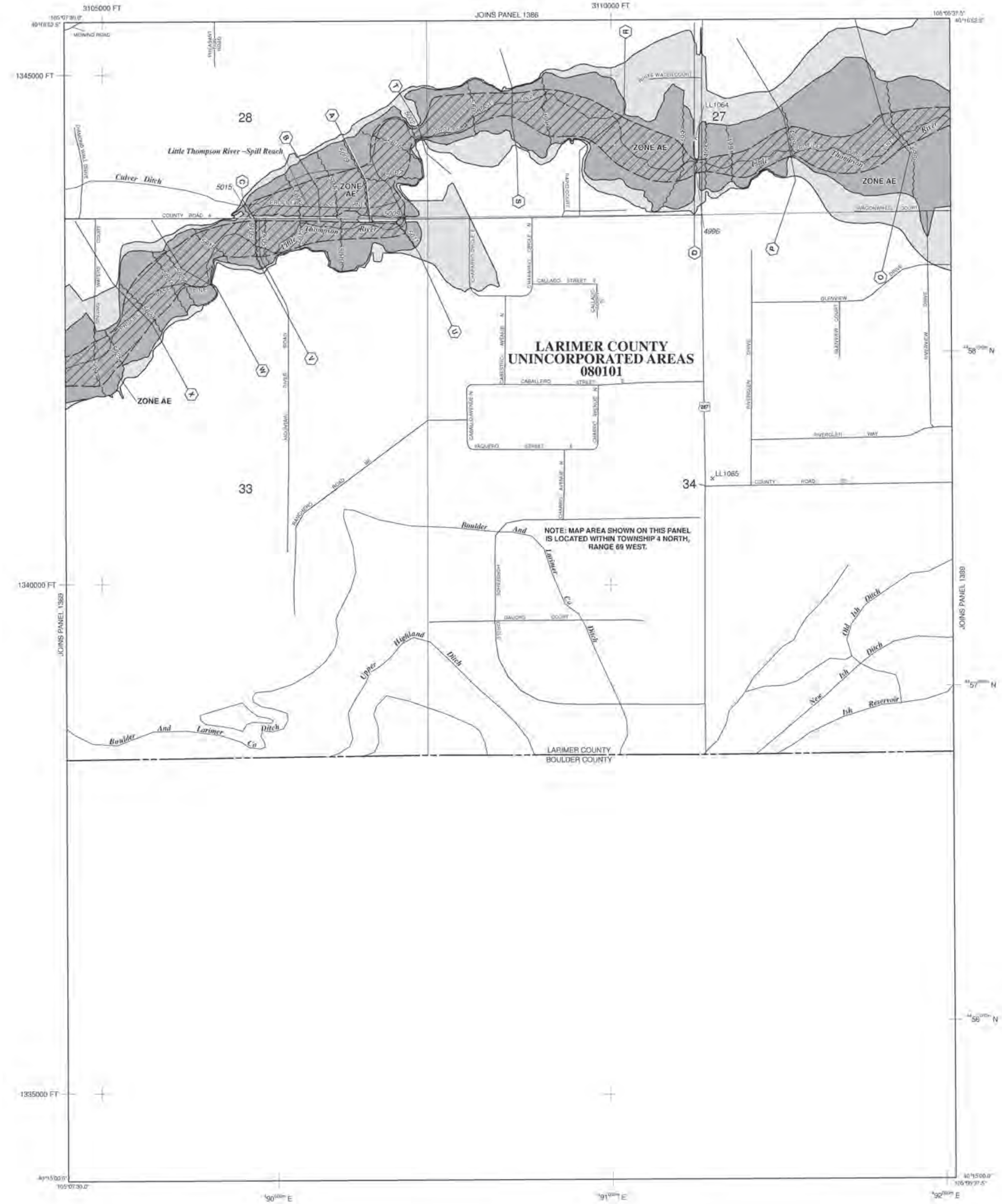


LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

	Floodplain boundary
	Floodway boundary
	Zone D boundary
	CBRS and OPA boundary
	Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
~~ 513 ~~~~	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988 (NAVD 88)

(A)———(A)	Cross section line
(23)- - - -(23)	Transect line
97°07'30", 32°22'30"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83)
4275000mN	1000-meter Universal Transverse Mercator grid ticks, zone 13
6000000 FT	5000-foot grid ticks: Colorado State Plane coordinate system, north zone (FIPSZONE 0501), Lambert Conformal Conic
DX5510	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5	River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
December 19, 2006
EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
February 6, 2013 - to change Special Flood Hazard Areas, to add floodway, to add roads and road names, and to add Base Flood Elevations.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'
250 0 500 1000 FEET
150 0 150 300 METERS

NFIP

PANEL 1388G

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP
LARIMER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 1388 OF 1420
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
LARIMER COUNTY	080101	1388	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08069C1388G

MAP REVISED
FEBRUARY 6, 2013

Federal Emergency Management Agency

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0 North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures.** Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Colorado State Plane north zone (FIPSZONE 0501). The **horizontal datum** was NAD83, GRS1980 spheroid. Differences in datum, spheroid, projection or State Plane zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of the FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum.** For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov/ or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, MD 20910-3282

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713-3242,** or visit its website at http://www.ngs.noaa.gov/.

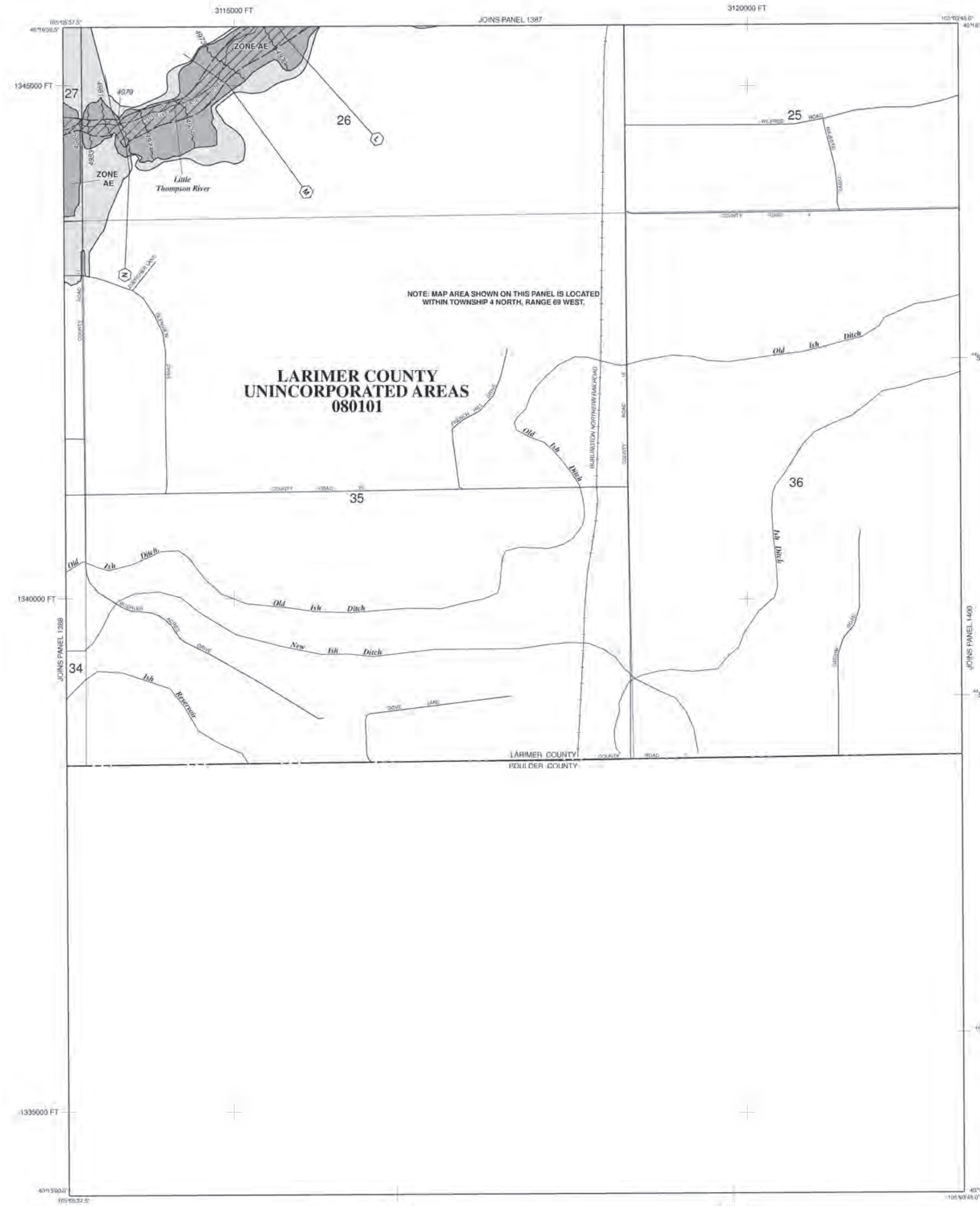
Base map information on this FIRM was provided by the Larimer County GIS and Mapping Department. Additional input was provided by the City of Fort Collins Geographic Information Services Division. These Data are current as of 2010. Additional base map information provided by the Town of Berthoud 2011.

This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables *in the Flood Insurance Study report (which contains authoritative hydraulic data)* may reflect stream channel distances that differ from what is shown on this map.

Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

For information and questions about this map, available products associated with this FIRM including historic versions of this FIRM, how to order products or the National Flood Insurance Program in general, please call the FEMA Map Information eXchange at 1-877-FEMA-MAP (1-877-336-2627) or visit the **FEMA Map Service Center** website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the website. Users may determine the current map date for each FIRM panel by visiting the **FEMA Map Service Center** website or by calling the FEMA Map Information eXchange.



LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

	Floodplain boundary
	Floodway boundary
	Zone D boundary
	CBRS and OPA boundary
	Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
~~ 513 ~~~	Base Flood Elevation line and value; Elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988 (NAVD 88)

(A)———(A)	Cross section line
(23)- - - -(23)	Transect line
97°07'30", 32°22'30"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83)
4275000mN	1000-meter Universal Transverse Mercator grid ticks, zone 13
6000000 FT	5000-foot grid ticks: Colorado State Plane coordinate system, north zone (FIPSZONE 0501), Lambert Conformal Conic
DX5510	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5	River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
December 19, 2006
EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
February 6, 2013 - to change Special Flood Hazard Areas, to add floodway, to add roads and road names, and to add Base Flood Elevations.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

250 0 500 1000 FEET

150 0 150 300 METERS

NFIP

PANEL 1389G

FIRM
FLOOD INSURANCE RATE MAP

LARIMER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 1389 OF 1420
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
LARIMER COUNTY	080101	1389	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

NATIONAL FLOOD INSURANCE PROGRAM

MAP NUMBER
08069C1389G

MAP REVISED
FEBRUARY 6, 2013

Federal Emergency Management Agency

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures.** Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Colorado State Plane north zone (FIPSZONE 0501). The **horizontal datum** was NAD83, GRS1980 spheroid. Differences in datum, spheroid, projection or State Plane zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of the FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum.** For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov/ or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, MD 20910-3282

To obtain current elevation, description and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713-3242,** or visit its website at http://www.ngs.noaa.gov/.

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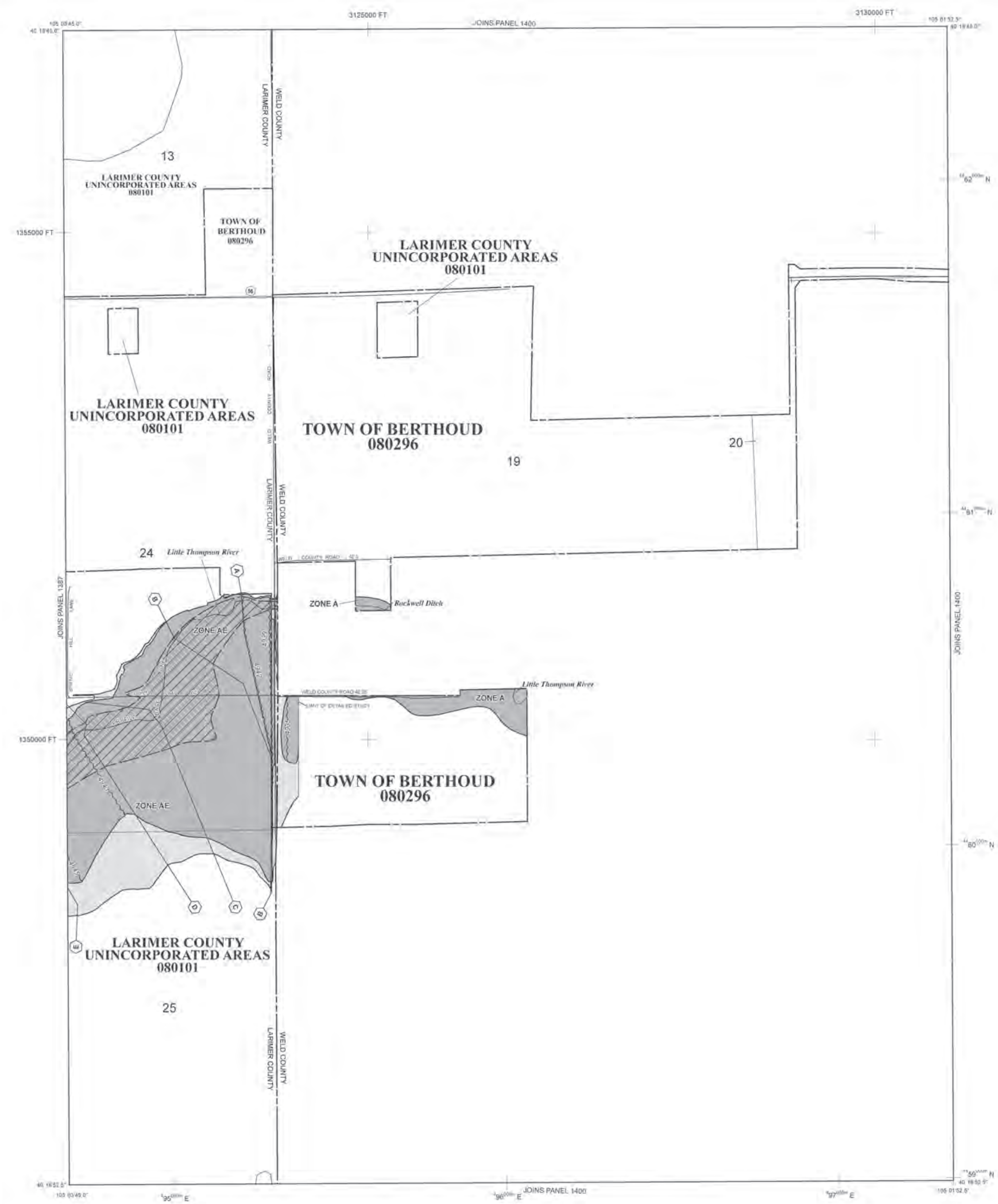


LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

	Floodplain boundary
	Floodway boundary
	Zone D boundary
	CBRS and OPA boundary
	Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
513	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988 (NAVD 88)

(A)——(A)	Cross section line
(23)- - - -(23)	Transect line
97°07'30", 32°22'30"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83)
4275000mN	1000-meter Universal Transverse Mercator grid ticks, zone 13
6000000 FT	5000-foot grid ticks: Colorado State Plane coordinate system, north zone (FIPSZONE 0501), Lambert Conformal Conic
DX5510	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5	River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
December 19, 2006
EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
February 6, 2013 - to change Special Flood Hazard Areas, to add floodway, to add roads and road names, and to add Base Flood Elevations

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

250 0 500 1000 FEET
150 0 150 300 METERS

NFIP

PANEL 1391G

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP

LARIMER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 1391 OF 1420
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
LARIMER COUNTY	080101	1391	G
BERTHOUD, TOWN OF	080296	1391	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08069C1391G

MAP REVISED
FEBRUARY 6, 2013

Federal Emergency Management Agency

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Floodway Data table shown on this FIRM.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

FEMA recommends that a Flood Insurance Policy be purchased for structures in areas where **levees** are shown as providing protection from the 1% annual chance flood. Flooding is not covered by standard property/fire/dwelling insurance policies nor is it covered by Homeowners Insurance, Renters Insurance, Condominium Owners Insurance, or Commercial Property insurance. Contact your insurance agent and local floodplain administrator for further information.

Visit http://www.fema.gov/pdf/fhm/frm_gsah.pdf for information on levees and the risk of flooding in areas shown as being protected by levees.

The **projection** used in the preparation of this map was State Plane Colorado North (feet). The **horizontal datum** was NAD 83, GRS80 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

Spatial Reference System Division
National Geodetic Survey, NOAA
Silver Spring Metro Center
1315 East-West Highway
Silver Spring, Maryland 20910
(301) 713-3191

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242**, or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was provided by the Larimer County GIS and Mapping Department. Additional input was provided by the City of Fort Collins Geographic Information Service Division. These data are current as of 2005.

The **profile baselines** depicted on this map represent the hydraulic modeling baselines that match the flood profiles in the Flood Insurance Study report. As a result of improved topographic data, the profile baseline, in some cases, may deviate significantly from the channel centerline or appear outside the Special Flood Hazard Area.

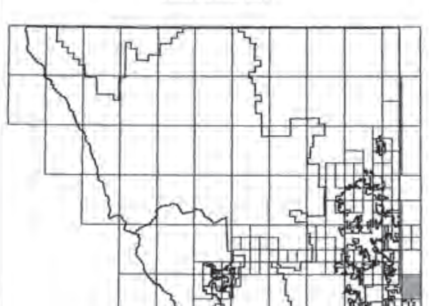
Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

Contact the **FEMA Map Service Center** at 1-800-358-9616 for information on available products associated with this FIRM. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. The FEMA Map Service Center may also be reached by Fax at 1-800-358-9620 and its website at http://www.msc.fema.gov.

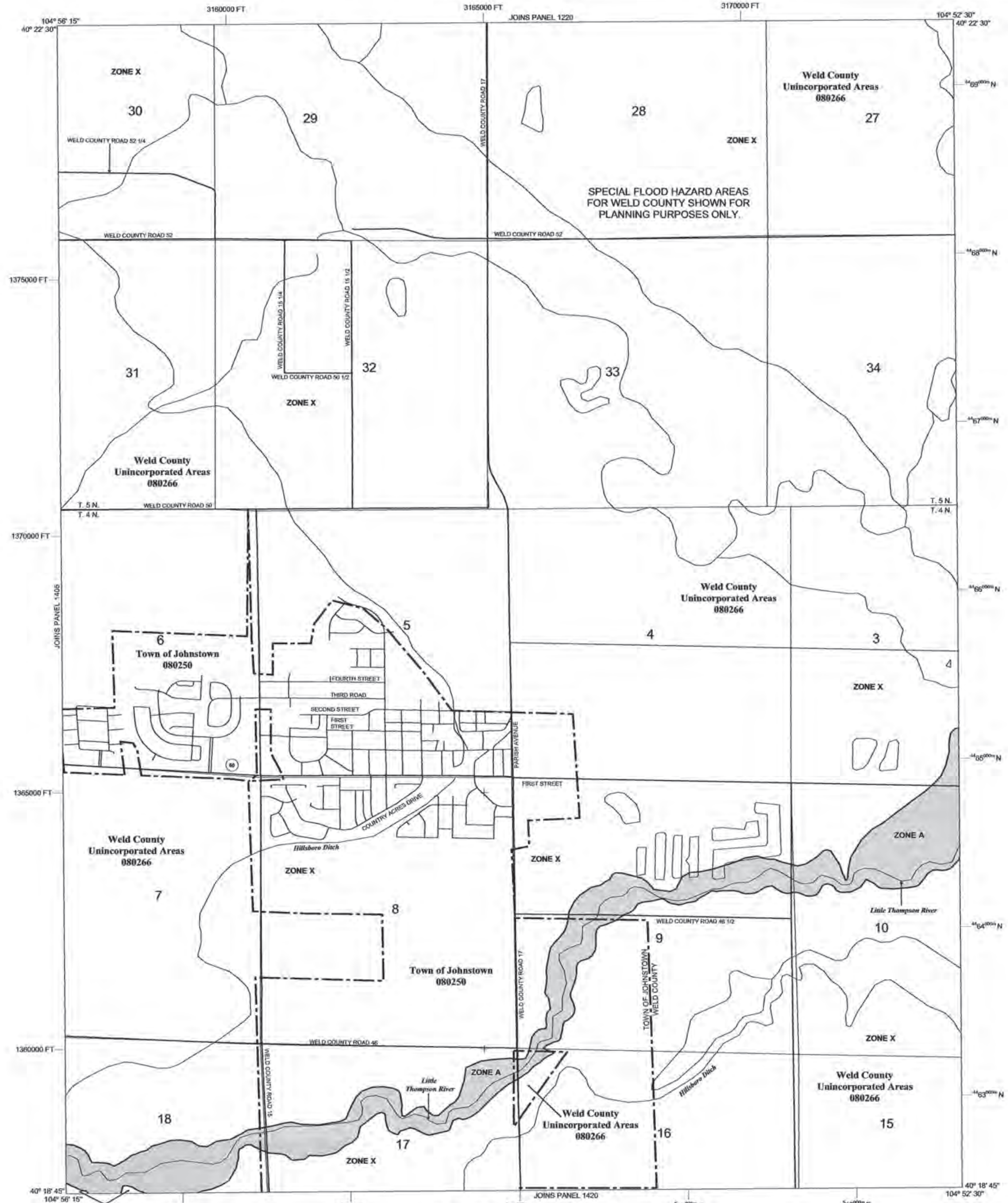
If you have **questions about this map** or questions concerning the National Flood Insurance Program in general, please call **1- 877- FEMA MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov.

Panel Location Map



This Digital Flood Insurance Rate Map (DFIRM) was produced through a Cooperating Technical Partner (CTP) agreement between the State of Colorado Water Conservation Board and the Federal Emergency Management Agency (FEMA).

Additional Flood Hazard information and resources are available from local communities and the Colorado Water Conservation Board.



SPECIAL FLOOD HAZARD AREAS
FOR WELD COUNTY SHOWN FOR
PLANNING PURPOSES ONLY.

NOTE: MAP AREA SHOWN ON THIS PANEL IS LOCATED WITHIN TOWNSHIP 4 NORTH, RANGE 68 WEST, AND TOWNSHIP 5 NORTH, RANGE 68 WEST.

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

Floodplain boundary
Floodway boundary
Zone D boundary

Boundary dividing Special Flood Hazard Area zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.

513	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

(A)—(A)	Cross section line
104° 56' 37.5", 39° 30' 00"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83), Western Hemisphere
3180000 FT	5000-foot ticks: Colorado State Plane coordinate system, North zone, Lambert Conformal Conic projection
4476000mN	1000-meter Universal Transverse Mercator grid ticks, zone 13
KK6400 ×	National Geodetic Survey bench mark (see explanation in Notes to Users section of this FIRM panel)

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
DECEMBER 19, 2006

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 1000'

500 0 1000 2000 FEET
300 0 300 600 METERS

NATIONAL FLOOD INSURANCE PROGRAM

NFIP

PANEL 1410F

FIRM

FLOOD INSURANCE RATE MAP

LARIMER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 1410 OF 1420

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
JOHNSTOWN, TOWN OF	080250	1410	F

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08069C1410F

EFFECTIVE DATE
DECEMBER 19, 2006

Federal Emergency Management Agency

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Floodway Data table shown on this FIRM.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

FEMA recommends that a Flood Insurance Policy be purchased for structures in areas where **levees** are shown as providing protection from the 1% annual chance flood. Flooding is not covered by standard property/fire/dwelling insurance policies nor is it covered by Homeowners Insurance, Renters Insurance, Condominium Owners Insurance, or Commercial Property Insurance. Contact your insurance agent and local floodplain administrator for further information.

Visit http://www.fema.gov/pdf/fhm/frm_gsah.pdf for information on levees and the risk of flooding in areas shown as being protected by levees.

The **projection** used in the preparation of this map was State Plane Colorado North (feet). The **horizontal datum** was NAD 83, GRS80 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

Spatial Reference System Division
National Geodetic Survey, NOAA
Silver Spring Metro Center
1315 East-West Highway
Silver Spring, Maryland 20910
(301) 713-3191

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713-3242**, or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was provided by the Larimer County GIS and Mapping Department. Additional input was provided by the City of Fort Collins Geographic Information Service Division. These data are current as of 2005.

The **profile baselines** depicted on this map represent the hydraulic modeling baselines that match the flood profiles in the Flood Insurance Study report. As a result of improved topographic data, the profile baseline, in some cases, may deviate significantly from the channel centerline or appear outside the Special Flood Hazard Area.

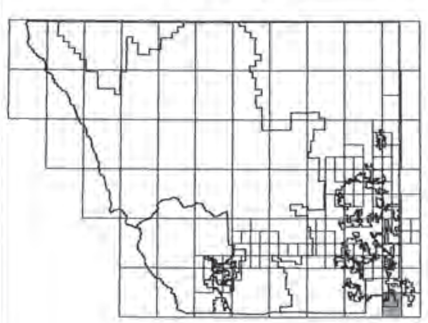
Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

Contact the **FEMA Map Service Center** at 1-800-358-9616 for information on available products associated with this FIRM. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. The FEMA Map Service Center may also be reached by Fax at 1-800-358-9620 and its website at http://www.msc.fema.gov.

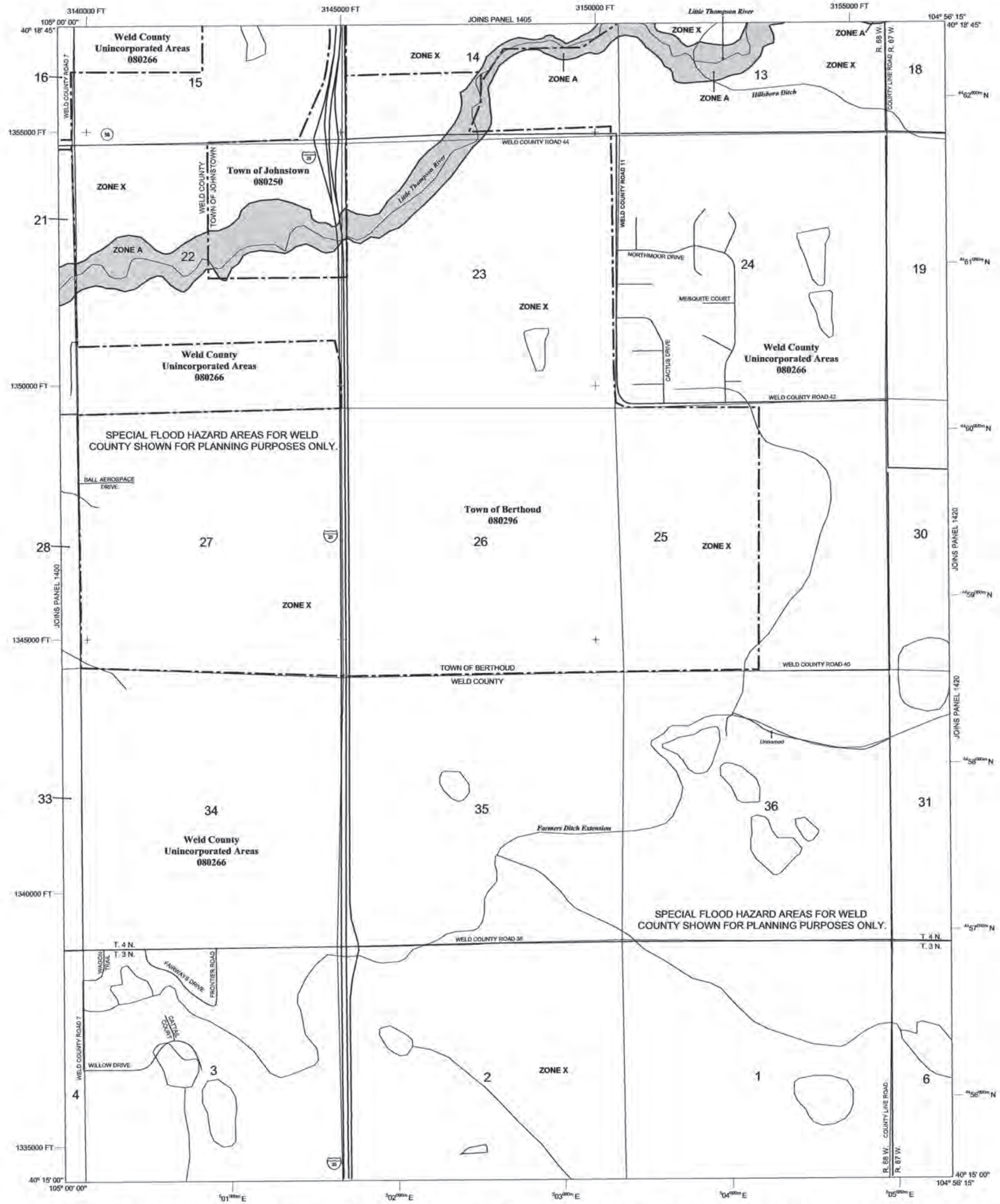
If you have **questions about this map** or questions concerning the National Flood Insurance Program in general, please call **1- 877- FEMA MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov.

Panel Location Map



This Digital Flood Insurance Rate Map (DFIRM) was produced through a Cooperating Technical Partner (CTP) agreement between the State of Colorado Water Conservation Board and the Federal Emergency Management Agency (FEMA).

Additional Flood Hazard Information and resources are available from local communities and the Colorado Water Conservation Board.



NOTE: MAP AREA SHOWN ON THIS PANEL IS LOCATED WITHIN TOWNSHIP 3 NORTH, RANGE 67 WEST AND TOWNSHIP 4 NORTH AND RANGE 67 WEST, TOWNSHIP 3 NORTH, RANGE 68 WEST AND TOWNSHIP 4 NORTH AND RANGE 68 WEST.

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

Floodplain boundary
Floodway boundary
Zone D boundary

Boundary dividing Special Flood Hazard Area zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.

513	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

A — A	Cross section line
104° 50' 37.5", 39° 30' 00"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83), Western Hemisphere
3180000 FT	5000-foot ticks: Colorado State Plane coordinate system, North zone, Lambert Conformal Conic projection
76 N	1000-meter Universal Transverse Mercator grid ticks, zone 13
KK8400 ×	National Geodetic Survey bench mark (see explanation in Notes to Users section of this FIRM panel)

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
DECEMBER 19, 2006

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 1000'

500 0 1000 2000 FEET
300 0 300 600 METERS

NFIP
NATIONAL FLOOD INSURANCE PROGRAM

PANEL 1415F

FIRM

FLOOD INSURANCE RATE MAP

LARIMER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 1415 OF 1420

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BERTHOUD, TOWN OF	080296	1415	F
JOHNSTOWN, TOWN OF	080250	1415	F

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08069C1415F

EFFECTIVE DATE
DECEMBER 19, 2006

Federal Emergency Management Agency

FLOOD INSURANCE STUDY

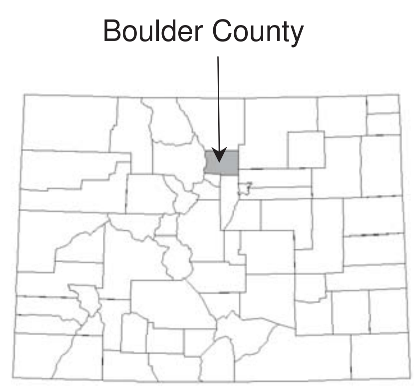
VOLUME 1 OF 4

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

Community Name	*Community Number*
BOULDER, CITY OF	080024
BOULDER COUNTY (UNINCORPORATED AREAS)	080023
ERIE, TOWN OF	080181
JAMESTOWN, TOWN OF	080216
LAFAYETTE, CITY OF	080026
LONGMONT, CITY OF	080027
LOUSIVILLE, CITY OF	085076
LYONS, TOWN OF	080029
NEDERLAND, TOWN OF	080255
SUPERIOR, TOWN OF	080203
*WARD, TOWN OF	080292

* No Special Flood Hazard Areas Identified



Revised: December 18, 2012

Federal Emergency Management Agency

FLOOD INSURANCE STUDY NUMBER
08013CV001B

Table 4 – Summary of Discharges (Continued)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance
Lefthand Creek (South Overflow Channel)					
At Divergence from Lefthand Creek	--[1]	--[1]	--[1]	472	--[1]
At Confluence with Lefthand Creek (North Overflow Channel)	--[1]	--[1]	--[1]	798	--[1]
Little James Creek					
At Confluence with James Creek	2.8	130	650	1,160	3,220
At Confluence of Balarat Creek	2.25	130	650	1,160	3,220
Little James Creek (continued)					
At Upstream Limit of Detailed Study	1.8	109	544	970	2,690
Little Thompson River					
At Larimer-Weld County Line	--[1]	2,800	5,500	7,200	12,800
Middle Boulder Creek					
At Cross Section A	36.3	693	884	960	1,130
At Cross Section G	29.9	596	760	825	971
Middle St. Vrain Creek					
At Confluence with South St. Vrain Creek	32.4	590	1,430	2,000	4,070
North Beaver Creek					
At Cross Section A	5.3	74	117	135	185
At Cross Section T	5.0	70	112	129	178
North Goose Creek					
At Confluence with Goose Creek	--[1]	3,865	3,865	3,865	6,075
North St. Vrain Creek					
At Confluence with St. Vrain Creek and South St. Vrain Creek	125.0	1,000	2,850	4,310	10,630

[1] Data Not Available

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study Report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study Report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) zone 13. The **horizontal datum** was NAD 83, GRS 1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242**, or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was provided by the FEMA Map Service Centerand the Boulder Area Spatial Data Cooperative (BASIC). Additional input was provided by the Town of Erie and the City of Longmont. These data are current as of 2004.

This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables for multiple streams in the Flood Insurance Study Report (which contains authoritative hydraulic data) may reflect stream channel distances that differ from what is shown on this map.

Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

For information on available products associated with this FIRM visit the **Map Service Center (MSC)** website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the MSC website.

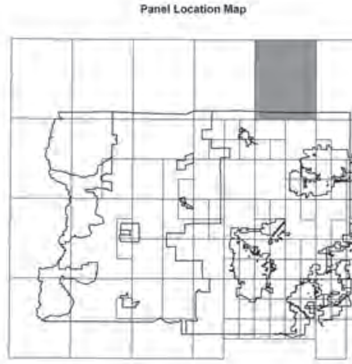
If you have **questions about this map**, how to order products, or the National Flood Insurance Program in general, please call the **FEMA Map Information eXchange (FMIX)** at **1-877-FEMA-MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov/business/nfip.

Boulder County Vertical Datum Offset Table

Flooding Source	Vertical Datum Offset (ft)	Flooding Source	Vertical Datum Offset (ft)
Little Thompson River	3.3		

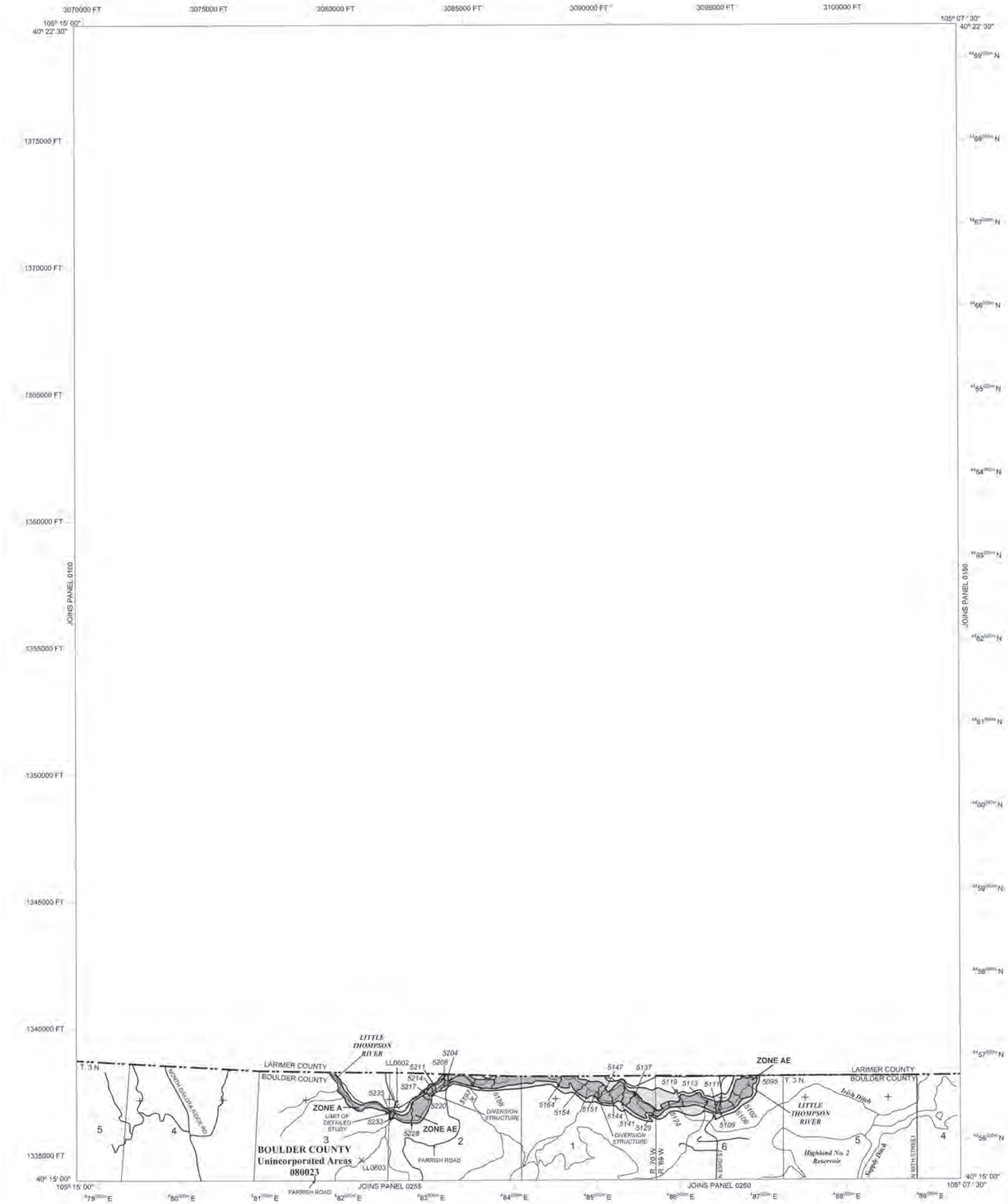
Example: To convert Little Thompson River elevations to NAVD 88, 3.3 feet were added to the NGVD 29 elevations.

Panel Location Map



This digital Flood Insurance Rate Map (FIRM) was produced through a cooperative partnership between the State of Colorado Water Conservation Board, the Urban Drainage and Flood Control District, and the Federal Emergency Management Agency (FEMA). The State of Colorado Water Conservation Board and the Urban Drainage and Flood Control District have implemented a long-term approach of floodplain management to reduce the costs associated with flooding. As part of this effort, both the State of Colorado and the Urban Drainage and Flood Control District have joined in Cooperating Technical Partner agreements with FEMA to produce this digital FIRM.

Additional Flood Hazard information and resources are available from local communities, the Colorado Water Conservation Board, and the Urban Drainage and Flood Control District.



LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X — Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X — Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D — Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

Floodplain Boundary
Floodway Boundary
Zone D boundary
CBRS and OPA boundary
Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
~~~513~~~ Base Flood Elevation line and value; elevation in feet*
(EL 987) Base Flood Elevation value where uniform within zone; elevation in feet*
*Referenced to the North American Vertical Datum of 1988
(A)——(A) Cross section line
(23)- - - -(23) Transect line
45° 02' 08", 93° 02' 12" Geographic coordinates referenced to the North American Datum of 1983 (NAD 83) Western Hemisphere
4989000m N 1000-meter Universal Transverse Mercator grid values, zone 13
3160000 FT 5000-foot ticks: Colorado State Plane North Zone (FIPS Zone 0501), Lambert Conformal Conic projection
DX5510 Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5 River Mile

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
June 2, 1995

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
May 8, 1996 - to incorporate previously issued Letters of Map Revision; to add roads and road names; and to update corporate limits.
October 4, 2002 - to change base flood elevations, to change special flood hazard areas, to change zone designations, to update roads and road names, to reflect updated topographic information, to incorporate previously issued Letters of Map Revision, and to change floodway.
December 18, 2012 - to update corporate limits, to update roads and road names, to add Special Flood Hazard Areas previously shown on Town of Erie, Colorado Flood Insurance Rate Map dated December 2, 2004, and to incorporate previously issued Letters of Map Revision.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 2000'

1000 0 2000 4000 FEET
600 0 600 1200 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0125J

FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 125 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0125	J

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08013C0125J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency
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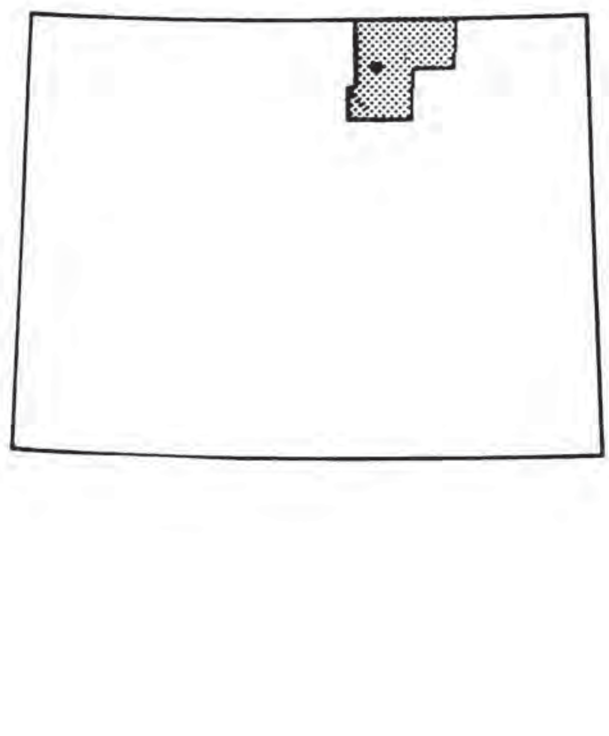
FLOOD INSURANCE STUDY



WELD COUNTY, COLORADO
UNINCORPORATED AREAS
AND
TOWN OF EATON, COLORADO
WELD COUNTY

REVISED: SEPTEMBER 22, 1999

Federal Emergency Management Agency

COMMUNITY NUMBER - 080266

FLOOD INSURANCE STUDY

WELD COUNTY, COLORADO

AND INCORPORATED AREAS

Community Name	*Community Number*
AULT, TOWN OF	080179
DACONO, CITY OF	080236
EATON, TOWN OF	080180
EVANS, CITY OF	080182
FIRESTONE, TOWN OF	080241
FORT LUPTON, CITY OF	080183
FREDERICK, TOWN OF	080244
GARDEN CITY, TOWN OF *	080246
GILCREST, TOWN OF	080213
GREELEY, CITY OF	080184
GROVER, TOWN OF *	080025
HUDSON, TOWN OF	080249
KEENESBURG, TOWN OF	080251
KERSEY, TOWN OF *	080185
LA SALLE, TOWN OF	080186
LOCHBUIE, TOWN OF *	080012
MEAD, TOWN OF	080218
MILLIKEN, TOWN OF	080187
NUNN, TOWN OF	080188
PIERCE, TOWN OF	080189
PLATTEVILLE, TOWN OF	080190
RAYMER, TOWN OF *	080069
SEVERANCE, TOWN OF	080317
WELD COUNTY (UNINCORPORATED AREAS)	080266
WINDSOR, TOWN OF	080264

* No Special Flood Hazard Areas Identified

Notice

This preliminary FIS report includes only revised Flood Profiles and Floodway Data Tables. See "Notice to Flood Insurance Study Users" page for additional details.

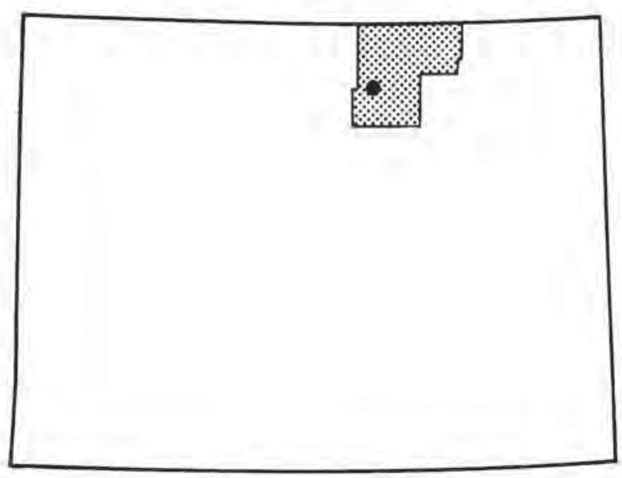
Preliminary:

Federal Emergency Management Agency

FLOOD INSURANCE STUDY NUMBER
08123CV000A

FLOOD INSURANCE STUDY

TOWN OF MILLIKEN, COLORADO
WELD COUNTY



FEBRUARY 1979

U.S. DEPARTMENT of HOUSING & URBAN DEVELOPMENT
FEDERAL INSURANCE ADMINISTRATION

Table 2 – Summary of Discharges (Continued)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance
John Law Ditch – WCR 23 Flow Path (Continued)					
At River Station 4441	--[1]	--[1]	--[1]	235	--[1]
At River Station 4901	--[1]	--[1]	--[1]	521	--[1]
At River Station 5818	--[1]	--[1]	--[1]	802	--[1]
At River Station 7564	--[1]	--[1]	--[1]	855	--[1]
At River Station 8173	--[1]	--[1]	--[1]	805	--[1]
At River Station 9327	--[1]	--[1]	--[1]	834	--[1]
At River Station 9746	--[1]	--[1]	--[1]	305	--[1]
John Law Ditch – West Tributary					
At River Station 15590	--[1]	--[1]	--[1]	665	--[1]
At River Station 17435	--[1]	--[1]	--[1]	153	--[1]
John Law Ditch – Whitney Flow Path					
At Confluence with John Law Ditch – WCR 23 Flow Path	--[1]	--[1]	--[1]	144	--[1]
Little Thompson River					
At Milliken	200	1,630	3,600	4,800	8,400
Pumpkin Ridge Split Flow Path					
At Confluence with Sheep Draw	--[1]	763	2,307	3,606	6,579
St. Vrain River					
At Downstream Limit of Study	--[1]	5,950	12,850	16,700	41,960
St. Vrain River – Existing Lakes					
At Confluence with St. Vrain River	--[1]	1	1	1	1
Sheep Draw					
At upstream side of Greeley No. 3 Ditch	--[1]	1,221	3,212	4,673	8,065
At upstream side of C Street	--[1]	1,200	3,156	4,596	7,940
Downstream of Hunter's Cove Detention Pond	--[1]	1,176	3,117	4,556	7,897
Downstream of Summer Park Detention Pond	--[1]	1,163	3,102	4,558	7,939
At upstream side of 4th Street	--[1]	1,134	3,055	4,502	7,862
Downstream of HP Detention Pond	--[1]	1,104	3,002	4,436	7,766

[1] Data Not Available

of 10, 50, 100, and 500 years have been selected as having special significance for flood plain management and for flood insurance premium rates. The analyses reported here reflect current conditions in the watersheds of the flooding sources.

3.1 Hydrologic Analyses

Hydrologic analyses were carried out to establish the peak discharge-frequency relationships for floods of the selected recurrence intervals for each stream studied in detail in the community.

Discharges were computed for the Little Thompson River by the U.S. Army Corps of Engineers (Reference 4). The records for the Berthoud gaging station were analyzed using a log-Pearson Type III analysis (Reference 5). The period of record for the gage is 17 years. The gage is located approximately 14 miles west of Milliken. The peaks from these analyses were applied to unit hydrographs that were developed based on regional relationships. The hydrographs were routed through three reaches to get the peak discharges at Milliken. The 50- and 500-year peak discharges were plotted using log-probability and 10- and 100-year discharges.

Peak discharge-drainage area relationships for the Little Thompson River are shown in Table 1.

Table 1. Summary of Discharges

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (Cubic Feet per Second) 10-Year	50-Year	100-Year	500-Year
Little Thompson River At Milliken	200	1630	3600	4800	8400

3.2 Hydraulic Analyses

Analyses of the hydraulic characteristics of streams in the community were carried out to provide estimates of the elevations of floods of the selected recurrence intervals along each stream studied in the community.

Starting water-surface elevations for Milliken were computed by the slope-area method.

Cross section data for the Little Thompson River were obtained from field surveys. All bridges and backwater-producing structures were surveyed to obtain elevation data and structural geometry.

ELEVATION REFERENCE MARKS

REFERENCE MARK	ELEVATION (FT. NGVD)	DESCRIPTION OF LOCATION
RM1*	4747.16	Northeast end of Quentine Avenue bridge over Little Thompson River. Gingery Associates, Inc.

*OUTSIDE CORPORATE LIMITS

KEY TO MAP

500-Year Flood Boundary — ZONE B
100-Year Flood Boundary
Zone Designations* With Date of Identification e.g., 12/2/74 — ZONE A1 DATE / ZONE A5 DATE
100-Year Flood Boundary — ZONE B
500-Year Flood Boundary

Base Flood Elevation Line With Elevation In Feet** — 513

Base Flood Elevation in Feet Where Uniform Within Zone** — (EL 987)

Elevation Reference Mark — RM7×

River Mile — • M1.5

**Referenced to the National Geodetic Vertical Datum of 1929

*EXPLANATION OF ZONE DESIGNATIONS

ZONE	EXPLANATION
A	Areas of 100-year flood; base flood elevations and flood hazard factors not determined.
A0	Areas of 100-year shallow flooding where depths are between one (1) and three (3) feet; average depths of inundation are shown, but no flood hazard factors are determined.
AH	Areas of 100-year shallow flooding where depths are between one (1) and three (3) feet; base flood elevations are shown, but no flood hazard factors are determined.
A1-A30	Areas of 100-year flood; base flood elevations and flood hazard factors determined.
A99	Areas of 100-year flood to be protected by flood protection system under construction; base flood elevations and flood hazard factors not determined.
B	Areas between limits of the 100-year flood and 500-year flood; or certain areas subject to 100-year flooding with average depths less than one (1) foot or where the contributing drainage area is less than one square mile; or areas protected by levees from the base flood. (Medium shading)
C	Areas of minimal flooding. (No shading)
D	Areas of undetermined, but possible, flood hazards.
V	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors not determined.
V1-V30	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors determined.

NOTES TO USER

Certain areas not in the special flood hazard areas (zones A and V) may be protected by flood control structures.

This map is for flood insurance purposes only; it does not necessarily show all areas subject to flooding in the community or all planimetric features outside special flood hazard areas.

INITIAL IDENTIFICATION:
MAY 17, 1974

FLOOD HAZARD BOUNDARY MAP REVISIONS:
MARCH 12, 1976

FLOOD INSURANCE RATE MAP EFFECTIVE:
AUGUST 1, 1979

FLOOD INSURANCE RATE MAP REVISIONS:

Refer to the FLOOD INSURANCE RATE MAP EFFECTIVE date shown on this map to determine when actuarial rates apply to structures in the zones where elevations or depths have been established.

To determine if flood insurance is available in this community, contact your insurance agent, or call the National Flood Insurance Program, at (800) 638-6620, or (800) 424-8872.

APPROXIMATE SCALE
400 — 0 — 400 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP

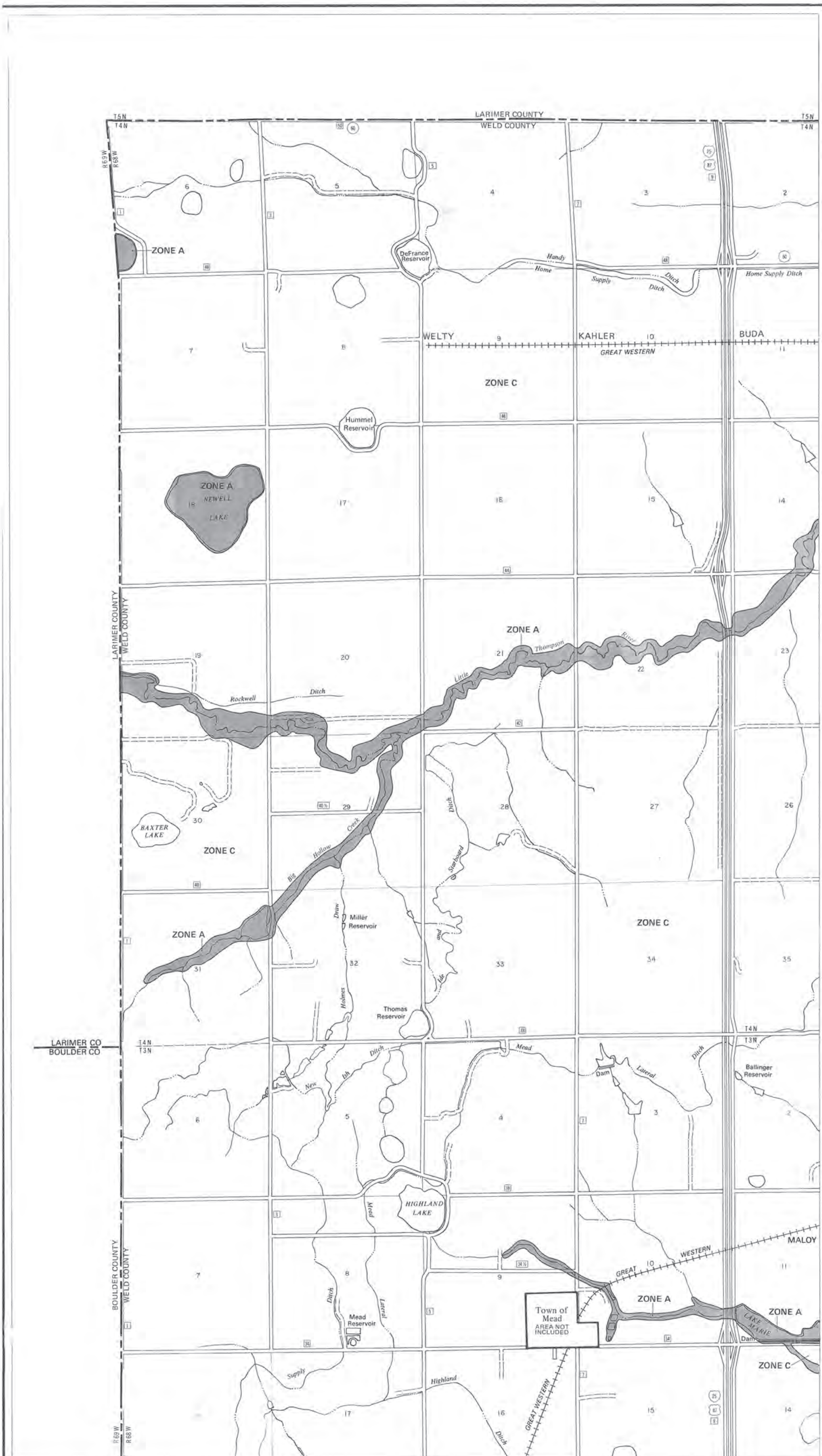
TOWN OF
MILLIKEN, COLORADO
WELD COUNTY

ONLY PANEL PRINTED

COMMUNITY-PANEL NUMBER
080187 0001 B

EFFECTIVE DATE:
AUGUST 1, 1979

U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
FEDERAL INSURANCE ADMINISTRATION



KEY TO MAP

500-Year Flood Boundary	ZONE B
100-Year Flood Boundary	
Zone Designations*	ZONE A1 / ZONE A5
100-Year Flood Boundary	ZONE B
500-Year Flood Boundary	
Base Flood Elevation Line With Elevation In Feet**	513
Base Flood Elevation in Feet Where Uniform Within Zone**	(EL 987)
Elevation Reference Mark	RM7×
River Mile	• M1.5

**Referenced to the National Geodetic Vertical Datum of 1929

*EXPLANATION OF ZONE DESIGNATIONS

ZONE	EXPLANATION
A	Areas of 100-year flood; base flood elevations and flood hazard factors not determined.
A0	Areas of 100-year shallow flooding where depths are between one (1) and three (3) feet; average depths of inundation are shown, but no flood hazard factors are determined.
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A1-A30	Areas of 100-year flood; base flood elevations and flood hazard factors determined.
A99	Areas of 100-year flood to be protected by flood protection system under construction; base flood elevations and flood hazard factors not determined.
B	Areas between limits of the 100-year flood and 500-year flood; or certain areas subject to 100-year flooding with average depths less than one (1) foot or where the contributing drainage area is less than one square mile; or areas protected by levees from the base flood. (Medium shading)
C	Areas of minimal flooding. (No shading)
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V	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors not determined.
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NOTES TO USER

Certain areas not in the special flood hazard areas (zones A and V) may be protected by flood control structures.

This map is for flood insurance purposes only; it does not necessarily show all areas subject to flooding in the community or all planimetric features outside special flood hazard areas.

For adjoining map panels, see separately printed Index To Map Panels.

INITIAL IDENTIFICATION:
MARCH 21, 1978

FLOOD HAZARD BOUNDARY MAP REVISIONS:

FLOOD INSURANCE RATE MAP EFFECTIVE:
MARCH 18, 1980

FLOOD INSURANCE RATE MAP REVISIONS:
SEPTEMBER 28, 1982 | Panel revised to reflect F.E.M.A. title block.

To determine if flood insurance is available in this community, contact your insurance agent, or call the National Flood Insurance Program at (800) 638-6620.

APPROXIMATE SCALE
2000 0 2000 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP

WELD COUNTY, COLORADO
UNINCORPORATED AREA

PANEL 725 OF 1075
(SEE MAP INDEX FOR PANELS NOT PRINTED)

COMMUNITY-PANEL NUMBER
080266 0725 C

MAP REVISED:
SEPTEMBER 28, 1982

federal emergency management agency

KEY TO MAP

500-Year Flood Boundary	ZONE B
100-Year Flood Boundary	
Zone Designations*	ZONE A1 / ZONE A6
100-Year Flood Boundary	ZONE B
500-Year Flood Boundary	
Base Flood Elevation Line With Elevation In Feet**	513
Base Flood Elevation in Feet Where Uniform Within Zone**	(EL 987)
Elevation Reference Mark	RM7×
River Mile	•M1.5

**Referenced to the National Geodetic Vertical Datum of 1929

*EXPLANATION OF ZONE DESIGNATIONS

ZONE	EXPLANATION
A	Areas of 100-year flood; base flood elevations and flood hazard factors not determined.
A0	Areas of 100-year shallow flooding where depths are between one (1) and three (3) feet; average depths of inundation are shown, but no flood hazard factors are determined.
AH	Areas of 100-year shallow flooding where depths are between one (1) and three (3) feet; base flood elevations are shown, but no flood hazard factors are determined.
A1-A30	Areas of 100-year flood; base flood elevations and flood hazard factors determined.
A99	Areas of 100-year flood to be protected by flood protection system under construction; base flood elevations and flood hazard factors not determined.
B	Areas between limits of the 100-year flood and 500-year flood; or certain areas subject to 100-year flooding with average depths less than one (1) foot or where the contributing drainage area is less than one square mile; or areas protected by levees from the base flood. (Medium shading)
C	Areas of minimal flooding. (No shading)
D	Areas of undetermined, but possible, flood hazards.
V	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors not determined.
V1-V30	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors determined.

NOTES TO USER

Certain areas not in the special flood hazard areas (zones A and V) may be protected by flood control structures.

This map is for flood insurance purposes only; it does not necessarily show all areas subject to flooding in the community or all planimetric features outside special flood hazard areas.

For adjoining map panels, see separately printed Index To Map Panels.

INITIAL IDENTIFICATION:
MARCH 21, 1978

FLOOD HAZARD BOUNDARY MAP REVISIONS:

FLOOD INSURANCE RATE MAP EFFECTIVE:
MARCH 18, 1980

FLOOD INSURANCE RATE MAP REVISIONS:
SEPTEMBER 28, 1982 to change Corporate Limits, to add new Special Flood Hazard Areas, to reduce Special Flood Hazard Areas, to add Zone Designations, to add Base Flood Elevations, to add Street Names, and to add Streets.

To determine if flood insurance is available in this community, contact your insurance agent, or call the National Flood Insurance Program at (800) 638-6620.

N

APPROXIMATE SCALE
2000 0 2000 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP

WELD COUNTY, COLORADO
UNINCORPORATED AREA

PANEL 750 OF 1075
(SEE MAP INDEX FOR PANELS NOT PRINTED)

COMMUNITY-PANEL NUMBER
080266 0750 C

MAP REVISED:
SEPTEMBER 28, 1982

federal emergency management agency

Appendix B
Hydrologic Analysis and Parameters

Table B-1: 24-hour Little Thompson Models: Subbasin Hydrologic Zone, Area, and Curve Number
Table B-2: Little Thompson River Rainfall Depths at Subbasin Centroids
Table B-3: 5-minute Dimensionless 24-hour NRCS Type II Cumulative Rainfall Distribution
Table B-4: 24-hour Little Thompson Models: Unit Hydrograph Parameters
Table B-5: 24-hour Little Thompson Models: Routing Reach Parameters
Table B-6: Little Thompson River Land Use Conditions
Table B-7: Little Thompson River Proposed Model Results Summary

Table B-1

24-hour Little Thompson Models: Hydrologic Zone, Subbasin Area, and Curve Number (CN)

Basin ID	Hydrologic Zone	Hydrologic Condition	Calibrated		Predictive	
			Calibrated Model Area (mi^2)	CN	Predictive Model Area (mi^2)	CN
DC-3	Phase 2 Plains	Fair	9.69	83.39	9.69	83.39
LT-10	Phase 2 Plains	Fair	13.48	82.22	13.48	82.22
LT-11	Phase 2 Plains	Fair	13.27	85.26	13.27	85.26
LT-12	Phase 2 Plains	Fair	20.45	83.70	20.45	83.70
LT-13	Phase 2 Plains	Fair	20.62	83.27	20.62	83.27
LT-14	Phase 2 Plains	Fair	9.94	80.41	9.94	80.41
LT-1A	Phase I	Fair	2.89	59.91	2.89	59.91
LT-1B	Phase I	Fair	2.87	57.75	2.87	57.75
LT-2A	Phase I	Fair	2.99	54.64	2.99	54.64
LT-3A	Phase I	Fair	4.09	54.69	4.09	54.69
LT-3B	Phase I	Fair	1.00	59.98	1.00	59.98
LT-4A	Phase I	Fair	2.06	69.83	2.06	50.16
LT-4B	Phase I	Fair	1.89	76.69	1.89	58.85
LT-5	Phase I	Fair	0.62	73.72	0.62	54.95
LT-6	Phase 2 Mountains	Fair	10.18	79.28	10.18	62.46
LT-7	Phase 2 Mountains	Fair	12.03	85.07	12.03	71.24
LT-8	Phase 2 Mountains	Fair	6.30	74.44	6.30	74.44
LT-9	Phase 2 Plains	Fair	8.79	77.40	8.79	77.40
NF-1	Phase 2 Mountains	Poor	10.27	74.18	10.27	74.18
NF-2	Phase 2 Mountains	Poor	11.45	74.89	11.45	74.89
NF-3	Phase 2 Mountains	Poor	6.13	86.98	6.13	74.39
WF-1A	Phase I	Poor	2.84	86.13	2.84	72.97
WF-1B	Phase I	Poor	4.00	86.20	4.00	73.09
WF-2	Phase I	Fair	4.31	72.40	4.31	53.28
WF-3A	Phase I	Poor	2.10	87.86	2.10	75.89
WF-3B	Phase I	Fair	1.72	75.31	1.72	57.02
WF-4	Phase I	Poor	4.66	86.73	4.66	73.97
WF-5A	Phase I	Poor	1.19	84.59	1.19	70.46
WF-5B	Phase I	Fair	0.60	75.30	0.60	57.00
WF-6A	Phase I	Poor	2.02	83.23	2.02	68.33
WF-6B	Phase I	Fair	1.96	73.78	1.96	55.03
total:			**196.41**		**196.41**	

Table B-2 - Little Thompson River Rainfall Depths at Subbasin Centroids

Subbasin	24-hour September 2013 Total Precipitation	24-hour September 2013 Precipitation Recurrence	Antecedent Rainfall[a]	Antecedent Moisture Condition	24-hour Rainfall Total Precipitation				
					NOAA Atlas 14				
					10-year	25-year	50-year	100-year	500-year
DC-3	1.85	< 10 year	1.67	AMCII	2.890	3.710	4.440	5.240	7.430
LT-10	1.44	< 10 year	1.52	AMCII	2.860	3.660	4.360	5.130	7.230
LT-11	1.73	< 10 year	1.42	AMCII	2.900	3.700	4.400	5.170	7.260
LT-12	1.68	< 10 year	1.74	AMCII	2.470	3.220	3.890	4.620	6.640
LT-13	1.77	< 10 year	1.83	AMCII	2.830	3.600	4.250	4.970	6.910
LT-14	1.73	< 10 year	1.79	AMCII	2.800	3.550	4.190	4.890	6.670
LT-1A	6.61	> 500 year	1.12	AMCII	2.430	3.130	3.770	4.500	6.580
LT-1B	6.33	100 to 500 year	0.80	AMCII	2.500	3.230	3.890	4.640	6.790
LT-2A	7.07	> 500 year	1.25	AMCII	2.510	3.230	3.890	4.630	6.740
LT-3A	7.54	> 500 year	1.71	AMCII	2.580	3.310	3.980	4.730	6.840
LT-3B	7.07	> 500 year	1.69	AMCII	2.600	3.350	4.030	4.800	6.960
LT-4A	8.06	> 500 year	2.52	AMCIII	2.650	3.400	4.080	4.850	6.990
LT-4B	7.93	> 500 year	2.50	AMCIII	2.670	3.440	4.130	4.900	7.070
LT-5	8.29	> 500 year	2.77	AMCIII	2.710	3.480	4.170	4.940	7.080
LT-6	6.73	100 to 500 year	2.56	AMCIII	2.780	3.570	4.280	5.060	7.230
LT-7	4.25	50 to 100 year	2.23	AMCIII	2.890	3.720	4.450	5.270	7.500
LT-8	3.24	10 to 25 year	1.87	AMCII	2.890	3.710	4.430	5.240	7.430
LT-9	2.21	< 10 year	1.86	AMCII	2.880	3.710	4.430	5.230	7.430
NF-1	6.60	100 to 500 year	1.83	AMCII	2.750	3.550	4.270	5.090	7.400
NF-2	6.71	100 to 500 year	2.06	AMCII	2.730	3.520	4.230	5.040	7.280
NF-3	6.42	100 to 500 year	2.24	AMCIII	2.810	3.620	4.340	5.150	7.400
WF-1A	8.72	> 500 year	3.20	AMCIII	2.640	3.370	4.030	4.780	6.860
WF-1B	8.98	> 500 year	2.97	AMCIII	2.660	3.390	4.040	4.780	6.820
WF-2	9.02	> 500 year	2.80	AMCIII	2.630	3.360	4.030	4.790	6.920
WF-3A	8.72	> 500 year	2.72	AMCIII	2.630	3.360	4.020	4.760	6.830
WF-3B	8.49	> 500 year	2.85	AMCIII	2.650	3.390	4.050	4.780	6.830
WF-4	8.41	> 500 year	2.40	AMCIII	2.610	3.340	4.010	4.750	6.840
WF-5A	7.94	> 500 year	2.73	AMCIII	2.650	3.400	4.070	4.820	6.910
WF-5B	7.70	> 500 year	2.94	AMCIII	2.670	3.420	4.090	4.830	6.910
WF-6A	8.25	> 500 year	2.77	AMCIII	2.670	3.420	4.100	4.860	6.980
WF-6B	7.87	> 500 year	2.90	AMCIII	2.700	3.460	4.140	4.890	7.000

[a] Total Rainfall for 5 Days Preceding 24-hour Analysis Window

Table B-3

5-minute Dimensionless 24-hr NRCS Type II Cumulative Rainfall Distribution

Time: Hours \ Minutes	0	5	10	15	20	25	30	35	40	45	50	55
0	0.000	0.001	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010
1	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.021	0.022
2	0.023	0.024	0.025	0.026	0.027	0.028	0.029	0.030	0.031	0.032	0.033	0.034
3	0.035	0.036	0.037	0.038	0.039	0.040	0.041	0.042	0.043	0.044	0.045	0.047
4	0.048	0.049	0.051	0.052	0.053	0.055	0.056	0.057	0.059	0.060	0.061	0.063
5	0.064	0.065	0.067	0.068	0.069	0.071	0.072	0.073	0.075	0.076	0.077	0.079
6	0.080	0.082	0.083	0.085	0.087	0.088	0.090	0.092	0.093	0.095	0.097	0.098
7	0.100	0.102	0.103	0.105	0.107	0.108	0.110	0.112	0.113	0.115	0.117	0.118
8	0.120	0.122	0.124	0.126	0.128	0.131	0.133	0.135	0.138	0.140	0.142	0.145
9	0.147	0.150	0.152	0.155	0.158	0.160	0.163	0.166	0.169	0.172	0.175	0.178
10	0.181	0.184	0.188	0.191	0.195	0.199	0.203	0.208	0.213	0.218	0.224	0.230
11	0.236	0.243	0.250	0.257	0.266	0.274	0.283	0.318	0.352	0.387	0.479	0.571
12	0.663	0.678	0.692	0.707	0.716	0.726	0.735	0.743	0.750	0.758	0.764	0.770
13	0.776	0.781	0.786	0.791	0.795	0.800	0.804	0.808	0.811	0.815	0.818	0.822
14	0.825	0.828	0.831	0.834	0.837	0.839	0.842	0.844	0.847	0.849	0.851	0.854
15	0.856	0.858	0.861	0.863	0.865	0.867	0.869	0.871	0.873	0.875	0.877	0.879
16	0.881	0.883	0.885	0.887	0.889	0.891	0.893	0.895	0.896	0.898	0.900	0.901
17	0.903	0.905	0.906	0.908	0.910	0.911	0.913	0.915	0.916	0.918	0.919	0.921
18	0.922	0.923	0.925	0.926	0.927	0.929	0.930	0.931	0.933	0.934	0.935	0.937
19	0.938	0.939	0.941	0.942	0.943	0.945	0.946	0.947	0.949	0.950	0.951	0.952
20	0.953	0.954	0.955	0.956	0.957	0.958	0.959	0.960	0.961	0.962	0.963	0.964
21	0.965	0.966	0.967	0.968	0.969	0.970	0.971	0.972	0.973	0.974	0.975	0.976
22	0.977	0.978	0.979	0.980	0.981	0.982	0.983	0.984	0.985	0.986	0.987	0.988
23	0.989	0.990	0.991	0.992	0.993	0.994	0.995	0.996	0.997	0.998	0.999	0.999
24	1.000											

Table B-4
24-hour Little Thompson Models: Unit Hydrograph Parameters

Basin ID	K_{n*}	L *mi*	L_c *mi*	S *ft/mile*	TLAG *hours*	Cp
DC-3	0.10	6.19	3.71	40	3.4	0.7
LT-10	0.10	8.09	3.59	40	3.7	0.7
LT-11	0.10	5.96	2.66	30	3.1	0.7
LT-12	0.10	9.43	4.50	30	4.3	0.7
LT-13	0.10	9.57	3.63	30	4.1	0.7
LT-14	0.10	5.57	2.57	40	2.9	0.7
LT-1A	0.15	3.61	2.31	370	2.5	0.6
LT-1B	0.15	2.69	1.38	150	2.2	0.6
LT-2	0.15	3.10	2.72	450	2.4	0.6
LT-3A	0.15	3.63	1.76	400	2.3	0.6
LT-3B	0.15	2.34	0.93	770	1.4	0.6
LT-4A	0.15	3.43	2.25	990	2.1	0.6
LT-4B	0.15	3.18	1.77	170	2.5	0.6
LT-5	0.15	1.79	0.79	750	1.2	0.6
LT-6	0.15	9.59	5.30	130	5.4	0.6
LT-7	0.10	6.23	3.30	130	2.7	0.6
LT-8	0.09	4.67	1.81	130	1.8	0.6
LT-9	0.08	7.07	4.18	70	2.7	0.7
NF-1	0.10	8.26	4.75	360	2.8	0.6
NF-2	0.15	8.88	4.55	410	4.2	0.6
NF-3	0.15	5.83	2.86	510	3.0	0.6
WF-1A	0.15	4.34	1.88	490	2.0	0.6
WF-1B	0.15	3.68	1.57	560	2.1	0.6
WF-2	0.15	3.37	1.73	690	2.0	0.6
WF-3A	0.15	2.96	1.91	200	2.4	0.6
WF-3B	0.15	2.59	1.90	390	2.1	0.6
WF-4	0.15	5.29	3.31	320	3.3	0.6
WF-5A	0.15	2.93	1.68	180	2.4	0.6
WF-5B	0.15	1.19	1.45	730	1.3	0.6
WF-6A	0.15	2.39	1.51	1340	1.5	0.6
WF-6B	0.15	4.08	2.55	280	2.8	0.6

Table B-5
24-hour Little Thompson Models: Routing Reach Parameters

Reach ID	Stream Name	L	Slope	Calibrated Model			Predictive Model			Invert
		ft	*ft/ft*	Method	$n_{channel}$	$n_{overbank}$	Method	$n_{channel}$	$n_{overbank}$	*ft (NAVD88)*
DC-R1	Dry Creek	17,521	0.0034	Muskingum-Cunge	0.1	0.1	Muskingum-Cunge	0.1	0.1	4977
LT-R1	Little Thompson	2,014	0.0199	Muskingum-Cunge	0.045	0.08	Muskingum-Cunge	0.045	0.08	7594
LT-R10	Little Thompson	34,292	0.0044	Muskingum-Cunge	0.1	0.1	Muskingum-Cunge	0.1	0.1	4979
LT-R11	Little Thompson	19,702	0.0563	Muskingum-Cunge	0.1	0.1	Muskingum-Cunge	0.1	0.1	4909
LT-R12	Little Thompson	31,421	0.0025	Muskingum-Cunge	0.1	0.1	Muskingum-Cunge	0.1	0.1	4902
LT-R13	Little Thompson	33,407	0.0021	Muskingum-Cunge	0.1	0.1	Muskingum-Cunge	0.1	0.1	4809
LT-R14	Little Thompson	25,251	0.0024	Muskingum-Cunge	0.1	0.1	Muskingum-Cunge	0.1	0.1	4754
LT-R2	Little Thompson	9,129	0.0307	Muskingum-Cunge	0.045	0.08	Muskingum-Cunge	0.045	0.08	7443
LT-R3	Little Thompson	15,599	0.0359	Muskingum-Cunge	0.045	0.08	Muskingum-Cunge	0.045	0.08	6998
LT-R4	Little Thompson	4,539	0.0352	Muskingum-Cunge	0.045	0.08	Muskingum-Cunge	0.045	0.08	6585
LT-R5	Little Thompson	32,106	0.0249	Muskingum-Cunge	0.08	0.08	Muskingum-Cunge	0.08	0.08	6169
LT-R6	Little Thompson	10,364	0.0154	Muskingum-Cunge	0.08	0.08	Muskingum-Cunge	0.08	0.08	5640
LT-R7	Little Thompson	21,404	0.0093	Muskingum-Cunge	0.08	0.08	Muskingum-Cunge	0.08	0.08	5528
LT-R8	Little Thompson	17,138	0.0093	Muskingum-Cunge	0.08	0.08	Muskingum-Cunge	0.08	0.08	5267
LT-R9	Little Thompson	20,978	0.0076	Muskingum-Cunge	0.1	0.1	Muskingum-Cunge	0.1	0.1	5141
NF-R1	North Fork Little Thompson	9,597	0.0250	Muskingum-Cunge	0.08	0.08	Muskingum-Cunge	0.08	0.08	6072
NF-R2	North Fork Little Thompson	10,336	0.0194	Muskingum-Cunge	0.08	0.08	Muskingum-Cunge	0.08	0.08	5834
WF-R1	West Fork Little Thompson	10,725	0.0280	Muskingum-Cunge	0.045	0.08	Muskingum-Cunge	0.045	0.08	7670
WF-R2	West Fork Little Thompson	15,775	0.0342	Muskingum-Cunge	0.045	0.08	Muskingum-Cunge	0.045	0.08	7630
WF-R3	West Fork Little Thompson	4,364	0.0137	Muskingum-Cunge	0.045	0.08	Muskingum-Cunge	0.045	0.08	7490
WF-R4	West Fork Little Thompson	6,342	0.0315	Muskingum-Cunge	0.045	0.08	Muskingum-Cunge	0.045	0.08	7380
WF-R5	West Fork Little Thompson	13,666	0.0380	Muskingum-Cunge	0.045	0.08	Muskingum-Cunge	0.045	0.08	6930

Table B-6 - Little Thompson River Land Use Conditions

Land Cover	TR-55 Classification
11 - Open Water	Open Water
12, 41, 42, 43 - Deciduous Forest	Deciduous Forest, Oak- Aspen
21- Developed Open Space	Developed Open Space, 2 Acre Lots
22 - Developed, Low Intensity	Developed Low Intensity, 1 Acre Lots
23 - Developed, Medium Intensity	Developed Medium Intensity, 1/4 Acre Lots
24 - Developed, High Intensity	Developed High Intensity, 1/8 Acre Lots
31 - Barren Land	Barren Land
51, 52 – Shrub/Brush	Shrub, Brush
71, 72, 81 - Grassland/Pasture	Grassland, pasture
82 - Row Crops	Crops, Row Crops
90, 95 - Woody Wetlands, Herbaceous	Woody Wetlands, Herbaceous

TABLE B-7
Little Thompson River Proposed Model Results Summary (DARF = 0.92)

Hydrologic Element	Drainage Area (sq mi)	Calibrated 24 hour			10 Percent Annual Chance			4 Percent Annual Chance			2 Percent Annual Chance			1 Percent Annual Chance			0.2 Percent Annual Chance		
		Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)
DC-3	9.69	267	28	0.61	1,089	112	1.20	1,674	173	1.82	2,223	229	2.39	2,843	293	3.05	4,591	474	4.92
DC-J1	9.69	267	28	0.61	1,089	112	1.20	1,674	173	1.82	2,223	229	2.39	2,843	293	3.05	4,591	474	4.92
DC-R1	9.69	263	27	0.60	1,069	110	1.20	1,646	170	1.82	2,190	226	2.40	2,803	289	3.05	4,533	468	4.92
LT-10	13.48	188	14	0.31	1,294	96	1.11	2,013	149	1.69	2,682	199	2.23	3,445	256	2.85	5,602	416	4.61
LT-11	13.27	404	30	0.61	1,789	135	1.33	2,659	200	1.95	3,450	260	2.52	4,339	327	3.17	6,803	513	4.98
LT-12	20.45	425	21	0.51	1,450	71	0.93	2,345	115	1.46	3,203	157	1.98	4,174	204	2.57	6,969	341	4.27
LT-13	20.62	471	23	0.55	1,907	92	1.15	2,899	141	1.72	3,784	184	2.23	4,795	233	2.81	7,612	369	4.45
LT-14	9.94	203	20	0.42	986	99	0.96	1,557	157	1.48	2,082	209	1.95	2,681	270	2.50	4,272	430	3.95
LT-1A	2.89	299	103	2.32	17	6	0.11	58	20	0.29	117	40	0.51	204	71	0.83	539	187	1.95
LT-1B	2.87	304	106	1.95	14	5	0.09	53	19	0.26	112	39	0.47	203	71	0.78	564	196	1.89
LT-2	2.99	290	97	2.13	8	3	0.05	33	11	0.18	77	26	0.36	149	50	0.62	450	151	1.61
LT-3A	4.09	388	95	2.43	13	3	0.06	52	13	0.20	119	29	0.39	226	55	0.66	663	162	1.66
LT-3B	1.00	147	147	2.64	12	12	0.14	38	38	0.36	75	75	0.62	129	129	0.97	328	328	2.19
LT-4A	2.06	379	184	4.47	3	1	0.02	14	7	0.12	38	18	0.27	82	40	0.49	280	136	1.37
LT-4B	1.89	404	214	5.14	16	8	0.14	49	26	0.36	93	49	0.61	157	83	0.96	392	207	2.15
LT-5	0.62	178	288	5.12	3	5	0.08	15	24	0.25	34	54	0.46	63	102	0.76	180	291	1.82
LT-6	10.18	1,162	114	4.34	113	11	0.25	262	26	0.54	438	43	0.86	666	65	1.26	1,438	141	2.59
LT-7	12.03	1,233	103	2.67	581	48	0.58	1,103	92	1.03	1,640	136	1.47	2,305	192	2.02	4,318	359	3.66
LT-8	6.30	523	83	1.08	532	84	0.72	950	151	1.21	1,367	217	1.68	1,871	297	2.26	3,351	532	3.95
LT-9	8.79	335	38	0.57	799	91	0.86	1,352	154	1.39	1,881	214	1.90	2,502	285	2.50	4,320	491	4.26
LT-J1	5.76	559	97	2.13	32	5	0.10	111	19	0.27	228	40	0.49	405	70	0.80	1,093	190	1.92
LT-J10	132.13	15,491	117	3.22	3,650	28	0.58	6,942	53	0.99	10,643	81	1.40	15,346	116	1.90	30,769	233	3.44
LT-J11	145.40	15,732	108	2.98	3,951	27	0.65	7,438	51	1.08	11,381	78	1.50	16,370	113	2.02	32,743	225	3.58
LT-J12	165.85	15,233	92	2.67	4,144	25	0.68	7,093	43	1.12	10,947	66	1.56	16,007	97	2.08	33,486	202	3.68
LT-J13	186.47	14,879	80	2.44	4,480	24	0.73	7,145	38	1.18	10,700	57	1.63	15,654	84	2.16	32,119	172	3.77
LT-J14	196.41	14,696	75	2.33	4,452	23	0.74	7,134	36	1.19	10,542	54	1.64	15,391	78	2.18	31,369	160	3.77
LT-J2	8.75	815	93	2.13	39	4	0.08	143	16	0.24	305	35	0.45	553	63	0.74	1,543	176	1.81
LT-J3	13.84	1,271	92	2.26	59	4	0.08	221	16	0.24	476	34	0.44	866	63	0.73	2,422	175	1.80
LT-J4	43.19	9,280	215	4.90	832	19	0.25	1,777	41	0.50	2,958	68	0.78	4,572	106	1.15	10,253	237	2.37
LT-J5	43.81	9,378	214	4.90	835	19	0.25	1,788	41	0.50	2,980	68	0.78	4,611	105	1.14	10,352	236	2.37
LT-J6	81.84	14,343	175	4.54	2,176	27	0.39	4,261	52	0.71	6,630	81	1.06	9,724	119	1.50	19,953	244	2.91
LT-J7	93.87	15,338	163	4.30	2,573	27	0.41	5,044	54	0.75	7,829	83	1.11	11,468	122	1.57	23,416	249	3.01
LT-J8	100.17	15,512	155	4.09	2,755	28	0.43	5,378	54	0.78	8,325	83	1.15	12,142	121	1.61	24,715	247	3.07
LT-J9	108.96	15,569	143	3.81	3,002	28	0.46	5,849	54	0.83	9,043	83	1.21	13,137	121	1.68	26,666	245	3.16
LT-R1	5.76	559	97	2.13	32	5	0.10	111	19	0.27	228	40	0.49	405	70	0.80	1,093	190	1.92
LT-R10	108.96	15,346	141	3.81	2,897	27	0.46	5,653	52	0.83	8,784	81	1.21	12,783	117	1.68	25,917	238	3.16
LT-R11	132.13	15,487	117	3.22	3,649	28	0.58	6,941	53	0.99	10,641	81	1.40	15,339	116	1.90	30,753	233	3.44
LT-R12	145.40	14,899	102	2.98	3,777	26	0.65	6,611	45	1.07	10,366	71	1.50	15,113	104	2.01	31,304	215	3.60
LT-R13	165.85	14,570	88	2.67	4,014	24	0.68	6,930	42	1.11	10,504	63	1.55	15,276	92	2.08	30,836	186	3.68
LT-R14	186.47	14,623	78	2.43	4,416	24	0.73	7,077	38	1.18	10,537	57	1.63	15,375	82	2.16	31,251	168	3.77
LT-R2	8.75	815	93	2.13	39	4	0.08	143	16	0.24	305	35	0.45	553	63	0.74	1,542	176	1.81
LT-R3	13.84	1,271	92	2.26	59	4	0.08	221	16	0.24	476	34	0.44	866	63	0.73	2,421	175	1.80
LT-R4	43.19	9,279	215	4.90	831	19	0.25	1,777	41	0.50	2,957	68	0.78	4,571	106	1.15	10,247	237	2.37
LT-R5	43.81	9,374	214	4.90	834	19	0.25	1,787	41	0.50	2,978	68	0.78	4,607	105	1.14	10,339	236	2.37
LT-R6	71.66	13,338	186	4.56	2,083	29	0.41	4,050	57	0.74	6,286	88	1.09	9,219	129	1.53	18,929	264	2.96
LT-R7	81.84	14,331	175	4.54	2,174	27	0.39	4,257	52	0.71	6,624	81	1.06	9,712	119	1.50	19,922	243	2.91
LT-R8	93.87	15,316	163	4.30	2,570	27	0.41	5,036	54	0.75	7,816	83	1.11	11,436	122	1.57	23,343	249	3.01
LT-R9	100.17	15,484	155	4.09	2,744	27	0.43	5,361	54	0.78	8,301	83	1.15	12,104	121	1.61	24,627	246	3.07
NF-1	10.27	1,530	149	3.69	542	53	0.63	993	97	1.09	1,459	142	1.56	2,040	199	2.13	3,833	373	3.89
NF-2	11.45	1,449	127	3.86	466	41	0.65	834	73	1.11	1,211	106	1.58	1,677	146	2.15	3,092	270	3.87
NF-3	6.13	1,217	199	4.89	329	54	0.67	592	97	1.15	859	140	1.62	1,184	193	2.19	2,173	355	3.92
NF-J1	10.27	1,530	149	3.69	542	53	0.63	993	97	1.09	1,459	142	1.56	2,040	199	2.13	3,833	373	3.89
NF-J2	21.72	2,939	135	3.78	965	44	0.64	1,735	80	1.10	2,530	116	1.57	3,518	162	2.14	6,536	301	3.88

TABLE B-7
Little Thompson River Proposed Model Results Summary (DARF = 0.92)

Hydrologic Element	Drainage Area (sq mi)	Calibrated 24 hour			10 Percent Annual Chance			4 Percent Annual Chance			2 Percent Annual Chance			1 Percent Annual Chance			0.2 Percent Annual Chance		
		Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Runoff Volume (in)
NF-J3	71.66	13,344	186	4.56	2,084	29	0.40	4,051	57	0.74	6,289	88	1.09	9,222	129	1.53	18,941	264	2.96
NF-J3 wo LT	27.85	4,004	144	4.03	1,259	45	0.65	2,271	82	1.11	3,316	119	1.58	4,619	166	2.15	8,605	309	3.89
NF-J3 wo NF	43.81	9,374	214	4.90	834	19	0.25	1,787	41	0.50	2,978	68	0.78	4,607	105	1.14	10,339	236	2.37
NF-R1	10.27	1,530	149	3.69	541	53	0.63	992	97	1.09	1,459	142	1.56	2,038	198	2.13	3,832	373	3.89
NF-R2	21.72	2,938	135	3.78	965	44	0.64	1,735	80	1.10	2,530	116	1.57	3,518	162	2.14	6,535	301	3.88
OUTFALL	196.41	14,696	75	2.33	4,452	23	0.74	7,134	36	1.19	10,542	54	1.64	15,391	78	2.18	31,369	160	3.77
WF-1A	2.84	1,061	373	7.01	155	55	0.53	292	103	0.92	436	154	1.32	618	218	1.82	1,180	415	3.35
WF-1B	4.00	1,622	406	7.28	217	54	0.54	404	101	0.94	598	150	1.33	841	210	1.83	1,588	397	3.33
WF-2	4.31	1,092	253	5.63	12	3	0.05	50	12	0.18	121	28	0.36	239	55	0.62	734	170	1.59
WF-3A	2.10	778	371	7.22	127	61	0.64	225	107	1.07	325	155	1.50	447	213	2.03	819	390	3.62
WF-3B	1.72	499	290	5.49	10	6	0.10	37	21	0.28	75	43	0.50	130	76	0.80	343	199	1.85
WF-4	4.66	1,359	292	6.79	187	40	0.55	342	73	0.95	508	109	1.37	708	152	1.87	1,339	287	3.43
WF-5A	1.19	369	310	6.07	45	38	0.44	90	76	0.81	139	117	1.19	201	168	1.66	396	333	3.14
WF-5B	0.60	183	306	4.78	5	8	0.11	17	29	0.29	37	61	0.52	65	109	0.82	175	292	1.90
WF-6A	2.02	729	361	6.21	86	42	0.38	186	92	0.72	299	148	1.08	444	220	1.54	913	452	2.98
WF-6B	1.96	393	201	4.75	8	4	0.08	30	15	0.25	62	31	0.46	110	56	0.74	297	152	1.78
WF-J1	6.84	2,683	392	7.17	371	54	0.54	695	102	0.93	1,033	151	1.33	1,458	213	1.82	2,762	404	3.33
WF-J2	4.31	1,092	253	5.63	12	3	0.05	50	12	0.18	121	28	0.36	239	55	0.62	734	170	1.59
WF-J3	14.97	4,935	330	6.54	507	34	0.36	956	64	0.66	1,483	99	0.98	2,213	148	1.39	4,602	307	2.70
WF-J4	19.63	6,240	318	6.60	677	35	0.41	1,263	64	0.73	1,949	99	1.07	2,848	145	1.50	5,778	294	2.87
WF-J5	21.42	6,712	313	6.52	725	34	0.40	1,365	64	0.72	2,108	98	1.06	3,087	144	1.49	6,284	293	2.86
WF-R1	6.84	2,681	392	7.17	371	54	0.54	694	101	0.93	1,032	151	1.33	1,457	213	1.82	2,761	404	3.33
WF-R2	4.31	1,091	253	5.63	12	3	0.05	50	12	0.18	121	28	0.36	239	55	0.62	734	170	1.59
WF-R3	14.97	4,935	330	6.54	507	34	0.36	956	64	0.66	1,483	99	0.98	2,212	148	1.39	4,598	307	2.70
WF-R4	19.63	6,238	318	6.60	677	34	0.41	1,263	64	0.73	1,948	99	1.07	2,846	145	1.50	5,775	294	2.87
WF-R5	21.42	6,711	313	6.52	725	34	0.40	1,365	64	0.72	2,107	98	1.06	3,086	144	1.49	6,281	293	2.86
Without LT	25.40	7,593	299	6.36	791	31	0.37	1,518	60	0.68	2,362	93	1.02	3,488	137	1.44	7,186	283	2.79
Without WF	17.79	1,902	107	2.82	75	4	0.08	281	16	0.24	604	34	0.44	1,096	62	0.73	3,069	172	1.79

Appendix C
Ayres Associates Flood Frequency Analyses

HEC-SSP Output for USGS Gage 06742000 / CDWR Gage LTCANYO, Little Thompson River near Berthoud, CO

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Bulletin 17B Frequency Analysis
    10 Jun 2014   06:19 PM
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--- Input Data ---

Analysis Name: LITTLE T -BERTHOUD 2012 ST
Description:

Data Set Name: LITTLE T BERTHOUD 2012
DSS File Name: H:\32-176904 Big Thompson Hydrology\CH2M_F\CH2M_F.dss
DSS Pathname: /LITTLE THOMPSON RIVER/BERTHOUD/FLOW ANNUAL
PEAK/01jan1900/IR-CENTURY/MANUAL ENTRY 2012/

Report File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\LITTLE_T_-BERTHOUD_2012_ST\LITTLE_T_-
BERTHOUD_2012_ST.rpt
XML File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\LITTLE_T_-BERTHOUD_2012_ST\LITTLE_T_-
BERTHOUD_2012_ST.xml

Start Date:
End Date:

Skew Option: Use Station Skew
Regional Skew: -Infinity
Regional Skew MSE: -Infinity

Plotting Position Type: Median

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---

----------------------
<< Low Outlier Test >>
----------------------
 Based on 36 events, 10 percent outlier test deviate K(N) = 2.639
                            Computed low outlier test value = 5.2

              0 low outlier(s) identified below test value of 5.2
-----------------------
<< High Outlier Test >>
-----------------------
 Based on 36 events, 10 percent outlier test deviate K(N) = 2.639
                      Computed high outlier test value = 17,907.7

        0 high outlier(s) identified above test value of 17,907.7
```

--- Final Results ---

<< Plotting Positions >>
LITTLE T BERTHOUD 2012

Events Analyzed		Ordered Events			
Day Mon Year	FLOW CFS	Rank	Water Year	FLOW CFS	Median Plot Pos
20 Jul 1929	218	1	1957	4,000	1.92
10 Aug 1930	3,620	2	1930	3,620	4.67
08 Jul 1947	1,360	3	1949	3,500	7.42
27 Jun 1948	101	4	1995	2,870	10.16
06 Jun 1949	3,500	5	1961	2,380	12.91
04 Jun 1950	82	6	1951	2,380	15.66
03 Aug 1951	2,380	7	1999	2,200	18.41
25 Apr 1952	279	8	1958	1,470	21.15
09 Jul 1953	95	9	1947	1,360	23.90
29 Oct 1953	232	10	1994	1,260	26.65
19 Sep 1955	115	11	2005	651	29.40
18 Jun 1956	262	12	2003	467	32.14
09 May 1957	4,000	13	2004	358	34.89
08 May 1958	1,470	14	1996	348	37.64
22 May 1959	261	15	1997	331	40.38
05 May 1960	203	16	1952	279	43.13
03 Jun 1961	2,380	17	2010	270	45.88
18 May 1993	48	18	1998	267	48.63
10 Aug 1994	1,260	19	1956	262	51.37
29 May 1995	2,870	20	1959	261	54.12
26 May 1996	348	21	1954	232	56.87
29 Apr 1997	331	22	1929	218	59.62
23 Apr 1998	267	23	1960	203	62.36
30 Apr 1999	2,200	24	2011	186	65.11
07 Apr 2000	30	25	1955	115	67.86
06 May 2001	108	26	2001	108	70.60
12 Sep 2002	27	27	2012	104	73.35
15 May 2003	467	28	1948	101	76.10
23 Jul 2004	358	29	1953	95	78.85
03 Jun 2005	651	30	2008	86	81.59
12 Jul 2006	8	31	1950	82	84.34
05 Jun 2008	86	32	2009	67	87.09
23 Apr 2009	67	33	1993	48	89.84
16 May 2010	270	34	2000	30	92.58
18 May 2011	186	35	2002	27	95.33
03 Jul 2012	104	36	2006	8	98.08

<< Skew Weighting >>

Based on 36 events, mean-square error of station skew = 0.141
Mean-square error of regional skew = -?

<< Frequency Curve >>

LITTLE T BERTHOUD 2012

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
25,656	37,406	0.2	83,636	11,238
16,126	21,443	0.5	47,402	7,547
10,992	13,735	1.0	29,711	5,424
7,229	8,545	2.0	17,868	3,772
3,854	4,280	5.0	8,378	2,174
2,204	2,353	10.0	4,309	1,321
1,119	1,158	20.0	1,957	711
306	306	50.0	471	199
83	81	80.0	131	48
42	40	90.0	70	22
24	22	95.0	43	11
8	7	99.0	17	3

<< Systematic Statistics >>

LITTLE T BERTHOUD 2012

Log Transform: FLOW, CFS		Number of Events	
Mean	2.485	Historic Events	0
Standard Dev	0.670	High Outliers	0
Station Skew	-0.005	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	-0.005	Systematic Events	36

--- End of Analytical Frequency Curve ---

```
------------------------------
Bulletin 17B Frequency Analysis
    10 Jun 2014   06:19 PM
------------------------------


--- Input Data ---

Analysis Name: LITTLE T -BERTHOUD 2012 WT
Description:

Data Set Name: LITTLE T BERTHOUD 2012
DSS File Name: H:\32-176904 Big Thompson Hydrology\CH2M_F\CH2M_F.dss
DSS Pathname: /LITTLE THOMPSON RIVER/BERTHOUD/FLOW ANNUAL
PEAK/01jan1900/IR-CENTURY/MANUAL ENTRY 2012/

Report File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\LITTLE_T_-BERTHOUD_2012_WT\LITTLE_T_-
BERTHOUD_2012_WT.rpt
XML File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\LITTLE_T_-BERTHOUD_2012_WT\LITTLE_T_-
BERTHOUD_2012_WT.xml

Start Date:
End Date:

Skew Option: Use Weighted Skew
Regional Skew: -0.02
Regional Skew MSE: 0.095

Plotting Position Type: Median

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---

----------------------
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----------------------
 Based on 36 events, 10 percent outlier test deviate K(N) = 2.639
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              0 low outlier(s) identified below test value of 5.2

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<< High Outlier Test >>
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 Based on 36 events, 10 percent outlier test deviate K(N) = 2.639
                      Computed high outlier test value = 17,907.7

        0 high outlier(s) identified above test value of 17,907.7
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--- Final Results ---

<< Plotting Positions >>

LITTLE T BERTHOUD 2012

Events Analyzed		Ordered Events			
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10 Aug 1930	3,620	2	1930	3,620	4.67
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09 Jul 1953	95	9	1947	1,360	23.90
29 Oct 1953	232	10	1994	1,260	26.65
19 Sep 1955	115	11	2005	651	29.40
18 Jun 1956	262	12	2003	467	32.14
09 May 1957	4,000	13	2004	358	34.89
08 May 1958	1,470	14	1996	348	37.64
22 May 1959	261	15	1997	331	40.38
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23 Apr 2009	67	33	1993	48	89.84
16 May 2010	270	34	2000	30	92.58
18 May 2011	186	35	2002	27	95.33
03 Jul 2012	104	36	2006	8	98.08

<< Skew Weighting >>

Based on 36 events, mean-square error of station skew =	0.141
Mean-square error of regional skew =	0.095

<< Frequency Curve >>
LITTLE T BERTHOUD 2012

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
25,232	36,665	0.2	81,946	11,079
15,919	21,119	0.5	46,659	7,464
10,880	13,574	1.0	29,346	5,377
7,175	8,473	2.0	17,708	3,748
3,839	4,260	5.0	8,338	2,167
2,200	2,349	10.0	4,301	1,319
1,120	1,159	20.0	1,958	711
306	306	50.0	472	199
83	81	80.0	131	48
42	39	90.0	70	22
24	22	95.0	43	11
8	7	99.0	17	3

<< Systematic Statistics >>
LITTLE T BERTHOUD 2012

Log Transform: FLOW, CFS		Number of Events	
Mean	2.485	Historic Events	0
Standard Dev	0.670	High Outliers	0
Station Skew	-0.005	Low Outliers	0
Regional Skew	-0.020	Zero Events	0
Weighted Skew	-0.014	Missing Events	0
Adopted Skew	-0.014	Systematic Events	36

--- End of Analytical Frequency Curve ---

Appendix D
Project Correspondence and Response to Review Comments

Meeting Minutes
Phase 1 Hydrology Response Letter [Response to CDOT Flood Hydrology Team Review Comments]
Phase 1 Hydrology Response Letter [Response to Public Review Comments]
Phase 2 Hydrologic Analysis – Response to CDOT Flood Hydrology Team Review Comments

Hydrology Weekly Meeting

ATTENDEES:

Keith Sheaffer
Steve Griffin
Steven Humphrey
Holly Linderholm
Cory Hooper
Heidi Schram
Will Carrier
Collin Haggerty
Bob Jarrett (PH)
John Hunt
Kevin Houck
Jim Wulliman
Derek Rapp

FROM: ICC OPS

DATE: January 9, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

Preliminary Findings

The Consultant team memos regarding the preliminary findings are on track and will be delivered tomorrow Jan. 10th. Kevin Houck will combine into one memo presenting the preliminary findings of the Hydrology Team.

Current Progress and Findings

The Consultant teams are progressing well and have identified their additional needs recorded below.

Some questions that resulted from the discussion on progress are below:

- Should URS combine the gauge data of the two gauges from the South Platte in order to have a larger data set? Is that practice justifiable?
- How to handle skew and outliers? Should be answered by John Hunt and Bob Jarrett
- The Barker reservoir used as a volume calibration?

Steve Griffin has an unpublished HEC-HMS model that can be used and referenced in the memo.

It was determined that Bob has confidence in NRCS numbers and the consultants can include them in their analysis where they do not have numbers from Jarrett.

Kevin Houck brought up the importance of how the memo is messaged in order to reduce misinterpretation.

There was discussion on multiple parameters of the models. Specifics will not be provided here unless the Consultant teams would like to include any specifics.

Additional Data Needs

The Lake Estes dam release information has been requested from the Bureau of Reclamation. We are currently waiting to hear if we need to request the information through a FOIA. Keith Sheaffer will also inquire about the information along with the information on the Button Rock Dam with Jason Smith.

URS cannot complete their evaluation until Bob Jarrett is able to obtain the S. Platte data.

Still need to get the remainder of the rainfall run off data from AWA.

CH2MHill still needs numbers for Boulder Creek near Orodell.

Bob wants authorization to capture the flow estimate that the Jacobs team requested from the site south of Drake. Until the data is collected we will report a range for the findings. At this time Jacobs findings are reporting the additive value.

Additional information needed from Bob Jarrett:

- Points downs stream of critical confluence in the next 4 to 5 days downstream Drake on Big Thompson
- Lyons site – full survey .5 mile length to get longer reach length
- John Hunt will provide LIDAR to Bob
- Little Thompson natural flow estimate to use in the calibration of the model
- Atkins has comparative pre and post aerials (can ICC get these also)
- Bob plans to go out to the S. Platte next week and get data from the field offices the week after that.
- Kevin Houck would like to know whether he should use Jarrett or NRCS (Yokum's) numbers.
- The team would like to get Jarrett's opinion on using gauge analysis.

Project Schedule

Next meeting: Jan.16th 1 to 3pm

We will look at the working Models (not calibrated) in order to get questions answered and consistencies addressed.

S. Platte Extended Scope

Steven Humphrey explained the desire of evaluating the entire South Platte watershed all the way to the Nebraska border that came out of the Staff Bridge Meeting. The Consultants have been asked to provide a draft scope, schedule and cost for the additional effort to complete this additional evaluation. Preliminary limits of the scope are from Platteville to the Nebraska border. The proposal provided by the consultants should be submitted by COB on Friday, January 17th.

Discussion about the additional request resulted in using gauge data from USGS for the additional analysis.

For the additional effort the IC is interested in of the South Platte from Platteville to Nebraska there was discussion on the limits and structure of scope to be in the proposal. It was decided that it will most likely be a gauge study. What is the use of this analysis? Implications of use will likely be used for hydrology design. Will need to limit the scope to just the S. Platte not including any tributaries and a gauge analysis and a tributary chase for calcs gauge analysis

Action Item List

Action Item	Due	By
GIS Map Exhibit to accompany the Memo Deliverable		ICC – Ops Desk
Share all reports with the three consultant teams.		ICC- Ops Desk

Hydrology Weekly Meeting

ATTENDEES:

Keith Sheaffer
Steve Griffin
Steven Humphrey (PH)
Holly Linderholm
Cory Hooper (PH)
Heidi Schram
Will Carrier
Mike Tilko
Bob Jarrett
Morgan Lynch
Kevin Houck
Jim Wulliman
Derek Rapp
Gina DeRosa
Jeff Wulliman (PH)
Spence Kelly (PH)

FROM: ICC OPS

DATE: January 16, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

Preliminary Findings

To finish up the preliminary findings memo these are the additional items needed:

- Bob to get the remaining East sites and visit the field offices to obtain data from the records
  - Ft. Lupton and Kersey are priority sites at US 85, US 34A and US 34D.
  - If Bob needs a survey team then he should contact Will Carrier to coordinate.
- Lake Estes Dam information is needed immediately, Holly to contact Kara at the Bureau of Reclamation to get an ETA of the information.

Kevin Houck and Bob Jarrett discussed presenting the results in a range or a specific number. It was decided that specific numbers will be reported with a note regarding the % uncertainty. Jim Wulliman added that since we reference the NRCS report within our data that we should know what their "fair" rating is so that we include their % uncertainty within ours.

Steve Griffin brought up the concern about timing of different audiences and how the memo is messaged. Right now gearing toward the upward audience and not the local agencies etc…. the dissemination of information should be a phased approach to ensure we keep our partners at the local agencies involved.

Kevin Houck would like to be able to present the preliminary findings to the Colorado Conservation Board on Tuesday the 28th and then to Water Congress that Thursday. Will the results be review and approved to be presented and does the team consider that appropriate timing of making the information public.

USGS is also analyzing the Storm Event, we should recognize their efforts and be aware of the timing of their release of information incase their findings are different than ours.

Bob and Kevin will get together about the areas in the memo where we are missing regulatory information and decide what to present in the Memo.

The team would like to have the memo and exhibits finalized by next Friday the 24th.

Current Progress and Findings

Models:

Bob Jarret asked that if the consultants can't get the model numbers close to his to let him know immediately so they can evaluate the model together. Still need the non-dam break/normal flow numbers from Bob Jarrett as well as confirmation of the Little Thompson River. Bob requested the max rainfall per hour in order to help with his confirmation.

As the teams calibrate their models there needs to be consistency as well as decisions on what the group is comfortable with and what/how they will defend their assumptions as they calibrate their models and find they have to use values outside the commonly accepted ranges.

It was decided to use the AMC 2 throughout the models and to not adjust it for the different time frames of the storm.

Need to be consistent through the analysis on all teams, URS will run a HEC HMS model also to confirm since they are currently using a gauge analysis for the S. Platte.

URS still needs the rainfall data from AWA.

Project Schedule

The next meeting will be held Thursday the 23rd from 1 to 3 pm the meeting after that will be Feb. 3rd or the 4th.

Action Item List

Action Item	Due	By
Get John Hunt's opinion on how to handle outliers and skew coefficients		Via email

Hydrology Weekly Meeting

ATTENDEES:

Keith Sheaffer
Steve Griffin
Steven Humphrey
Holly Linderholm
Heidi Schram
Will Carrier
John Hunt
Morgan Lynch
Kevin Houck
Jim Wulliman
Derek Rapp
Collin Haggerty (PH)
Cory Hooper (PH)

FROM: ICC OPS

DATE: January 23, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

Peak Flow Estimate Memo

The draft memo was reviewed and approved by the IC, Johnny Olson. The ICC is comfortable with Kevin Houck of CWCB presenting the findings to his Board as well as the Water Congress the week of Jan. 27th.

This team would like to look at the results of the USGS study. Bob Kimbrough can provide the information to the ICC. We need to make sure to communicate with Josh Kiel about getting this info.

CWCB does not have a preference on how the memo is distributed to other agencies. It was decided that an effective method of distribution could be through email.

Review Modeling Efforts

Continue to review progress of the consultant's models and discuss consistencies to the teams approach.

Specific details on the modeling:

St. Vrain – the sensitivity of different parameters was analyzed.

- The model is mainly dependent on the curve number.
    - The range is from the mid to low 40's up to 60. The resulting average curve number is 56 between C & D

The consultants would like to have Bob Jarrett review the outcomes of the models to see if he is comfortable with the output.

Ask Bob about the 14 cfs/square mile discharge

James creek – the team has not been able to calibrate the model to some of the discharge outliers.

The team decided to have the rainfall consistent within basins but can change between basins. With this approach it was suggested that an analysis be done if there are differences between basins.

Ayers will have the rainfall runoff match flood frequency model. Are these just for analysis or should the models be calibrated to them?

ICC Ops to contact Bureau of Reclamation about the additional Lake Estes Dam information needed. The policy of the dam storage and handling of attenuation play into the calibration of the model

The model of Lefthand does not match the peak flow numbers at the top or bottom but does match in the middle.

There was concern expressed that the emergency reconstruction of roadways effected the high water marks and consequently the calculations of peak flows. Bob Jarrett was not present at the meeting but it was discussed that his methods take those variables into consideration and account for them in numerous ways.

The consultant teams will continue to collaborate about the models through email. **The ICC Ops will forward on the additional information provided by CH2MHill.**

Data Needs

The team still needs to know what to do about the skew coefficients and handling of outliers. Ayers suggested doing a skew analysis to provide new regional skew coefficients for this analysis.

There was discussion about using Bulletin 17B, the current standard, or the possibility of using the new "expected moments" approach that may be accepted soon by FEMA. There may be an opportunity to use a combination of the two approaches. The new approach includes additional outlier threshold equations. Kevin Houck will check with FEMA to see if they are planning on accepting the Expected Moments approach.

Need additional natural flows from Bob Jarrett.

URS is running a CUHP model on Coal Creek Canyon, they will also run a HEC-HMS to compare. URS still needs S. Platte information and bridge plans.

Project Schedule

The next meeting is scheduled for Monday February 3rd from 1 to 3 pm at the ICC.

Decision Register

Decision	Made By
CWCB approved to present findings to the Board and Water Congress	ICC- Johnny Olson
Email distribution of the Memo	Hydrology Team
Keep rainfall consistent within the sub basins but can vary between basins	Hydrology Team

Action Item List

Action Item	Due	By
Forward the information from CH2MHill to team		ICC Ops

Hydrology Weekly Meeting

ATTENDEES:

Steve Griffin
Steven Humphrey
Holly Linderholm
Heidi Schram
Will Carrier
Gina DeRosa
John Hunt
Morgan Lynch
Doug Stewart
John Hunt
Kevin Houck
Jim Wulliman
Naren Tayal (PH)
Cory Hooper (PH)

FROM: ICC OPS

DATE: February 3, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

Peak Flow Estimate Memo

It seems that the memo was distributed in some fashion, now that it is public the team can provide to anyone who is asking for it. **ICC Ops will provide the most current version for the team to distribute.**

It is important to ensure that the local agencies understand that this is just the start of these efforts. CDOT will be collaborating with them throughout the rest of the process. This effort was completed to have a starting point for the future efforts that the Region and Local Agencies will complete in the future.

Lyons is particularly interested in the memo and the hydrology efforts, ICC Ops should ensure they received the memo and should start coordinating with them in these efforts.

The Drake numbers are a concern, there are no places that allow for attenuation so how is it possible that the flow is smaller downstream. Needs further analysis. At this time there is no way to explain these differences.

FEMA is starting to work on St. Vrain and Lefthand and looking at structure flow rates as they pertain to the Boulder County Structures (Apple Valley Road, Longmont Dam Road). There is work currently in these locations that CFL is performing. The results of FEMAs efforts will not impact the current work being completed. Naren Tayal from FEMA will attend these meetings in order to coordinate the two efforts.

Review Modeling Efforts

Jacobs

The best comparison was the discharge/max rainfall by square mile and the best fit curve number was 50.

Ran a comparison to some of the CH2MHill stuff and the results were pretty consistent.

The operation of the Lake Estes Dam is to pass the flows through so surface water doesn't rise or fall that much. It was asked if the dam operations waited until the water arrived in the reservoir or if they opened it up in anticipation of the higher flows.

So if the models won't match Jarrett's numbers should those values be abandoned?

All information related to this evaluation is in the email Jim Wulliman sent out.

CH2MHill

Orodell gauge and Bob Jarrett's peak flow estimate were very close, this time they calibrated the model to Jarrett's numbers.

They reduced the peaking coefficient to 0.1 and the generally accepted value is 0.4. If the parameter is changed back to 0.4 then the flows would raise but still not above the NOAA.

Barker Reservoir was completed in 1910 approx.10 years after data started being collected; so can be considered natural flows since the dam has been in place with similar operations for more than 50 years.

Is this how the team wants to treat the reservoir in this analysis? There needs to be a policy decision made.

An option would be to analyze when the peaks occurred and how that relates to the storage in the reservoir. Morgan will look into if the reservoir has any surface level or discharge information.

Andersons updated the 77 FIS model in 2012.

It was confirmed that the routing method being used is the Muskingum-Cunge.

Are we at the point on this that there needs to be a meeting with Anderson, Boulder and FEMA to discuss appropriate approach?

CH2MHill will re-run the model with the current parameters but with a full reservoir to further the analysis.

The email that Houck provided to the team expressed that there is presence of regulatory rates for the Little Thompson. However, the location that is referenced in the email is actually 10 miles downstream so the hydrology is different.

The Little Thompson model is calibrated to Bob Jarrett's natural flows only at this time.

Regional skew analysis efforts need to be completed in order to finish this analysis. John Hunt with Ayers will get costs to ICC Ops could come from remaining CH budget or ICC. The immediate priority is the new regional skew for mountain regions in order to apply to Orodell

URS

For Coal Creek Canyon the infiltration rate change is unjustifiable. In order to match flows had to increase the infiltration rate at first than decrease it later in the model to reach the design points.

What direction would CDOT want to go with this watershed? The URS recommendation would be to update the watershed to the NOAA Atlas 14.

Look at the Jefferson County recommendation/replacement memo and get the hydrology teams thoughts.

Deliverables

Provide recommendations of changing/updating the regulatory rate s to CWCB and CDOT to review by the end of Feb.

Format should follow closely to a FEMA submittal, CDOT and CWCB will coordinate on what they would like to see and get back to the Consultants.

Project Schedule

The next meeting is scheduled for Monday February 10th from 1 to 3 pm at the ICC.

Action Item List

Action Item	Due	By
Find out who F&A has distributed the memo to.		ICC Ops
Send a copy of the Phase I memo to Naren with FEMA		ICC Ops
URS needs S. Platte from Bob		Bob Jarrett
Find out if there are any videos at US 85.		Steve Griffin
Boulder Creek: Comparison with and without a full reservoir with the current parameters		CH2MHill
Big Thompson: compare sept. rainfall to NOAA rainfall, what affect it has, good with Lake Estes approach		Jacobs
St. Vrain: Updated flood frequency from Ayers (for Left hand also)		Jacobs
Coal Creek: Additional analysis just for fun, send data to Jacobs to add to the comparison analysis		URS
Regional skews (approach to be emailed and approved by CWCB and CDOT, hopefully have preliminary skews by Friday)		Ayers
Jacobs and CH2MHill to run aerial reduction		Jacobs and CH2Mhill
Format of recommendations on regulatory rates		CDOT and CWCB

Hydrology Weekly Meeting

ATTENDEES:

Steve Griffin	Doug Stewart
Steven Humphrey	John Hunt
Holly Linderholm	Kevin Houck
Heidi Schram	Jim Wulliman
Will Carrier (PH)	Naren Tayal
Gina DeRosa (PH)	Cory Hooper
John Hunt	Derek Rapp
James Hitchenson	Bob Jarrett (PH)
Morgan Lynch	Ed Tomlinson (PH)

FROM: ICC OPS

DATE: February 10, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

US 36 CFL Project

The meeting began with the request of the peak flow numbers this team would like CFL to use in the existing hydrology model to make sure there are no fatal flaws in the current design. 3,400cfs will be used for the Little Thompson and the Jacobs team will need until COB to provide the number to be used for the N. St. Vrain.

FEMA

FEMA requested shape files for the CDOT structures, these can be provided by Staff Bridge.

FEMA will be continuing to participate in these meetings to ensure that CDOT and FEMA are aware of the efforts by both agencies.

Feedback and Historical Information

Kevin Houck then asked to add an agenda item. He would like Bob Jarrett to comment on the current feedback on memo, and specifically speak to the questions regarding the variance of flows on Boulder Creek.

It was mentioned that the hydrologic evaluations done back in ‘76 and ‘90 caused diverging opinion’s especially when it was found that on average the insurance floodplain was 60% larger than the analyzed gage’s 100yr data.

The resulting discussion concluded with an emphasis that this team is a technical group and to stay committed to what we are doing here and there will be other teams who will consider the other ramifications of this effort.

Bob Jarrett suggests that in order to support the technical expertise behind the analysis the team should do the best they can to quantify the uncertainty in the analysis. There was an expressed interest in what feedback has been received on the phase I memo.

The main feedback has been the question of how the flows decrease from 30,000 cfs to 15,000 cfs on the Big Thompson downstream of Drake? Along that stretch there isn't much opportunity for attenuation so hard to explain the large drop in flows. Bob Jarrett indicated that this was a location where he had used an additive method since he was unable to find a good location to collect data, he will try again to get data from this area. The only place where there may be some attenuation would be around Cedar Cove but not enough to justify the significant drop in estimates peak flows.

This team needs to be prepared to justify their assumptions and estimates especially since the USGS isn't currently sharing any information and their analysis is scheduled to come out shortly.

With additional information the Big Thompson below Drake data may change after further analysis.

The debris bulking and dam failures could potentially account for some of the attenuation as well as sediment. Obtaining the timing of the wave through Glen Haven would be beneficial in the analysis of this area.

Bob Jarrett would like the information provided on the Lake Estes dam releases. Bob is interested to see if there is any evidence of dam failures along Fish creek, would like any aerials that CDOT or the Consultants teams may have of this area.

The St. Vrain information at Lyons and I-25 were also questioned. Steve Griffin collected data at I-25 and with his available resources along with his conservative method to keep the resulting cfs numbers high; it is difficult to provide a rebuttal without more information regarding the USGS' "significantly higher" findings.

Team Efforts

<u>Gauge Analysis:</u>

Ayers has begun to developed regional skew estimate have not yet finalized, An example from the analysis resulted in a weighted average by drainage area of 0.46 which would have been -0.2 from 17B Map. Using the new skew analysis the Boulder Creek watershed would result in "100-year flood" cfs to between the "100 and 50-year flood"

For the St. Vrain the 100-year would be lower without proper use of outliers. Outliers get a much lower weighting.

Ayers analysis is complete however, they will confirm that Bob Jarrett supports the results and will then finish up and finalize. The final analysis will be provided in a memo and be distributed to the team. URS will send Ayers their Coal Creek gage analysis to include in the current analysis.

<u>Jacobs Modeling:</u>

The team changed the modeling approach to look at an adjusted 24-hr period of only the max rainfall. The team expressed concern with how the curve number method oversimplifies the model for timing and infiltration.

The timing of this event is what is causing the issues in the modeling efforts. What is the right way to proceed and which approach is this team going to move forward with as the "correct" approach? It was discussed and decided to move forward with the curve number approach and raise back up with a logical approach to get back to gages. Take the 24-hr max range and compare to the NOAA. (Jacobs team will send an example: of this in an email to the team). A memo will be generated to document the approach, and test in an alternate modeling approach such as Green-Ampt Infiltration Modeling

Next steps:

Complete the gage analysis, finalize the flood frequency of the following locations:

a. Big Thompson at the mouth Canyon
b. Big Thompson in Loveland
c. Big T confluence with Buckhorn Creek
d. North Fork of the Big Thompson
e. St. Vrain below the confluence
f. Boulder Creek at Orodell

Regional analysis is not applicable to the S. Platte, Ayers only did the mountain region at this time but will complete the analysis of the plains region if asked and have a contractual vehicle to use to do the work.

Additional Needs

URS needs As-builts for S. Platte River Bridges.

Steve Griffin has reports that Bob Jarrett requested if he still wants them.

The teams will communicate by email until the next meeting and send along results of the continued analysis.

ICC/CWCB needs to provide the Consultants expectations of the deliverable for Phase II. The audience for this will be two-fold, technical and a brief easy to understand executive summary that the general public can understand.

It was decided the meeting with City of Boulder should be postponed until the hydrology efforts are to a point that they can contribute value to the meeting.

Project Schedule

The next meeting is scheduled for Tuesday, February 25th from 1 to 4 pm at the ICC.

Hydrology Weekly Meeting

ATTENDEES:

Steve Griffin
Steven Humphrey
Holly Linderholm
Heidi Schram
Will Carrier
Gina DeRosa
Kevin Houck
Jim Wulliman
Naren Tayal
Doug Stewart
Cory Hooper
Derek Rapp

FROM: ICC OPS

DATE: March 11, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

General

Concern about the USGS numbers that were presented at the CASFM event. Kevin Houck will schedule a meeting with Bob Jarrett and USGS to discuss the differing findings.

From the publicity recently it is even more important now that this team provides the same messaging of the information.

Steve Yokum would like the Big Thompson information, Steve Griffin to provide this to him.

For the stakeholder meetings regarding each of the watersheds, **the consultants will send their availability for the month of April and first week of May**. **The ICC will coordinate the meetings per watershed.** It is anticipated that these meetings will consist of a short presentation of our findings and model results in order to engage the coalitions in this effort as we now have a starting point.

Review of Reporting Efforts

CH2M Hill

It was confirmed that Boulder Creek will move forward with the 24hr storm with an AMC III for reporting instead of the 48hr storm.

A meeting with Boulder County and the City of Boulder will be scheduled hopefully before the 10^{th}. This meeting is critical in moving forward as this watershed information needs to be incorporated into the remaining watersheds. This team would like to know where the regulatory rates are coming from.

Jacobs

Drafts will be ready for the next meeting.

URS

Drafts will be ready and the **team will check into the rumored 2006 Army Corps of Engineering model of the S. Platte Watershed**.

Final Draft for the next Meeting (3/21)

The final drafts of the reports will be provided in an electronic form with the modeling on a CD/DVD as well as 5 hard copies.

After submission, there will be a designated review and comment time frame. **The ICC OPS will combine and distribute all comments for the consultants to address.**

Ayers' contribution to the reports is still needed, ICC Ops to request from John Hunt.

The description of the process on how the presented results were reached only needs to be expressed qualitatively within the text.

Additional Hydrologic Services

The local watershed meetings will be added to the additional services scope.

AWA rainfall information will be used and requested. URS needs to indicate if AWA will need additional budget or time on their contract and include that in their task order amendment. The consultants should provide AWA with the additional sites they will want for the extended scope and if they will be providing additional flood frequency analysis. Along with this it needs to confirmed or denied that Ayers should complete the regional skew analysis for the plains region and if there needs to be contractual modifications associated with that.

As the teams start these additional efforts the **ICC will check for available LiDAR.**

Schedule

The next meeting is scheduled for 8 AM to 11 AM on March 21st at the Downtown Denver Jacobs Office.

Action Item List

Action Item	Due	By
Availability to meet with coalitions for the month of April and first week of May		Consultant Teams
Coordinate the meetings per watershed.		ICC OPS
2006 Army Corps of Engineering model of the S. Platte Watershed.		URS
Combine and distribute all comments for the consultants to address.		ICC OPS
Ayers' contribution to the draft reports.		ICC OPS
Additional available LiDAR		ICC OPS

Hydrology Weekly Meeting

ATTENDEES:

Steve Griffin
Steven Humphrey
Holly Linderholm
Heidi Schram
Will Carrier
Gina DeRosa
Kevin Houck
Jim Wulliman
Naren Tayal
Doug Stewart
Derek Rapp
John Hunt (PH)

FROM: ICC OPS

DATE: March 21, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

General

The ICC leadership team currently does not share the team's perspective that teaming with the coalitions and bringing them into this effort now as valuable. This team agrees that it is worth an additional meeting with ICC leadership to convey the long term benefits of teaming with the local agencies and coalitions on the revised hydrology in the flood effected areas. **Steve Griffin, Kevin Houck and Steve Humphrey will meet with the ICC leadership the first week of April.**

The anticipated revisions to the Phase I memo can take place now. There will be a meeting with USGS regarding the discrepancy in reported peak flows on the St. Vrain Friday, March 28th at the Muller office in Lakewood.

The ICC DAR reports that are applicable to the studied watersheds will need a brief write up regarding the hydrology. **ICC OPS will send the template out to the consultants in order to facilitate the brief write up.**

Final Draft Review of Reporting Efforts

The consultant teams provided the draft reports in electronic and hard copy format.

Steve Griffin will provide a review comment template that will be used for the review process that will conclude Friday March 28th. At that time **ICC OPS will compile all the comments and distribute to the consultant teams.**

AWA Gridded Rainfall Data

Kevin Houck will follow up with Bill McCormick on what information is being requested.

Additional Hydrologic Services

Everything is in order to move forward with the amendments to the existing task order for the additional services. **Once URS receives the additional information from AWA they will need to resubmit their Task Order #2 Amendment.**

ICC Ops checked for new processed LiDAR of the extended scope areas but there hasn't been anything new posted. In order to request what is needed for this effort the **consultant teams should provide ICC Ops with a shape file of the limits of the additional study areas** so that **Ops can request specific tiles** in order to expedite the information transfer.

Schedule

Review comments should be in by Friday the 28th then will be combined and sent out to the Consultant teams.

The next meeting is scheduled for April 10th from 1-3 PM at the Flood Recovery Office, located at 1901 56th Ave., Greeley, CO.

Action Item List

Action Item	Due	By
FEMA acceptance of the 48-hr storm parameter on Boulder Creek	April 3rd AM	ICC OPS, CDOT & CWCB
DAR template for Hydrology summary		ICC OPS
Review Comments to the teams		ICC OPS
Revised Amendment to TO #2		URS
Shape files of extended study area limits		Consultant Teams
US34 Presentations to Jacobs team		ICC OPS
Consultants provide availability for April 21st through May 2nd for watershed meetings		Consultant Teams

COLORADO
Department of Transportation
Region 4

Flood Recovery Office
1901 56th Ave, Suite 110
Greeley, CO 80634

2013 Flood Hydrology Meeting

Attendees:

Steven Humphrey
Holly Linderholm
Kevin Houck
Bob Jarrett (PH)
Steve Griffin
Will Carrier (PH)
Ed Tomlinson
Cory Hooper
Morgan Lynch
Derek Rapp
Jim Wulliman
Heidi Schram
Naren Tayal
Doug Stewart (PH)

FROM: Flood Recovery Office

DATE: April 21, 2014

The following is a summary of the 2013 Flood Hydrology Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

1. Introductions and General

N/A

2. Incorporation of Review Comments

The consultant teams have addressed most of the comments provided. There was discussion of sharing between the teams the responses to the general comments to ensure consistency in the responses. At this time CH2MHill delivered their revised draft reports, Jacobs will delivered once their executive summary has been reviewed in the next 24 hrs, and URS will deliver their revised reports on Thursday at the FRO.

There was discussion around the type of Executive Summary the team wants for these reports. It was settled that the summaries would be more technical in nature as typical in these reports. Every summary will include the standard language that was provided by Steven Humphrey and then the teams will include the information necessary per watershed. It was noted that each summary should include the tables of "modeled peak flows compared to current regulatory discharges" and the "Estimate of Sept. 2013 peak discharge recurrence interval."

The consultant teams should deliver 5 hard copies of the revised draft reports.

3. Scheduling of Meetings with the Local Jurisdictions

The team would like to complete all the local meetings by May 16th 2014.

In general, the information from this team will not be provided prior to the meetings but will be communicated along with the teams' process and intent at the meeting. The general structure of the meeting will be introductions, purpose and intent by Steve Griffin, Steven Humphrey or Kevin Houck followed by the study and results from the consultant teams. The consultant teams should use a method of communication that works best to walk the audience through the results and process.

The desired order of the meetings is:

- Big Thompson – week of 4/28
- St. Vrain / Lefthand Creek - TBD
- Boulder Creek - TBD
- Coal Creek - TBD
- Little Thompson – TBD

Houck and Griffin will check their schedules for available times and Steven Humphrey will engage PIO to ensure messaging and coordination is completed to CDOT's expectations.

CDOT to check into the requirements of the Open Records Department as they relate to this effort and these draft reports as we intend to share all this information with our local partners.

4. Additional Hydrologic Services

The task orders for the additional services are moving forward. The consultant teams who have not already, need to provide which LiDAR tiles they will need for the additional study areas. **Ed Tomlinson will get Bob Jarrett's most recent list of peak flow estimate locations** so that the consultants can check that against their desired locations in order to keep the additional locations to be evaluated to the 20 sites in the scope.

Steven Humphrey will provide the HEC-RAS model from RESPEC to Steven Griffin and Bob Jarrett.

5. Project Schedule

The next meeting will be held at the Jacobs Denver Office on May 7th from 9 am – 11 am in the Echo Lake Conference Room.

6. Action Item List

Action Item	Due	By
PIO involvement in the Local meetings		Steven Humphrey
Availability for Local meetings		Kevin Houck, Steve Griffin, Jacobs Team
Open records requirements		Steven Humphrey
Bob Jarrett's latest locations and estimates list		Ed Tomlinson
Consultants cross check Bob Jarrett's lists with their wish list of locations, then provide remaining desired additional sites.		Consultant Teams
HEC-RAS model to Bob Jarrett and Steve Griffin		Steven Humphrey

COLORADO
Department of Transportation
Region 4

Flood Recovery Office
1901 56th Ave, Suite 110
Greeley, CO 80634

2013 Flood Hydrology Meeting

Attendees:

Steven Humphrey
Holly Linderholm
Kevin Houck
Naren Tayal
Steve Griffin
Will Carrier
Cory Hooper (PH)
Morgan Lynch
Derek Rapp
Jim Wulliman
Heidi Schram

FROM: Flood Recovery Office

DATE: May 7, 2014

The following is a summary of the 2013 Flood Hydrology Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

1. Introductions and General

N/A

2. Status of Phase 1 Hydrology Reports

The updated reports and models need to be posted to the CDOT FTP site. The consultant teams will be included in this distribution.

3. Little Thompson Meeting with DWR

Little Thompson DWR doesn't agree with the assumption of the dam failures and would like this team to remove the language from the reports. This team has agreed to remove the language but not change the model ect. The DWR report is anticipated to be public within 2 weeks and then the two teams can meet again.

Bob Jarret thinks he could get a new peak flow number of the main stem. This team would need very compelling evidence to change our numbers. So far our analysis still contains more data than the other analysis.

As we continue to encounter debate CDOT should strategize how they prefer to handle disagreements to our analysis in the future in order to be prepared.

4. I-25 Crossings

Steve Griffin will push on the email about the I-25 crossings. Will Carrier will coordinate with Bob Jarrett on what needs to be collected from the plains sites.

This team will move forward since the USGS is not ready for another meeting at this time. Additional analysis is warranted in this situation and there is potential to need additional survey data.

This team is in agreement that we will stick with our numbers at the St. Vrain.

5. Big Thompson Meeting

This meeting went very well and the presentation was excellent and delivered the intended amount of information. Any changes will come from the comments received from the meeting attendees.

6. St. Vrain, Left Hand and Boulder Creek Meeting

In order to prepare for this meeting the power point from the Big Thompson meeting will be distributed for the other watersheds to be adapted into the same format. The power points will be merged into one in order to reference more quickly during the Q&A section. The Q&A section will be held at the end for all watersheds. **CH2MHill will provide their slides to the Jacobs team to incorporate by Thursday the 8th.**

7. Additional Hydrologic Services

CWCB is being asked when the extended scope will be completed. At this time the team feels that Phase II will be complete in approx. 3 months after we collect all the data required.

8. Project Schedule

The next meeting will be held at the Flood Recovery Office in Greeley on May 28th from 9 am – 11 am.

9. Action Item List

Action Item	**Due**	**By**
Check on delivery of LOT 8 & 9 of the LiDAR		Steven Humphrey / Naren Tayal
Delivery of the Rainfall Data		Will Carrier / AWA
Data needed from plains as well as Bob Jarrett availability		Will Carrier

COLORADO
Department of Transportation
Region 4

Flood Recovery Office
1901 56th Ave, Suite 110
Greeley, CO 80634

2013 Flood Hydrology Meeting

Attendees:

Steven Humphrey
Holly Linderholm
Kevin Houck
Naren Tayal
Steve Griffin
Cory Hooper
Morgan Lynch
Derek Rapp
Jim Wulliman
Heidi Schram

FROM: Flood Recovery Office

DATE: May 28, 2014

The following is a summary of the 2013 Flood Hydrology Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

1. Introductions and General

Kevin Houck inquired about the timeline of this effort in order to get an idea of the flood plain timeline that Lyons has asked about. The effected communities are more interested in the schedule of the revised flood plain mapping since that affects them more.

Confirmed that the review schedule of the different watersheds so that the teams are aware of the dates:

St. Vrain by Friday, June 6th
Left Hand Creek by Wednesday, June 18th
Boulder Creek by Thursday, July 3rd

The main push from the communities is for the new flood plain mapping so they can move forward with projects and policy.

2. Boulder County Meeting (May 12th)

The meeting went well. Longmont is concerned with their current design projects along the watershed.

3. Scheduling of Coal Creek Meeting

We would like to schedule the Coal Creek meeting within the next couple weeks. This team along with Region 1 will confirm who should attend this meeting. The attendees list needs to be confirmed for this meeting.

Holly Linderholm will get the updated reports posted to the CDOT FTP site.

4. Executive Summary of South Platte River

Still need an executive summary for the South Platte.

5. Little Thompson

Little Thompson is in a holding pattern but have decided to leave out the language about the dam failures**.**

Additionally, the St. Vrain at I-25 numbers are also on hold until the USGS ready.

Kevin Houck will check in with DWR to see if their report is ready.

6. Big Thompson Review and Comments

Loveland comments were sent electronically to Steve Griffin, he will forward along to the teams. Hard copies were reviewed briefly during this meeting.

Derek Rapp will email John Hunt and AWA about the rainfall information needed to address some of the comments.

Objective to this effort not go deep into tributaries but provide to the locals in order to get where they want.

7. Additional Hydrologic Services

Will Carrier to provide Bob Jarrett's availability and peak flows, what is his staffs' availability. From previous communication it sounds like Bob will not be available. The other teams will start identify staff and times that they can get high water marks. Steve Griffin will provide the list of models that CDOT has. The other teams will also check into who can offer survey or other people for high water marks if griffin can't get them in this week. The data needs to be collected quickly and we need to identify options outside of Bob Jarrett.

It may work out better for the schedule is the consultants collect data for their own watersheds. This has not been decided but considered in order to address the limited timeframe. If this is decided then there would need to be contract amendments to each consultant's scope and budget.

Steven Humphrey will talk with Will Carrier when he is back from vacation and then communicate if URS will collect all the data or if the other Consultants will be needed.

All LiDAR has come in and all the consultants have indicated they have what they need for now.

We will provide response to B.T. comments and collect the additional data and then see if the USGS would like to meet again.

8. Project Schedule

The next meeting will be held at the Jacobs Office in Denver on June 11th, from 9 am – 11 am.

9. Action Item List

Action Item	Due	By
Post updated reports to the FTP Site		Holly Linderholm
DWR Little Thompson report ready		Kevin Houck
Rainfall data from AWA		Derek Rapp

Phase I Hydrology Response Letter

PREPARED FOR: Colorado Department of Transportation

COPY TO: Colorado Water Conservation Board

PREPARED BY: Morgan Lynch, PE, CFM

DATE: April 18, 2014

PROJECT NUMBER: 482330

General Comments

1. **Comment:** The following comment was appropriate for all six reports. Within the model calibration discussion, three concepts are being explained at the same time. One concept is the incorporation of actual September 2013 rainfall data into rainfall-runoff model. The second concept is the calibration of the outputs of that model to estimates of actual peak flows from September 2013 *(estimates usually made by Bob Jarrett)*. The third concept is the development via the calibrated model of various frequencies of rainfall hydrographs and resultant frequencies of peak flows, including those utilized by FEMA. The discussion could be edited to better clarify each of these three concepts. It appears that they represent the heart of this report and the other 5 reports, so it should be easy for the reader to distinguish the three concepts from each other and to follow how they tie together. The informed readers can then decide if they buy the reasoning *(i.e. "Does the set of assumptions modeled for the role of landslides make sense or not?")*
   Response: Additional language has been added to Section 2.4.1 to better define the models and subsequent sections.
2. **Comment:** This approach is dependent upon the fundamental assumption that the rainfall amounts used in these studies are accurate. One of the key problematic issues with rainfall-runoff modeling of actual storms is simulating with accurate rainfall depths. There are well-known issues with using NEXRAD estimates for rainfall depth estimates. These issues should be at least discussed in a brief literature review, so that readers are aware of the potential problems. These DRAFT reports do not introduce the potential sources of error in these values, leading readers to believe that they should be used without question.
   Response: Additional information on how the rainfall was analyzed has been included.
3. **Comment:** The NOAA precipitation depths have confidence intervals that express some of the expected uncertainty in the rainfall depths. This uncertainty was not addressed in the methods or mentioned as a caveat on the accuracy of the rainfall depth values used in the modeling.
   Response: Additional language has been added to Section 2.4.5 to better explain the inherent error with these depths.
4. **Comment:** A brief literature review should also be provided to discuss the appropriateness of the CN method for rainfall-runoff modeling in forested landscapes. In general, the selection of appropriate CN values in forested landscapes is problematic, though this may be less of a concern for large rain events (i.e. the Sept floods) and due to the calibration efforts implemented. Though these caveats should be discussed in each report.

Response: A discussion was included documenting why the curve number parameter was appropriate for calibration.

5. **Comment:** For reaches that have stream gages with a reasonable length of record, the frequency analysis of these gage data should be used to develop the recommended flow frequency. Actual data are preferred to the results of rainfall-runoff analyses. Is this planned but just unclear in the reports?
   Response: The flood frequency analysis was incorporated for comparison purposes only. For this analysis it was critical to be able to document flows in areas where gage information was not available.
6. **Comment:** I noticed that each report completed by separate agencies has a different way of phrasing the purpose of these studies. It seems to be, after reading them, that it would be best if each report had an identical statement of purpose and identification of the project sponsors. We could just copy the language verbatim from one report to the next.
   Response: Language has been standardized.

<u>Little Thompson</u>

1. **Comment:** I like that an Executive Summary has been placed at the beginning of the report. However, it is quite verbose for an Exec Summary and much of the information is more appropriately contained later in the report. I would recommend 1-2 paragraphs max. with the appropriate tables showing the new recommended regulatory numbers, 2013 flood peak estimate, and comparison with accepted hydrology.
   Response: The Executive Summary has been updated with standardized text provided by CDOT.
2. **Comment:** The site numbers won't hold any meaning for the reader, unless referred to a map.
   Response: Site numbers have been added to the figures.
3. **Comment:** I would recommend a different term instead of "Measured Peak". These discharges were reconstructed based on field observations, but were not actually "measured" using a flow meter or real-time river measurements during the flood event. The term might be confusing.
   Response: Has been updated to Observed Peak.
4. **Comment:** "…were then compared to concurrent alternative estimates of high-flow hydrology." This phrase is unclear.
   Response: This sentence has been rephrased.
5. **Comment:** Page 1-2 - Be careful to refer to "data" as a plural term.
   Response: Revised.
6. **Comment:** Page 1-2 - "The Little Thompson River has no record of flooding prior to September 2013." I would eliminate or rephrase. There are records of previous flooding on the Little Thompson.
   Response: Statement has been omitted.
7. **Comment:** There are slight differences in the predicted flows presented in Table 7 and Table 8.
   Response: These tables have been combined to omit confusion.
8. **Comment:** Dam Safety has just completed a hydrology analysis of the Little Thompson above 7 Bar Ranch using HEC-HMS, might be a useful for comparison.
   Response: This report is currently not available but will be considered in the next Phase of work.

9. **Comment:** In **Section 2.4.2**, is it possible to create a graphic of the rainfall over the 7 days simultaneously illustrating the ebbs and peaks of the streamflows? That way the reader understands more clearly why the choices about 24-hours vs. 7-days were made in the development of the calibrated model.
   Response: A graphic was added to the Appendix to show the rainfall event.
10. **Comment:** In **Section 2.4.5 – Rainfall Inputs subsection**, it would be helpful to have graphics of the actual rainfall distribution over the entire time and the 24-hour rainfall used in the model for the various sub-basins. The basic questions are, "*How well, in terms of rainfall input throughout the watershed, does the model represent what actually happened in September 2013?*" and "*Should we be persuaded or not?*" -
    Response: A graphic was added highlighting the 24-hour window used for the calibrated model.
11. **Comment:** In **Section 3.1**, it would be interesting to add one more table showing the actual 24-hour rainfall *(for the specific time period that was used to build the model)* at various points to the various frequencies of rainfall for each of those various points. That way, the conclusion later on in the report that the September 2013 peak flows in the Little Thompson were greater than a 500-year frequency flow, we can look at the estimated frequency of the rainfall that lead to those peak flows and decide if they make sense.
    Response: Table B-4 has been updated to show the rainfall for the September 2013 storm for each basin.
12. **Comment:** The conclusion in **Section 4.2** that the peak flows experienced in the study area in September 2013 were all greater than 500-year flows raises the question, *"So what happened on the Little Thompson downstream of Highway 36, all the way to Milliken, during that event?"* Although it is beyond the scope of this contract, the inclusion of a very short description of estimated peak flows, and, perhaps a brief discussion of some of the flood damages, in the more populated areas of the watershed downstream of Highway 36 would provide a useful context for this report's findings. A 500-year flood in a forested area with few inhabitants is too easily forgotten. Maybe CWCB can provide that information.
    Response: More on what happened downstream will be provided with the next phase of work. Some discussion on this item has been added to the conclusion.
13. **Comment:** The USGS collected 17 years of record at the Little Thompson River gaging station near Berthoud (06742000) before the station was discontinued in 1961. Apparently the station is now operated by the Colorado Division of Water Resources. If the total record at this station greatly exceeds 17 years, then frequency analyses at this gaging station could be used to evaluate the reasonableness of flood discharges in the upstream study reach.
    Response: This gage was referenced in the report. However, due the location relative to the study area was not utilized for this study but will be evaluated for the next phase of work.
14. **Comment:** The peak discharges for the September 2013 flood are referenced as being determined from "paleoflood methodology". Paleoflood methods use slackwater deposits, peak stage indicators and carbon dating of deposits for floods that occurred prior to systematic data collection. The peak discharges for September 2013 floods are based on recent high-water marks and channel geometry during the recent flood and should be referred to as indirect measurements (such as the slope-area method, critical depth computations, flow over the road computations, etc.).
    Response: More discussion was provided in Section 2.3 to document how the observed discharges were collected.
15. **Comment:** Evaluate if the large differences in 1-percent chance discharge between the Little Thompson River sub-watersheds and West Fork Little Thompson River sub-watersheds (shown

in Figure 1) are reasonable.

Response: More documentation was included on the differences in land use cover and soil types between the two watersheds. These differences lead us to conclude that the results are reasonable.

16. **Comment:** Determine if the 1-percent chance discharges for Little Thompson River are reasonable. The trend line through the 1-percent chance discharge is greater than 1 suggesting that the upstream 1-percent chance discharges may be too low relative to downstream areas.
    Response: The trendline for Little Thompson included a point that is downstream of the confluence at drainage area 43 sq. miles. This point was omitted from the trendline and this figure was added to the appendix.
17. **Comment:** The September 2013 was determined to be greater than a 500-year flood at all locations where the peak discharge of the September 2013 flood was available from indirect measurements. The study team should determine if this assessment is consistent with other nearby watersheds (e.g., Big Thompson River, St. Vrain, etc.) given the geographic distribution of rainfall for the September 2013 flood.
    Response: The Big Thompson generally had 100 year rainfall and 100 year discharge. We added 24 hour September 2013 precipitation totals to Table B-4 (Little Thompson River Rainfall Depths) to show the same correlation with 500 year rainfall and 500 year discharge.
18. **Comment:** Page 1-1: It is stated that LiDAR data includes changes in channel geometry. LiDAR does not penetrate water; in non low flow conditions and anything but riffle areas, LiDAR does not well define the channel bed. This has less significance for higher flows and it is not expected that this significantly impact results. This should simply be discussed as a dataset limitation.
    Response: This is correct and it was noted that the LiDAR documented horizontal changes.
19. **Comment:** At the calibration point, flow was reduced from the estimated peak flow of 12,300 cfs to 7800 cfs. How was this reduction performed? Details on how this lower value was obtained needs to be provided.
    Response: A clarification was provided in Section 2.3 documenting that the values were determined based on nearby sites and similar watersheds.

<u>Boulder Creek</u>

1. **Comment:** Section 2.4.2 under Calibration of Model to Entirety of September 2013 Event says that using the 7 day timeframe resulted in inappropriate model parameters and the methodology was rejected, but a summary of the model is still included in Appendix B. It seems confusing to leave those parameters in the report; the explanation was enough to show why it was rejected.
   Response: This information has been omitted from the reports.
2. **Comment:** Not sure if it is necessary to include the discussion of the calibration to the 48-hour storm. It seemed to work well, but was rejected because 48-hour is an unusual storm to report. Since the exercise didn't seem to affect the resulting model, maybe it can be left out of the report.
   Response: This information has been omitted from the reports.
3. **Comment:** Table 9 compares the predicted flows to other data sources, including the FIS discharges. I can't seem to match up the flows in Table 9 with the Summary of Discharges Table provided in the appendix. Were those FIS flows taken directly from the USACE model or report? An explanation of the data source and documentation should be included.
   Response: Additional documentation has been added to clarify the source of the table values.

4. **Comment:** In **Section 1.2**, "The watershed is generally bounded by…the City of Boulder to the ***east*** *(not the west)*…"
   Response: This has been updated.
5. **Comment:** In **Section 1.5.2**, is it possible to create a graphic of the rainfall over the 7 days simultaneously illustrating the ebbs and peaks of the streamflows? That way the reader understands more clearly why the choices about 24-hours vs. 7-days were made in the development of the calibrated model.
   Response: A graphic was added to the Appendix to show the rainfall event.
6. **Comment:** In **Section 2.4.2** the current final sentence reads, "*Therefore, this method was discarded in favor of calibration to the peak 24-hour event and use of the commonly accepted 24-hour design hyetograph.*" Having just read about how well the application of the peak 48-hour event worked, the reader is left wondering if the 24-hour event works well enough or not, or if it was used simply for convenience.
   Response: This discussion has been removed from the report per Comment 2.
7. **Comment:** In **Section 2.4.4** there is no mention of the 4-Mile Fire and its hydrologic impacts. I realize that complicates things, but wouldn't it be wise either to incorporate some representation of those impacts or to state explicitly that a conscious decision was made not to do so, for whatever reasons that decision might be made?
   Response: Additional discussion regarding the Four Mile burn area has been included in the report.
8. **Comment:** In **Section 2.4.5 – Rainfall Inputs subsection**, it would be helpful to have graphics of the actual rainfall distribution over the entire time and the 24-hour rainfall used in the model for the various sub-basins.
   Response: A graphic was added highlighting the 24-hour window used for the calibrated model.
9. **Comment:** In **Section 3.1**, it would be interesting to add one more table showing the actual 24-hour rainfall *(for the specific time period that was used to build the model)* at various points to the various frequencies of rainfall for each of those various points. That way, if the conclusion later on in the report is that the September 2013 peak flow was such and such frequency *(perhaps lower or higher than we might have anticipated)*, we can look at the estimated frequency of the rainfall that lead to that peak flow and decide if it makes sense.
   Response: Table B-4 has been updated to show the rainfall for the September 2013 storm for each basin.
10. **Comment:** In **Section 4.1** it would be helpful to provide a comparison of the proposed flows to the current design/regulatory flows. The reader should see immediately just how much of a change is recommended.
    Response: This information was provided in Table 9 and has been clarified with additional documentation in the report.
11. **Comment:** In **Section 4.2** there are some extremely sobering thoughts. I fear they may be lost. Is there a good way to give them a lot more punch? Maybe it could be done graphically???? There is a very big lesson here, but much of it could easily be lost.
    Response: Additional discussion was added to Section 4.2
12. **Comment:** Base flood estimate of Fourmile Creek near Orodell by the prediction model is approximately 55% of the effective estimate, which is based on an USGS 1977 analysis. Comparison of unit flow (cfs/sq mi.) with the other sites in Boulder Creek watershed indicates that the unit discharge at Fourmile Creek is 83% higher than the value of Middle Boulder Creek, which has the second highest unit discharge value. Impact of burned area in Fourmile Creek watershed is difficult to assess; however flood peaks of Sept 2013 event were estimated (measured) at several other locations in the watershed (Figure B-2), is it possible to use these estimates/measurements to further confirm the calibration?
    Response: Table 5 includes calibration points for Fourmile Creek.

13. **Comment:** Base flood of Boulder Creek at Orodell station estimated by the prediction model is 86% of the effective discharge. It is still a conservative estimate compared to the much lower estimate from gage frequency analysis. One of the reasons could be due to mixed population of peaks from rain-on-snow and storm events in the frequency analysis. Impact of Barker Reservoir could be another reason that modeled peak flow is on high side. Although the base flood estimate in this study is lower than the effective value, it is unlikely that the peak is underestimated.
    Response: Comment noted.
14. **Comment:** Gage 06725500, Middle Boulder Creek at Nederland has 87 year of record, with annual peak recorded from 1945 to 1995. Frequency curve from this station was not mentioned in the report. Is there any reason that the gage data are not suitable to use to calibrate the HMS model?
    Response: This gage has been added to the analysis and included in the report where applicable.
15. **Comment:** The source cited is from 1948, but contains data from 1969…? Double-check.
    Response: The source for the 1969 reference has been added.
16. **Comment:** May want to include additional background on how the Ayres stream gage analysis supplements the rainfall-runoff models.
    Response: Discussion was included and these points were used for comparison.
17. **Comment:** Table 5: The site numbers will not hold any significance for the reader unless shown on a map and referenced.
    Response: These locations were shown in the Appendix. A note has been added to direct the reader to the appendix.
18. **Comment:** Table 11: It is unclear here if the Annual Chance Peak Discharge numbers are the current regulatory numbers or a proposed set of numbers.
    Response: The headings and title of the table have been revised to help eliminate confusion.
19. **Comment:** See the comments for the Little Thompson for any text that was copied between the two reports.
    Response: Updated with the same responses for Little Thompson.

Phase I Hydrology Response Letter

PREPARED FOR: Tetra Tech – Little Thompson Watershed Coalition

COPY TO: Colorado Water Conservation Board, Colorado Department of Transportation

PREPARED BY: Morgan Lynch, PE, CFM

DATE: August 27, 2013

PROJECT NUMBER: 482330

General Comments

1. **Comment:** ES: Figure ES-1 is included in the Executive Summary, but I believe that the actual reference for it was missed. Providing that before referencing Table ES-1 may help the reader better understand where the discharge points in Table ES-1 are located.
   Response: A reference to Figure ES-1 was added to the text before referencing Table ES-1.
2. **Comment:** Section 1.2: there is some discussion of the overall Little Thompson watershed, but the description refers only to the study area portion of the watershed. For example: the report states that the watershed is located in Larimer and Boulder County. In reality, it is also located in Weld County too. I would recommend some small changes to clarify whether it is referring to the entire watershed or only the study area. Along those same lines in the same section, it states that there are no regulatory flow rates published for the river. To clarify, that statement is true only for the study area portion of the river.
   Response: Text was added to clarify that only the study portion of the Little Thompson watershed is predominately within Larimer County and that the entire Little Thompson River watershed extends approximately 47 miles until it reaches the Big Thompson River confluence.
3. **Comment:** Section 2.1.1: I recommend also possibly mentioning the results from CDOT's 2011 study for the same location as are being reported in the current study (i.e. data indicated in Table 6 Section 3.2).
   Response: Text was added that a discharge comparison is made in Section 3.2
4. **Comment:** Section 2.2: since this is the only source of actual streamflow data on the river, it might be worthwhile to examine what the gage results would predict at the same location as the model results using a drainage area ratio method. Not sure what the results would show, but it could possibly provide some additional validation information.
   Response: The USGS National Streamflow Statistics program provides a method to estimate flood frequency at an ungagged location using the historic record of a gage location provided that the ratio of drainage areas is between 0.5 to 1.5 (Reis, 2007). The ratio of the drainage area of the Little Thompson River study area to the drainage area of the downstream gage (Little Thompson River at Canyon Mouth Near Berthoud-LTCANYO) is 0.43 and is outside the recommended range. (Ries III, K.G., 2007, The national streamflow statistics program: A computer program for estimating

streamflow statistics for ungaged sites: U.S. Geological Survey Techniques and Methods 4-A6, 37 p.) This program will be used to provide an estimate for Phase II hydrology.

5. **Comment:** Section 2.3: I do not have a copy of Jarrett's 2013 publication on the paleoflood methodologies applied to the 2013 flood, and therefore I do not know the details of some of his assumptions. However, even though the use of the critical-depth methodology may be appropriate, I expect that this may be an item that draws some attention. A common argument would be that the flows could be approaching critical flow conditions (high Froude numbers), but critical depth might not actually be sustainable under these conditions. Therefore, if some additional language could be pulled from Jarrett 2013 that further supports the use of this method, that may help address future questions/comments about this report. Another approach could be to do a qualitative check by taking the estimated discharge, and assuming normal depth conditions, back calculate a Manning's n-value to assess reasonableness. A third approach could be to compare some of the paleoflood estimates from other basins where supporting gage data may exist
   Response: Bob Jarrett is in the process of documenting his work for the 2013 flood event. This would address any concerns with the use of the critical-depth methodology. This document will be referenced in the report. The information provided by Jarrett is the best available for estimating the peak discharges during the September 2013 storm event.
6. **Comment:** Section 3.1 (Figure B-14): To provide comparison and additional validation of the results, it would be good to add data from similarly sized, nearby basins (assuming similar characteristics) that have measured streamflow data from which 1-percent peak flows have been computed (if the data exists).
   Response: The 1-percent peak flows per drainage area for Boulder Creek have been added to Figure B-14 for comparison. This report has been referenced for the reader. The values are in a similar range as Little Thompson River and West Fork Little Thompson River from approximately 25 to 150 cfs /square mile for subbasins sized from approximately 0.5 to 5 square miles.

Phase 2 Little Thompson River Hydrologic Analysis – Response to CDOT Flood Hydrology Team Review Comments

PREPARED FOR: Colorado Department of Transportation

COPY TO: Colorado Water Conservation Board

PREPARED BY: CH2M HILL

DATE: March 27, 2015

PROJECT NUMBER: 494613

The Colorado Department of Transportation (CDOT) and the Colorado Water Conservation Board (CWCB) partnered with CH2M HILL to extend the Phase 1 hydrologic analysis of the Little Thompson River watershed above US Highway 36 to the confluence of the Little Thompson River and Big Thompson River. The results of this analysis were published in the Draft report "*Little Thompson River Hydrologic Analysis, Phase 2: Little Thompson River above Big Thompson River*", February 2015. This report was distributed to the CDOT Flood Hydrology Team for comments prior to public release. The comments received are captured below with responses to how the comments were addressed.

Colorado Water Conservation Board Review Comments:

1. **Comment:** The calibration process mainly focused on CNs and peaking coefficients. It appears that land cover descriptions were generally downgraded from fair to poor. Reality may be that antecedent rains in the days prior to the 2013 peak were the culprit rather than poor forest conditions, but it may be ok as a surrogate parameter. Are you comfortable with the calibration process?
   Response: *Yes, we are comfortable with the calibration process. Antecedent rainfall was considered as part of the calibration process by calculating the total depth of rainfall that occurred in the 5 days prior to the 24-hour analysis window (see Section 2.4.6 of the reports). Where antecedent rainfall depths exceeded 2.1 inches, Curve Numbers were assigned commensurate to Antecedent Moisture Condition III to account for antecedent rainfall conditions (per Novotny, 2002). Antecedent Moisture Condition III applied to the entirety of the Little Thompson watershed upstream of the Canyon Mouth, where most "forest" areas occur. Therefore, the "poor" condition of forest land use is "above and beyond" adjustments that were made to account for antecedent rainfall conditions. While "poor" conditions are generally associated with sparse tree cover, it also may be representative of historic land uses (e.g., timber harvest [Wohl, 2001]) and shallow depths to bedrock in the upper Little Thompson watershed.*
2. **Comment:** If time, money, and data were available, a verification run on a different known storm would be interesting.
   Response: *While verifying the hydrologic model through the analysis of a separate storm event would provide considerable justification for the hydrologic models, no such verification is currently planned or scoped.*

Colorado Department of Transportation Review Comments:

3. **Comment:** Under the References at the back of the report, for "URS 2015" - we should probably indicate that this was a memo/letter, not a full-blown report.
   Response: *The reference has been updated to reflect a memorandum.*

4. **Comment:** Section 2.1.4, a couple quick notes of clarification:
   a. -Regression eqns were only used as a reasonableness check for the HMS results. The primary analysis behind the hydrology study of 2011 was the HMS model.
   b. -Only one bridge was being studied: C-17-BN was replaced with C-17-FS. This is the frontage road bridge, which is downstream (not upstream) of the mainline I-25 lanes.

   Response: *The section has been reworded to clarify that regression equations were used as a check. Likewise the text has been updated to state that only one bridge was being studied.*
5. **Comment:** 3.2, consider revising slightly to clarify that the CDOT 2011 model was not calibrated *to the 2013 flood events*, whereas the current effort is. I would also add that the predictive model should be preferred over the CDOT model as the CDOT model is only interested in the peak flow at one location (I-25) whereas the current model is designed to predict accurately at a number of discrete locations.

   Response: *The text has been updated to reflect the suggestions in the comment.*
6. **Comment:** 4.0, first paragraph - same note as above. Also, please make a bit clearer that the CDOT 2011 model did not rely on regression equations (they are only a "check" against the HMS results), whereas the Larimer County results are based on regression as the primary analysis tool.

   Response: *The text has been updated to reflect the suggestions in the comment.*

<u>Review comments by Michael Baker International for the Federal Emergency Management Agency (FEMA):</u>

7. **Comment:** Page ES-2 – The NRCS Type II temporal distribution is used with NOAA Atlas 14 rainfall depths. Apparently in the area of Volume 8 of Atlas 14, the NRCS has not developed or published new Atlas 14 temporal distributions. In the east, NRCS has developed new Atlas 14 temporal distributions at least for the Volume 2 area (Ohio River Basin and neighboring states). An additional statement could be added to the report to indicate that the NRCS Type II temporal distribution is still being used in the Volume 8 area of Atlas 14 (Midwestern States).

   Response: *The text has been updated to reflect the suggestions in the comment.*
8. **Comment:** Page 2-4 – The use of station skew is the most reasonable approach because the flood data in the foothills area exhibit mixed distributions (rainfall and snowmelt floods). The previous regional skew analysis completed in Phase 1 did not include a mixed population analysis and therefore, should not have been used.

   Response: *Noted; following a comment received for the draft Phase 1 report that was released to the public, station skew was used in flood frequency analyses for both the final Phase 1 and current Phase 2 reports.*
9. **Comment:** Page 2-5 – The statement is made "Flow estimates were less certain where bridge structures were overtopped and the high water mark was limited to the top of the bridge." This seems to indicate the high water marks could not be determined in the approach section to the bridge. Is that the implication? If there is adequate fall through the bridge or from the upstream to downstream side of the bridge, accurate flow estimates can be made with width contraction and flow over the road indirect measurements.

   Response: *As the author of the* Estimated Peak Discharges – Phase 2 *memo documenting this analysis, URS provided the following response:*

   > "In areas where flow overtopped the road, high water marks were recorded upstream and downstream of the structure; beyond the contraction and expansion limits. Flow estimates were made based on these high water marks and top of bridge elevations were used in the approach sections. In some cases, such as Little Thompson at County Road 17 and N. 107th St., flow backed up against the upstream face of the bridge structure until a split flow

condition was created at an adjacent low point in the road and at the bridge. Flow estimates were made at these areas; however, due to the complexity of the flow paths and the possible attenuation at the split flows (or if the split even returned to the source flow), a relative uncertainty exists with these estimates."

10. **Comment:** Page 2-9 – Figure 4 is supposed to provide the various DARF curves but Figure 4 actually provides the Phase 2 AWA 10-day precipitation. The DARF curves are only given in the AWA report.
    Response: *The figures and associated references will be updated accordingly.*
11. **Comment:** Page 2-10 – The lag time for the Snyder unit hydrograph method is defined incorrectly. It should be defined as the time from the centroid of the hyetograph to the centroid of the runoff hydrograph, not to the peak of the hydrograph.
    Response: *The HEC-HMS technical reference defines the Snyder unit hydrograph method as the time from the centroid of the hyetograph to the peak of the hydrograph.*
12. **Comment:** Page 2-12 – A higher Snyder peaking coefficient was used for the Plains area than for the Mountains and Foothills area. One would expect the steeper sloped areas to have a higher peaking coefficient. What is the justification for a higher peaking coefficient in the flatter sloped sub-watersheds?
    Response: *The Snyder peaking coefficient was a calibration parameter with 0.6 in mountain areas as compared to 0.7 in plains areas. The plains have flatter slopes but are generally more developed as compared to the mountain areas.*
13. **Comment:** Page 3-1 – There is the statement "Little Thompson River Phase 2 Mountains and Plains have higher discharge than Little Thompson Phase 1 due to higher peaking coefficients and higher CNs due to increased urbanization." The reference is to Figure 13 that shows 1-percent chance discharges versus drainage area. The 1-percent chance discharges are, of course, higher in the Phase 2 study because of the large increase in drainage area. I think the implication is that the 1-percent chance discharges are higher even when considering the increased drainage area. The quoted statement should be clarified.
    Response: *This statement concerns Figure 14, not Figure 13. The reference has been updated and the statement has been moved to a location following the reference about Figure 14 - 1 Percent Annual Chance Peak Unit Discharge vs. Subbasin Area.*

<u>Department of Natural Resources Review Comments:</u>

14. **Comment:** Table ES-1: Modeled Discharge values should not be shown with this many significant figures later in the report (Table 9, 11, 12) and should account for the estimated percent differences shown in this table.
    Response: *The report will be revised to present modeled discharge values with three significant figures; percent differences will be updated accordingly.*
15. **Comment:** Figure ES-2: Flipping the x axis to show distance downstream of initial estimate makes more sense.
    Response: *Peak discharge profiles were developed to be consistent with Flood Profiles presented in FEMA Flood Insurance Studies; this includes the orientation of the X axis.*
16. **Comment:** Section 2.4.3: Using GIS software (basin delineation hydrology tools) along with the new LiDAR and NED datasets to delineate sub-basins would lead to more refined sub-basin boundaries, and estimates for basin characteristics.
    Response: *This comment is noted. It was decided that the additional detail of using GIS to delineate subbasins was not justified by the time required to "clean" the LiDAR dataset and manually revise subbasins where such tools did not accurately model subbasins east of the Front Range.*

17. **Comment:** Open water areas should not be excluded from CN calculations in order to remain as representative as possible.
    Response: *The open water areas have been added back to the CN calculations and the model and tables revised accordingly.*
18. **Comment:** Section 2.4.5: Subbasin Parameters: First paragraph, 3rd sentence should be revised to read: "The CN also considers saturation as the more saturated a soil becomes, the less interstitial space is available for the storage of rainfall, and thus a greater proportion of the rainfall will runoff." A saturated soil by definition can't store anymore water, and will have a CN of or close to 100.
    Response: *The sentence has been revised.*
19. **Comment:** Section 1.5 flood history mentions that 2013 flood did not occur during typical peak snowmelt months of May, June and July. Peak floods on the LT may be more commonly rain driven, vs snow driven. In any case, the first sentence caught my eye and may need to be revised, especially since rainfall runoff modeling was done for this study rather than evaluation of snowmelt peaks from the record.
    Response: *The text has been revised to not reference snowmelt months and a summary of the flood history of the Little Thompson River, per the FIS, has been added to the report.*
20. **Comment:** Suggest having DWR review section 2.1.5 if they haven't done so already.
    Response: *DWR has reviewed this report and provided comments.*
21. **Comment:** The bookmarks should have another TAB to list Figures separately. Hard to find initially as I wasn't exactly sure where it was located.
    Response: *The bookmarks have been updated.*
22. **Comment:** Page 23, provide description of acronyms, CN, AMC for consistency.
    Response: *This is provided in the introduction of the report on page VII.*
23. **Comment:** Seems the connectivity map should be provided before the land use and soils map, like it was in the Boulder report.
    Response: *The connectivity map has been relocated for consistency.*

Department of Water Resources Review Comments:

24. **Comment:** In reading the latest report the only comment I would like to make is with respect to the date of OUR report on the Little Thompson. If you could revise that to be "June 2015, revised Dec 2014", that would be consistent with us. We found and error in the AWA rainfall data in that they reported it as PST in the Excel spreadsheet, but in reality it was OTC. As a result we revised our analysis by shifting the rainfall back 6 hours. Our conclusions remained the same but the timing of the flows made a bit more sense compared to eyewitness accounts, so that was good. We provided an ERRATA sheet for that revision if you are interested in having your team take a look.
    Response: *The text and reference has been revised to reflect this.*

Phase 2 Little Thompson River Hydrologic Analysis – Response to CDOT Flood Hydrology Team Review Comments

PREPARED FOR: Colorado Department of Transportation

COPY TO: Colorado Water Conservation Board

PREPARED BY: CH2M HILL

DATE: June 10, 2015

PROJECT NUMBER: 494613

The Colorado Department of Transportation (CDOT) and the Colorado Water Conservation Board (CWCB) partnered with CH2M HILL to extend the Phase 1 hydrologic analysis of the Little Thompson River watershed above US Highway 36 to the confluence of the Little Thompson River and Big Thompson River. Following review by the Colorado Department of Transportation, the Colorado Department of Natural Resources (which includes CWCB), and the Federal Emergency Management Agency, the results of this analysis were published for stakeholder review in the Draft report "*Little Thompson River Hydrologic Analysis, Phase 2: Little Thompson River above Big Thompson River*", April 2015. This report was distributed to representatives of the Town of Berthoud, Boulder County, the Town of Johnstown, Larimer County, the Little Thompson Watershed Restoration Coalition, the Town of Milliken, and Weld County for review and comment prior to public release. The comments received are captured below with responses to how the comments were addressed.

General Comments Received at April 8, 2015 Community Presentation:

1. **Comment:** FEMA had delineated Dry Creek north of W County Road 8E, and the watershed boundary shown between the Little Thompson Watershed and Big Thompson Watershed did not support the FIRM delineation.
   Response: It is our understanding that the basin delineation concern between the Little Thompson and Big Thompson Watersheds originated due to the FEMA floodplain delineation along Dry Creek. Our team further examined the effective FIRM and discovered that near County Road 8E and the headwaters of Dry Creek, the floodplain delineation in question follows "Unnamed Stream" rather than Dry Creek that originates Southeast of County Road 8E. It is our opinion that the approximate floodplain for Dry Creek to the north of County Road 8E was based on USGS quad topography (which identifies Dry Creek on the north side of County Road 8E, thus opposite the FIRM) versus what is observed in the field. It is our interpretation and understanding that there are two conveyance systems at County Road 8E, Unnamed Stream conveying water to the north and Dry Creek conveying water to the south.

   Based on these findings it is our recommendation that the Big Thompson and Little Thompson watershed boundaries remain unchanged from what is presented in the hydrology reports.

Little Thompson Watershed Restoration Coalition Review Comments:

1. **Comment:** Section 2.1.5, Page 2.2 -- The final sentence of that section, highlighted in yellow below, is missing this important fact: Bill McCormick of the Colorado Dam Safety Division issued a revised report stating that the BEM dam failures timed exactly with X Bar 7 residents' direct observation of surges in that area in the early morning hours of September 13, 2013. The Dam Safety Division's initial report used an incorrect time zone and therefore did not make that connection. After

correcting the time zone to Mountain Time, they issued a revision to their report stating that each of the dam failure times matched with the surge times reported in X Bar 7 Ranch area. This is a fact that I request be included in the next and final version of this report. I would be happy to discuss this with you further, or get you a copy of that revised report. I am copying Bill McCormick here. The study determined that the dam failure occurred after the peak discharge caused by rainfall alone and did not cause incremental damage to the downstream channel.
Response: The statement has been revised to discuss the observed timing along Little Thompson, "The study was able to confirm eye witness accounts of the dam failures and timing of surge flow reported by X Bar 7 Ranch residents."

2. **Comment:** Section 2.4.6, Page 2.12, Table -- There is a footnote that the bridge overtopped at County Road 17 (the last item in the table) which it did. The bridge also overtopped and washed out at X Bar 7 Ranch (the first item listed in the table) and this is not noted. Is there a reason why? Again, this seems to me to be a fact that I request be included in the next and final version of this report.

TABLE 5
Little Thompson River Comparison of Modeled Discharges to Observed Discharges

HMS Node	Location	Observed Peak Discharge (cfs)	Modeled Peak Discharge (cfs)	% Difference	Runoff Volume (in)
LT-J6	Little Thompson River at X Bar 7 Ranch	15,731	14,300	-9%	4.54
LT-J10	Little Thompson River at South County Line Road	13,400	15,500	16%	3.23
LT-J12	Little Thompson River at Interstate 25	15,700	15,200	-3%	2.69
LT-J13	Little Thompson River at County Road 17	18,000[a]	14,900	-17%	2.45

[a] Bridge overtopped, (URS, 2015).

Response: The intent of this footnote was to summarize the level of confidence in this observed peak discharge as documented in the URS Memorandum. This footnote has been updated as well as the reference to the CDWR report for LT-J6 has been added. Information regarding the flooding that was observed is documented in Section 1.6.2.

Appendix E
September 2013 Peak Discharge Estimates Documentation

Estimated Peak Discharge – Phase 2 (URS, 2015)

URS

Technical Memorandum

Date: March 27, 2015

To: Steven Griffin, CDOT- Region 4
Kevin Houck, Colorado Water Conservation Board

From: William Carrier, P.E.

Subject: **ESTIMATED PEAK DISCHRGES – PHASE 2**

Introduction

In late summer 2013, the Colorado Front Range experienced an extensive rainstorm event spanning approximately ten days from September 9th to September 18th. The event generated widespread flooding as the long-duration storm saturated soils and increased runoff potential. Flooding resulted in substantial erosion, bank widening, and realigning of stream channels; transport of mud, rock and debris; failures of dams; landslides; damage to roads, bridges, utilities, and other public infrastructures; and flood impacts to many residential and commercial structures. Ten fatalities were attributed to the floods.

During and immediately following the rainstorm event, the Colorado Department of Transportation (CDOT) engaged in a massive flood response effort to protect the traveling public, rebuild damaged roadways and bridges to get critical travel corridors open again, and engage in assessments and analyses to guide longer term rebuilding efforts. As part of this effort, CDOT partnered with the Colorado Water Conservation Board (CWCB) to initiate hydrologic analyses in several key river systems impacted by the floods. The work was contracted to three consultant teams led by the following firms.

Boulder Creek, Little Thompson River	CH2M HILL
Big Thompson River, St. Vrain Creek, Lefthand Creek	Jacobs
Coal Creek, South Platte River	URS

The purpose of the analyses is to ascertain the approximate magnitude of the September flood event in key locations throughout the watershed and to prepare estimates of peak discharge that can serve to guide the design of permanent roadway and other infrastructure improvements along the impacted streams. These estimates of peak discharges for various return periods will be shared with local floodplain administrators for their consideration in revising or updating any current regulatory discharges.

The primary tasks of the hydrologic analyses include:

1. Estimate peak discharges that were believed to have occurred during the flood event at key locations along the study streams. Summarize these discharges along with estimates provided

by others in comparison to existing regulatory discharges. Document the approximate return period associated with the September flood event based on current regulatory discharges.

2. Prepare rainfall-runoff models of the study watersheds, input available rainfall data representing the September rainstorm, and calibrate results to provide correlation to estimated peak discharges.

3. Prepare updated flood frequency analyses using available gage data and incorporate the estimated peak discharges from the September event.

4. Use rainfall-runoff models to estimate predictive peak discharges for a number of return periods based on rainfall information published by the National Oceanic and Atmospheric Administration (NOAA) [NOAA Atlas 14, Volume 8, Updated 2013]. Compare results to updated flood frequency analyses and unit discharge information and calibrate as appropriate.

The hydrologic analyses were divided into two phases of work. Phase 1 focused on the mountainous areas in the upper portion of the watersheds, extending from the upper divides of the Big Thompson River, Little Thompson River, St. Vrain Creek, Lefthand Creek, Coal Creek, and Boulder Creek watersheds to the mouth of their respective canyons. The Phase 1 analyses have been documented in six reports with the following titles and dates.

1. Hydrologic Evaluation of the Big Thompson Watershed, August 2014
2. Little Thompson River Hydrologic Analysis Final Report, August 2014
3. Hydrologic Evaluation of the St. Vrain Watershed, August 2014
4. Hydrologic Evaluation of the Lefthand Creek Watershed, August 2014, revised December 2014
5. Coal Creek Hydrology Evaluation, August 2014
6. Boulder Creek Hydrologic Evaluation Final Report, August 2014

Copies of these Phase 1 reports can be downloaded from the CWCB website at the following link:

http://cwcb.state.co.us/water-management/flood/pages/2013floodresponse.aspx

Phase 2 of the hydrologic analyses focused on the plains region of the Big Thompson River, Boulder Creek, Little Thompson River, and St. Vrain Creek from the downstream limit of the Phase 1 studies at the mouth of the canyons to the downstream confluences of the watersheds with their respective receiving streams. The hydrologic analyses were contracted to two consultant teams led by the following firms:

Boulder Creek, Little Thompson River	CH2M HILL
Big Thompson River, St. Vrain Creek	Jacobs

Phase 2 hydrologic analyses for each of the watersheds included flows from the original Phase 1 watersheds, as appropriate: the downstream reach of the Big Thompson River was modeled to include flows from the Little Thompson River. Likewise, the downstream reach of St. Vrain Creek included flows from Lefthand Creek and Boulder Creek, with Boulder Creek in turn receiving flows from Coal Creek.

This Memorandum documents the Phase 2 the high water estimation at designated locations along the watersheds. The purpose of the analyses is to ascertain the approximate magnitude of the September flood event in key locations throughout the watersheds and to prepare estimates of peak discharge that can serve to guide the design of permanent roadway and other infrastructure improvements along the impacted streams.

Methodology

Collection of Data:

URS sent a survey team to each bridge location that was to be calibrated with the high flow. . At each location, the team surveyed at least four cross sections that included the main channel and the floodplain. The locations were surveyed even though pre-flood models existed as the flood changed the topography of the landscapes. A minimum of four cross sections is are needed to properly evaluate flows by the modeling program, HEC-RAS, in order to properly evaluate flows at each location; a cross section directly upstream and downstream of the bridge, a cross section located upstream of the bridge roughly the distance of the bridge opening upstream of the bridge (1:1 opening), and a downstream cross section located about four times the bridge opening downstream of the bridge (4:1 opening). These distances are based on approximate expansion and contraction zones as recommended by the HEC-RAS manual. Additional cross sections were surveyed at a location if deemed necessary due to increased complexity at a location such as drop structures near the bridge or bends in the area.

During the surveys, the team looked for evidence of high water marks from the September 2013 floods. This included debris in bushes, trees, bridges, or a high point on the ground. These points were recorded during the survey as high water marks. In order to help with calibration, the locations of these points were near the surveyed cross sections.

In addition, information about the bridges was collected in order to properly model each location. The information collected included, the width of the bridge, the length of the bridge opening, the number of piers, the width of the piers, the location of the piers, abutment information, the distance from the bottom of the channel to the low chord of the of the bridge (the bridge opening), the distance from the bottom of the bridge to top of the guard rails, and any other bridge information deemed necessary for use in the modeling software.

Processing of Data:

Once the data was collected, it was transformed from the local surveying system to the Northern Colorado State Plane System where each point in the cross section had a northing, an easting, and an elevation. The surveyed cross sections and high water marks were exported into ESRI shapefiles. These were then reviewed for accuracy and completeness in ArcMap. The data was converted into excel format and exported to HEC-RAS. The left side facing downstream of each cross section was initially set as Station 0. There were about 30 to 50 surveyed points for each cross section. The distances between the cross sections were used to assign the river station with the most downstream cross section arbitrarily labeled as station 1000.

In some cases, the field surveyed cross sections did not extend far enough to contain flows in the modeled cross section. This occurred in areas where the floodplain was extremely wide, exceeding 2,000 feet in width or in locations that were adjacent to rock and gravel quarry ponds. In these instances, the surveyed cross sectional data was supplemented with post flood LiDAR data. The LiDAR was used to create a digital elevation model (DEM) to extract elevation points.

<u>HEC-RAS Modeling:</u>

HEC-RAS, Version 4.1.0, is a 1-dimensional step backwater river analysis system created by the United States Army Corps of Engineers. It was selected due to wide spread use, prominent use in previous models at the same locations, and the many tools for bridge modeling that exist in this software.

Many of the locations had existing HEC-RAS (or HEC-2) models from when the bridges were designed and constructed and were provided by CDOT. In these cases, the bridge data was already available and stations were adjusted to reflect these models. For all locations, the new surveyed cross sections were added into the HEC-RAS model. The bridge data was also verified with the field survey data. For locations without existing models, the bridge data recorded in the field was included as well.

The Manning's "n" values in the model were selected based upon field conditions and existing model values. In order to test the sensitivity of the flow in relation to the Manning's value, the Manning's value was increased and decreased in at least two (2) models on each stream, Big Thompson, Little Thompson, and St. Vrain. Results of this sensitivity analysis are summarized below.

The contraction and expansion coefficients were selected based on recommendations used in the HEC-RAS manual. To properly model bridges, ineffective areas were added to the upstream and downstream of bridges to account for the flow contraction and expansion at the bridge openings. For upstream of the bridge, there was a 1:1 contraction ratio meaning at the bridge the ineffective area would extend at a 45 degree angle to the bridge. Downstream of the bridge, a 3:1 expansion ratio was modeled. Generally, the ineffective areas extend for the two cross sections upstream and downstream of the river. In some cases, they were extended into additional cross sections depending on the width of the floodplain and cross section versus the bridge opening.

The bridges were modeled using the Energy Equation with over topping weir coefficient of 2.6. The energy Equation was selected as the High Flow Bridge Modeling Method. This method was selected as the majority of the bridges modeled were not overtopped, and as a result pressure and/or weir flow was not present.

Once the model parameters were complete, the estimated flow at each location was adjusted until the model water surface elevation approached the high water marks. In the case where the high water marks couldn't be matched well with the all of the cross sections, emphasis was placed on the cross section just downstream or upstream of the bridge The downstream locations provided a better representation of free flow during the flood event as compared to the upstream locations that could have potentially had backups and created artificially high debris marks.

For each model, subcritical and subcritical flow regimes were run and each calibrated to the surveyed high water mark.

Results

Most of the sites had consistent correlation between the field observations and the results of the model at each location. Generally, the calculated water surface elevations were within 0.1 feet of the observed high water elevation with a few exceptions. Subcritical flow modeling produced a more consistent match of water surface values. This could be attributed to the mild slopes of the channel in the lower reaches located in the plains and the wide floodplains. In some locations such as at Coal and Rock Creek, running the model as supercritical resulted in more accurate results as both of these tributaries have steeper slopes and more incised channels.

For some sites, the HEC-RAS model was unable to match the field observations. This was mainly due to overtopping of the bridge or nearby road. The high water survey occurred months after the floods and in some cases emergency repairs had been performed making it difficult to locate high water locations. There were also few photos from which to estimate the flood widths. In areas where flow overtopped the road, high water marks were recorded upstream and downstream of the structure; beyond the contraction and expansion limits. Flow estimates were made based on these high water marks and top of bridge elevations were used in the approach sections. In some cases, such as Little Thompson at County Road 17 and N. 107th St., flow backed up against the upstream face of the bridge structure until a split flow condition was created at an adjacent low point in the road and at the bridge. Flow estimates were made at these areas; however, due to the complexity of the flow paths and the possible attenuation at the split flows (or if the split even returned to the source flow), a relative uncertainty exists with these estimates.

The models had little sensitivity to changes in the Manning's n values. For the models tested, a 0.01 change in the Manning's value resulted in variance of less than 5% in the modeled flows. This held true regardless of the magnitude of the flows from the smaller flows 1,500 cfs to larger flows exceeding 20,000 cfs.

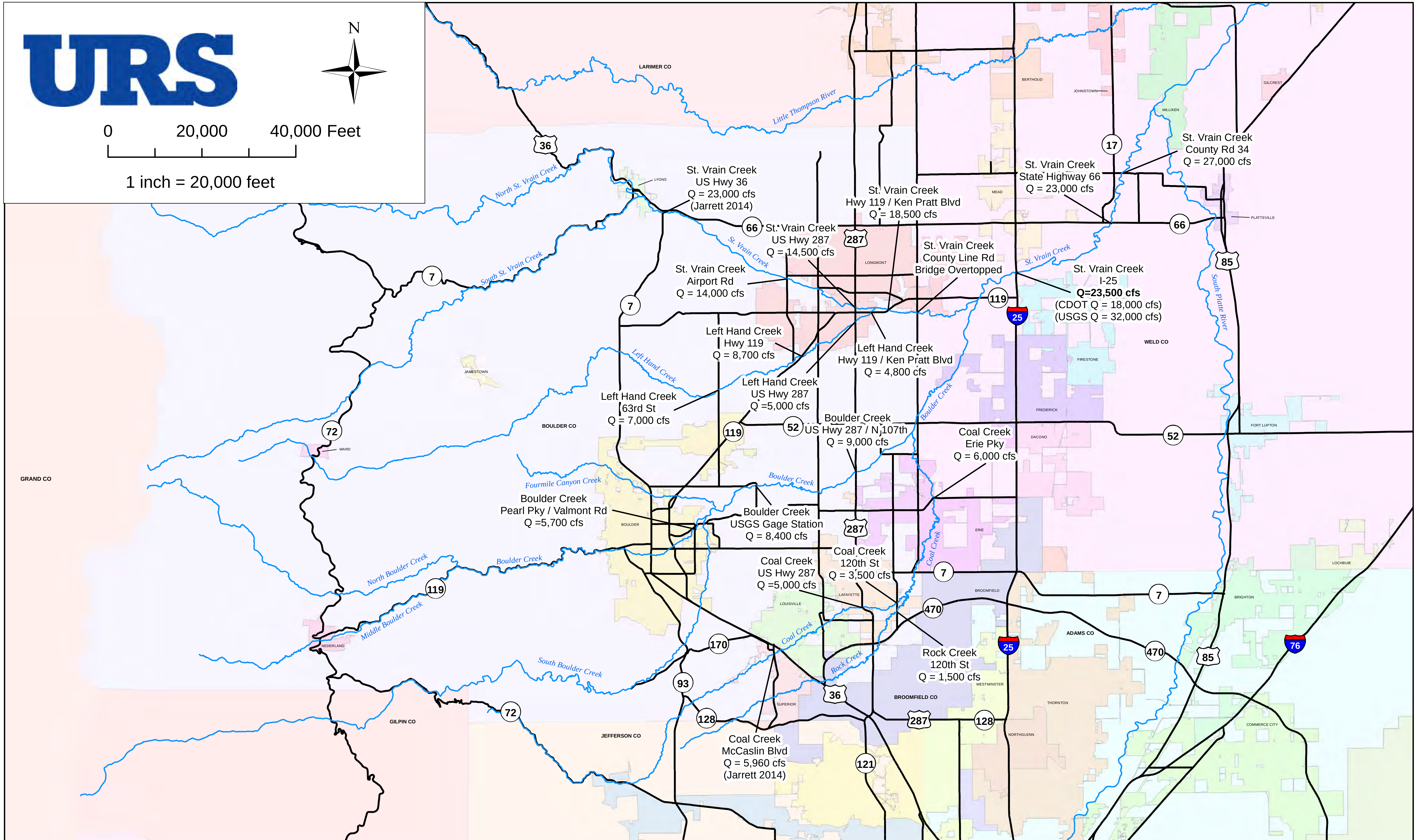
The following table summarizes the discharge estimates, the high water marks, and the calculated water surface elevation, and comments regarding each location.

Summary of Estimated Discharges for September 2013

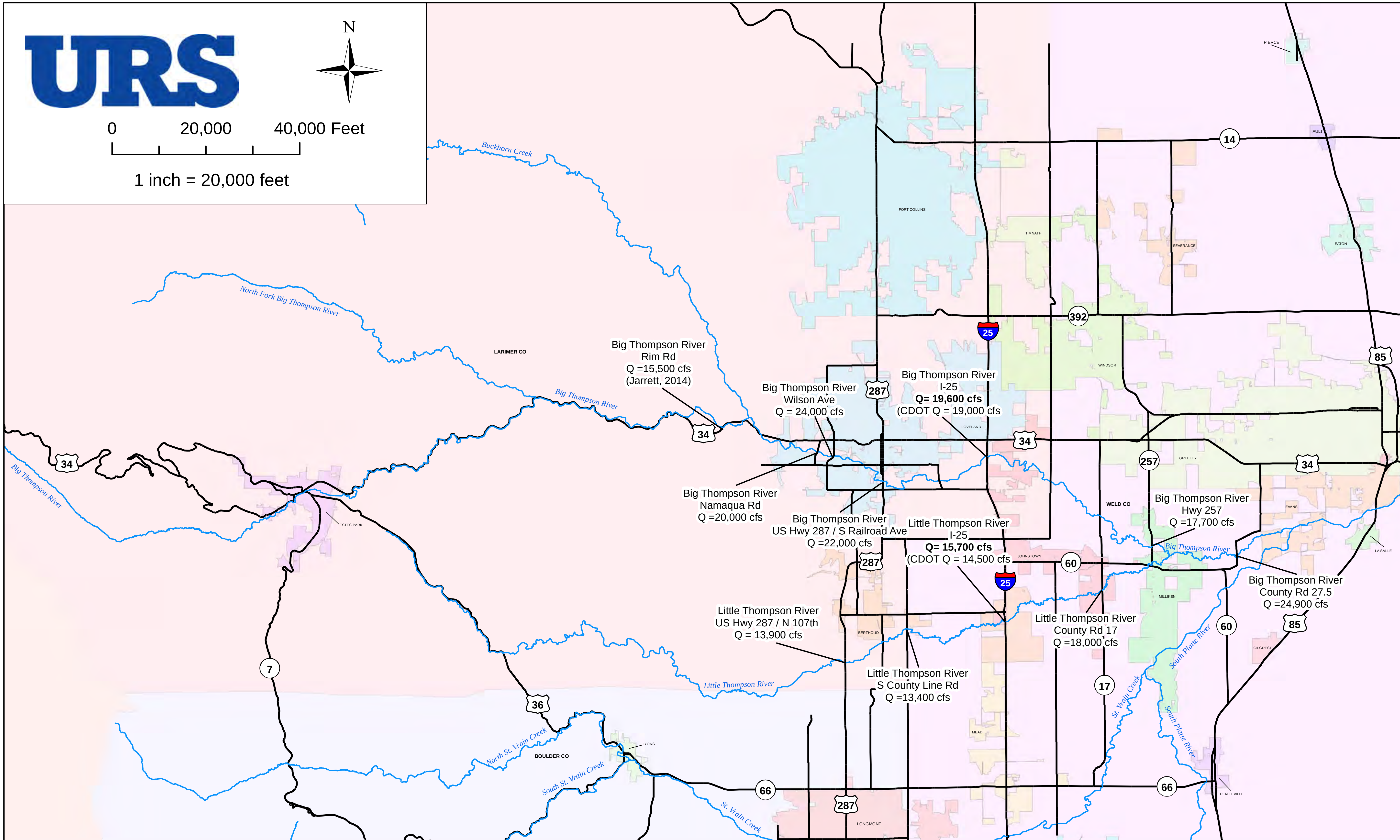
Location			Discharge (cfs)	High Water Elevation (ft) NAVD 88	Water Surface Elevation (ft) NAVD 88	Comments
Little Thompson						
1	At N 107th Crossing (287)		13,900	4998.73	4998.74	
2	At S County Line Road Crossing	FEMA Point	13,400	4938.17	4938.58	
3	At I-25 Crossing		15,700	4857.11	4857.12	
4	At County Road 17 Crossing		18,000			Bridge overtopped/unreliable
Big Thompson						
1	Namaqua Road *		20,000	5002.42	5002.04	Area very hard to calibrate given ponds and overtopping.
2	Wilson Avenue*		24,000	4990.07	4990.26	Flows rates based on downstream ponds being full.
3	S. Railroad Avenue or Hwy 287	FIS Location	22,000	4933.3	4933.3	
4	I-25	FIS Location	19,600	4849.91	4849.97	3,000 cfs overtopped I-25 north of cross section.
5	County Line Road (Larimer-Weld)	FIS Location	8,800	4813.44	4813.47	Unreliable results. Bridge was overtopped.
6	U/S of Confl with Little Thompson (Hwy 257, CR 21)		17,700	4746.7	4746.73	
7	D/S of Confl with Little Thompson (CR 25)					No Model
8	County Road 27.5		24,900	4701.93	4701.93	
Boulder Creek						
1	Boulder Creek at Pearl Pky / Valmont Road	FEMA Point	5,700	5200.51	5200.49	4300 cfs at subcritical flows
2	Boulder Creek at N 107 Street/Boulder 287		9,000	5016.35	5016.38	
3	Coal Creek at Bridge Street (N of Erie)	FEMA Point				No Model
4	Coal at Erie		6,000	5021.267	5021.66	
5	Coal Creek at Highway 287		5,000	5206.66	5206.65	Possible attenuation /blowouts DS of structure
6	Coal Creek at the Confluence with Rock Creek	FEMA Point				No Model
7	Rock Creek at S 120th Street	FEMA Point	1,500	5149.65	5149.8	
8	Coal Creek At 120th		3,500	5140.59	5140.5	
Lefthand						
1	N. 63rd St.		7,000	5159.71	5159.7	
2	Diagonal Highway (Hwy 119 near Airport Road)		8,700	5019.09	5019.07	Model does not account for influence of railroad bridge.
3	Hwy 287 (Main Street)		5,000	4950.17	4950.7	
4	U/S of Confl with St. Vrain (Hwy 119/Ken Pratt Blvd.)	FIS Location	4,800	4937.36	4937.36	
St. Vrain						
1	85th Street/Airport Road	FIS Location	14,000	5027.85	5027.77	No Bridge in HEC-RAS model.
2	U/S of Confluence w/ Lefthand Creek (US Hwy 287)		14,500	4948.87	4949.37	
3	D/S of Confl. w/ Lefthand Creek and UIS of Confl w/ Boulder Creek (Hwy 119/Ken Pratt Blvd)		18,500	4924.81	4924.29	
4	County Line Road (Boulder-Weld)	FIS Location				Not a good point-road washed out around the bridge, downstream work completed.
5	D/S of Confl. w/ Boulder Creek (1-25)		23,500	4834.93	4834.73	
6	State Hwy 66 (CR 30)		23,000	4791.11	4791.13	
7	Country Road 34		27,000	4770.88	4770.88	

*Recommended flow value of 22,000 cfs.

Peak Flow Discharge for the September 2013 Floods - St. Vrain Creek Drainage Area



Peak Flow Discharge for the Spetember 2013 Floods - Big Thompson River Drainage Area



As previously mentioned, for most locations high water elevation observed in the field correlated well with the calculated water surface elevations in the models. There were a few exceptions. A summary of the model results for each stream reach are included below.

Little Thompson River

1. North 107th Crossing (US Hwy 287) - The cross section directly upstream of the bridge was calibrated to the high water mark. The calculated water surface for the downstream cross sections did not match well with the surveyed high water marks. This was due to the bridge overtopping and may have resulted in a split flow into the adjacent farmland.
2. S County Line Road – No issues. The model correlated very well.
3. I-25-For this location there were three bridges modeled, North I-25, South I-25 and the frontage road to the east. This location gave good results which allowed it to be calibrated at three different high water marks. Both cross sections on either side of the frontage road were calibrated and the most upstream cross section was calibrated.
4. County Road 17- Flow backed up against the upstream face of the bridge structure until a split flow condition was created at an adjacent low point in the road and at the bridge. Flow estimate were made at these areathis site; however, due to the complexity of the flow paths and the possible attenuation at the split flows (or if the split even returned to the source flow), relative uncertainty exists with this estimate.

Big Thompson River

The Namaqua Road and Wilson Avenue locations were very difficult to determine flow rates. The locations have numerous quarry ponds directly upstream and downstream of each location. When the sections were modeled, the water surface elevation was assumed to be 1 foot below the pond embankment. Because these ponds occupy approximately 1,500 feet of the floodplain, the actual water surface elevation plays a large role in the flow calculation. A 1 foot increase or decrease in the water surface of the ponds varies the flow by approximately 1,000 cfs. In addition, flows jumped the northern bank upstream of the Namaqua Road crossing.

1. Namaqua Road – Flows estimated at 20,000 cfs but, it is recommended that flows be averaged with Wilson Avenue crossing. Suggested value of 22,000cfs.
2. Wilson Avenue – See Namaqua Road note.
3. Hwy 287 – Model correlated well to high water marks.
4. I-25- This location has three different bridges, North I-25, South I-25 and the frontage road. For modeling purposes, the cross section between the two I-25 bridges was calibrated to the high water location. The water surface elevation was 4849.9’. The flow value includes 3,000 cfs that overtopped I-25 north of the cross section road.

5. County Line Road (Larimer-Weld) - This didn't yield reliable results as it overtopped the road.

6. Hwy 257-This location was calibrated to the section just upstream of the bridge to a water surface elevation of 4746.73'.

7. Downstream confluence with Little Thompson – No model developed.

8. County Road 27.5 – Model match field observations.

The cross sections at Namaqua Road, Wilson Avenue and US Hwy 287 were supplemented with LiDAR data to fully contain the flow and be calibrated correctly.

Boulder Creek:

1. Boulder Creek at Pearl Parkway and Valmont Road - This section was calibrated to the upstream section.

2. Boulder Creek at 287 - This section was calibrated to just downstream of the bridge and has an extra cross section both down and upstream.

Rock and Coal Creek:

3. Coal Creek at Bridge Street (N of Erie) – No Model developed due to limited access.

4. Coal Creek at Erie - At this location three bridges were modeled: one for a pedestrian bridge before the road, one for the road, and one for a railroad bridge downstream. It was calibrated to the cross section just before the road bridge. Reliability of the estimated flow is questionable due to the complexity of the model.

5. Coal Creek at Highway 287- Here there was some attenuation possible as well as blowouts of downstream of the structure.

6. Coal Creek at the Confluence with Rock Creek – No Model developed as high water elevation could no e determined.

7. Rock Creek at 120th Street - An additional cross section was modeled upstream of the bridge. The calibration point here is the cross section just downstream of the bridge.

8. Coal Creek at 120th- An additional cross section was modeled upstream of the bridge. The calibration point here is the cross section just downstream of the bridge.

The calibration of the confluence of Coal Creek and Rock Creek was not modeled as the high water mark was difficult to establish.

Lefthand Creek:

1. N. 63rd St. - This location was calibrated to the most downstream cross section. The two upstream cross sections were close to the surveyed high water marks.

2. Diagonal Highway (Hwy 119 near Airport Road) - Two separate bridges were modeled for this location. The most downstream cross section was added using LiDAR data. The cross section between the two bridges was the calibration point.

3. Hwy 287- The cross section just downstream at this location was used for the calibration point.

4. Hwy 119/ Ken Pratt Blvd- This model included two additional cross sections upstream of the bridge.

St. Vrain Creek

1. Hwy 287/Airport Road – Model correlated well to the observed high water marks. However, bridge information was not available and therefore not included in the HEC-RAS model. There were no bridge as-built plans available and at the time of the survey, the creek flows were too great to safely perform a bridge survey.

2. U/S of Confluence w/ Lefthand Creek (US Hwy 287) – Model matched survey data.

3. Hwy 119/Ken Pratt Blvd. - This section had two extra cross sections upstream and downstream to help increase the accuracy of the model. The upstream cross section and the cross section just downstream of the bridge were used as calibration points.

4. County Line Road (Boulder-Weld) - This location was not modeled. The road on both sides of the bridge had washed away and there had been downstream work completed.

5. I-25 - In this location, it was modeled as two bridges. The drop structure downstream of the bridges was also added. The structure was not in the original model. The model was calibrated to the upstream face of the upstream bridge.

6. State Highway 66 (CR33) – model match field observations. Te bridge was replaced as part of the emergency repairs.

7. County Road 34 – No Issues.

REFERENCES

US Army Corps of Engineers (USACE) HEC-RAS River Analysis System, Ver. 4.1.0, January 2010.

CDOT hydraulic models

Appendix A
HEC-RAS Results

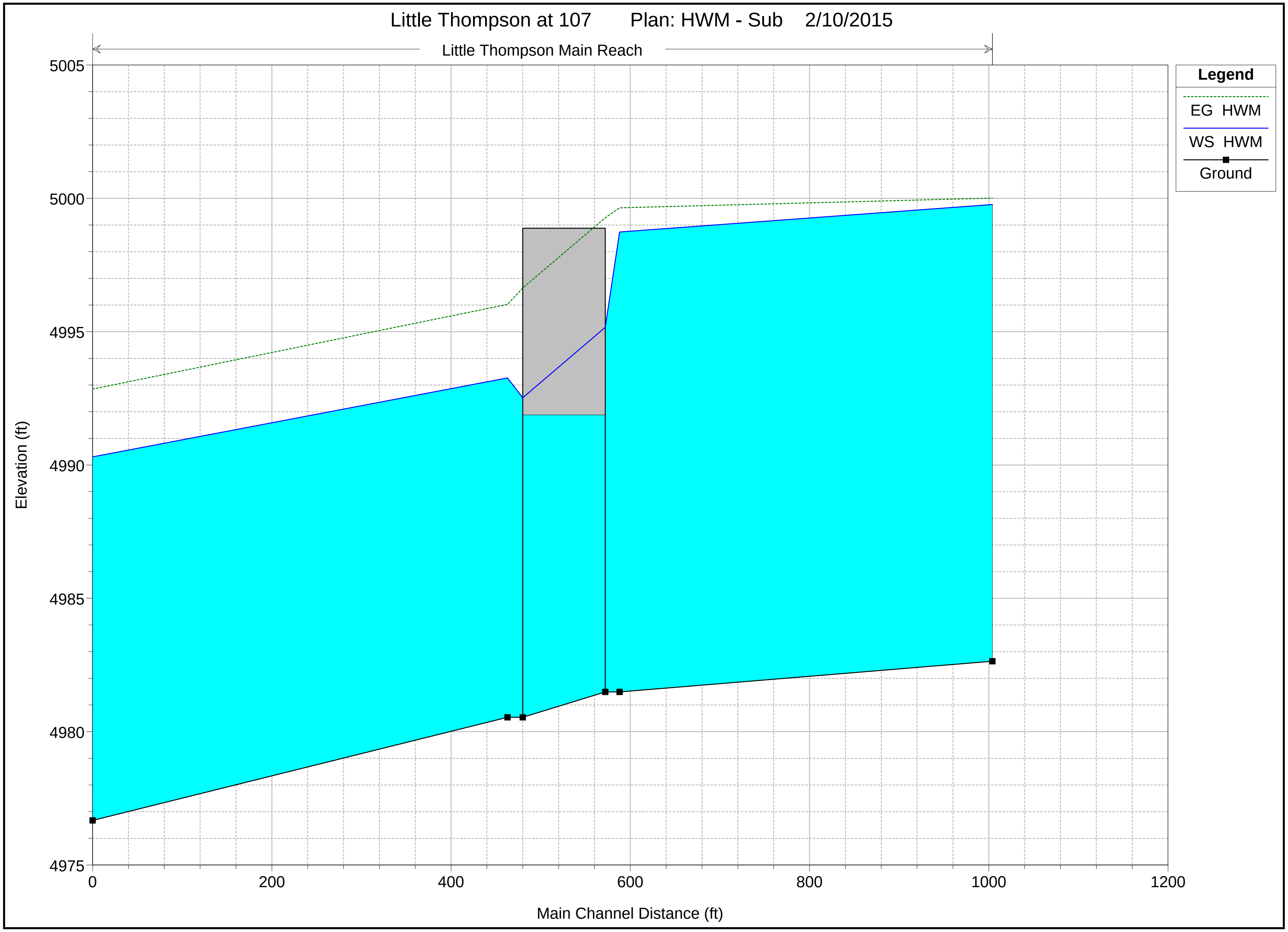
Little Thompson

HEC-RAS Results

Little Thompson at 107th

HEC-RAS Plan: HWM - Sub   River: Little Thompson   Reach: Main Reach   Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main Reach	1104	HWM	13900.00	4982.64	4999.77	4992.93	5000.01	0.000459	4.65	3771.28	337.29	0.22
Main Reach	688	HWM	13900.00	4981.49	4998.74	4992.27	4999.65	0.001247	8.07	1892.70	224.74	0.36
Main Reach	625		Bridge									
Main Reach	563	HWM	13900.00	4980.54	4993.26	4992.22	4996.02	0.006745	13.63	1086.86	158.47	0.77
Main Reach	100	HWM	13900.00	4976.67	4990.30	4990.30	4992.85	0.006698	14.99	1316.99	224.29	0.76

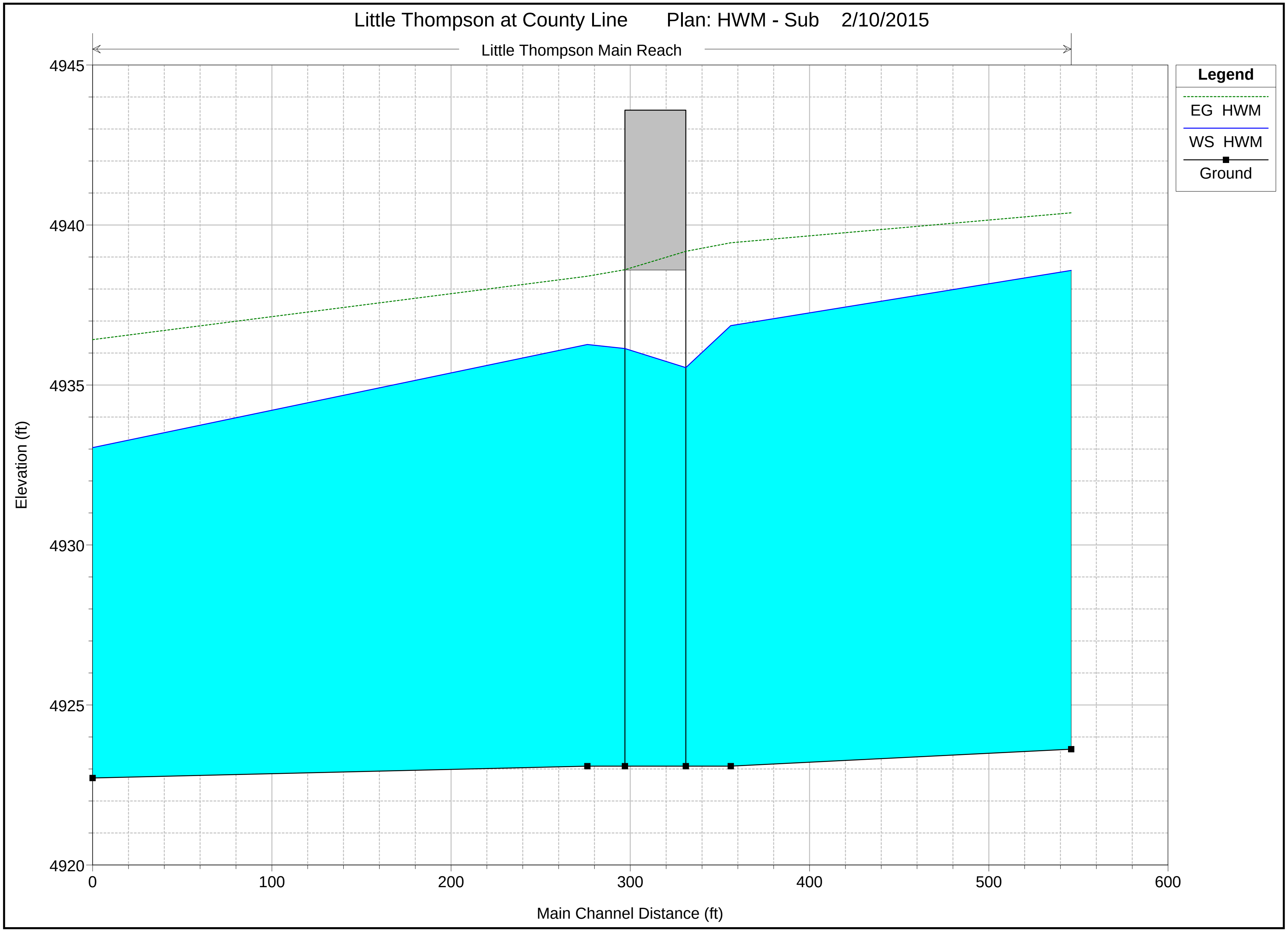


Little Thompson at 107 Plan: HWM - Sub 2/10/2015
Little Thompson Main Reach
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
5005
5000
4995
4990
4985
4980
4975
0
200
400
600
800
1000
1200
Main Channel Distance (ft)

Little Thompson at S County Line

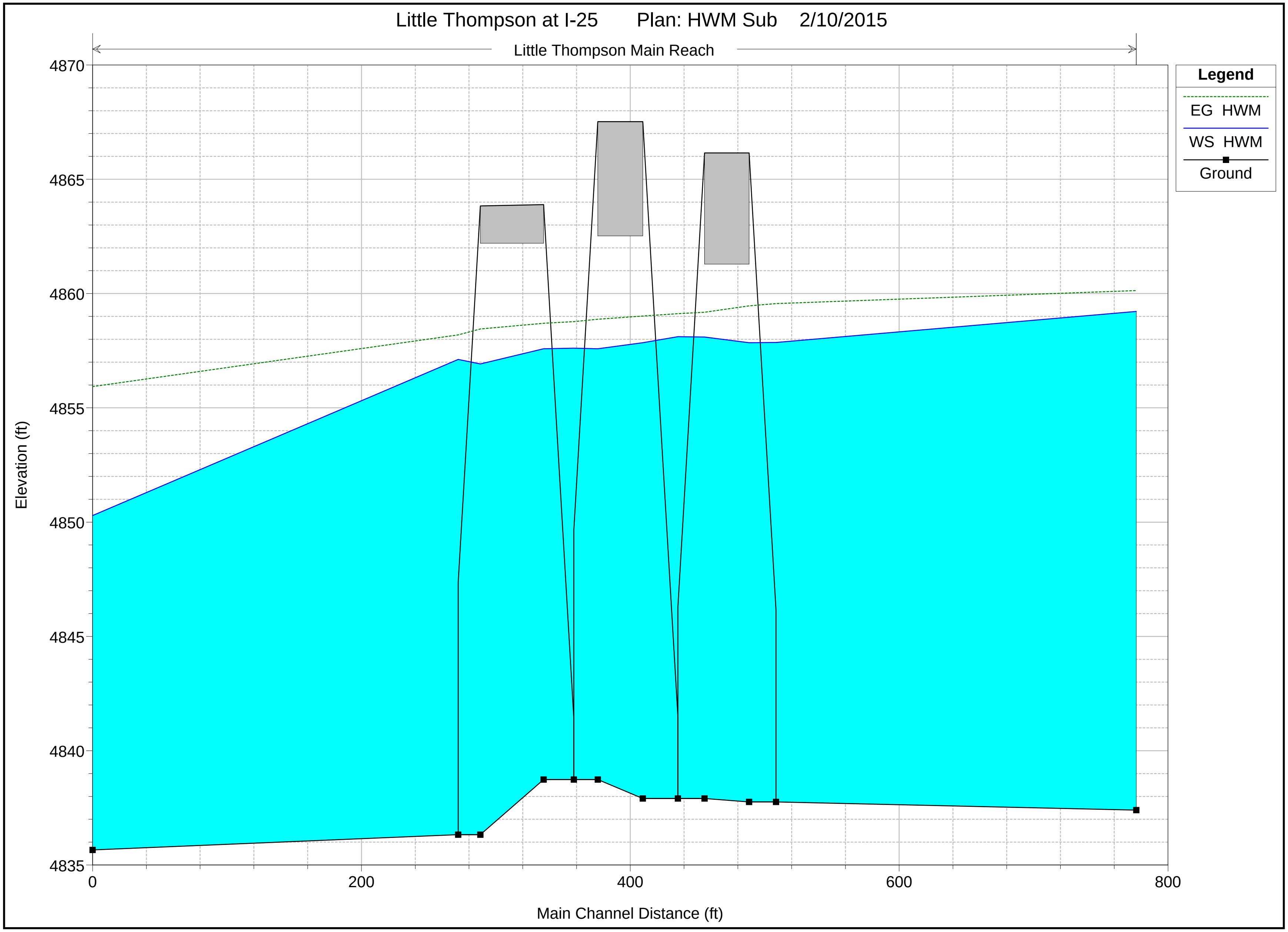
HEC-RAS Plan: HWM - Sub   River: Little Thompson   Reach: Main Reach   Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main Reach	675	HWM	13400.00	4923.62	4938.58	4936.06	4940.38	0.003837	12.09	1361.73	144.75	0.59
Main Reach	460	HWM	13400.00	4923.09	4936.85	4934.82	4939.44	0.005135	13.29	1078.23	153.78	0.69
Main Reach	420		Bridge									
Main Reach	381	HWM	13400.00	4923.09	4936.27	4933.71	4938.40	0.004802	11.87	1152.04	150.34	0.65
Main Reach	100	HWM	13400.00	4922.72	4933.04	4933.04	4936.42	0.010002	15.26	983.02	159.49	0.92


Little Thompson at County Line Plan: HWM - Sub 2/10/2015
Little Thompson Main Reach
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4945
4940
4935
4930
4925
4920
0
100
200
300
400
500
600
Main Channel Distance (ft)

HEC-RAS Plan: HWM - Sub   River: Little Thompson   Reach: Main Reach   Profile: HWM

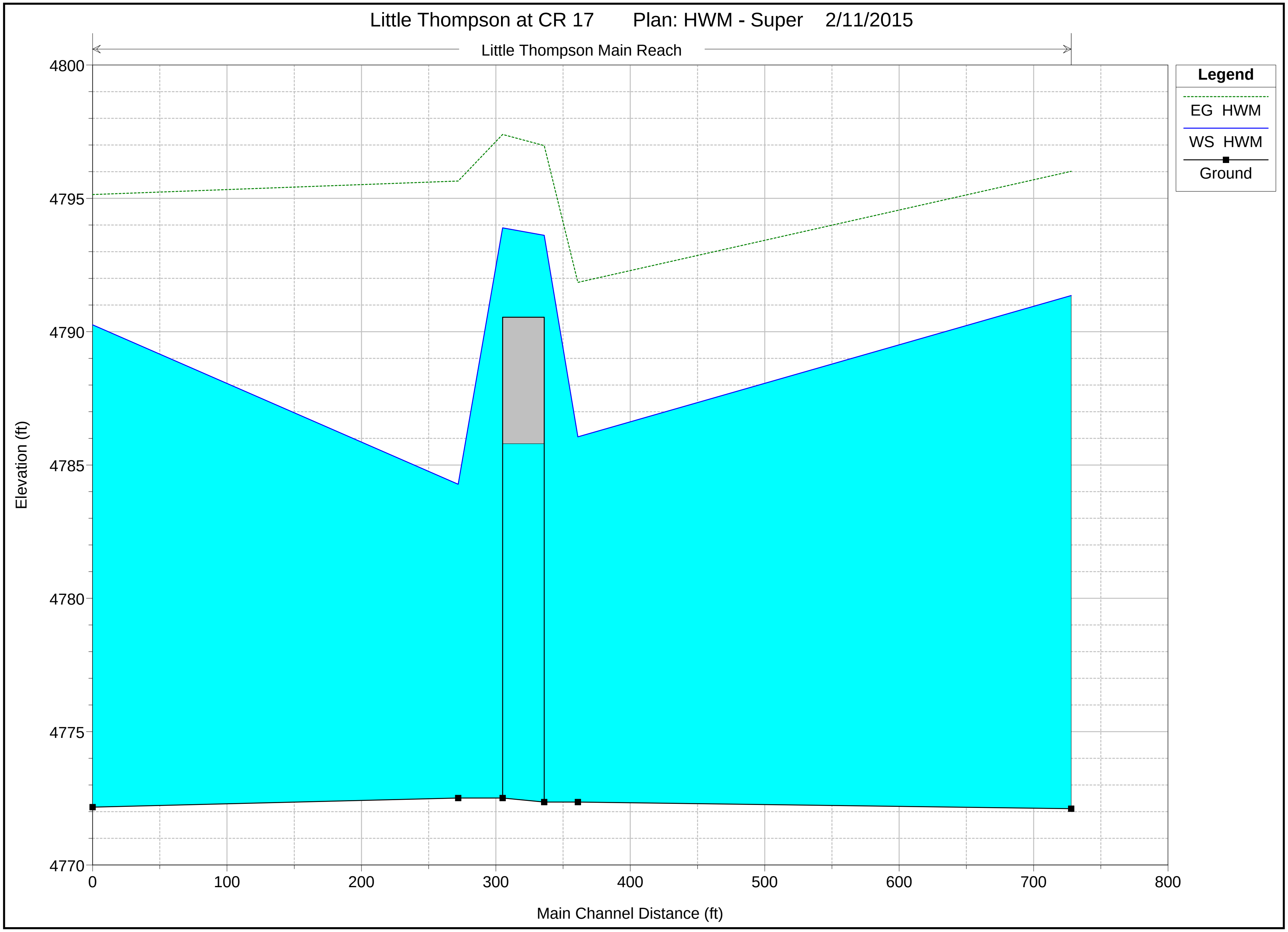
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main Reach	2595.635	HWM	15700.00	4837.40	4859.22	4853.35	4860.13	0.001358	8.57	2069.01	219.51	0.35
Main Reach	2327.635	HWM	15700.00	4837.76	4857.86	4853.99	4859.56	0.002620	12.67	1744.94	170.12	0.52
Main Reach	2307.635		Bridge									
Main Reach	2254.640	HWM	15700.00	4837.91	4858.12	4850.56	4859.12	0.001423	8.17	2010.57	152.53	0.38
Main Reach	2228.62		Bridge									
Main Reach	2177.256	HWM	15700.00	4838.74	4857.61	4851.13	4858.77	0.001664	10.19	2053.02	182.47	0.43
Main Reach	2154.767		Bridge									
Main Reach	2091.285	HWM	15700.00	4836.33	4857.12	4850.02	4858.19	0.001588	10.42	2114.56	177.43	0.42
Main Reach	1819.285	HWM	15700.00	4835.66	4850.29	4850.29	4855.93	0.010311	20.10	881.95	82.62	0.99


Little Thompson at I-25 Plan: HWM Sub 2/10/2015
Little Thompson Main Reach
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4870
4865
4860
4855
4850
4845
4840
4835
0
200
400
600
800
Main Channel Distance (ft)

Little Thompson at CR 17

HEC-RAS Plan: HWM - Super River: Little Thompson Reach: Main Reach Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main Reach	828	HWM	18000.00	4772.11	4791.35	4791.35	4796.01	0.009333	19.37	1163.14	119.08	0.89
Main Reach	461	HWM	18000.00	4772.36	4786.06	4786.87	4791.85	0.013259	19.61	962.00	131.26	1.07
Main Reach	417		Bridge									
Main Reach	372	HWM	18000.00	4772.51	4784.28	4787.77	4795.65	0.032953	27.31	689.21	139.47	1.61
Main Reach	100	HWM	18000.00	4772.17	4790.26	4790.26	4795.14	0.009435	20.71	1130.05	108.67	0.91

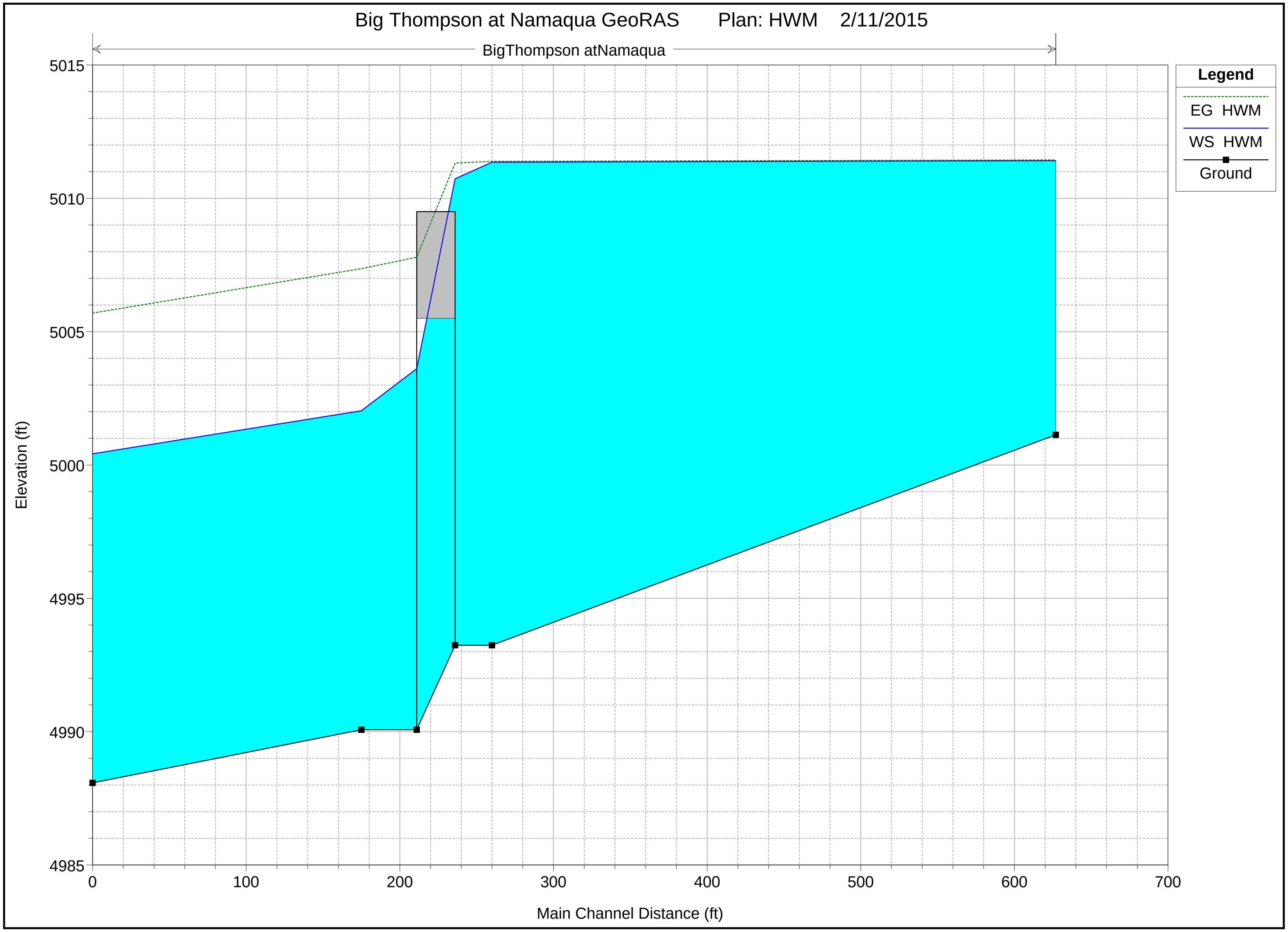

Little Thompson at CR 17 Plan: HWM - Super 2/11/2015
Little Thompson Main Reach
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4800
4795
4790
4785
4780
4775
4770
0
100
200
300
400
500
600
700
800
Main Channel Distance (ft)

Big Thompson
HEC-RAS Results

Big Thompson at Namaqua

HEC-RAS Plan: HWM - Sub River: BigThompson Reach: atNamaqua Profile: HWM

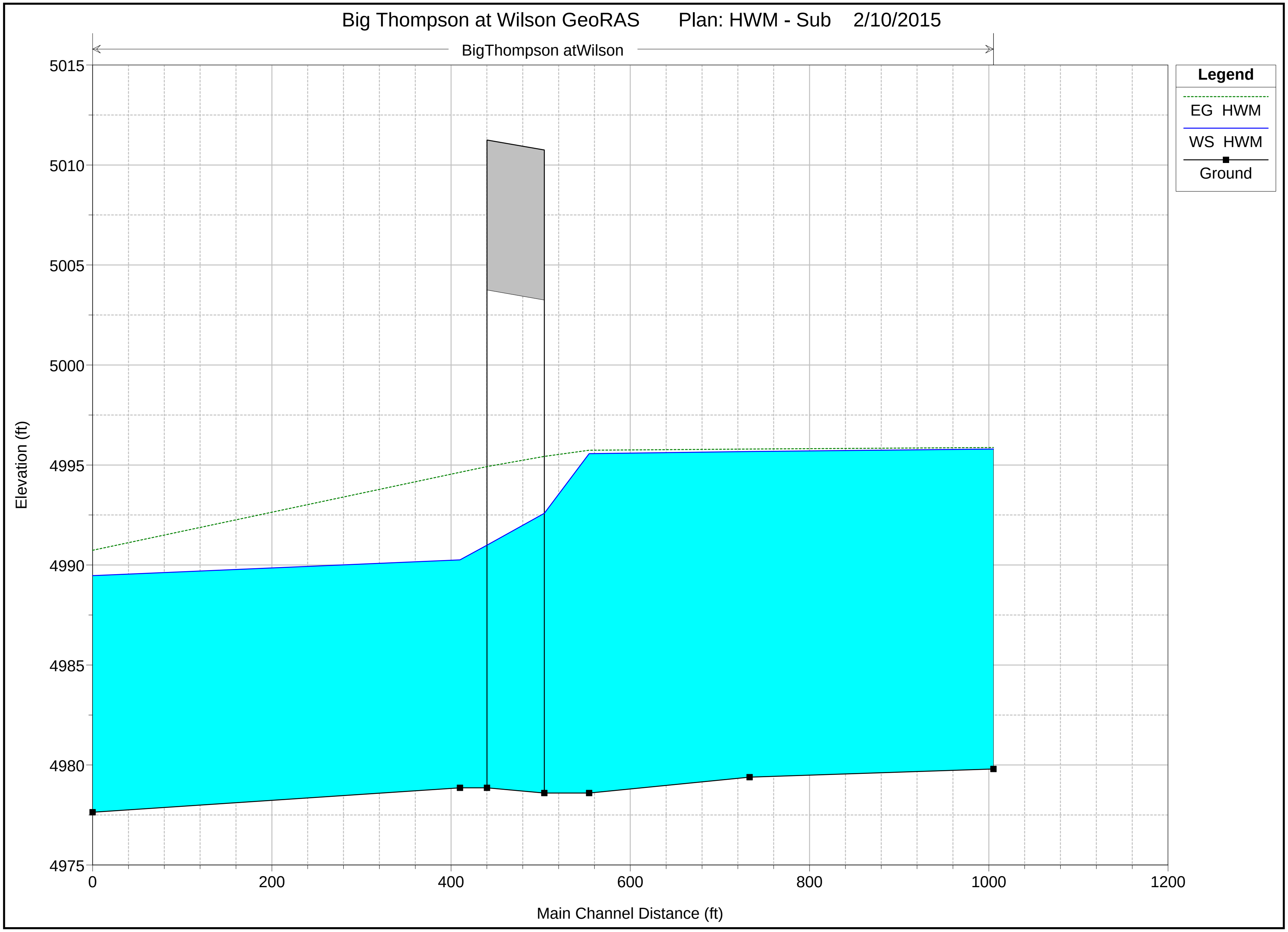
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
atNamaqua	906.0839	HWM	20000.00	5001.13	5011.41	5007.42	5011.44	0.000185	2.62	16549.89	3325.48	0.15
atNamaqua	539.4245	HWM	20000.00	4993.24	5011.35	5005.94	5011.39	0.000110	2.89	17214.33	2673.16	0.12
atNamaqua	512.7339		Bridge									
atNamaqua	454.7339	HWM	20000.00	4990.07	5002.04	5001.46	5007.36	0.008801	19.67	1206.31	631.62	1.04
atNamaqua	279.7508	HWM	20000.00	4988.08	5000.42	5000.42	5005.70	0.010125	18.87	1210.15	764.12	1.08


Big Thompson at Namaqua GeoRAS Plan: HWM 2/11/2015
BigThompson atNamaqua
Legend
EG HWM
WS HWM
Ground
5015
5010
5005
5000
4995
4990
4985
0
100
200
300
400
500
600
700
Elevation (ft)
Main Channel Distance (ft)

Big Thompson at Wilson

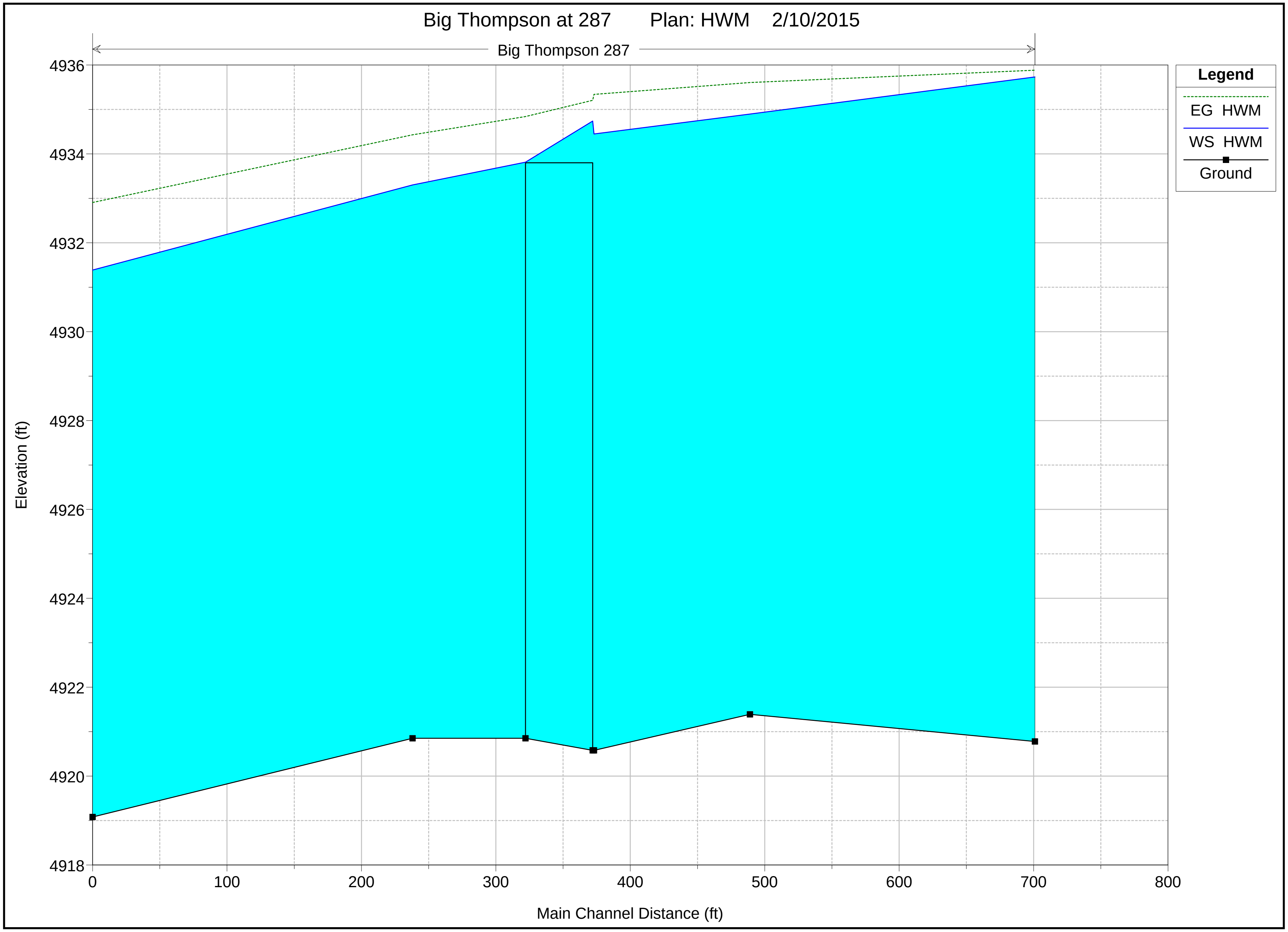
HEC-RAS Plan: HWM - Sub River: BigThompson Reach: atWilson Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
atWilson	1357.954	HWM	24000.00	4979.80	4995.80		4995.88	0.000217	3.71	14225.99	2419.93	0.17
atWilson	1085.827	HWM	24000.00	4979.39	4995.67		4995.80	0.000304	4.59	12241.83	2230.26	0.20
atWilson	906.7098	HWM	24000.00	4978.60	4995.57	4989.97	4995.74	0.000346	4.87	10839.57	1895.19	0.22
atWilson	852.6332		Bridge									
atWilson	762.6332	HWM	24000.00	4978.86	4990.26	4990.26	4994.64	0.008262	16.96	1467.20	675.66	0.97
atWilson	352.6946	HWM	24000.00	4977.64	4989.47	4989.47	4990.74	0.003542	12.20	4308.02	2150.21	0.65


Big Thompson at Wilson GeoRAS Plan: HWM - Sub 2/10/2015
BigThompson atWilson
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
5015
5010
5005
5000
4995
4990
4985
4980
4975
0
200
400
600
800
1000
1200
Main Channel Distance (ft)

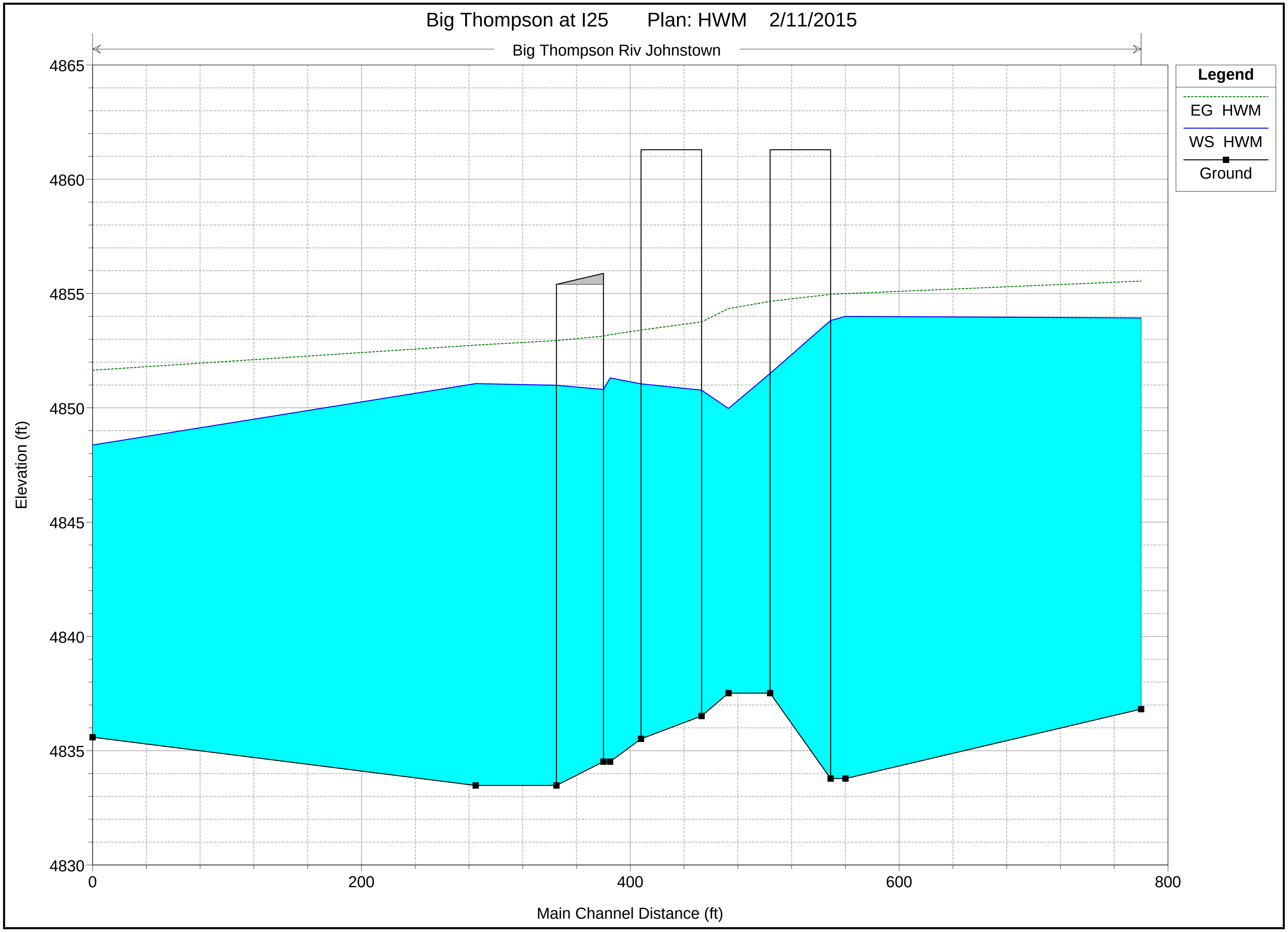
HEC-RAS Plan: HWM - Sub River: Big Thompson Reach: 287 Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
287	1201	HWM	22000.00	4920.78	4935.73	4930.86	4935.88	0.000626	5.56	9575.16	2281.27	0.27
287	989	HWM	22000.00	4921.39	4934.90	4933.99	4935.61	0.002111	9.49	5569.71	2200.01	0.50
287	873	HWM	22000.00	4920.58	4934.45	4933.82	4935.34	0.002171	10.62	5347.52	2444.13	0.53
287	872		Bridge									
287	738	HWM	22000.00	4920.85	4933.30	4933.30	4934.43	0.002943	11.69	4691.34	2662.32	0.61
287	500	HWM	22000.00	4919.08	4931.39	4931.39	4932.91	0.006289	15.01	4018.16	3198.84	0.84


Big Thompson at 287 Plan: HWM 2/10/2015
Big Thompson 287
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4936
4934
4932
4930
4928
4926
4924
4922
4920
4918
0
100
200
300
400
500
600
700
800
Main Channel Distance (ft)

HEC-RAS Plan: HWM - Sub River: Big Thompson Riv Reach: Johnstown Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Johnstown	1780	HWM	16600.00	4836.82	4853.93	4850.12	4855.54	0.002358	12.05	1918.19	163.39	0.54
Johnstown	1560	HWM	16600.00	4833.78	4854.00	4848.48	4855.00	0.001224	8.61	2247.86	321.14	0.40
Johnstown	1548		Bridge									
Johnstown	1473	HWM	16600.00	4837.52	4849.97	4849.97	4854.34	0.007920	18.81	1142.53	133.26	0.98
Johnstown	1453		Bridge									
Johnstown	1385	HWM	16600.00	4834.52	4851.31	4846.97	4853.20	0.002352	12.69	1761.16	152.12	0.56
Johnstown	1380		Bridge									
Johnstown	1285	HWM	16600.00	4833.48	4851.06	4846.08	4852.74	0.001838	10.83	1681.49	315.43	0.49
Johnstown	1000	HWM	16600.00	4835.59	4848.37	4848.37	4851.65	0.007493	16.81	1332.76	290.97	0.93

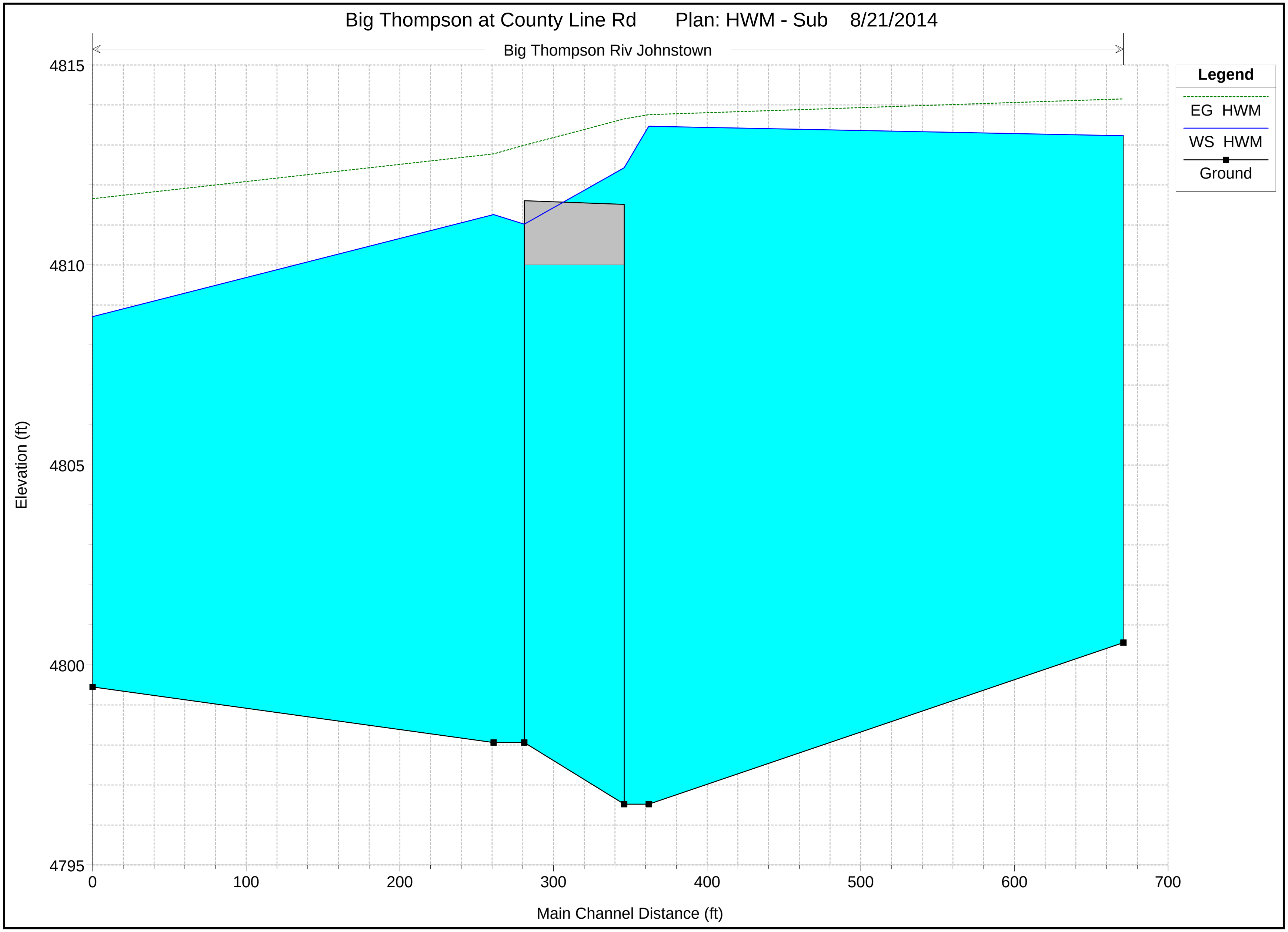


Big Thompson at I25 Plan: HWM 2/11/2015
Big Thompson Riv Johnstown
Legend
EG HWM
WS HWM
Ground
4865
4860
4855
4850
4845
4840
4835
4830
Elevation (ft)
0
200
400
600
800
Main Channel Distance (ft)

Big Thompson at County Line Road

HEC-RAS Plan: HWM Sub River: Big Thompson Riv Reach: Johnstown Profile: HWM

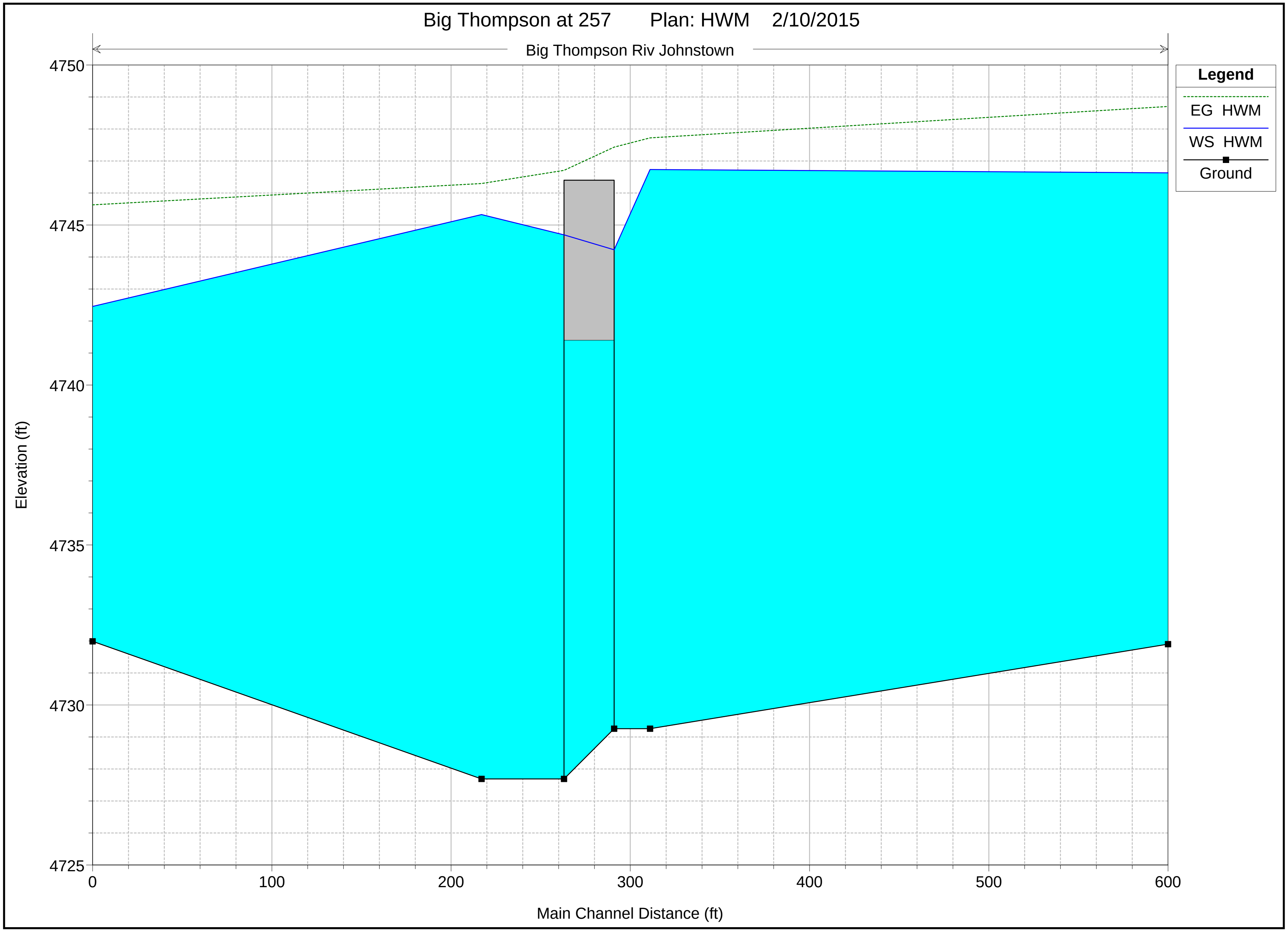
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Johnstown	1171	HWM	8800.00	4800.56	4813.23	4810.19	4814.15	0.001898	8.71	1320.61	162.61	0.47
Johnstown	862	HWM	8800.00	4796.52	4813.47	4804.86	4813.76	0.000330	4.83	2474.43	238.52	0.21
Johnstown	846		Bridge									
Johnstown	761	HWM	8800.00	4798.06	4811.26	4806.87	4812.78	0.002140	9.91	895.04	158.55	0.50
Johnstown	500	HWM	8800.00	4799.45	4808.71	4808.71	4811.66	0.008132	14.63	714.97	178.75	0.93


Big Thompson at County Line Rd Plan: HWM - Sub 8/21/2014
Big Thompson Riv Johnstown
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4815
4810
4805
4800
4795
0
100
200
300
400
500
600
700
Main Channel Distance (ft)

Big Thompson at 257

HEC-RAS Plan: HWM Sub   River: Big Thompson Riv   Reach: Johnstown   Profile: HWM

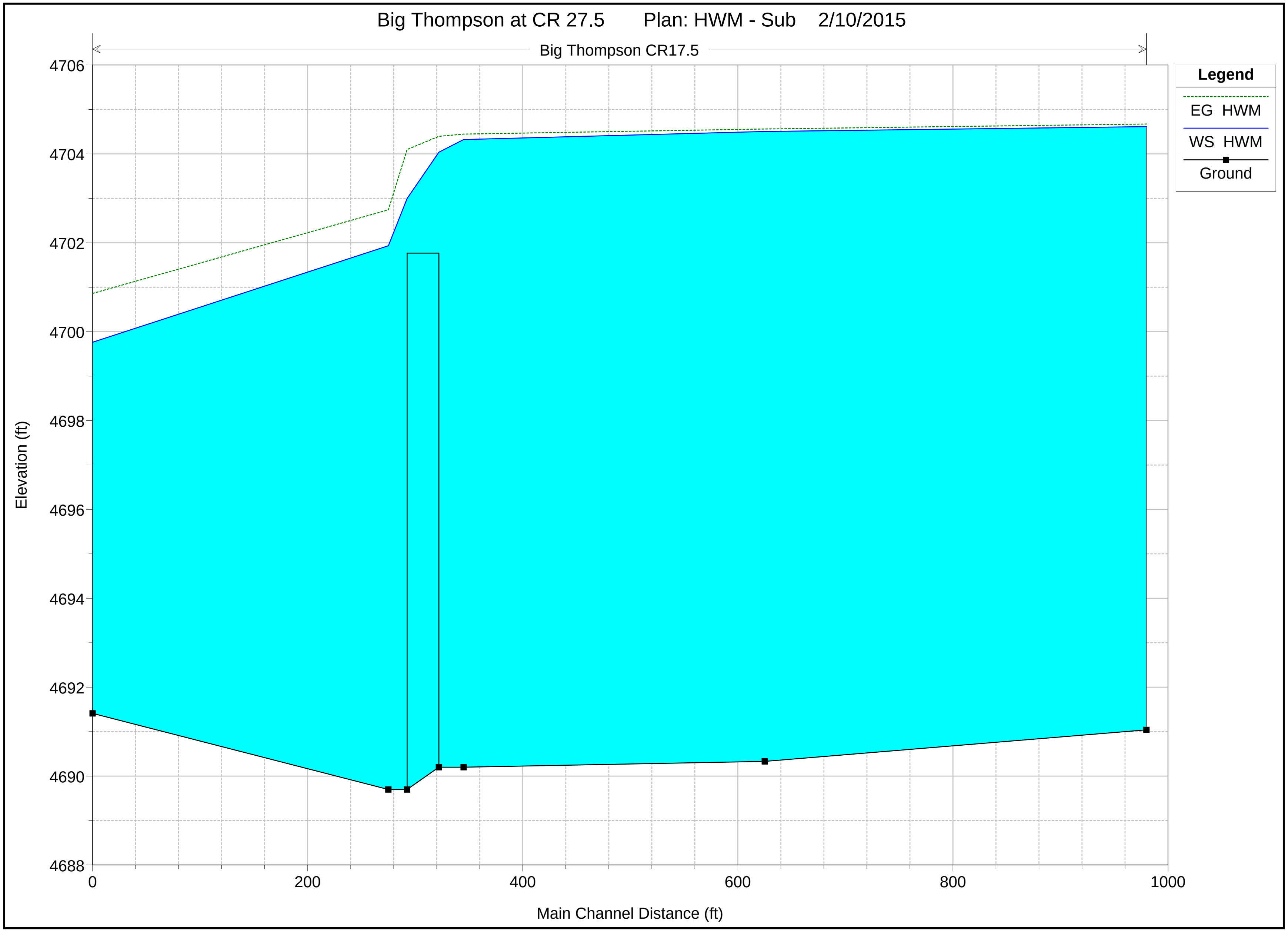
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Johnstown	1600	HWM	17700.00	4731.90	4746.63	4744.57	4748.70	0.004722	14.95	1728.32	172.67	0.72
Johnstown	1311	HWM	17700.00	4729.26	4746.73	4740.73	4747.72	0.001324	8.02	2288.56	255.13	0.40
Johnstown	1291		Bridge									
Johnstown	1217	HWM	17700.00	4727.69	4745.32	4737.62	4746.30	0.000936	8.10	2367.79	262.00	0.35
Johnstown	1000	HWM	17700.00	4731.99	4742.45	4742.45	4745.63	0.007722	15.49	1403.46	230.45	0.93


Big Thompson at 257 Plan: HWM 2/10/2015
Big Thompson Riv Johnstown
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4750
4745
4740
4735
4730
4725
0
100
200
300
400
500
600
Main Channel Distance (ft)

Big Thompson at CR 27.5

HEC-RAS Plan: HWM - Sub   River: Big Thompson   Reach: CR17.5   Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
CR17.5	1480	HWM	24900.00	4691.04	4704.61	4702.12	4704.67	0.000360	3.39	15809.33	3885.42	0.20
CR17.5	1125	HWM	24900.00	4690.33	4704.50	4701.53	4704.56	0.000277	3.06	16517.65	3683.36	0.18
CR17.5	845	HWM	24900.00	4690.20	4704.32	4702.41	4704.45	0.000558	4.58	12727.37	3473.96	0.26
CR17.5	822		Bridge									
CR17.5	775	HWM	24900.00	4689.70	4701.93	4701.93	4702.74	0.005179	10.37	5764.35	3171.61	0.72
CR17.5	500	HWM	24900.00	4691.41	4699.76	4699.76	4700.86	0.009108	11.97	4175.16	2008.44	0.92


Big Thompson at CR 27.5 Plan: HWM - Sub 2/10/2015
Big Thompson CR17.5
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4706
4704
4702
4700
4698
4696
4694
4692
4690
4688
0
200
400
600
800
1000
Main Channel Distance (ft)

URS

Technical Memorandum

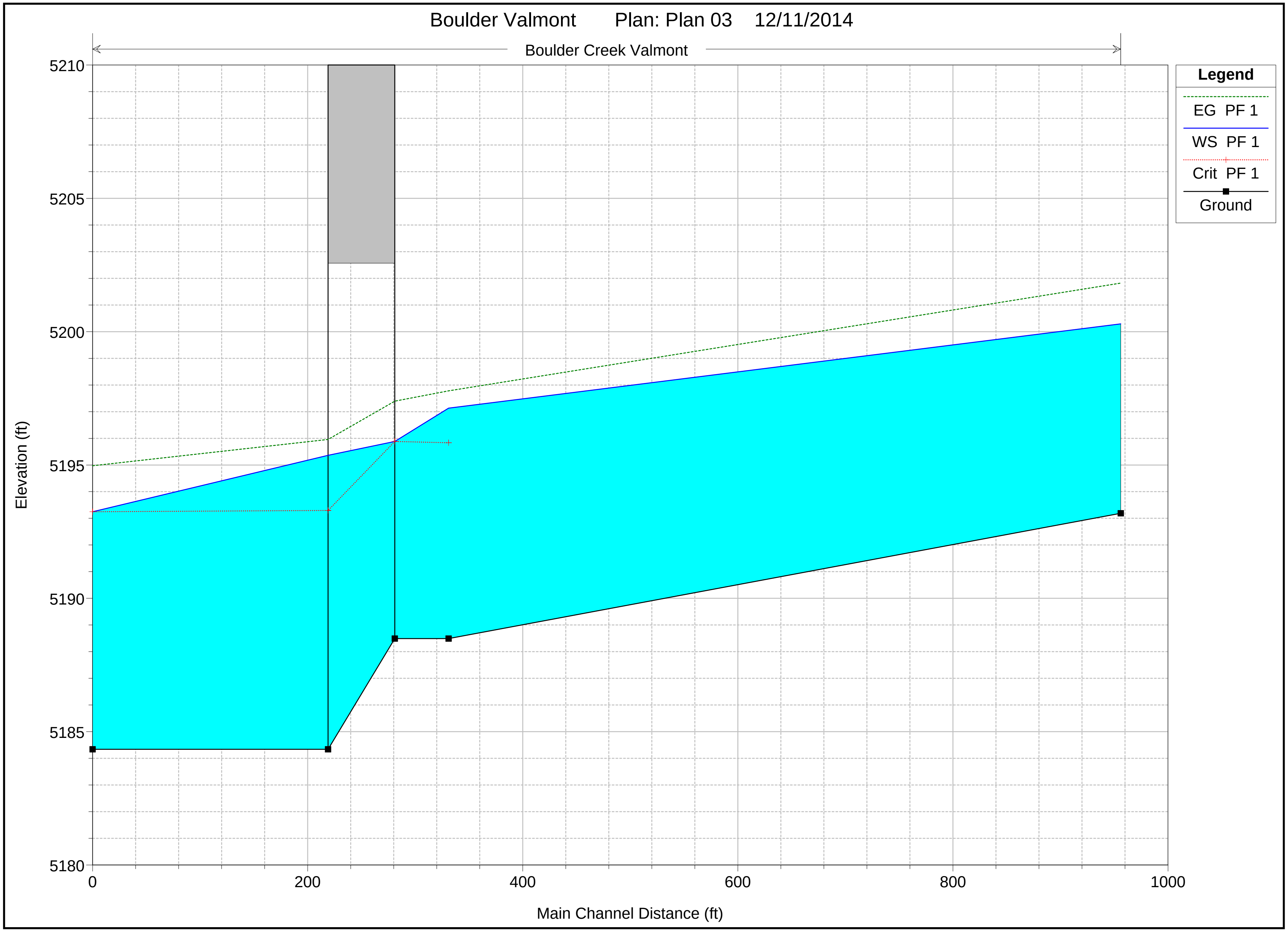
Boulder Creek

HEC-RAS Results

Boulder at Valmont

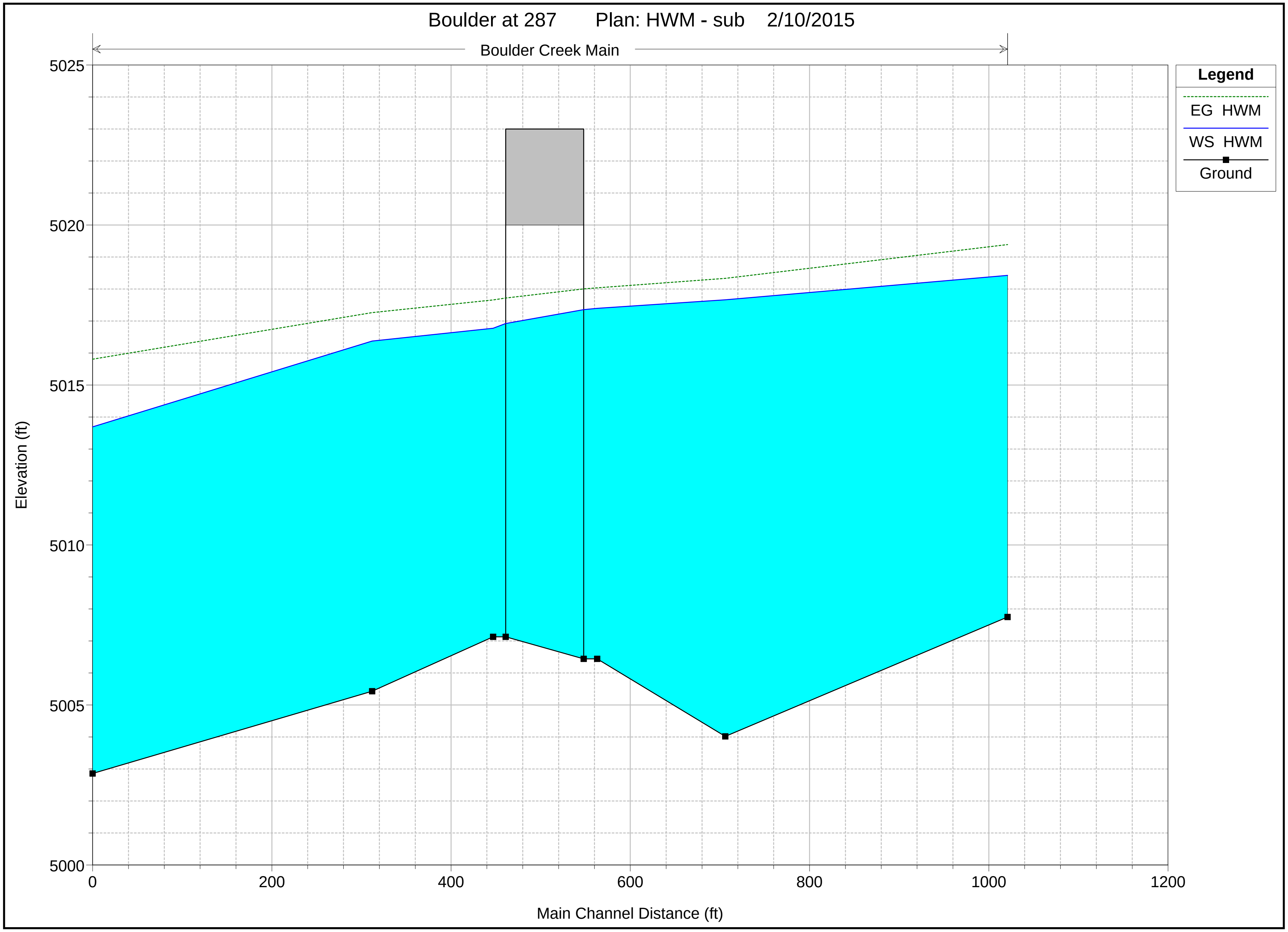
HEC-RAS Plan: Plan 03   River: Boulder Creek   Reach: Valmont   Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Valmont	1956	PF 1	4300.00	5193.19	5200.29		5201.82	0.010375	10.55	460.25	109.11	0.82
Valmont	1331	PF 1	4300.00	5188.49	5197.13	5195.83	5197.78	0.003751	7.73	760.05	180.19	0.53
Valmont	1081		Bridge									
Valmont	1000	PF 1	4300.00	5184.34	5193.25	5193.25	5194.97	0.008304	11.80	513.68	155.69	0.77


Boulder Valmont Plan: Plan 03 12/11/2014
Boulder Creek Valmont
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
Elevation (ft)
5210
5205
5200
5195
5190
5185
5180
0
200
400
600
800
1000
Main Channel Distance (ft)

HEC-RAS Plan: HWM - Sub River: Boulder Creek Reach: Main Profile: HWM

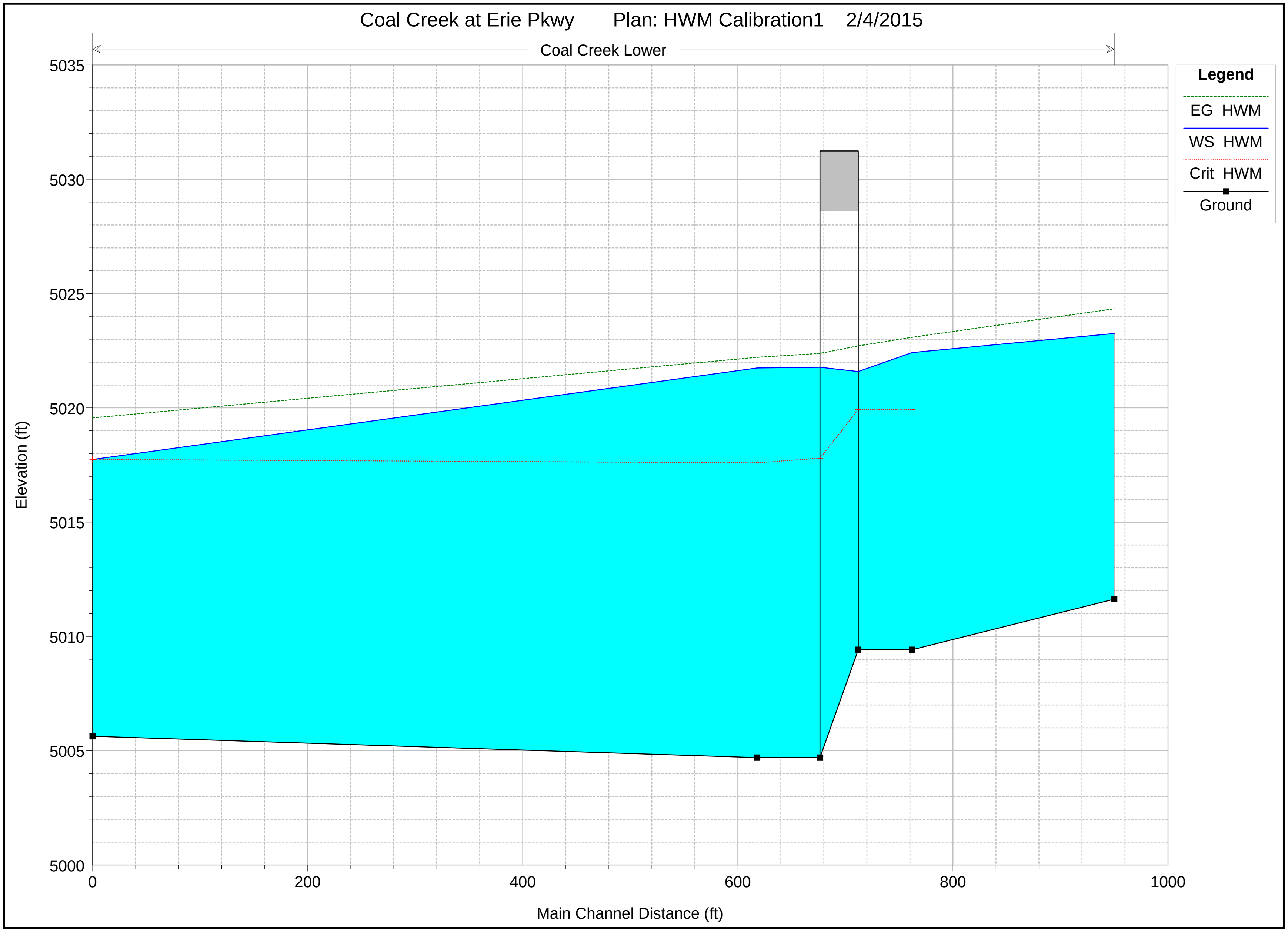
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	2021	HWM	9000.00	5007.75	5018.43	5018.10	5019.39	0.004807	10.13	1529.85	446.05	0.61
Main	1706	HWM	9000.00	5004.02	5017.66	5015.27	5018.33	0.002121	8.27	1687.08	282.04	0.43
Main	1563	HWM	9000.00	5006.44	5017.40	5014.00	5018.04	0.001876	7.35	1553.92	208.62	0.41
Main	1505		Bridge									
Main	1447	HWM	9000.00	5007.13	5016.77	5014.56	5017.66	0.003056	8.51	1324.66	208.55	0.52
Main	1312	HWM	9000.00	5005.43	5016.38	5014.19	5017.26	0.002832	8.22	1376.82	244.13	0.49
Main	1000	HWM	9000.00	5002.86	5013.69	5013.69	5015.81	0.007230	13.40	962.39	208.12	0.76


Boulder at 287 Plan: HWM - sub 2/10/2015
Boulder Creek Main
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
5025
5020
5015
5010
5005
5000
0
200
400
600
800
1000
1200
Main Channel Distance (ft)

HEC-RAS Plan: HWM 1 Bridge River: Coal Creek Reach: Lower Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Lower	19370	HWM	6000.00	5011.63	5023.26		5024.33	0.008024	9.22	740.79	143.95	0.51
Lower	19182	HWM	6000.00	5009.42	5022.42	5019.92	5023.09	0.004605	6.72	918.56	176.19	0.36
Lower	19154		Bridge									
Lower	19038	HWM	6000.00	5004.70	5021.75	5017.60	5022.21	0.001853	5.55	1155.46	204.33	0.27
Lower	18420	HWM	6000.00	5005.63	5017.74	5017.74	5019.56	0.014899	12.05	588.19	154.27	0.74

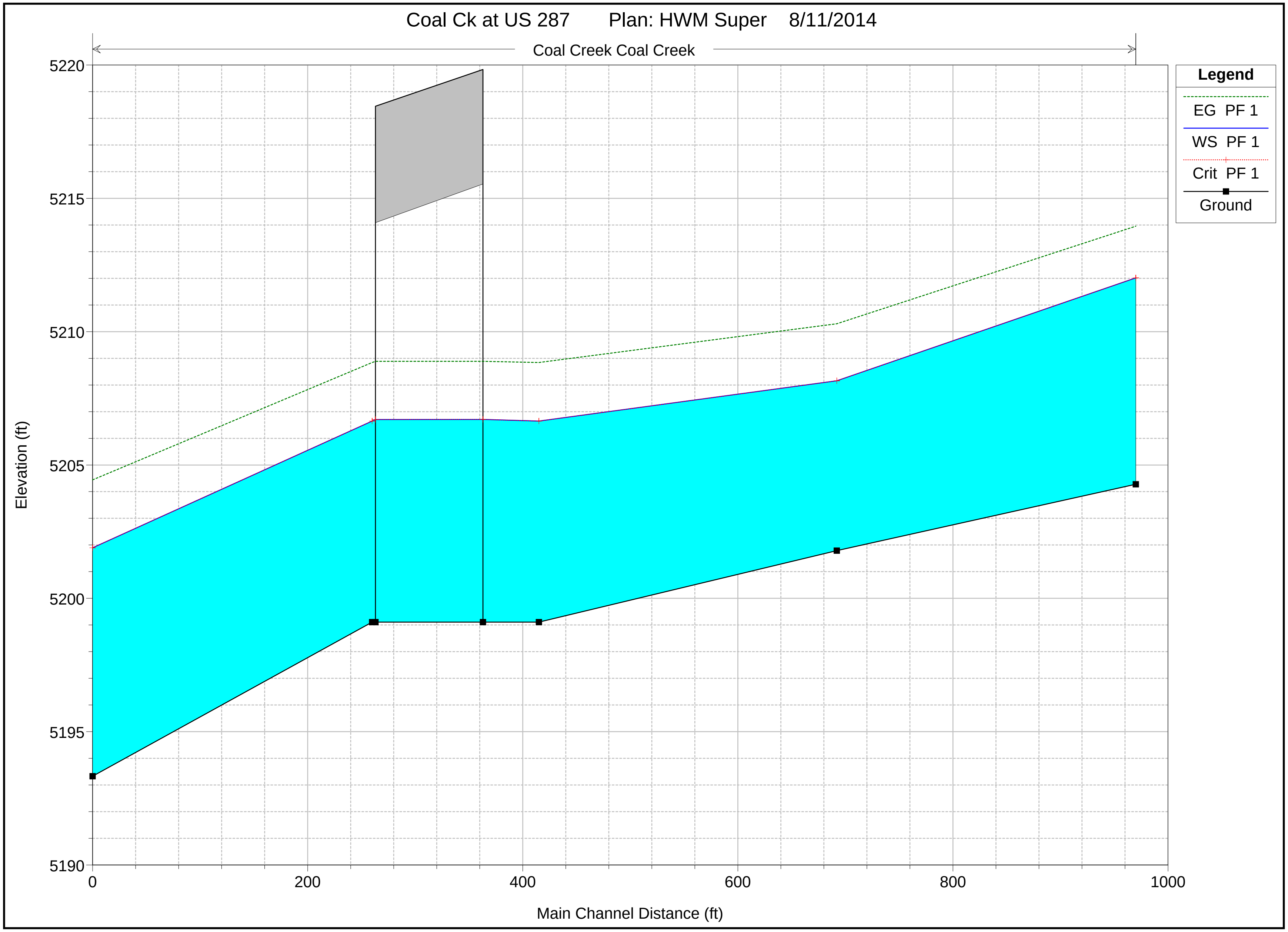
Coal at Erie Pkwy



HEC-RAS Plan: Super Crit   River: Coal Creek   Reach: Coal Creek   Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Coal Creek	82873.73	PF 1	5000.00	5204.28	5212.02	5212.02	5213.96	0.060211	12.09	458.53	114.90	0.92
Coal Creek	82595.73	PF 1	5000.00	5201.79	5208.16	5208.16	5210.30	0.067647	12.20	447.71	145.18	0.97
Coal Creek	82318.73	PF 1	5000.00	5199.11	5206.65	5206.65	5208.84	0.061620	12.75	430.27	97.03	0.94
Coal Creek	82260		Bridge									
Coal Creek	82163.73	PF 1	5000.00	5199.11	5206.65	5206.65	5208.84	0.061620	12.75	430.27	97.03	0.94
Coal Creek	81903.73	PF 1	5000.00	5193.33	5201.89	5201.89	5204.44	0.052203	13.60	411.22	79.80	0.90

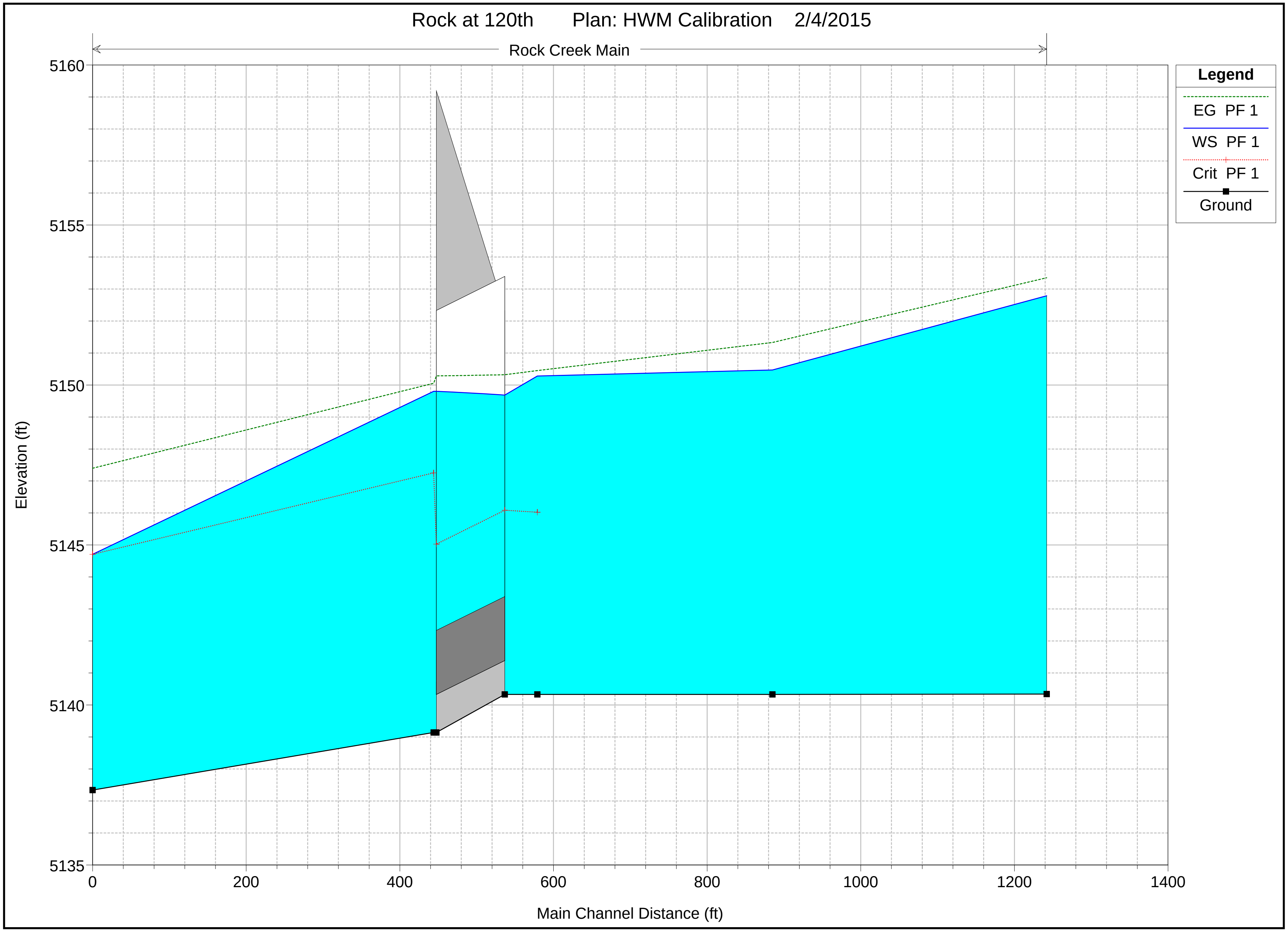
Coal at US 287



Rock at 120th

HEC-RAS Plan: HWM Calibration River: Rock Creek Reach: Main Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	207844	PF 1	1500.00	5140.34	5152.79		5153.35	0.004839	6.07	258.07	58.77	0.44
Main	207487	PF 1	1500.00	5140.33	5150.47		5151.33	0.006494	7.92	236.32	76.93	0.51
Main	207181	PF 1	1500.00	5140.33	5150.28	5146.02	5150.45	0.001093	3.82	485.95	83.66	0.23
Main	207119		Culvert									
Main	207046	PF 1	1500.00	5139.14	5149.80	5147.26	5150.05	0.002091	5.00	419.99	106.00	0.30
Main	206602	PF 1	1500.00	5137.34	5144.71	5144.71	5147.40	0.035533	13.48	119.51	35.59	1.07

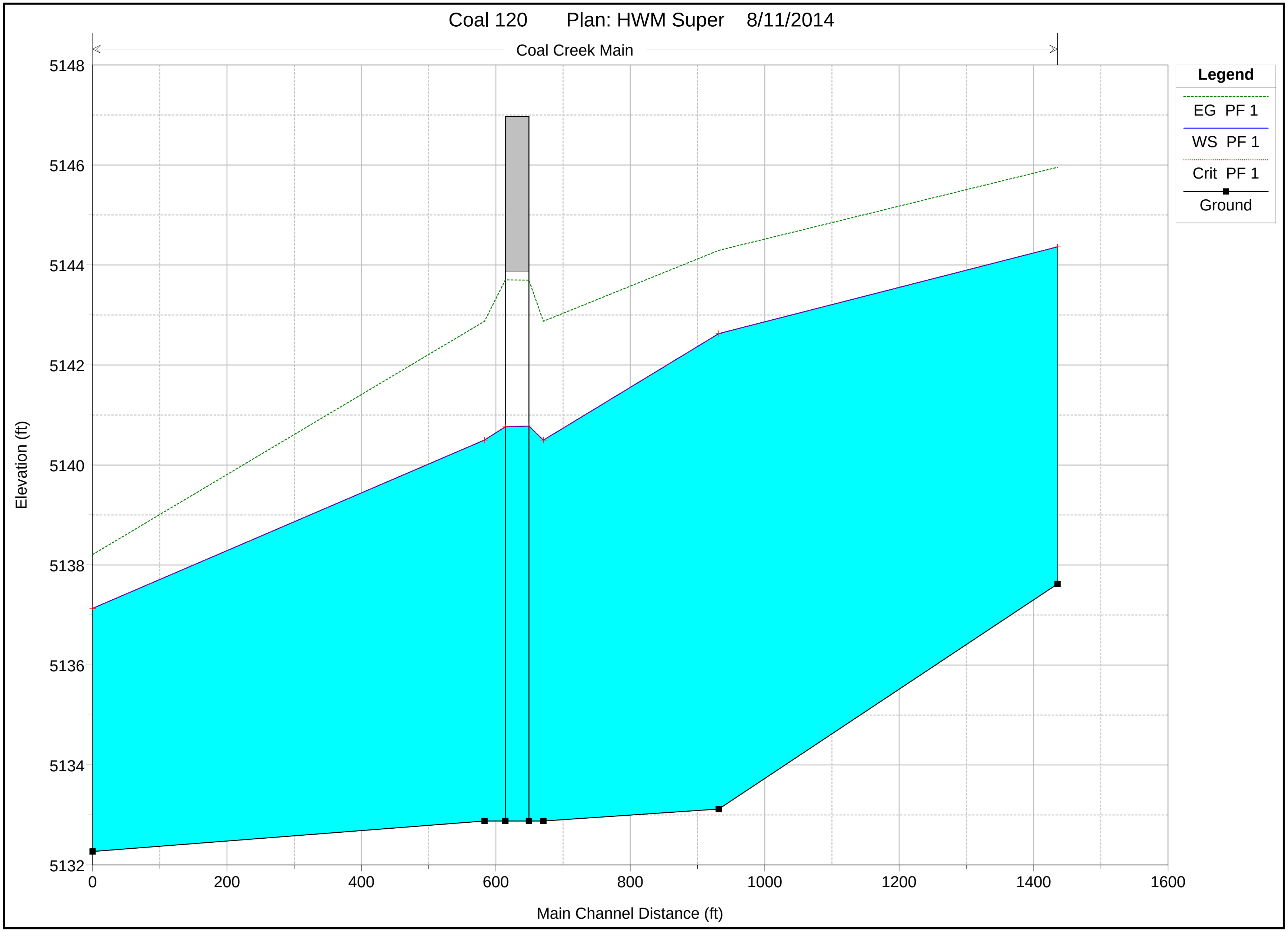

Rock at 120th Plan: HWM Calibration 2/4/2015
Rock Creek Main
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
Elevation (ft)
5160
5155
5150
5145
5140
5135
0
200
400
600
800
1000
1200
1400
Main Channel Distance (ft)

Coal at 120

HEC-RAS Plan: Super Crit River: Coal Creek Reach: Main Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	72657.6	PF 1	3500.00	5137.62	5144.36	5144.36	5145.96	0.020221	12.87	378.53	114.48	0.93
Main	72153.6	PF 1	3500.00	5133.12	5142.63	5142.63	5144.29	0.015926	13.03	397.17	112.42	0.81
Main	71892.6	PF 1	3500.00	5132.88	5140.50	5140.50	5142.87	0.019779	14.06	302.32	74.90	0.97
Main	71836		Bridge									
Main	71805	PF 1	3500.00	5132.88	5140.50	5140.50	5142.87	0.019727	14.05	302.62	74.97	0.97
Main	71222	PF 1	3500.00	5132.27	5137.13	5137.13	5138.21	0.016879	9.14	481.07	219.26	0.84

Coal at 120



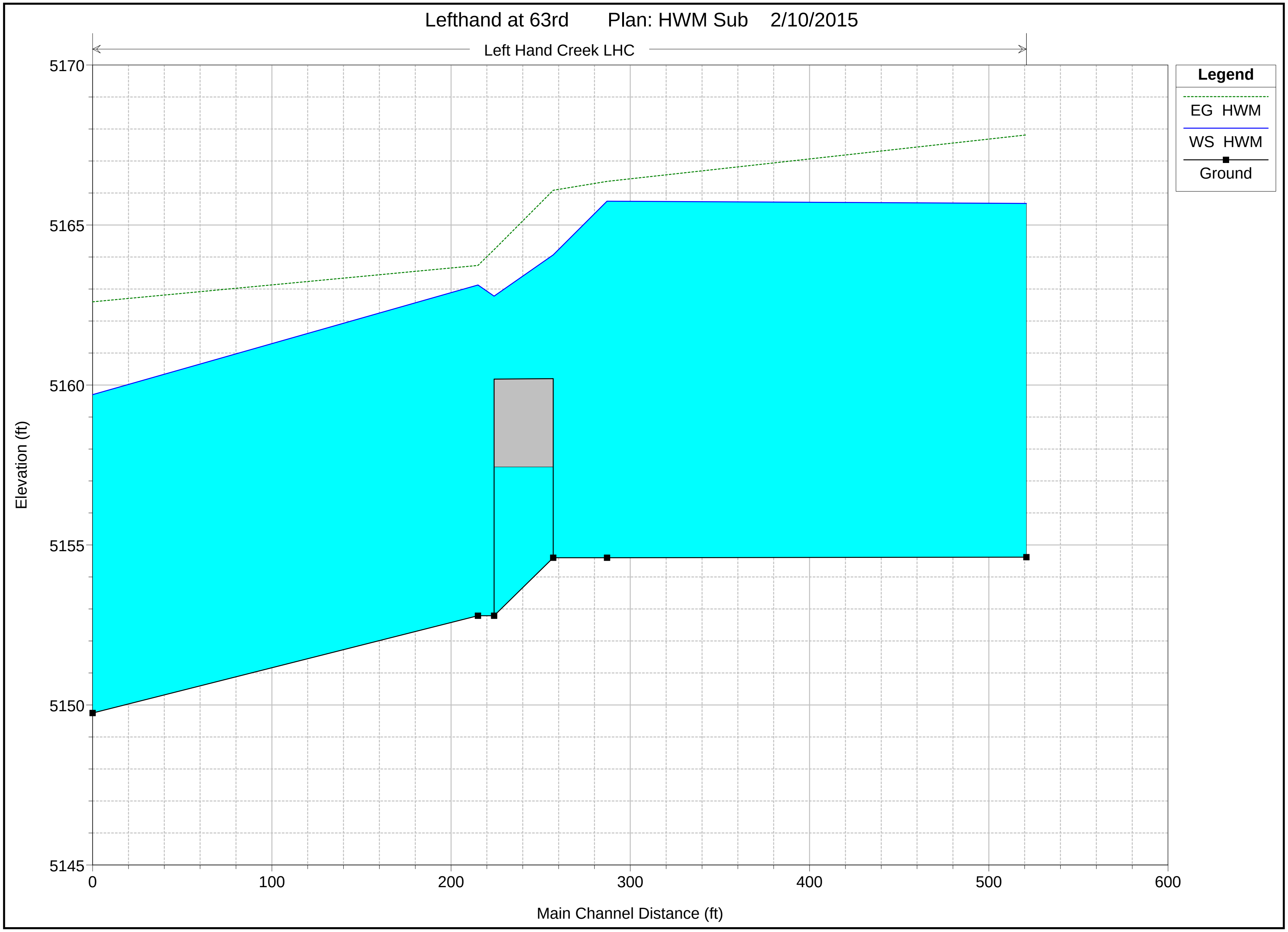
Coal 120 Plan: HWM Super 8/11/2014
Coal Creek Main
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
Elevation (ft)
5148
5146
5144
5142
5140
5138
5136
5134
5132
0
200
400
600
800
1000
1200
1400
1600
Main Channel Distance (ft)

Lefthand Creek
HEC-RAS Results

Left Hand at 63rd

HEC-RAS Plan: HWM Sub   River: Left Hand Creek   Reach: LHC   Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
LHC	1521	HWM	7000.00	5154.62	5165.67	5165.67	5167.81	0.008699	13.88	771.10	163.02	0.83
LHC	1287	HWM	7000.00	5154.60	5165.74	5161.55	5166.36	0.001709	6.44	1203.36	197.39	0.38
LHC	1257		Bridge									
LHC	1215	HWM	7000.00	5152.79	5163.13	5160.56	5163.74	0.002252	6.78	1290.28	246.23	0.43
LHC	1000	HWM	7000.00	5149.75	5159.70	5159.70	5162.60	0.010550	15.47	607.18	113.06	0.93

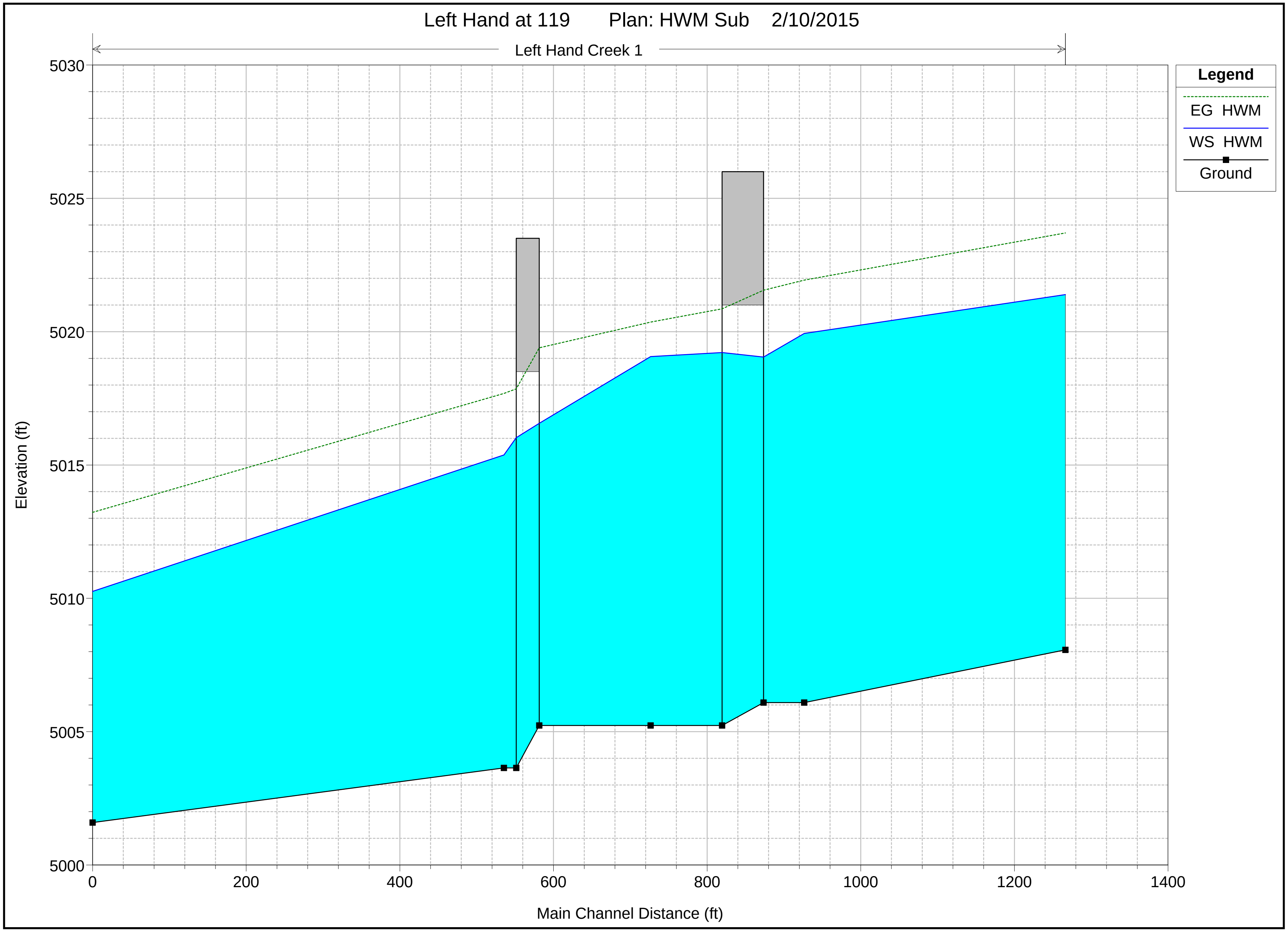

Lefthand at 63rd Plan: HWM Sub 2/10/2015
Left Hand Creek LHC
Legend
EG HWM
WS HWM
Ground
5170
5165
5160
5155
5150
5145
Elevation (ft)
0
100
200
300
400
500
600
Main Channel Distance (ft)

Left Hand at 119th

HEC-RAS Plan: HWM Sub   River: Left Hand Creek   Reach: 1   Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	1731	HWM	8700.00	5008.07	5021.39	5020.04	5023.70	0.006282	12.81	777.98	157.33	0.71
1	1391	HWM	8700.00	5006.09	5019.93	5017.19	5021.93	0.003965	11.74	858.66	131.02	0.60
1	1338		Bridge									
1	1191	HWM	8700.00	5005.23	5019.07	5016.48	5020.36	0.003057	10.27	1124.41	183.64	0.52
1	1046		Bridge									
1	1000	HWM	8700.00	5003.64	5015.38	5014.38	5017.68	0.006716	12.97	830.02	134.17	0.75
1	464.5513	HWM	8700.00	5001.59	5010.26	5010.26	5013.22	0.010261	14.17	687.36	247.13	0.92

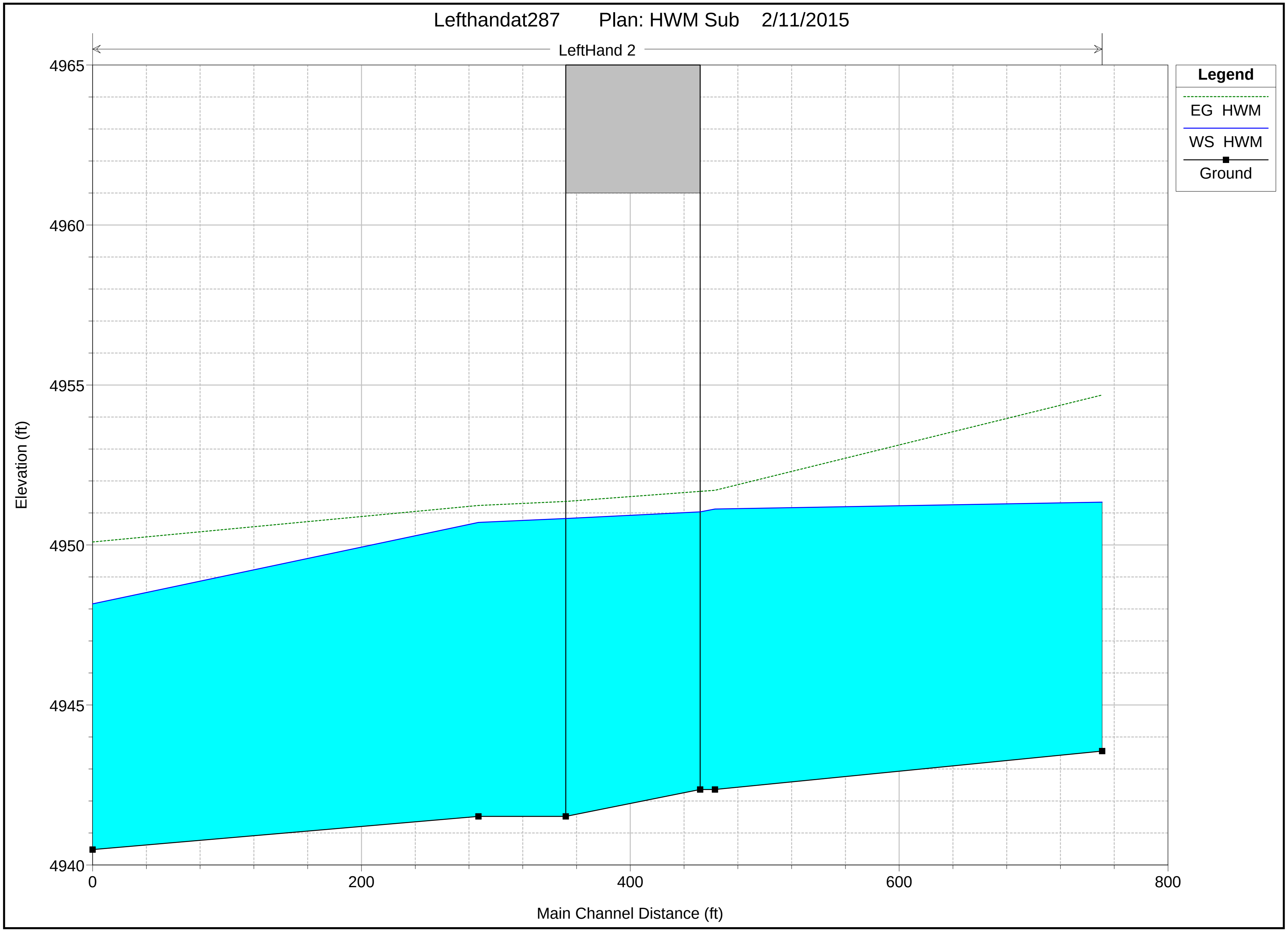
Left Hand at 119th



HEC-RAS Plan: HWM Sub River: LeftHand Reach: 2 Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
2	1751	HWM	5000.00	4943.56	4951.34	4951.34	4954.69	0.012627	14.68	340.50	70.85	0.99
2	1463	HWM	5000.00	4942.36	4951.12	4947.62	4951.71	0.001884	6.27	852.72	119.08	0.39
2	1452		Bridge									
2	1287	HWM	5000.00	4941.52	4950.70	4946.88	4951.24	0.001545	6.10	921.21	136.30	0.36
2	1000	HWM	5000.00	4940.48	4948.16	4948.16	4950.09	0.014139	12.55	499.97	152.36	0.99

Left Hand at 287

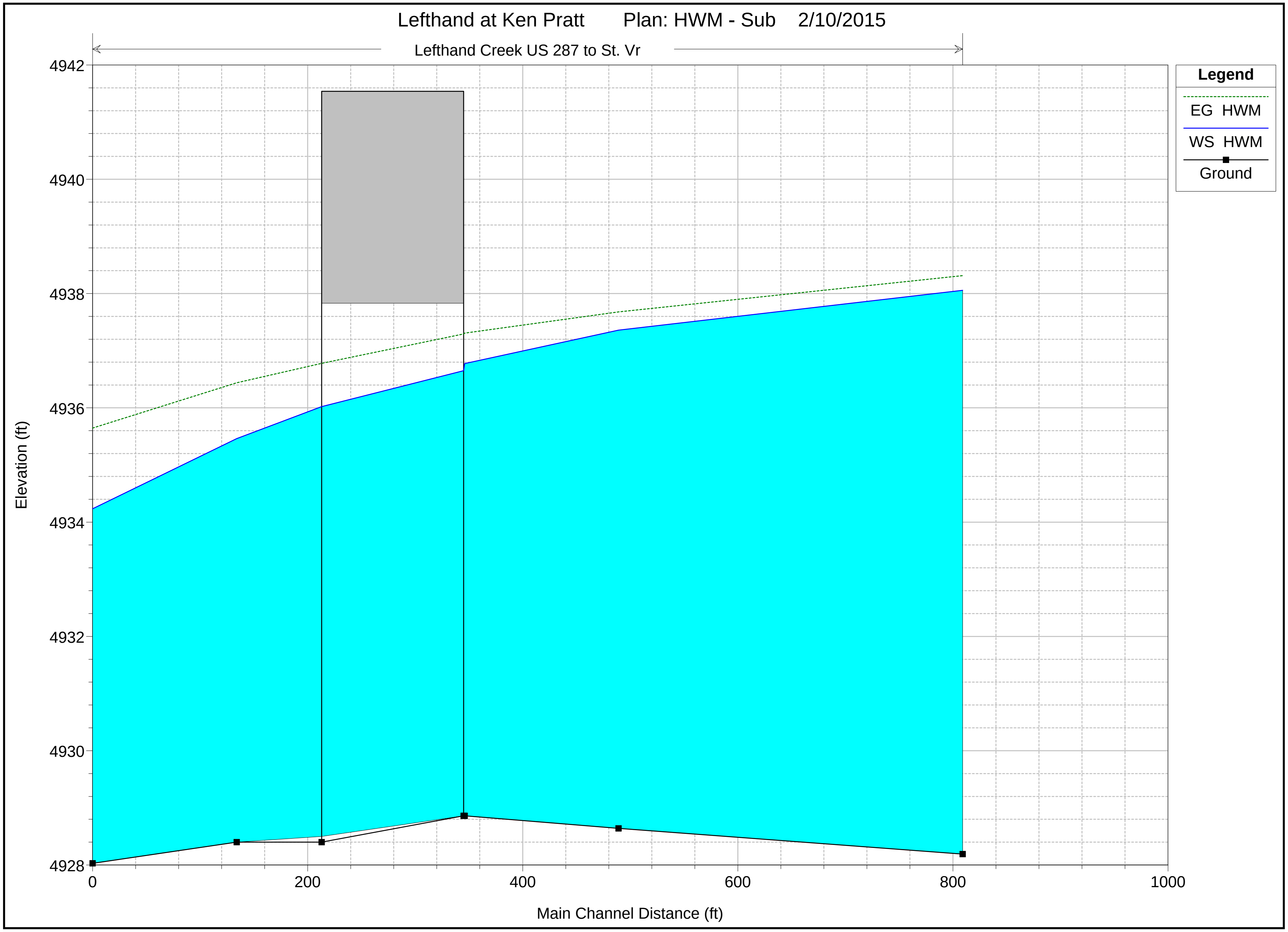


Left Hand at Ken Pratt

HEC-RAS Plan: HWM Sub River: Lefthand Creek Reach: US 287 to St. Vr Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
US 287 to St. Vr	1609	HWM	4800.00	4928.19	4938.06	4934.73	4938.31	0.001930	6.08	1304.98	232.20	0.38
US 287 to St. Vr	1289	HWM	4800.00	4928.64	4937.36	4933.80	4937.68	0.002011	6.43	1229.18	222.88	0.41
US 287 to St. Vr	1146	HWM	4800.00	4928.86	4936.77	4934.25	4937.31	0.003027	7.88	945.39	165.40	0.50
US 287 to St. Vr	1067		Bridge									
US 287 to St. Vr	934	HWM	4800.00	4928.40	4935.46	4934.11	4936.44	0.004171	9.00	724.98	147.51	0.65
US 287 to St. Vr	800	HWM	4800.00	4928.03	4934.23	4934.23	4935.65	0.007855	10.53	649.98	230.27	0.85

Left Hand at Ken Pratt

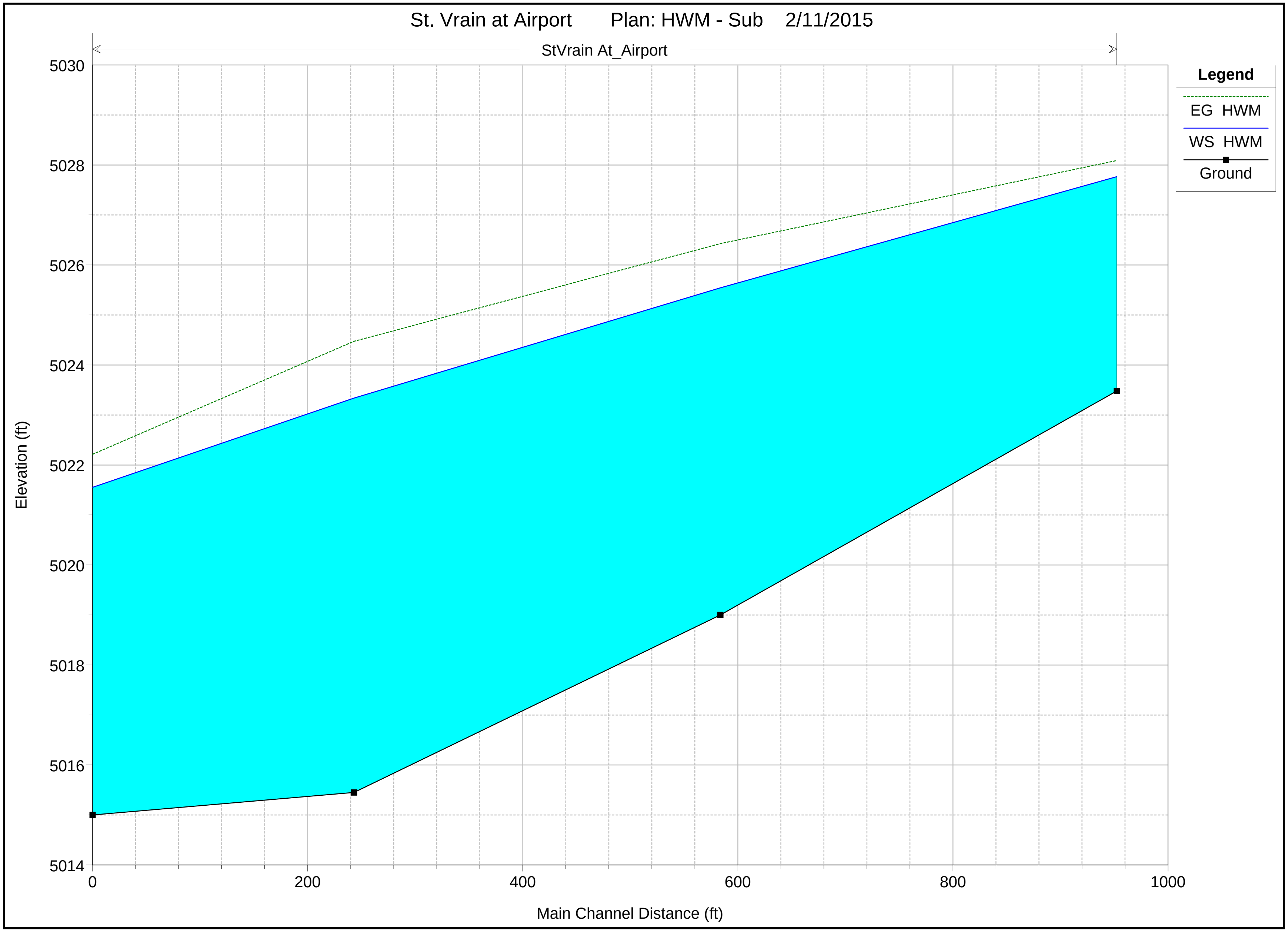


St. Vrain Creek
HEC-RAS Results

St. Vrain at Airport

HEC-RAS Plan: HWM Sub River: StVrain Reach: At_Airport Profile: HWM

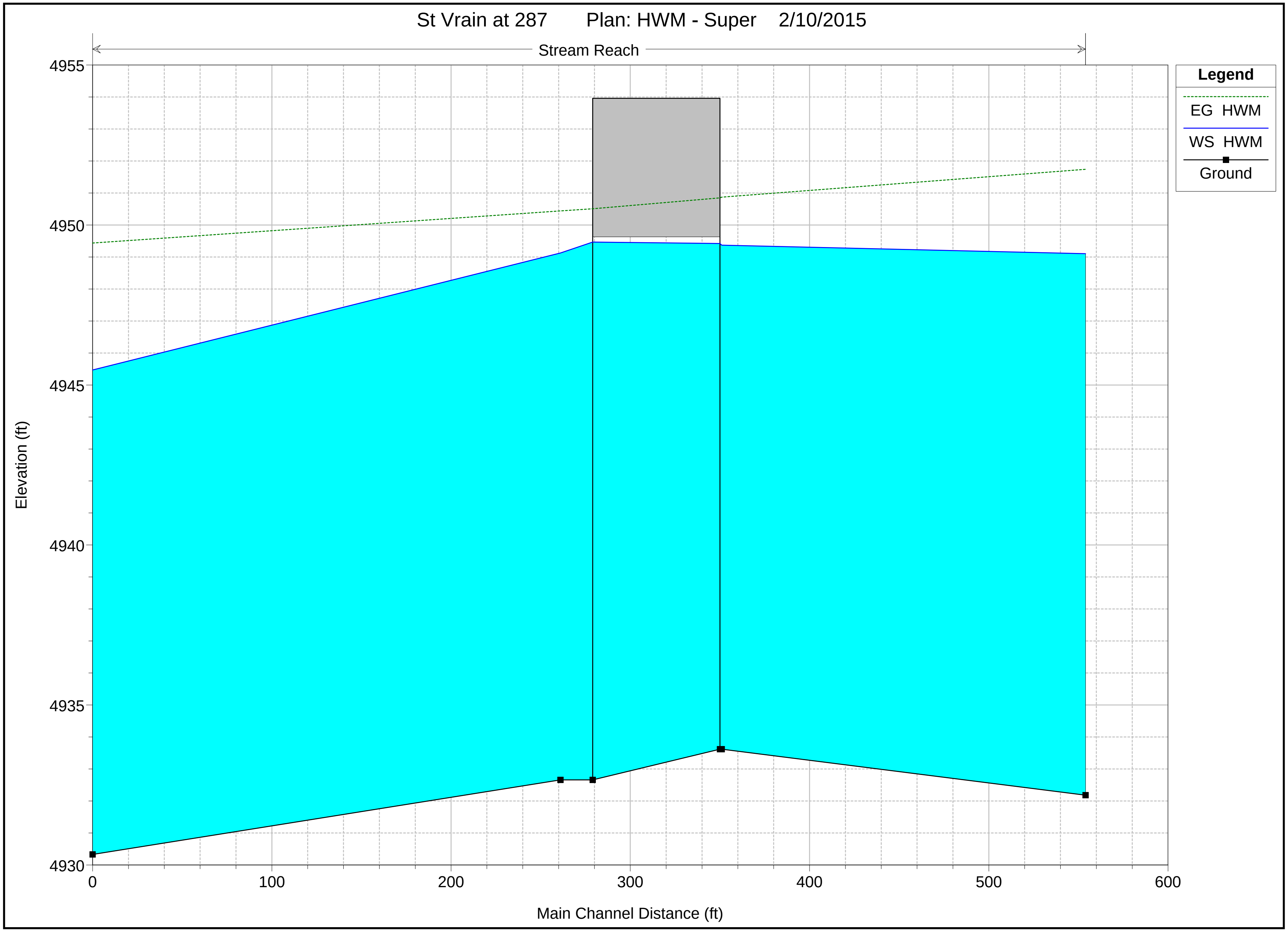
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
At_Airport	1486.316	HWM	14000.00	5023.48	5027.77	5026.83	5028.09	0.003893	6.35	4226.68	2147.94	0.58
At_Airport	1117.65	HWM	14000.00	5019.00	5025.54	5025.54	5026.43	0.004906	8.92	2986.14	1672.45	0.69
At_Airport	777.0211	HWM	14000.00	5015.45	5023.34	5023.34	5024.47	0.005145	9.85	2410.87	1751.79	0.72
At_Airport	533.9273	HWM	14000.00	5015.00	5021.55	5021.55	5022.22	0.004387	8.36	3757.45	2709.84	0.65


St. Vrain at Airport Plan: HWM - Sub 2/11/2015
StVrain At_Airport
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
5030
5028
5026
5024
5022
5020
5018
5016
5014
0
200
400
600
800
1000
Main Channel Distance (ft)

St. Vrain at 287

HEC-RAS Plan: HWM - Super   River: Stream   Reach: Reach   Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach	654	HWM	14500.00	4932.18	4949.10	4946.57	4951.74	0.003888	15.41	1423.46	148.47	0.71
Reach	451	HWM	14500.00	4933.62	4949.37	4944.80	4950.87	0.001850	10.87	1743.20	159.65	0.50
Reach	450		Bridge									
Reach	361	HWM	14500.00	4932.66	4949.13	4944.46	4950.44	0.001685	10.52	1846.43	181.47	0.48
Reach	100	HWM	14500.00	4930.33	4945.47	4945.47	4949.44	0.005772	17.65	1168.03	169.34	0.84

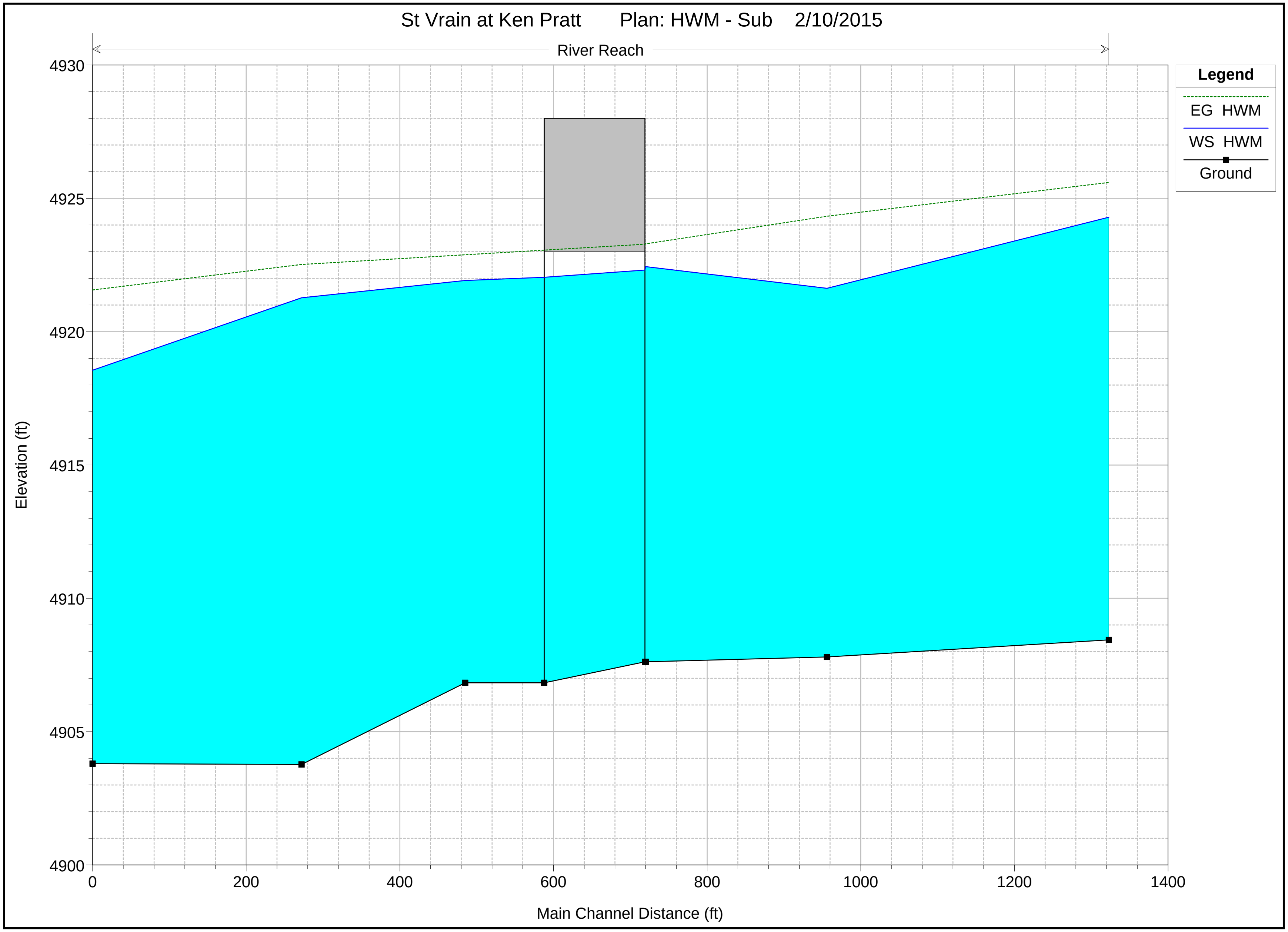

St Vrain at 287 Plan: HWM - Super 2/10/2015
Stream Reach
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4955
4950
4945
4940
4935
4930
0
100
200
300
400
500
600
Main Channel Distance (ft)

St. Vrain at Ken Pratt

HEC-RAS Plan: HWM - Sub   River: River   Reach: Reach   Profile: HWM

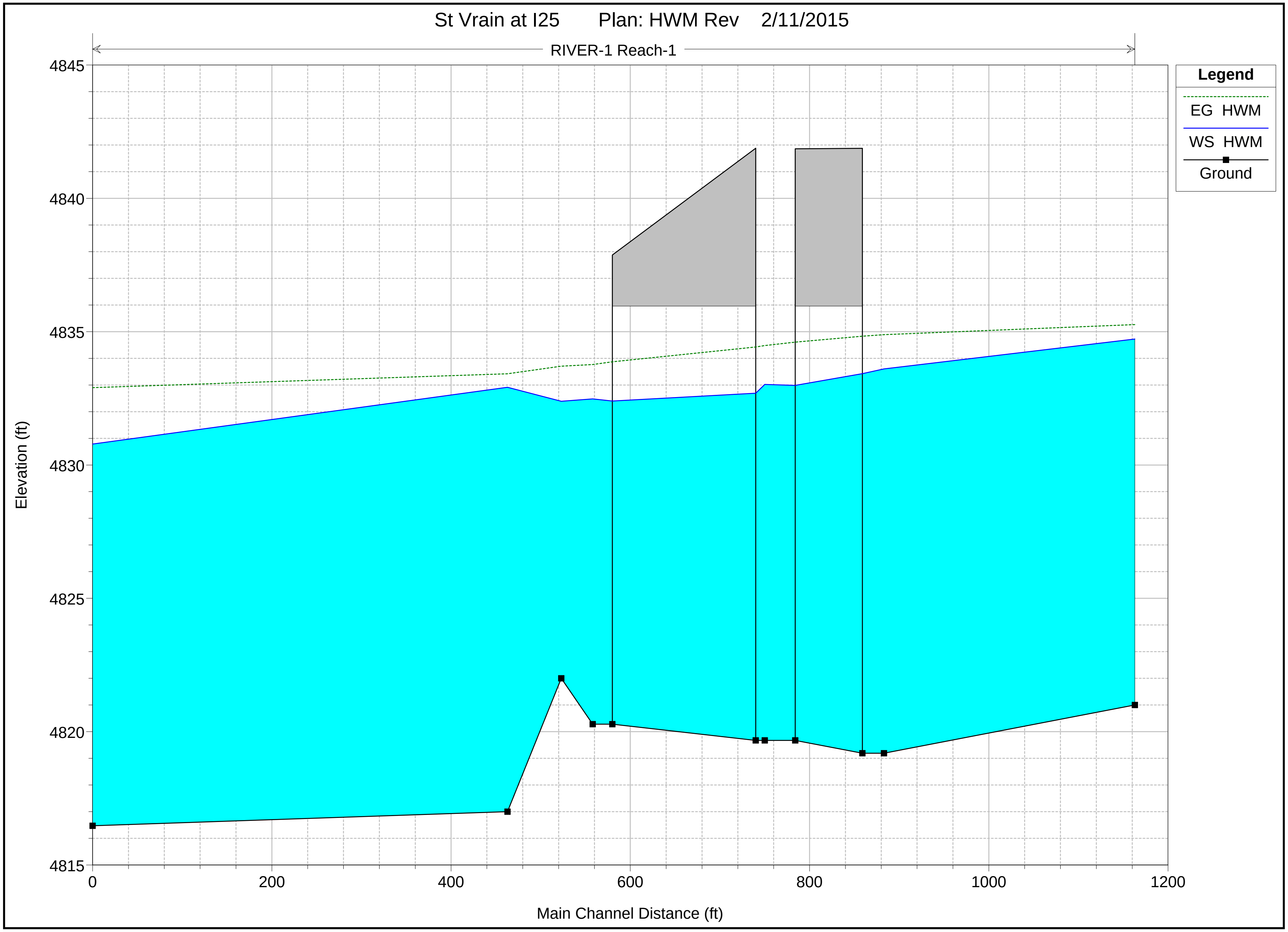
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach	1378	HWM	18500.00	4908.44	4924.29	4920.97	4925.59	0.002364	11.62	2608.53	263.71	0.54
Reach	1011	HWM	18500.00	4907.80	4921.63	4920.82	4924.33	0.004165	14.69	1821.17	239.69	0.72
Reach	775	HWM	18500.00	4907.62	4922.44	4917.13	4923.29	0.001192	7.67	2657.07	290.11	0.38
Reach	774		Bridge									
Reach	540	HWM	18500.00	4906.83	4921.92	4916.94	4922.89	0.001357	8.07	2494.23	282.47	0.41
Reach	327	HWM	18500.00	4903.77	4921.27	4917.26	4922.52	0.001858	10.54	2460.61	300.95	0.49
Reach	55	HWM	18500.00	4903.80	4918.55	4918.55	4921.56	0.005052	16.26	1844.45	278.21	0.79

St. Vrain at Ken Pratt



HEC-RAS Plan: HWM Rev River: RIVER-1 Reach: Reach-1 Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach-1	1766.598	HWM	23500.00	4821.00	4834.73	4829.05	4835.27	0.000851	6.74	4275.77	441.00	0.37
Reach-1	1486.598	HWM	23500.00	4819.19	4833.60	4829.64	4834.89	0.001444	9.37	2757.65	283.90	0.49
Reach-1	1462.498		Bridge									
Reach-1	1353.598	HWM	23500.00	4819.67	4833.02	4829.96	4834.48	0.001880	9.99	2571.49	289.39	0.55
Reach-1	1343.498		Bridge									
Reach-1	1161.598	HWM	23500.00	4820.28	4832.48	4829.18	4833.77	0.001689	9.27	2664.22	322.91	0.52
Reach-1	1126.598	HWM	23500.00	4822.00	4832.39	4829.14	4833.71	0.001722	9.36	2637.57	322.12	0.53
Reach-1	1066.598	HWM	23500.00	4817.00	4832.91	4824.14	4833.42	0.000372	5.86	4306.12	384.59	0.26
Reach-1	603.598	HWM	23500.00	4816.47	4830.78	4828.32	4832.90	0.002503	12.52	2418.26	357.78	0.65

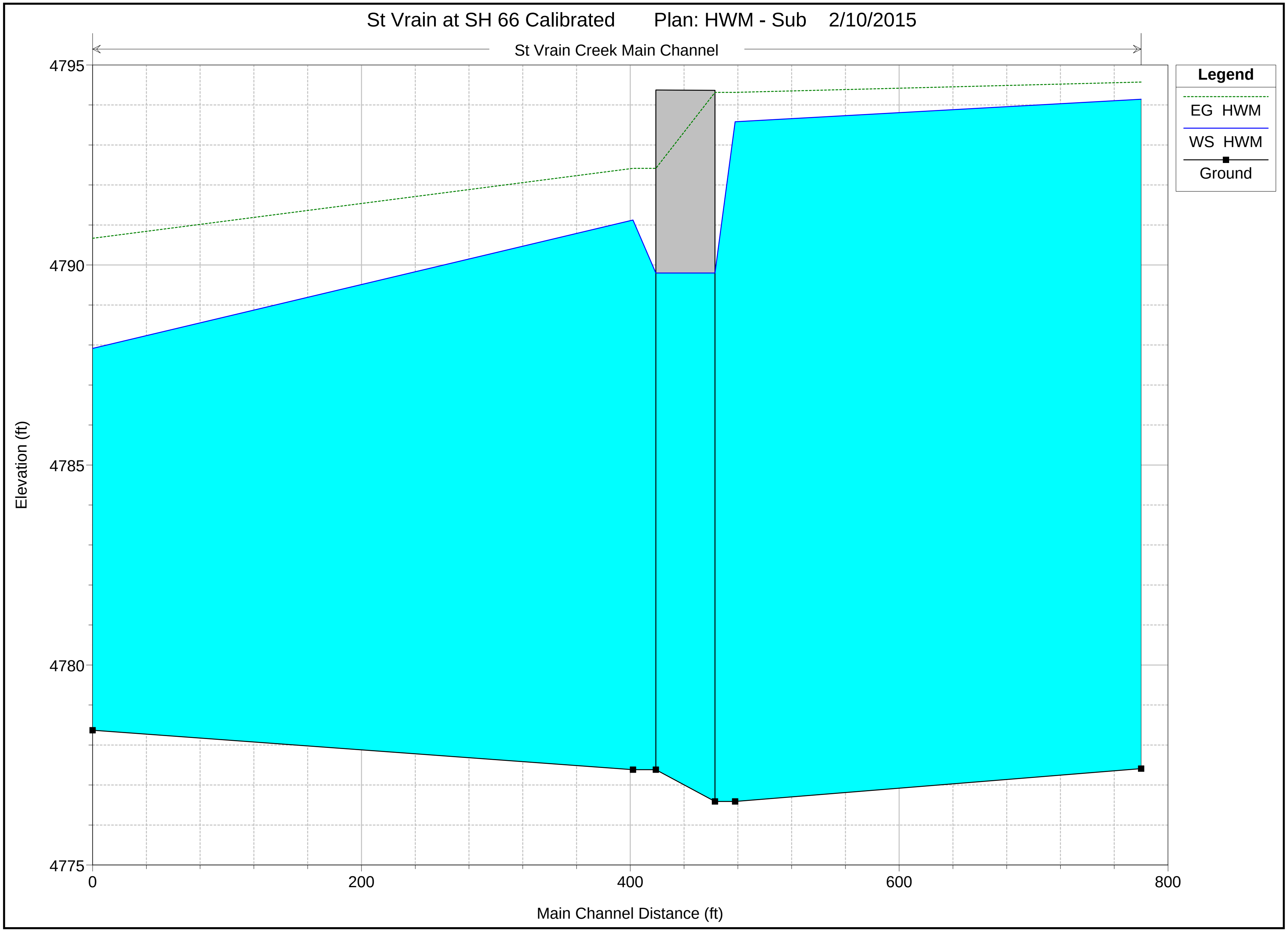


St Vrain at I25 Plan: HWM Rev 2/11/2015
RIVER-1 Reach-1
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4845
4840
4835
4830
4825
4820
4815
0
200
400
600
800
1000
1200
Main Channel Distance (ft)

St. Vrain at SH 66

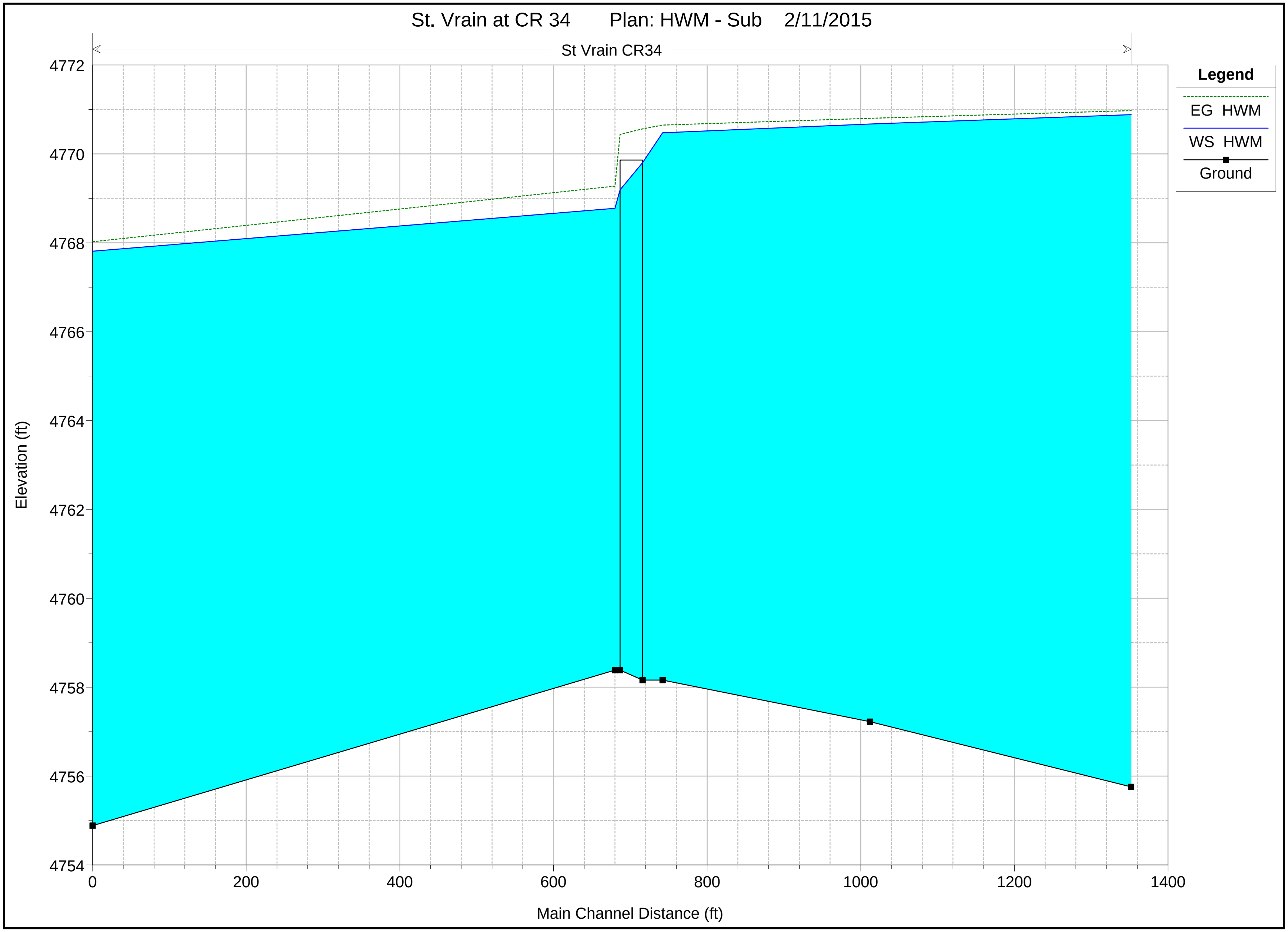
HEC-RAS Plan: HWM - Sub River: St Vrain Creek Reach: Main Channel Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main Channel	1780	HWM	23000.00	4777.41	4794.14	4786.83	4794.57	0.000586	5.82	4790.88	400.71	0.26
Main Channel	1478	HWM	23000.00	4776.59	4793.58	4786.94	4794.32	0.001041	6.90	3353.10	299.65	0.34
Main Channel	1463		Bridge									
Main Channel	1402	HWM	23000.00	4777.38	4791.13	4787.60	4792.42	0.002598	9.40	2570.84	276.69	0.52
Main Channel	1000	HWM	23000.00	4778.37	4787.92	4787.92	4790.67	0.008608	13.97	1882.23	333.27	0.89


St Vrain at SH 66 Calibrated Plan: HWM - Sub 2/10/2015
St Vrain Creek Main Channel
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4795
4790
4785
4780
4775
0
200
400
600
800
Main Channel Distance (ft)

HEC-RAS Plan: HWM - Sub   River: St Vrain   Reach: CR34   Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
CR34	1852	HWM	27000.00	4755.76	4770.88	4767.78	4770.97	0.000521	3.71	12188.08	3320.76	0.22
CR34	1512	HWM	27000.00	4757.22	4770.67	4767.64	4770.80	0.000477	4.38	12318.03	3639.24	0.22
CR34	1242	HWM	27000.00	4758.16	4770.48	4768.40	4770.65	0.000633	4.66	10680.74	2913.67	0.26
CR34	1206		Bridge									
CR34	1180	HWM	27000.00	4758.38	4768.78	4768.01	4769.28	0.002085	7.36	6862.47	2945.71	0.45
CR34	500	HWM	27000.00	4754.89	4767.81	4766.57	4768.02	0.001435	6.87	9135.60	3445.60	0.38



St. Vrain at CR 34 Plan: HWM - Sub 2/11/2015
St Vrain CR34
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4772
4770
4768
4766
4764
4762
4760
4758
4756
4754
0
200
400
600
800
1000
1200
1400
Main Channel Distance (ft)

Appendix F
Drainage Area Reduction Factor Documentation

Colorado Front Range 24-hr Rainfall Areal Reduction Factors (Applied Weather Associates, 2015)

PO Box 175
Monument, CO 80132
(719) 488-4311
http://appliedweatherassociates.com

March 27, 2015

Memo for Record

To: CDOT Flood Hydrology Committee

Subject: Colorado Front Range 24-hr Rainfall Areal Reduction Factors

1. Overview

The Colorado Department of Transportation (CDOT) Flood Hydrology Committee tasked Applied Weather Associates (AWA) to derive 24-hour areal reduction factors (ARFs) for the Front Range of Colorado for area sizes of 1- to 1000-sqmi. In addition, basin specific ARFs for the September 2013 rainfall event were calculated for four basins (Boulder Creek, St Vrain Creek, Big Thompson River, and Thompson River).

This study was initiated due to areal limitations associated with the National Ocean and Atmospheric Administration (NOAA) Atlas 2 ARF curves. NOAA Atlas 2 ARF curves extend from 1-sqmi to 400-sqmi. For Phase I of the CDOT September 2013 Flood Study, the NOAA Atlas 2 ARFs were used since drainage area sizes analyzed were less than 400-sqmi. For Phase II of the CDOT September 2013 Flood Study, the NOAA Atlas 2 ARFs required an update specific to each basin because the drainage area sizes were larger than 400-sqmi. The Phase II 24-hour ARF curve extends out to 1,000-sqmi and are only applicable to Phase II of the CDOT September 2013 Flood Study.

2. Introduction

Information about extreme precipitation is of interest for a variety of purposes, which include meteorological and hydrologic engineering applications such as dam design, river management, and rainfall-runoff-relations. These entail knowledge on the spatial and temporal variability of precipitation over an area. In order to obtain areal average values for an area, point rainfall amounts are transformed to average rainfall amounts over a specified area. These issues are addressed using depth-area curves which require the use of ARFs. The derivation of ARFs is an important topic that has been dealt with using several methodologies.

The National Ocean and Atmospheric Administration (NOAA) defines an ARF as the ratio between area-averaged rainfall to the maximum depth at the storm center (NOAA Atlas 2, 1973). The most common sources for generalized ARFs and depth-area curves in the United States are from the NOAA Atlas 2 (NOAA Atlas 2, 1973) (Figure 1), and the U.S. Weather

Bureau's Technical Paper 29 (U.S. Weather Bureau, 1957-60). Examples of site specific ARFs and depth-area curves are referenced in the NOAA Technical Report 24 (Meyers and Zehr, 1980) for the semi-arid southwest, the NOAA Technical Memorandum Hydro- 40 (NOAA Hydro-40, 1980) for the semi-arid southwest, and the city of Las Vegas, Nevada (Gou, 2011).

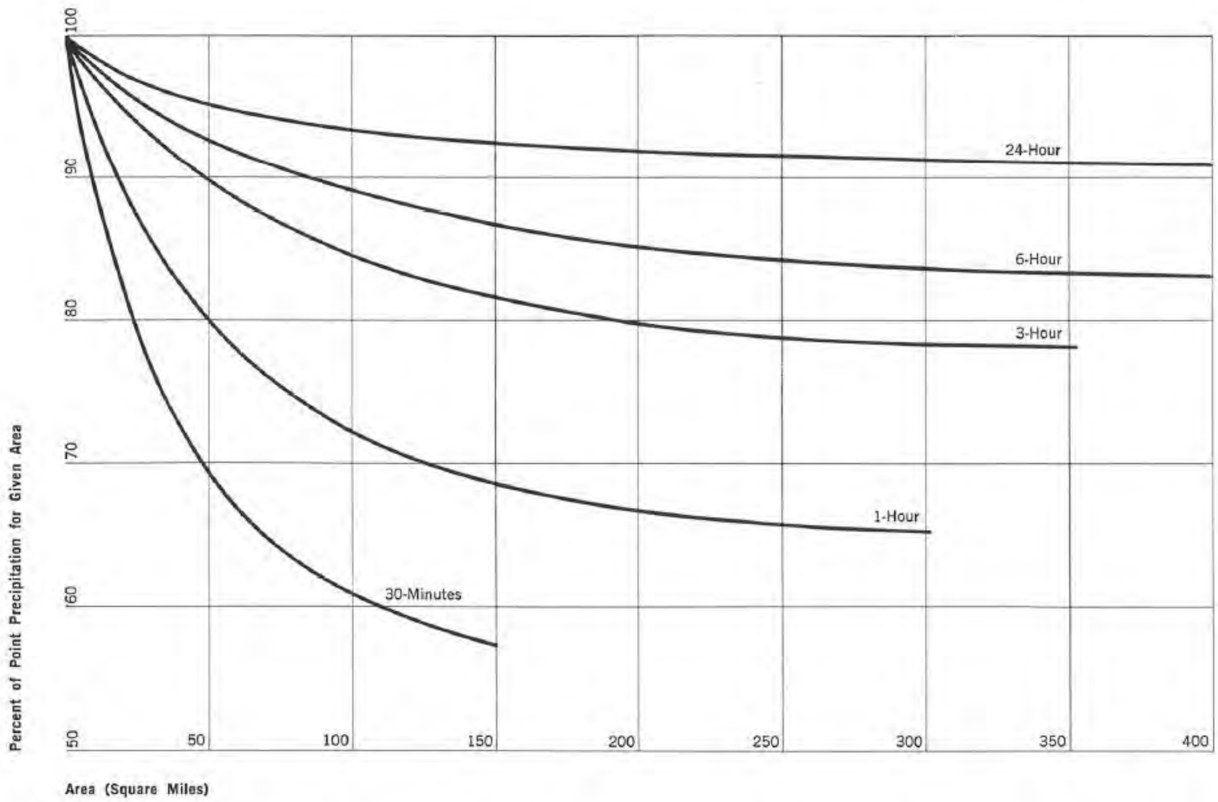


Figure 1: NOAA Atlas 2 Volume 3 ARF curves

There are two common methods for deriving ARFs: geographically fixed and storm centered. Geographically fixed ARFs originate from rainfall statistics, whereas storm centered ARF values are based on discrete rainfall events. Geographically fixed ARFs relate the precipitation depth at a point to a fixed area. The representative point is the mean of annual maximum point rainfall values at gauged points located within the network (U.S. Weather Bureau, 1957-60; NOAA Atlas 2, 1973; Osborn et al., 1980). This is a hypothetical point rather than a point for a particular location. The areas within the network are known beforehand and are both fixed in time and space (U.S. Weather Bureau, 1957-60; Osborn et al., 1980). With geographically fixed ARFs, the storm center does not correspond with the center of the location and does not need to fall within the area at all (Omolayo, 1993). Geographically fixed ARFs are based on different parts of different storms instead of the maximum point values located at the representative storm centers. A geographically fixed ARF is calculated as:

$$ARF_{Fixed} = \frac{\frac{1}{n}\sum_{j=1}^{n}\hat{R}_j}{\frac{1}{k}\sum_{i=1}^{k}\left(\frac{1}{n}\sum_{j=1}^{n}R_{ij}\right)},$$

where $\hat{R}_j$ is the annual maximum areal rainfall for year *j*, R_{ij} is the annual maximum point rainfall for year *j* at station *i*, *k* is the number of stations in the area, and *n* is the number of years.

The storm centered ARF does not have a fixed area in which rain falls but changes dynamically with each storm event (NOAA Atlas 2, 1973; Gou, 2011). Instead of the representative point being an average, the representative point is the center of the storm, defined as the point of maximum rainfall. Storm centered ARFs are calculated as the ratio of areal storm rainfall enclosed between isohyets equal to or greater than the isohyet value to the maximum point rainfall at the storm center. A storm centered ARF is calculated as:

$$ARF_{center} = \frac{\overline{R}_i}{R_{center}},$$

where $\overline{R}_i$ is the areal storm rainfall enclosed between isohyets equal to or greater than the isohyets, and R_{center} is the maximum point rainfall at the storm center.

3. Methods

AWA calculated ARFs using a storm centered depth-area approach based on gridded hourly rainfall data from the Storm Precipitation Analysis System (SPAS). SPAS has demonstrated reliability in producing highly accurate, high resolution rainfall analyses during hundreds of post-storm precipitation analyses (Tomlinson and Parzybok, 2004; Parzybok and Tomlinson, 2006). SPAS has evolved into a hydrometeorological tool that provides accurate precipitation data at a high spatial and temporal resolution for use in a variety of sensitive hydrologic applications. AWA and METSTAT, Inc. initially developed SPAS in 2002 for use in producing storm centered Depth-Area-Duration (DAD) values for Probable Maximum Precipitation (PMP) analyses. SPAS utilizes precipitation gauge data, “basemaps” and radar data (when available) to produce gridded precipitation at time intervals as short as 5-minutes, at spatial scales as fine as 1-km^2 and in a variety of customizable formats. To date, (January 2015) SPAS has analyzed over four-hundred storm centers across all types of terrain, among highly varied meteorological settings and with some events occurring over 100-years ago. For more detailed discussions on SPAS and DAD calculations refer to (Tomlinson et al., 2003-2012, Kappel et al., 2012-2014).

4. September 2013 Basin ARFs

The September 2013 can be classified as an upslope synoptic storm event associated with an area of low pressure to the east/southeast causing the air to flow into the Front Range (upslope) from the Midwest and Southern Plains. This air was forced to lift by both interaction with the terrain and the lift associated with the storm system. The storm event exhibited low to moderate intensity rainfall that occurred over long durations and contained periods of higher intensity rainfall. A detailed description of the meteorology associated with the storm can be found at http://coflood2013.colostate.edu/meteo.html.

The Colorado September 8-17, 2013 rainfall event was analyzed using the SPAS (SPAS number 1302) for use in several PMP and hydrologic model calibration studies (Figure 2). The hourly gridded rainfall data, based on gauge adjusted radar data, were used to derive basin specific ARFs. Four basins (Table 1) located along the Colorado Front Range were used to derive the 24-hour basin specific ARFs. The SPAS DAD program was used to derive basin specific 24-hour depth-area values. The point maximum (1-mi^2) 24-hour rainfall (within each basin) was selected as the storm center. The maximum average basin 24-hour rainfall depth for standard area sizes (1-, 10-, 25-, 50-, 100-, 200-, 300-, 400-, and 500-mi^2) up to the basin total area were calculated. The point maximum and maximum areal averages depths were used to calculate the basin specific ARFs.

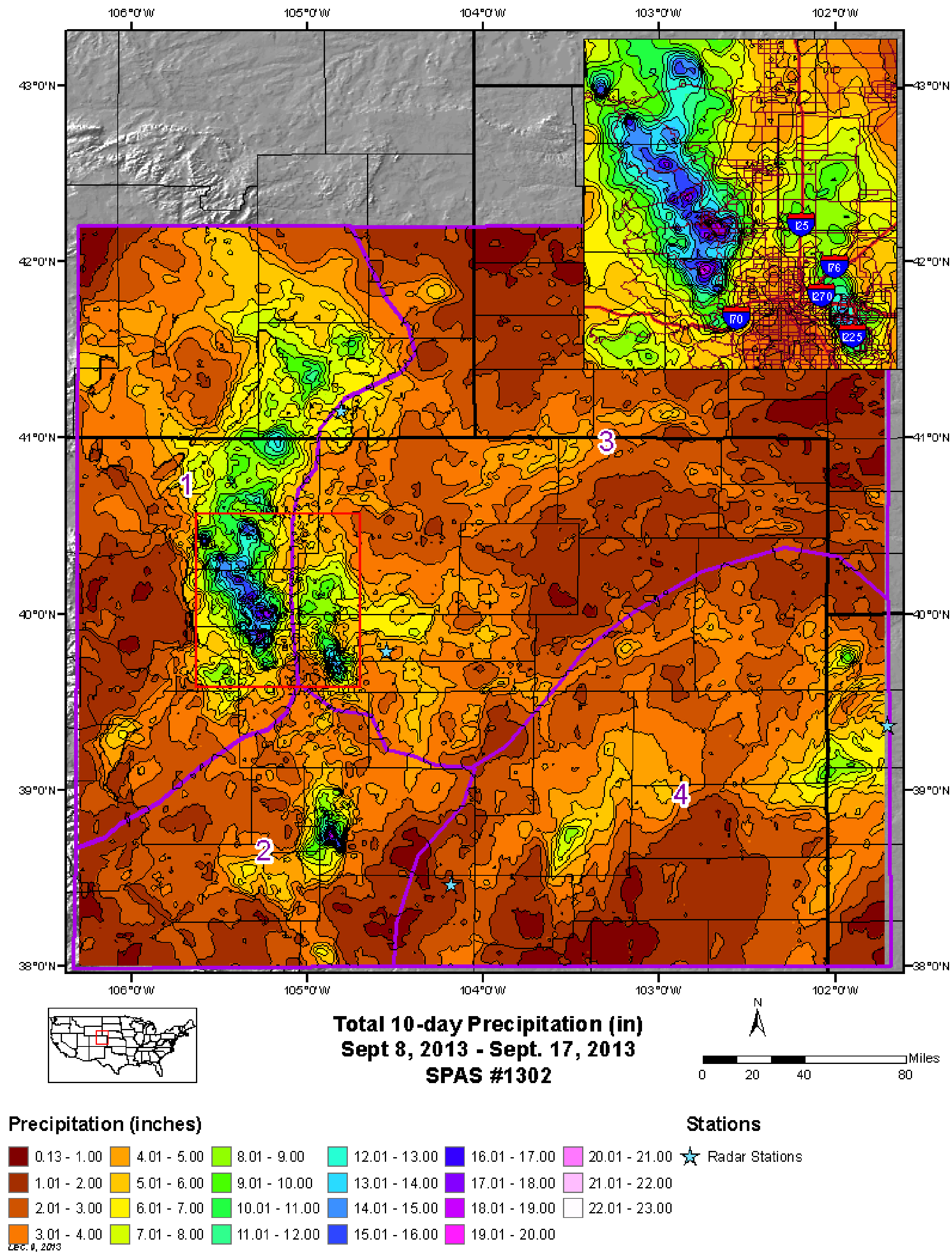


Figure 2: SPAS total rainfall for the Colorado September 8-17, 2013 storm event.

Table 1: Basin specific 24-hour ARFs for the September 2013 storm event

Basin	Area (mi^2)	ARF
Boulder Creek	446	0.352
St. Vrain Creek	982	0.384
Big Thompson River	630	0.357
Thompson River	827	0.355

The four calculated basin specific 24-hour ARFs for the September 2013 event were compared to NOAA Atlas 2 24-hour ARF curve and to the HMR 55A Orographic C 24-hour ARF curve (Hansen et al., 1988) (Figure 3). Table 1 shows the basin specific 24-hour ARF values. As expected, the four September 2013 basin ARF values have a significantly larger reduction in rainfall than published NOAA Atlas 2 and HMR 55A ARFs.

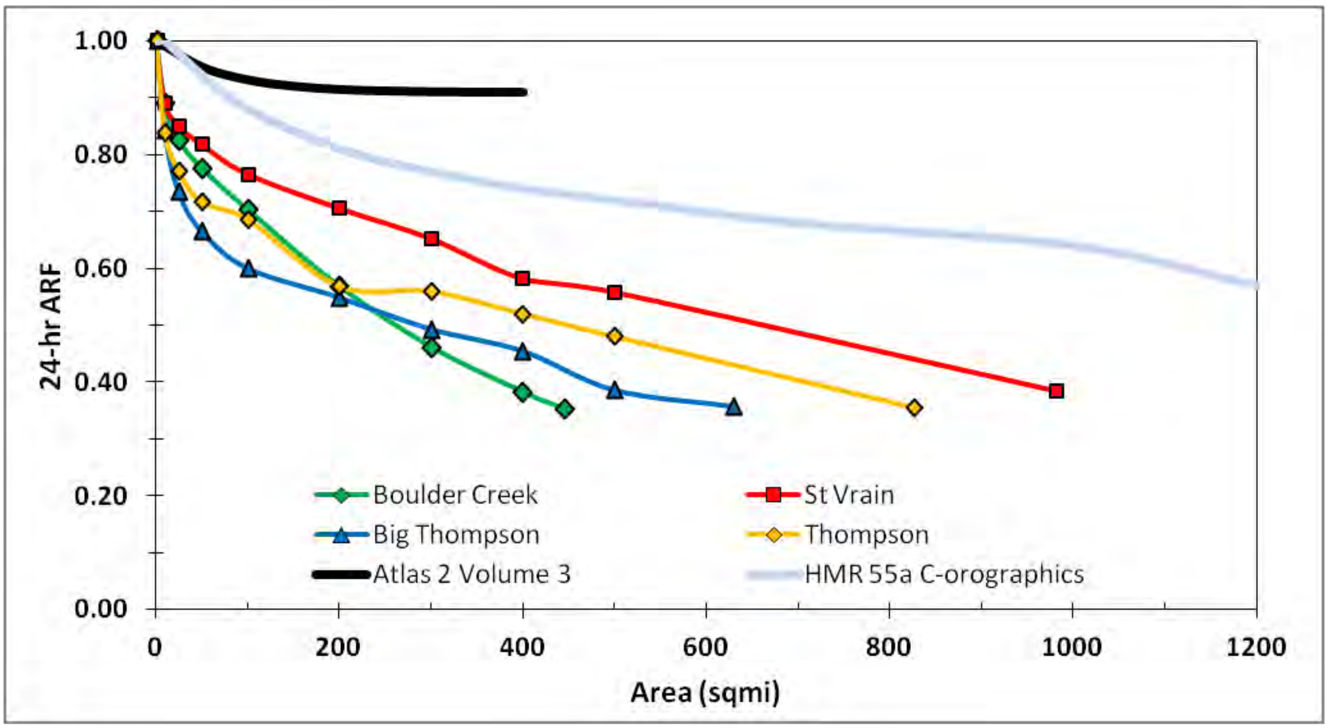


Figure 3: Basin specific 24-hour ARFs for the September 2013 event compared to NOAA Atlas 2 24-hour ARF curve and to the HMR 55A Orographic C 24-hour ARF curve

5. Colorado Front Range ARFs

Initially, 28 SPAS storm center DAD zones were identified to have occurred over similar meteorological and topographic regions as the September 2013 storm event that occurred along the Colorado Front Range (Figure 4). The initial list was refined to nine storm centers that had storm characteristics representative of an upslope synoptic event similar to the four basins analyzed in this study. Each storm event utilized in this analysis represented meteorological and topographical characteristics that were similar to each other and similar to the September 2013 event. All storms were of the synoptic type (aka HMR 55A General Storm). Each were associated with an area of low pressure to the east/southeast causing the air to flow into the Front Range (upslope) from the Midwest and Southern Plains. This air was forced to lift by both interaction with the terrain and the lift associated with the storm system. All nine events used exhibited low to moderate intensity rainfall, which occurred over long durations, interspersed with periods of higher intensity rainfall. Storm events removed from the initial list were representative of shorter duration, higher intensity storms, i.e. local storms/thunderstorms or occurred in significantly different topographical settings. This allowed the ARF data derived during this analysis to represent the same storm type and meteorological setting as occurred during the September 2013 event. The final set of nine storm centers (Table 2 and Figure 5) were used to derive 24-hour storm center ARFs.

The point maximum (1-mi^2) 24-hour rainfall (within each SPAS DAD zone) was selected as the storm center. The maximum average 24-hour rainfall depth for standard area sizes (1-, 10-, 25-, 50-, 100-, 150-, 200-, 250-, 300-, 350-, 400-, 450-, 500-, 700-, and 1000-mi^2) were calculated. The point maximum and maximum areal averages depths were used to calculate each events specific ARFs. Based on the nine events, an average ARF for each area size was calculated. Several other ARF curves were created for comparison purposes: maximum, minimum, +1-sigma, 85% confidence, 90% confidence, and 95% confidence. Based on discussions with the CDOT flood review committee and Nolan Doesken (Colorado State Climatologist), the 85% confidence ARF ($ARF_{85\%}$) was selected as the best representation of ARFs along the Colorado Front Range. The 85% confidence limit ARF was selected based on several justifications. Similar use of the 85% percentile was employed in the HMRs in determining various Depth-Area and Depth-Duration relationships. Further, during the site-specific Probable Maximum Precipitation (PMP) study for Lewis River, WA, the 85% was used to determine which Depth-Duration relationship were appropriate for deriving PMP values at durations other than 24-hours. That study was accepted for use by Federal Energy Regulatory Commission (Tomlinson et al., 2011). In addition, the 85% ARF curve is similar to independent study in HMR 55A (see Figure 6 and Table 3 below). Finally, the 85% ARF curve adds a level of conservatism compared to using the average ARF which is typical in most ARF studies. The final equation used to represent Colorado Front Range 24-hour ARFs is:

$$ARF_{85\%} = 0.646 + 0.354 * \exp(-kA)$$

where $ARF_{85\%}$ is the 85% confidence ARF, k is a decay coefficient, and A is storm area in square miles. The average ARF curve and final 85% confidence ARF curve are shown in Figure 6. The NOAA Atlas 2 ARF curve and HMR 55A Orographic C curve are also shown for comparison (Figure 6 and Table 3).

Table 2: Final SPAS storm centered locations with similar meteorology and topography as the September 2013 storm event used to derive 24-hr ARFs

ID	SPAS ID	Storm Location	Dates	Latitude	Longitude	Max Precipitation	HMR 55A CLASS	HMR 55A SUBUNIT
1	1211	Gibson Dam, MT	Jun. 6-8, 1964	48.3541	-113.3708	19.16	Orographic	Orographic "A"
2	1251	Lake Maloya, NM	May 17-21, 1955	37.0090	-104.3410	14.82	Orographic	Orographic "E"
3	1252	Waterton Red Rock, AB	June 14-21, 1975	49.0875	-114.0458	14.46	Orographic	Orographic "A"
4	1253	Big Elk Meadow, CO	May 3-8, 1969	40.2700	-105.4200	20.01	Orographic	Orographic "C"
5	1302	Northeast Colorado	Sep. 8-17, 2013	40.0150	-105.2650	20.41	Orographic	Orographic "C"
6	1320	Calgary, AB	Jun.19-22, 2013	50.6350	-114.8550	13.78	Orographic	Orographic "A"
7	1325	Savageton, WY	Sep. 27-Oct. 1, 1923	43.8458	-105.8042	17.56	Nonorographic	Min. Nonorographic "A"
8	1335	Warrick, MT	Jun. 5-10, 1906	48.0791	-109.7041	13.69	Orographic	Orographic "A"
9	1338	Spionkop Creek, AB	Jun. 4-7, 1995	49.1708	-114.1625	14.48	Orographic	Orographic "A"

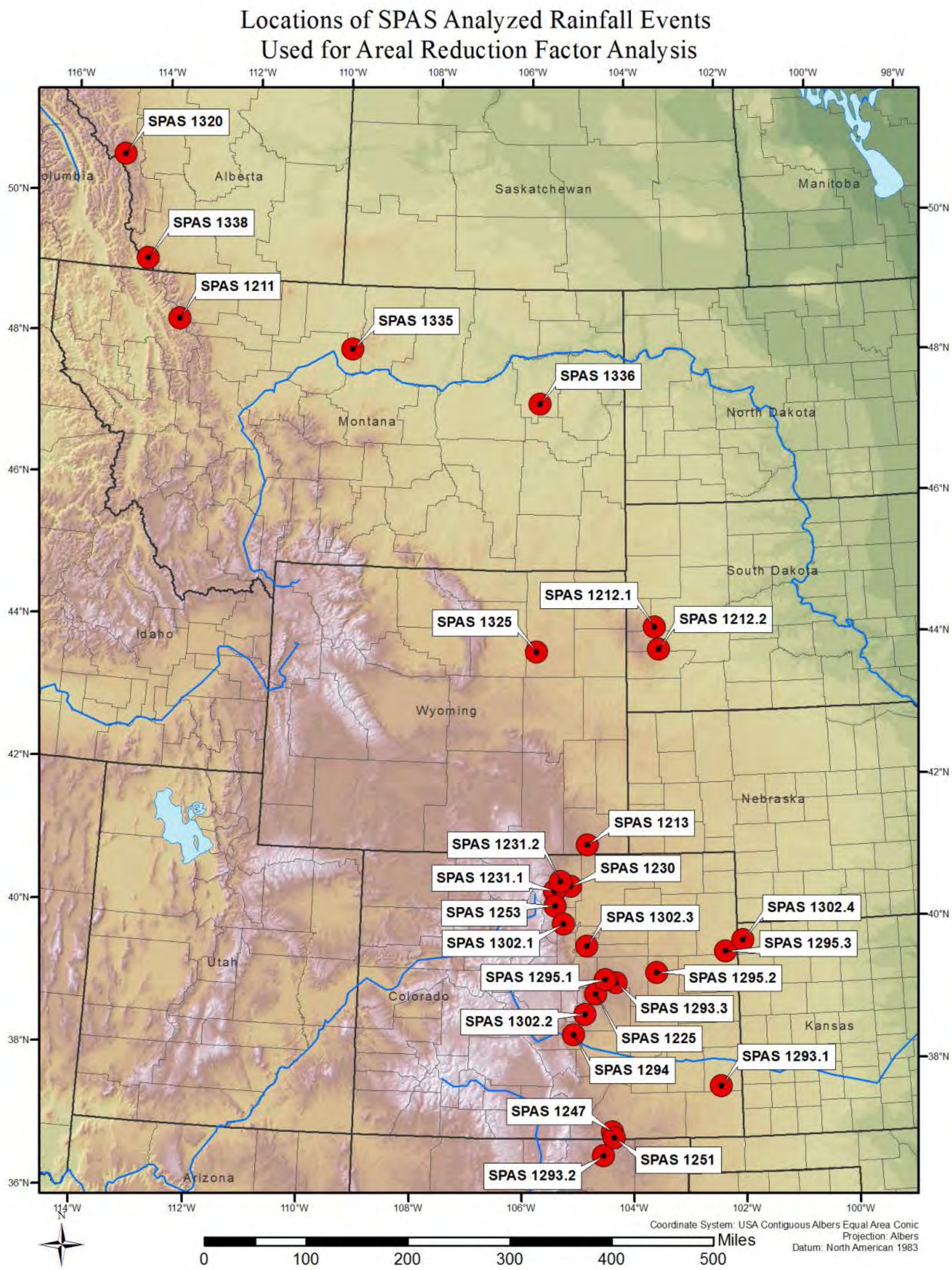


Figure 4: Initial 28 SPAS storm center locations with similar meteorology and topography as the September 2013 storm event

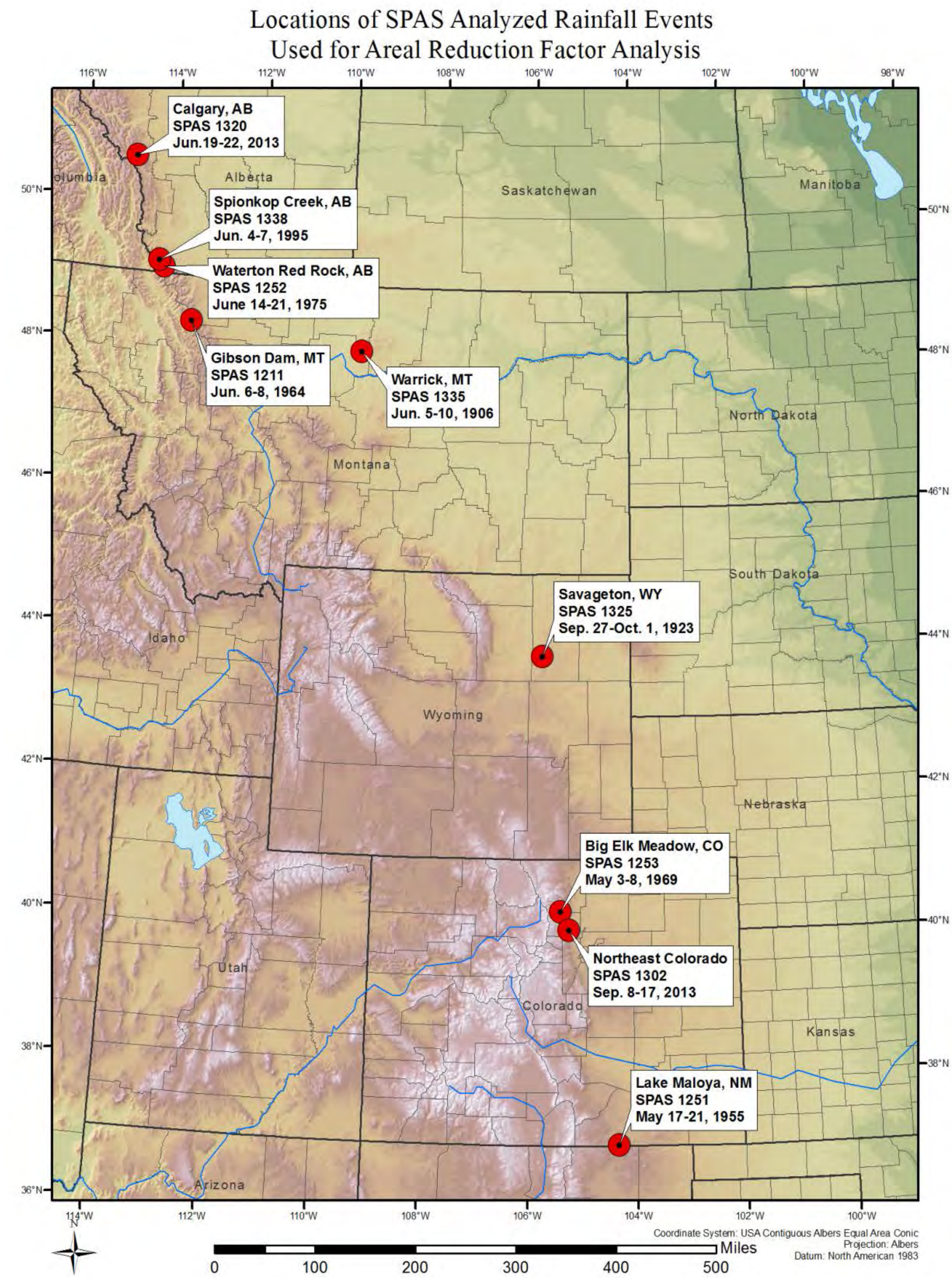


Figure 5: Final SPAS storm center locations used to derive 24-hr ARFs

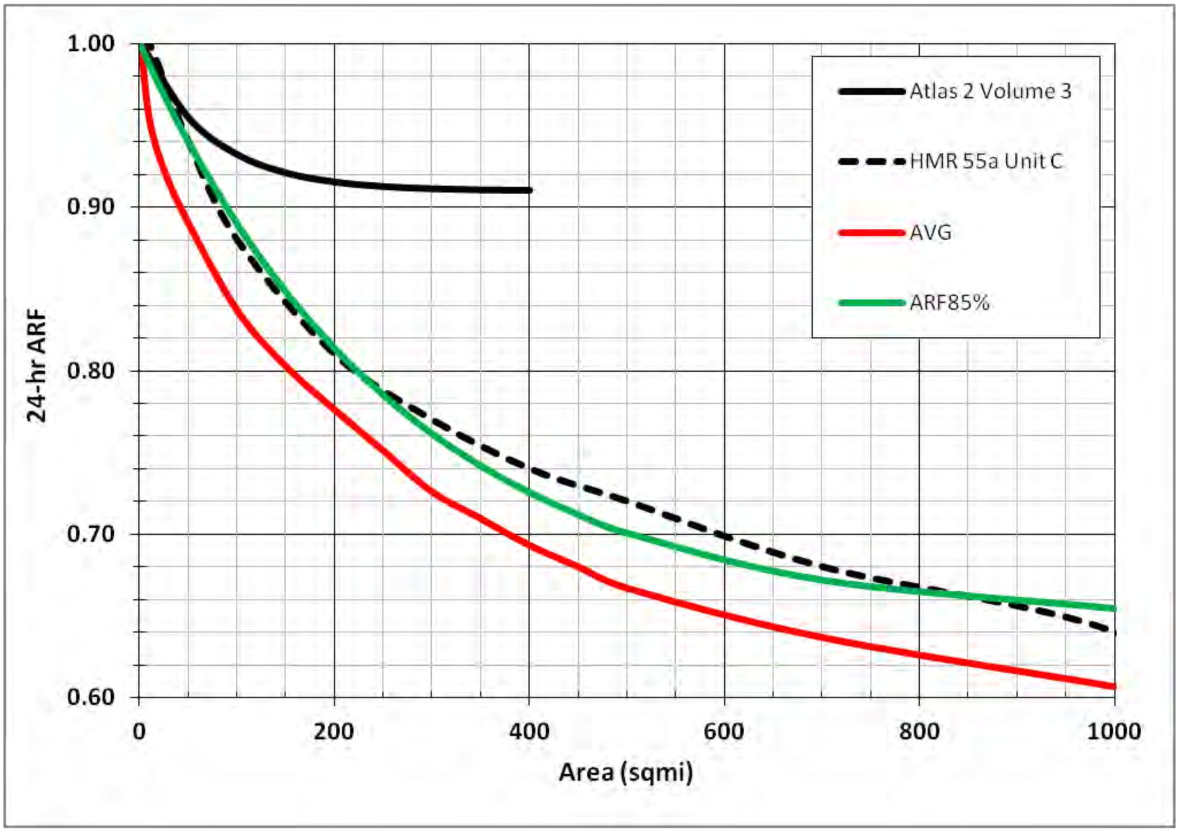


Figure 6: The average 24-hour ARF curve and final 85% confidence 24-hour ARF curve. The NOAA Atlas 2 24-hour ARF curve and HMR 55A Orographic C 24-hour ARF curve are shown for comparison.

Table 3: Comparison of 24-hour ARF values. AVG is the average ARF, ARF85% is the 85% confidence ARF, HMR 55A is HMR 55A Orographic C ARF, and Atlas 2 is NOAA Atlas 2 ARF.

*** General Storms 24-hr ARF				
Area (sqmi)	AVG	ARF85%	HMR 55a	Atlas 2
1	1.00	1.00	1.00	1.00
10	0.95	0.99	1.00	-
25	0.92	0.97	0.97	-
50	0.89	0.94	0.94	0.95
100	0.84	0.89	0.88	0.93
150	0.80	0.85	0.85	0.92
200	0.78	0.81	0.81	0.92
250	0.75	0.78	0.79	0.91
300	0.73	0.76	0.77	0.91
350	0.71	0.74	0.76	0.91
400	0.69	0.73	0.74	0.91
450	0.68	0.71	0.73	-
500	0.67	0.70	0.72	-
700	0.64	0.67	0.68	-
1000	0.61	0.65	0.64	-

6. Results

The final derived $ARF_{85\%}$ values created significantly larger reductions in point rainfall as compared to NOAA Atlas 2. Because results of the Phase I CDOT September 2013 Flood Study are not being changed as part of this work, a smooth transition between NOAA Atlas 2 24-hour ARF and the derived 24-hour $ARF_{85\%}$ is needed for Phase II basins. The largest basin used in Phase I was 315-mi^2 and the smallest basin used in Phase II was 446-mi^2. In order to maintain consistency between Phase I results and Phase II results, a linear transition was applied between NOAA Atlas 2 315-mi^2 ARF value and $ARF_{85\%}$ 500-mi^2 (Figure 7 and Table 4). Based on the areal limitations of NOAA Atlas 2, the larger point precipitation reductions based on $ARF_{85\%}$, and maintaining consistency with Phase I study the linear transition between NOAA Atlas 2 315-mi^2 ARF value and $ARF_{85\%}$ 500-mi^2 was chosen for application of Phase II of the CDOT September 2013 Flood Study. In addition, application of this transition in the hydrologic modeling for the four basins investigated showed good agreement and acceptable results. The final 24-hour $ARF_{85\%}$ curve is compared to the four basin specific 24-hour ARF curves for the September 2013 event (Figure 8).

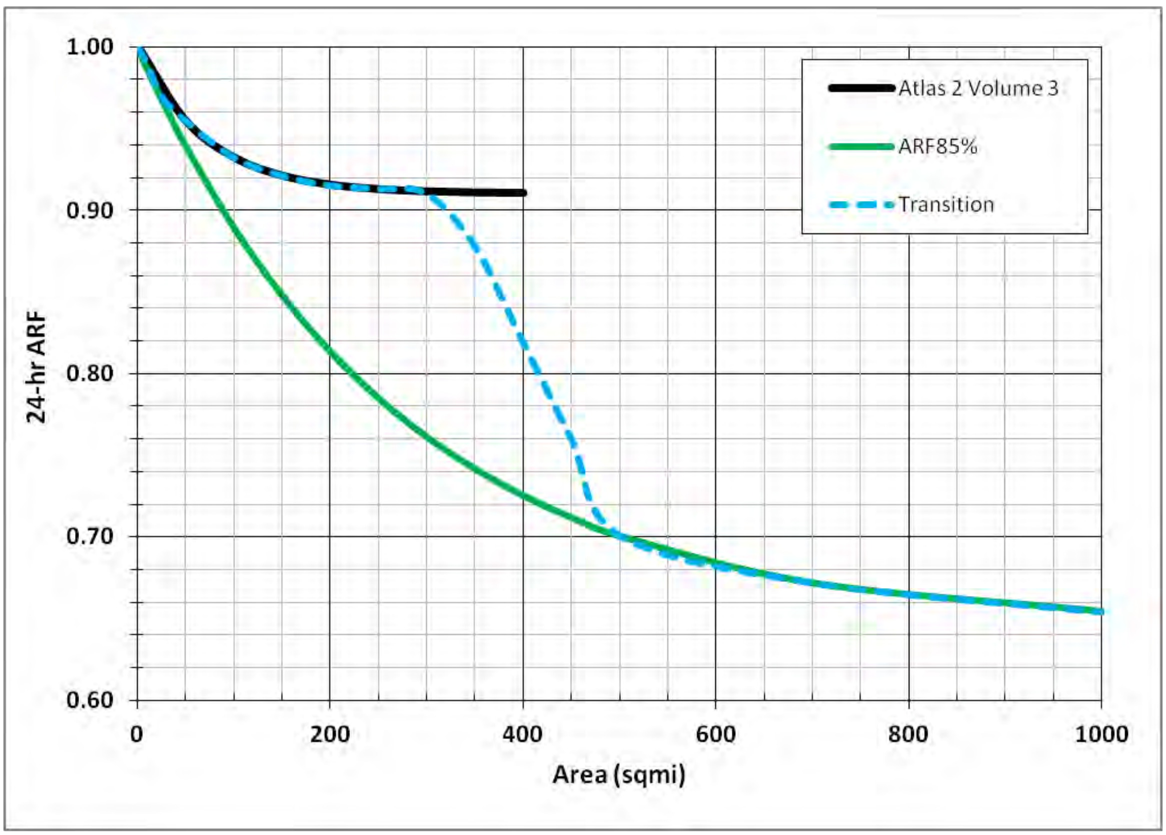


Figure 7: Final 24-hr ARF curve with transition between NOAA Atlas 2 and AWA $ARF_{85\%}$

Table 4: Comparison of final 24-hour ARF values. ARF85% is the 85% confidence ARF. Transition is the transition between NOAA Atlas 2 and ARF85%, and Atlas 2 is NOAA Atlas 2 ARF.

*** General Storms 24-hr ARF			
Area (sqmi)	ARF85%	Transition	Atlas 2
1	1.00	1.00	1.00
10	0.99	0.99	-
25	0.97	0.97	-
50	0.94	0.95	0.95
100	0.89	0.93	0.93
150	0.85	0.92	0.92
200	0.81	0.92	0.92
250	0.78	0.91	0.91
300	0.76	0.91	0.91
350	0.74	0.88	0.91
400	0.73	0.82	0.91
450	0.71	0.76	-
500	0.70	0.70	-
700	0.67	0.67	-
1000	0.65	0.65	-

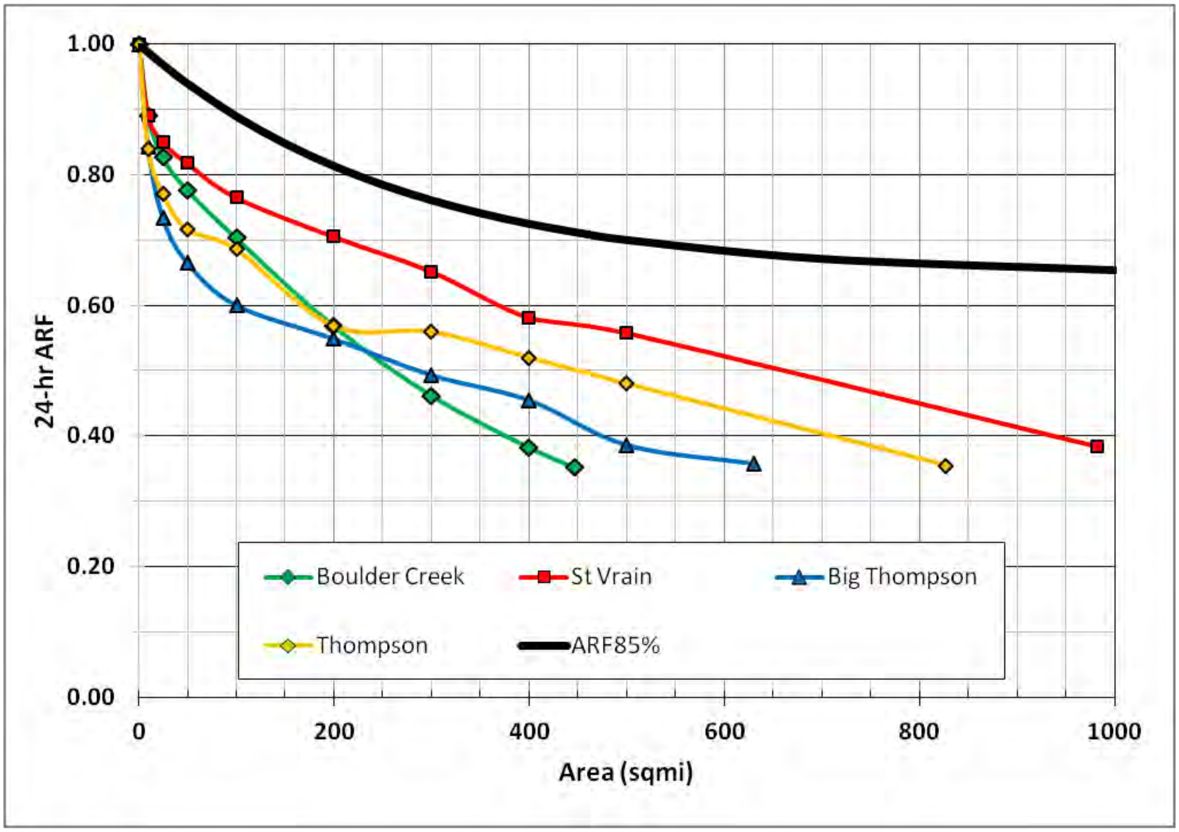


Figure 8: 24-hour ARF curve compared to basin specific ARFs for the September 2013 event

7. Conclusion

The final 24-hour $ARF_{85\%}$ values create significantly larger reductions of point rainfall at larger area sizes as compared to NOAA Atlas 2. These are based on actual storms that have occurred along the Front Range of the Rockies and of similar storm type as the September 2013 event. These updated ARF values produce more realistic and representative point to areal reductions for synoptic storm events along the Colorado Front Range. The 24-hour $ARF_{85\%}$ curve is only representative and applicable for large synoptic and orographic storm events similar to the September 2013 storm event in Colorado. Future hydrology and engineering flood studies should utilize a more site and duration specific ARF curve based on procedures applied in this study and storms specific to a given locations. This investigation has shown that the generalized ARF curves provided in NOAA Atlas 2 are not necessarily representative of spatial rainfall accumulations along the Colorado Front Range.

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Appendix G
Digital Data
(electronic only)

September 2013 Rainfall Data (Applied Weather Associates, 2014)
NOAA Rainfall Depths
ESRI ArcGIS Shapefiles
HEC-SSP Files
Calibrated HEC-HMS Hydrologic Model
Predictive HEC-HMS Hydrologic Model
Peak Discharge Table and Profile
Outfall Hydrographs for Big Thompson River Modeling [DARF = 0.66]