Final Report

Little Thompson River Hydrologic Analysis

Prepared for

Colorado Department of Transportation

August 2014

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
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Federal 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
SCS	Soil Conservation Service
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.

Signature:

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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 9 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 infrastructure; 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 reopen critical travel corridors, 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 determine the approximate magnitude of the September flood event in key locations throughout the watershed and to prepare estimates of peak discharge that can 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 the following:

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, 2013a). Compare results to updated flood frequency analyses and unit discharge information and calibrate as appropriate.

This report documents the 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) HEC-HMS hydrologic model. The hydrologic model was calibrated through adjustment of 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. In addition to closely evaluating land use cover, research was completed to determine how the water supply dams at Big Elk Meadows impacted flooding at U.S. Route 36 (US 36) during the September 2013 storm event. It was concluded that the Big Elk Meadow Dams were intended only for water supply and a series of the dams failed during the flooding event. It was determined by the State Engineer's Office that the Big Elk Meadows Dams did not increase the flooding on Little Thompson River due to the timing of the dam failures and the flood peaks. The results of this analysis are presented in *Report of September 2013 Little Thompson River Flooding and Big Elk Meadows Dam Failures* (Colorado Division of Water Resources Dam Safety Branch, 2014). Typically, water supply dams are not modeled when evaluating peak discharge rates; therefore, these dams and waters supply reservoirs were not included in the hydrologic modeling efforts. 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 are 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
#61	LT-J3	Little Thompson River Midpoint of Watershed	13.8	2,470	2,258	-9%
#59	LT-J4 Without WF	Little Thompson River Upstream of Confluence with West Fork Little Thompson River	17.8	2,680	2,836	6%
#60	LT-J4	Little Thompson River Downstream of Confluence with West Fork Little Thompson River	43.19	7,800[a]	8,955	15%
#64	LT-J4 Without LT	West Fork Little Thompson River Upstream of Confluence with Little Thompson River	25.4	6,200	6,221	0%

[a] – This site was inaccessible and the observed peak discharge was estimated based on observations along similar, adjacent watersheds.

cfs = cubic feet per second

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 storm event) 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 concurrent alternative estimates of annual chance peak discharges. The assumptions and limitations of the various methodologies were closely reviewed, compared, and contrasted. Considering the lack of historical data and previous studies, 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 US 36. These recommended values are shown in **Table ES-2**. With this recommendation, the peak discharges observed along the Little Thompson River during the September 2013 storm event had an estimated recurrence interval that exceeded the 0.2 percent annual chance peak discharge, or a 500 – year storm event.

TABLE ES-2
Little Thompson River Estimate of September 2013 High-Flow Recurrence Interval

		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 Midpoint of Watershed	2,470	58	186	376	660	1,777	> 500
Little Thompson River Upstream of Confluence with West Fork Little Thompson River	2,680	74	237	477	838	2,254	> 500

TABLE ES-2
Little Thompson River Estimate of September 2013 High-Flow Recurrence Interval

Location	Observed Discharge (cfs)	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 West Fork Little Thompson River	7,800	648	1,365	2,243	3,418	7,504	> 500
West Fork Little Thompson River Upstream of Confluence with Little Thompson River	6,200	600	1,139	1,769	2,582	5,251	> 500
Little Thompson River at US 36	N/A	651	1,376	2,264	3,455	7,600	N/A

cfs = cubic feet per second

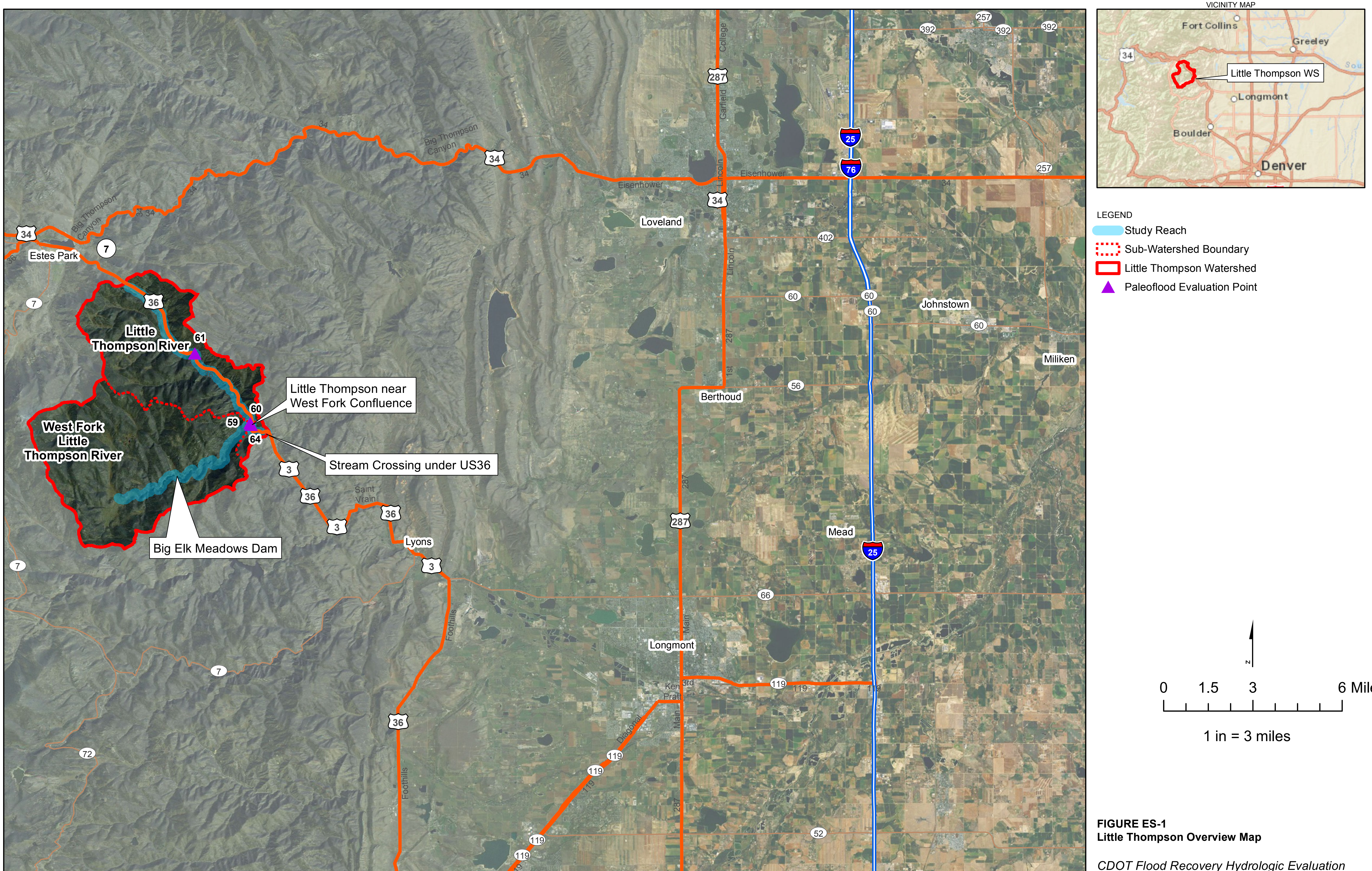

FIGURE ES-1
Little Thompson Overview Map

CDOT Flood Recovery Hydrologic Evaluation

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, calibrate the peak flow rate to the real-time data collected during September 2013, and determine the recurrence interval for the September 2013 event.

1.2 Project Area Description

The study portion of the Little Thompson River watershed is located predominately in Larimer County in extreme north-central Colorado (see **Figure B-1** in **Appendix B** for a vicinity map of the watershed). The watershed is adjacent to the towns of Estes Park and Lyons along U.S. Route 36 (US 36). The study reach extends from the uppermost limits of the watershed near the Town of Estes Park to the confluence with the West Fork Little Thompson River, and has a total area of approximately of 43.2 square miles. Downstream of this confluence, the Little Thompson River extends approximately 47 miles into Boulder and Weld counties where it joins the Big Thompson River. The Little Thompson River is a Federal Emergency Management Agency (FEMA)-designated Zone A floodplain in this study area, which is documented on Flood Insurance Rate Map (FIRM) Panel 08069C1325F. There are no regulatory flow rates published for the Little Thompson River within this study area. The FEMA FIRM map for the Little Thompson River is provided in **Appendix A**.

The Little Thompson River watershed has been divided into two contributing tributary sub-watersheds as shown in **Figure B-1** in **Appendix B** for purposes of discussion: the Little Thompson River and the West Fork Little Thompson River. The confluence of these two rivers is approximately 0.9 mile upstream from the location where the Little Thompson River passes under US 36.

1.2.1 Little Thompson River

The Little Thompson River begins approximately 2 miles southeast of Estes park and continues along US 36 until it passes under the highway at Pinewood Springs (the downstream limits of the model). From Pinewood Springs, the Little Thompson River continues east for approximately 26 miles, eventually converging with the Big Thompson River near Milliken. The Little Thompson River sub-watershed is approximately 17.8 square miles in area and consists largely of evergreen forest with areas of pasture.

1.2.2 West Fork Little Thompson River

The West Fork Little Thompson River watershed is approximately 25.4 square miles in area and is bordered by the Twin Sisters Mountain southwest of the Little Thompson River watershed. A series of water supply reservoirs in the center of the watershed reside in the Big Elk Meadows area. The West Fork Little Thompson River sub-watershed is also primarily evergreen forest with areas of pasture. In 2002, the watershed experienced a fire that affected approximately 4,400 acres. Portions of the damage from this fire are still visible in recent aerial photographs. The Big Elk Meadows Subdivision is located near the upper reaches of the sub-watershed. This housing development is unique to the overall watershed. Other homes in the watershed are on sparsely distributed multi-acre lots.

1.3 Mapping

Elevation data for the Study Area was 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, 2013). NED raster tile ID “n40w106” and “n41w106” covered the entirety of the watershed. In addition to the NED dataset, 2013 Light Detection and Ranging (LiDAR) data, in LAS format, was 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 (2012) from the ESRI ArcGIS online data catalogue was used for the background imagery (ESRI, 2012).

1.4 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	Author	Description
Aerial Imagery	ESRI, 2013	Aerial Raster
GIS Raster	U.S. Geological Survey, 2013	Elevation data for approximately 30’ x 30’ grid.
1-Foot Contour Data	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* (2011)
Peak Discharge Estimates	Jarrett, In press	Estimates of September 2013 peak discharges using indirect methods
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

1.5 Flood History

The high-flow event in September 2013 was one of only a few high-flow events on record that did not occur in the typical peak snowmelt months of May, June, and July. The days preceding the event 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 Little Thompson River sub-watershed and 1.32 inches per hour in the West Fork Little Thompson River sub-watershed. The confluence of the West Fork Little Thompson River and the Little Thompson River was severely flooded, resulting in roadway failures and the closure of US 36.

2.0 Hydrologic Analyses

When determining an appropriate method to develop watershed hydrology, it is common to compare the gaged and ungaged approaches. Gaged analyses rely on recorded flow data to provide statistical estimates of discharge based on a significant period of record. *Bulletin 17B: Guidelines for Determining Flood Flow Frequency* recommends a minimum of 10 years of data to perform a flood frequency analysis (USGS, 1982). Ungaged analyses are based on tools that estimate flows based on watershed characteristics. A method that does not rely on gaged data is a physical-based analysis, or a peak flow estimate. This type of analysis estimates a peak flow during a storm event based on physical changes to an existing channel and can be useful when gages do not exist within a study area, which is the case with the Little Thompson River upstream of where it passes under US 36.

For this analysis, it was concluded that a rainfall-runoff model would be used to determine peak flows for the 10, 4, 2, 1, and 0.2 percent chance storm events after it is calibrated to the physical-based observation from the September 2013 storm event.

2.1 Previous Studies

As described below, two studies have been published to date documenting the hydrology of the Little Thompson River within the study reach: *Little Thompson River Hydrology Analysis – I-25 Frontage Road Mile marker 249.847, Weld County, Colorado* (CDOT, 2011) and *Little Thompson River Hydrology Analysis – Report of September 2013 Little Thompson River Flooding* (CDWR Dam Safety, 2014). No regulatory discharges have been approved by FEMA in the study area. Portions of the Little Thompson River in Boulder County, downstream of the study area, are documented in the effective Federal Insurance Study (FIS). Effective hydrology downstream from the study reach is according to the U.S. Army Corps of Engineers' (USACE's) *Water and Related Land Resources Management Study, Metropolitan Denver and South Platte River and Tributaries, Colorado, Wyoming, and Nebraska, Volume V – Supporting Technical Reports Appendices, Appendix H – Hydrology* (USACE, 1977).

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

To support two bridge replacement projects, C-17BN and C-17-F, upstream of Interstate 25 (I-25), CDOT performed a hydrologic analysis in 2011 to develop peak discharge rates for the Little Thompson River. This analysis was based on regional regression equations and the development of a Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) model. The CDOT model is larger in scale and has 14 subbasins that cover a larger study area, approximately 129 square miles more than the current study. Two of the subbasins in the CDOT model coincide with the area studied with this project. A comparison is made between the discharge downstream of these two subbasins and the discharge estimated by the predictive model in Section 3.2 of this report. The 100-year annual peak flow estimated by the CDOT 2011 model is 2,585 cubic feet per second (cfs) compared to 3,418 cfs in the predictive model at the Little Thompson River Downstream of the Confluence with West Fork Little Thompson River location. 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 aerial 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.

In addition to 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. 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.

2.1.2 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. 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, West Fork Little Thompson River Upstream of the Little Thompson River Confluence and Little Thompson River Upstream of the West Fork Little Thompson River Confluence, 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 on West Fork Little Thompson River upstream of the confluence with the Little Thompson River was 6,148 cfs in the Dam Safety model as compared to 6,221 cfs in the calibrated model. The modeled peak flow on the Little Thompson River upstream of Confluence with West Fork Little Thompson River is 3,312 cfs in the Dam Safety model as compared to 2,836 cfs in the calibrated model. The physical-based peak flow discharge observation is within 10 percent of each other and 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 determined that the dam failure occurred after the peak discharge caused by rainfall alone and did not cause incremental damage to the downstream channel.

2.2 Stream Gage Analysis

The only recording stream gage near the Little Thompson River is located approximately 10 miles downstream of the study reach, as shown on **Figure B-2** in **Appendix B**. 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 quit working during the September 2013 storm event. Prior to this, USGS owned the gage (USGS # 06742000) and compiled 17 non-consecutive years of data from 1929 to 1961. Terrain at that site is relatively gentle as compared to the watershed associated with the study reach. Due to its location and the assumption that the September 2013 peak discharge occurred after the gage stopped working, it was determined that information available at this gaging station has limited value for determining peak flows along the study reach of the Little Thompson River.

2.3 Peak Flow Estimates

One technique for estimating the peak flow after a significant storm event is to apply indirect methods that utilize observed high-water marks, channel geometry, and hydraulic properties to estimate recent peak discharges. USGS has been actively developing and applying indirect methodologies to estimate peak discharges in various watersheds along the Front Range and have validated one such methodology, the critical-depth method, to be accurate to within 15 percent of direct discharge measurements for streams with gradients exceeding 0.005 ft/ft, such as the streams in the affected Front Range area (Jarrett, 2013). This methodology was applied by AWA and its subconsultant, Bob Jarrett, to estimate peak discharges along Front Range streams that witnessed high-flows during the September 2013 event. The locations used for evaluation are shown in **Figure B-2** in **Appendix B** for Little Thompson. Some of the peak flow estimates determined after the September 2013 storm event are shown on **Table 2** (Jarrett, In press). It was determined that peak discharges determined from the critical-depth methodology were the most reliable estimates of peak flows for the September 2013 storm event. During that event, five water impoundments along the West Fork Little Thompson River in the Big Elk Meadows area were breached. The peak flow estimates were determined at these locations based on observations upstream of the confluence with the West Fork Little Thompson to determine the approximate peak discharges along the West Fork. According to the CWCB criteria, bodies of water not used for flood storage shall be omitted from the hydrologic model. The project sponsors agreed that including a dam break analysis as part of the calibration effort would not meet the goals of the project, determining peak discharges during design storm events based on calibrated values.

TABLE 2
Little Thompson Physical-based Peak Flow Observations

Site Number	Site Description	Peak Discharge (cfs)
#61	Little Thompson River Midpoint of Watershed	2,470
#59	Little Thompson River Upstream of Confluence with West Fork Little Thompson River	2,680
#60	Little Thompson River Downstream of Confluence with West Fork Little Thompson River	7,800[a]
#64	West Fork Little Thompson River Upstream of Confluence with Little Thompson River	6,200

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

cfs = cubic feet per second

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, 2010) 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 (e.g., 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 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 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 4 p.m. on September 11 to 4 p.m. on September 12.

2.4.2 Summary of Modeling Approaches Considered

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. These alternative modeling methodologies are described briefly in the following subsections.

Calibration of Model to Entirety of September 2013 Event

Initially, hydrologic model development and calibration were performed for the entirety of the September 2013 rainfall event, which spanned approximately 7 days from September 9 to September 16. The calibration process resulted in calibrated parameters that were outside of published values, including CNs that were generally consistent with Antecedent Moisture Condition (AMC) I (usually associated with severe drought or unusually dry conditions). Due to the parameters outside of published ranges and acknowledgement that the SCS method was developed for single-event storms rather than several closely distributed events, such as occurred in September 2013, this methodology was noted for the modeling lessons learned and formed the foundation for development of the calibrated model. A comparison of the September 2013 incremental rainfall and model outfall discharge is presented in **Figure B-3** in **Appendix B**.

Calibration of Model using Green-Ampt Loss Method

Recognizing that the SCS method was developed for single-event storms and may not accurately model the closely distributed events that comprised the September 2013 rainfall event, CH2M HILL evaluated use of the Green-Ampt infiltration loss model, which accounts for the recovery of infiltration capacity between discrete events. Two methods were used in an attempt to calibrate the Green-Ampt parameters. The first method, which relied on assigning Green-Ampt parameters in accordance with the infiltration capacity of underlying soils provided in the U.S. Department of Agriculture's (USDA's) Web Soil Survey (USDA, 2013), resulted in Green-Ampt parameters that infiltrated the entire September 2013 event such that no runoff occurred. The second method assigned Green-Ampt parameters based on the surface texture of underlying soils provided in the Web Soil Survey. Using conservative literature-cited values of Green-Ampt Parameters based on soil texture, the resultant Green-Ampt parameters infiltrated the majority of the September 2013 event. Calibration of the Green-Ampt parameters resulted in parameters that were significantly beyond the values reported in literature and, as such, the Green-Ampt infiltration loss model was not carried further in favor of the SCS model.

2.4.3 Basin Delineation

Subbasins were developed using 40-foot USGS topographic map (NGS, 2013). The Little Thompson River watershed consists of various mountain streams and lakes. Subbasins were delineated to have a consistent size with design points at key locations including confluences. The subbasins are primarily mountains with steep terrain. In areas where steep valley conditions occur along the channel corridor, the basins were delineated extending from the high point along the overbank to the channel centerline, resulting in subbasins on both the left and right overbanks of the stream. This was done to better represent the runoff from the steep valley slopes. This approach resulted in 18 subbasins that varied in size from 0.6 square mile to approximately 4.7 square miles, with an average size of approximately 2.4 square miles. **Table B-1** in **Appendix B** summarizes the basin ID and areas for all 18 subbasins.

2.4.4 Basin Characterization

The entirety of the study area is located upstream of the Little Thompson River canyon mouth and, as such, is considered mountainous terrain with relatively rapid flood responses. Vegetative cover in the watershed is primarily evergreen forest with some pasture. Along the West Fork Little Thompson River, vegetative cover is generally sparser than other portions of the basin and, as such, may result in the potential for greater runoff and sediment delivery. As discussed later, the differences in vegetative cover were incorporated into the model based on visual characterization of land use and cover provided in the National Land Cover Dataset (USGS, 2006). 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 sub basins, 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, e.g., 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 Inputs

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 is depicted in **Figure B-4** in **Appendix B**.

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. A depth-area reduction factor of 0.95 was then applied to the NOAA point precipitation estimates based on Figure CH9-F415 of the *Colorado Floodplain and Stormwater Criteria*

Manual (CWCB, 2008). The depth-area reduction factor accounts for the gradual decrease in rainfall intensity with increasing distance from the storm epicentre, and corrects the NOAA point precipitation estimate to the average rainfall that would occur over the spatial extent of the storm. 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 three of the basins, the 24-hour rainfall depths from September 2013 exceeded the depths of the 0.2 percent chance precipitation. Three of the basins (LT-1A, LT-1B, and LT-3B) had rainfall depths greater than the 1 percent annual chance but just less than the 0.2 percent chance precipitation total. 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). The hyetograph is provided in **Figure B-5** in **Appendix B** and the dimensionless values are presented in **Table B-3** in **Appendix B.**

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 soil saturation as saturated soils have less interstitial space available for the storage of rainfall and thus runoff a greater proportion of rainfall. 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. Delineation of hydrologic soil groups was accomplished using the 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 the watershed is provided in **Figure B-6** in **Appendix B**. The soil data for the Little Thompson River watershed is presented in **Figure B-7** in **Appendix B**.

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 was selected as 0.4 to conform to literature values for mountainous areas. Lag time was estimated using the following equation (Equation CH9-511) provided in the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008) and recommended for use in subbasins larger than 1 square mile and with basin slopes greater than 10 percent, as occur in the hydrologic model:

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

Where K_n is the roughness factor for the basin channels, taken as 0.15 for pine forest, 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, 2013). Flowpaths for watersheds characterized by hillslopes and gulches draining directly to the main channel were determined using the watershed of a representative gulch. Verification of the appropriate selection of C_p and lag time was confirmed during the calibration process when modeled hydrographs closely reflected observed hydrographs. Lag times for each individual subbasins are provided in **Table B-4** in **Appendix B**.

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. The NED 1/3 arc-second data (USGS, 2013) was utilized to develop cross sections along the West Fork Little Thompson River and 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 are provided in **Figure B-8** in **Appendix B** and the cross sections for each reach are provided in **Figure B-9** in **Appendix B**.

A Manning's roughness values 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). Model sensitivity analysis indicated that hydrograph attenuation along the reach was relatively insensitive to Manning's roughness value.

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, which occurred between 4 p.m. on September 11 and 4 p.m. on September 12, was selected for model calibration. For all of the subbasins comprising the watershed, the peak rainfall intensity and volume occurred during the selected 24-hour period. **Figure B-10** in **Appendix B** 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 was the most logical calibration parameter and that parameters such as Snyder's peaking coefficient, Manning's roughness of routing elements, and lag time would not be adjusted for calibration (as described in preceding sections). The model was not sensitive to adjustments to Manning's roughness of routing elements or lag time.

CNs for each of the subbasins were adjusted iteratively until modeled discharges matched peak discharge estimates for the September 2013 event developed by Bob Jarrett (Jarrett, In press). Due to the heavy amounts of rainfall where at least 2.1 inches of rainfall accrued preceding the peaks of the selected 24-hour event, CNs with AMCIII were used for the calibration process (Novotny, 2011).

CNs provided in TR-55 are appropriate for AMCII; AMCII CNs were converted to representative AMCIII values 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 re-assignment of land cover descriptions to delineated land covers. The re-assignment 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 re-assigned at watershed scale but also at a sub-watershed (e.g., West Fork) if the unique re-assignment could be justified. For example, "forest" land cover in West Fork Little Thompson River was re-assigned as "poor condition" in several of the subbasins, in contrast to "fair condition" in the other sub-watershed, due to sparser vegetative cover as identified during aerial review. Land use conditions for the Little Thompson River are provided in **Table B-5** in **Appendix B**.

Calibration Results

The final calibrated model used "fair condition" AMCIII CNs for all of subbasins in the Little Thompson River sub-watershed and the following subbasins in the West Fork Little Thompson River sub-watershed: WF-2, WF-3B, WF-5B, and WF-6B. The following subbasins in the West Fork Little Thompson River sub-watershed used "poor condition" AMCIII CNs: WF-1A, WF-1B, WF-3A, WF-4, WF-5A, and WF-6A. The land use map and aerial for each subbasin within the Little Thompson River watershed were compared side by side to determine the hydrologic condition of the watershed for land use classifications that had a condition component such as Forest, Shrub, Grassland, and Woody Wetlands. Subbasins WF-1A, WF-1B, WF-3A, and WF-4 are primarily Forest land use. Close aerial inspection of these areas indicate gaps in the tree coverage. WF-4 also has large areas of fallen trees. Subbasins WF-5A and WF-6A have greater percentages of pasture as compared to the rest of the subbasins in the West Fork Little Thompson River sub-watershed. Close aerial inspection of these areas indicate large areas of barren rock where there should be pasture. Subbasins WF-4, WF-5, and WF-6A likely experienced tree loss due to the 2002 Big Elk Fire in the West Fork Little Thompson River sub-watershed. The aerial review of each subbasin within the Little Thompson River indicated that subbasins WF-1A, WF-1B, WF-3A, WF-4, WF-5A and WF-6A should be assigned a "poor condition" hydrologic classification. Calibrated CNs by subbasin are provided in **Table B-6** in **Appendix B**. In general, West Fork Little Thompson River sub-watershed had higher CNs mainly due to the "poor condition" classification in some of its subbasins. In addition, the West Fork Little Thompson River sub-watershed had greater amounts of Hydrologic Soil Group D and water that contributed to the higher CN values. Comparison of modeled discharge to observed discharges in provided in **Table 3**.

TABLE 3
Little Thompson River Comparison of Modeled Discharges to Observed Discharges

Site Number	HMS Node	Location	Drainage Area (sq miles)	Observed Peak Discharge (cfs)	Modeled Peak Discharge (cfs)	% Difference	Runoff Volume (in)
#61	LT-J3	Little Thompson River Midpoint of Watershed	13.8	2,470	2,258	-9%	2.9
#59	LT-J4 Without WF	Little Thompson River Upstream of Confluence with West Fork Little Thompson River	17.8	2,680	2,836	6%	2.9
#60	LT-J4	Little Thompson River Downstream of Confluence with West Fork Little Thompson River	43.2	7,800[a]	8,955	15%	4.0
#64	LT-J4 Without LT	West Fork Little Thompson River Upstream of Confluence with Little Thompson River	25.4	6,200	6,221	0%	4.8
	Outfall	Little Thompson River at US 36	43.8		9,056		4.0

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

cfs = cubic feet per second

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 revisions 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 4** 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 B-11** in **Appendix B**. The peak flow profile for Little Thompson River is provided in **Figure B-12** in **Appendix B** 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 and West Fork Little Thompson River sub-watersheds is provided in **Figure B-13**. West Fork Little Thompson River sub-watershed has a higher discharge due to the “poor hydrologic condition” assigned to land use cover versus “fair hydrologic condition” observed in the Little Thompson River sub-watershed. In addition, there is a greater amount of Hydrologic Soil Group D and water area in the West Fork Little Thompson River sub-watershed.

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

		Annual Chance Peak Discharge (cfs)				
Location	**Drainage Area (sq miles)**	**10 Percent**	**4 Percent**	**2 Percent**	**1 Percent**	**0.2 Percent**
Little Thompson River Midpoint of Watershed	13.8	58	186	376	660	1,777
Little Thompson River Upstream of Confluence with West Fork Little Thompson River	17.8	74	237	477	838	2,254
Little Thompson River Downstream of Confluence with West Fork Little Thompson River	43.2	648	1,365	2,243	3,418	7,504
West Fork Little Thompson River Upstream of Confluence with Little Thompson River	25.4	600	1,139	1,769	2,582	5,251
Little Thompson River at US 36	43.8	651	1,376	2,264	3,455	7,600

Modeled peak unit discharges, defined as peak discharge per square mile of contributing area, are provided in **Table 5**. A comparison of the 1 percent chance unit peak discharge versus subbasin area for Little Thompson River and West Fork Little Thompson River sub-watersheds is provided in **Figure B-14** in **Appendix B**. Modeled peak unit discharges for nearby Boulder Creek are also provided for comparison (CH2M HILL, 2014). The three sub-watersheds range in size from 0.5 to 5 square miles in area and the 1 percent chance unit peak discharges range from 25 to 150 cfs per square mile.

TABLE 5
Little Thompson River Modeled 10, 4, 2, 1, and 0.2 Percent Chance Unit Peak Discharge

		Annual Chance Peak Unit Discharge (cfs/sq mile)				
Location	**Drainage Area (sq miles)**	**10 Percent**	**4 Percent**	**2 Percent**	**1 Percent**	**0.2 Percent**
Little Thompson River Midpoint of Watershed	13.8	4.2	13.5	27.2	47.8	128.8
Little Thompson River Upstream of Confluence with West Fork Little Thompson River	17.8	4.2	13.3	26.8	47.1	126.6

TABLE 5
Little Thompson River Modeled 10, 4, 2, 1, and 0.2 Percent Chance Unit Peak Discharge

Little Thompson River Downstream of Confluence with West Fork Little Thompson River	43.2	15.0	31.6	51.9	79.1	173.8
West Fork Little Thompson River Upstream of Confluence with Little Thompson River	25.4	23.6	44.8	69.7	101.6	206.7
Little Thompson River at US 36	43.8	14.9	31.4	51.7	78.9	173.5

3.2 Comparison to Previous 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 6**.

TABLE 6
Predictive Model Comparison at the Little Thompson River Downstream of Confluence with West Fork Little Thompson

	Annual Chance Peak Discharge (cfs)				
Model	**10 Percent**	**4 Percent**	**2 Percent**	**1 Percent**	**0.2 Percent**
CDOT 2011 HEC-HMS Model	775	N/A	2,166	2,585	N/A
CH2M HILL HEC-HMS Predictive Model	648	1,365	2,243	3,418	7,504

Drainage Area = 43.2 square miles

Review of **Table 6** indicates that estimates of 1 percent annual chance peak discharges in the Little Thompson River watershed are greater compared to the previous model. The 2 percent annual chance peak discharge is slightly greater while the 10 percent annual chance peak discharge is slightly less.

The primary difference between the models is that the predictive model is more detailed in scale with an average subbasin size of 2.4 square miles compared to an average 12.3 square miles subbasin size in the CDOT 2011 model. The overall size of the CDOT 2011 model is much larger with two of the 18 total subbasins covering the predictive model study area. Due to the difference in subbasin size, the CDOT 2011 model has a slightly larger depth-area reduction factor of 0.958 compared to 0.95 in the predictive model. Both models used the SCS curve number method to estimate infiltration losses. The CDOT 2011 model had an average CN of 67 for the Little Thompson River sub-watershed compared to 56 in the predictive model. The CN values for the West Fork Little Thompson River sub-watershed were closer in both models: 66 for the CDOT 2011 model and 67 for the predictive model. 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. The CDOT 2011 model does not have any routing elements within the predictive model study area. The CDOT 2011 model also was not calibrated. There is likely higher confidence in the predictive model as compared to the CDOT 2011 model because the predictive model is more detailed and has been calibrated.

Comparisons of the calibrated model peak discharge to the Dam Safety model peak discharge estimates are provided in **Table 7**.

TABLE 7
Calibrated Model Comparison

Model	West Fork Little Thompson River Upstream of Confluence with Little Thompson River		Little Thompson River Upstream of Confluence with West Fork Little Thompson River	
	Observed Peak Flow (cfs)	Modeled Peak Flow (cfs)	Observed Peak Flow (cfs)	Modeled Peak Flow (cfs)
CDWR Dam Safety HEC-HMS model	6,215	6,148	2,420	3,312
CH2M HILL HEC-HMS calibrated model	6,200	6,221	2,680	2,836

Review of **Table 7** indicates a less than 10 percent difference in the physical-based peak flow discharge observation and less than a 15 percent difference in the modeled peak flow at the two locations upstream of the West Fork and Little Thompson River Confluence. 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 2.4 square miles in the calibrated model. The models used similar rainfall data and indirect peak flow estimate methods.

4.0 Conclusions and Recommendations

The assumptions and limitations of the hydrologic model and previous study were closely reviewed, compared, and contrasted. The previous peak discharge estimates were concluded less representative of the study area due the large scale of the model and lack of calibration. 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 US 36.

4.1 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 8** provides the comparison and assessment of the September 2013 flood recurrence interval.

TABLE 8
Little Thompson River Estimate of September 2013 High-Flow Recurrence Interval

		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 Midpoint of Watershed	2,470	58	186	376	660	1,777	> 500
Little Thompson River Upstream of Confluence with West Fork Little Thompson River	2,680	74	237	477	838	2,254	> 500
Little Thompson River Downstream of Confluence with West Fork Little Thompson River	7,800	648	1,365	2,243	3,418	7,504	> 500
West Fork Little Thompson River Upstream of Confluence with Little Thompson River	6,200	600	1,139	1,769	2,582	5,251	> 500
Little Thompson River at US 36	N/A	651	1,376	2,264	3,455	7,600	N/A

Reviewing **Table 8**, the estimated recurrence interval for the September 2013 event is less than 0.2 percent and discharge exceeded the 500-year event at all locations within the model. Considering that the 24-hour precipitation totals matched or exceeded a 500-year frequency in all but three of the subbasins, 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.

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U.S. Geological Survey (USGS). 2009. *Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado.* Scientific Investigations Report 2009-5136, 46 p. Reston, VA. Available at http://pubs.usgs.gov/sir/2009/5136/pdf/SIR09-5136.pdf.

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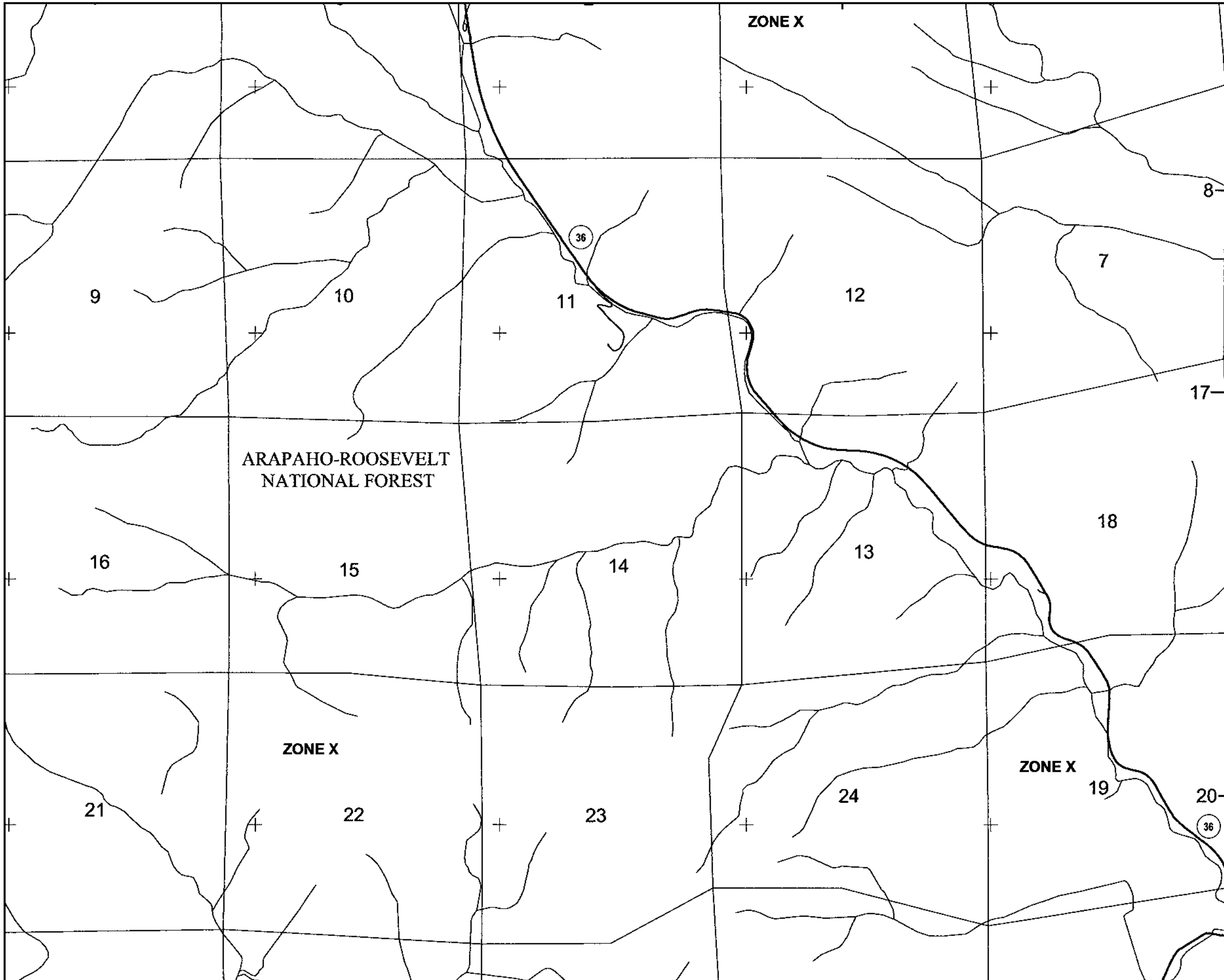
Appendix A
FEMA Information

FIRM Map Number 08069C1325F



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:

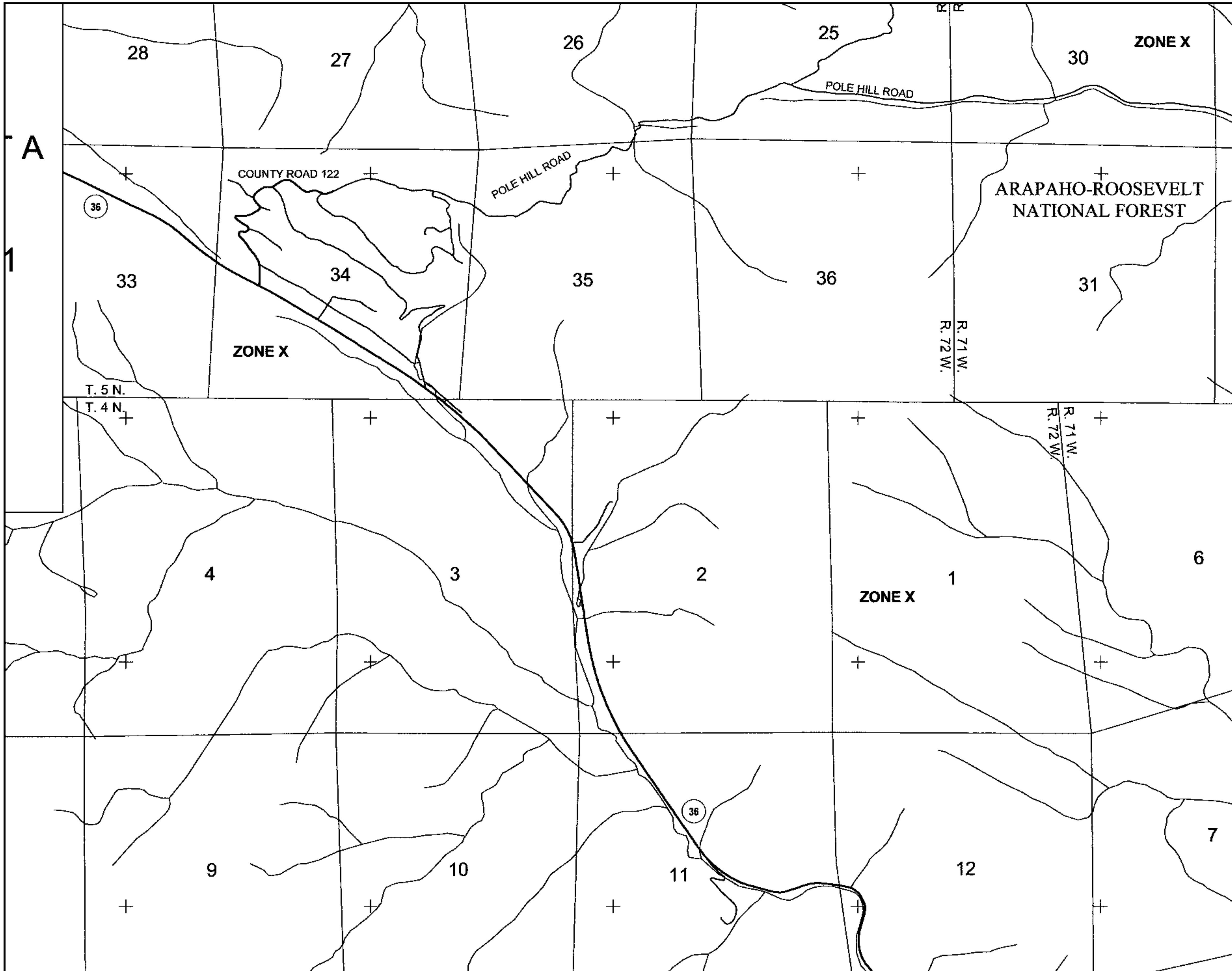
COMMUNITY	NUMBER	PANEL	SUFFIX
ESTES PARK, TOWN OF	080193	1325	F
LARIMER COUNTY	080101	1325	F

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



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

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

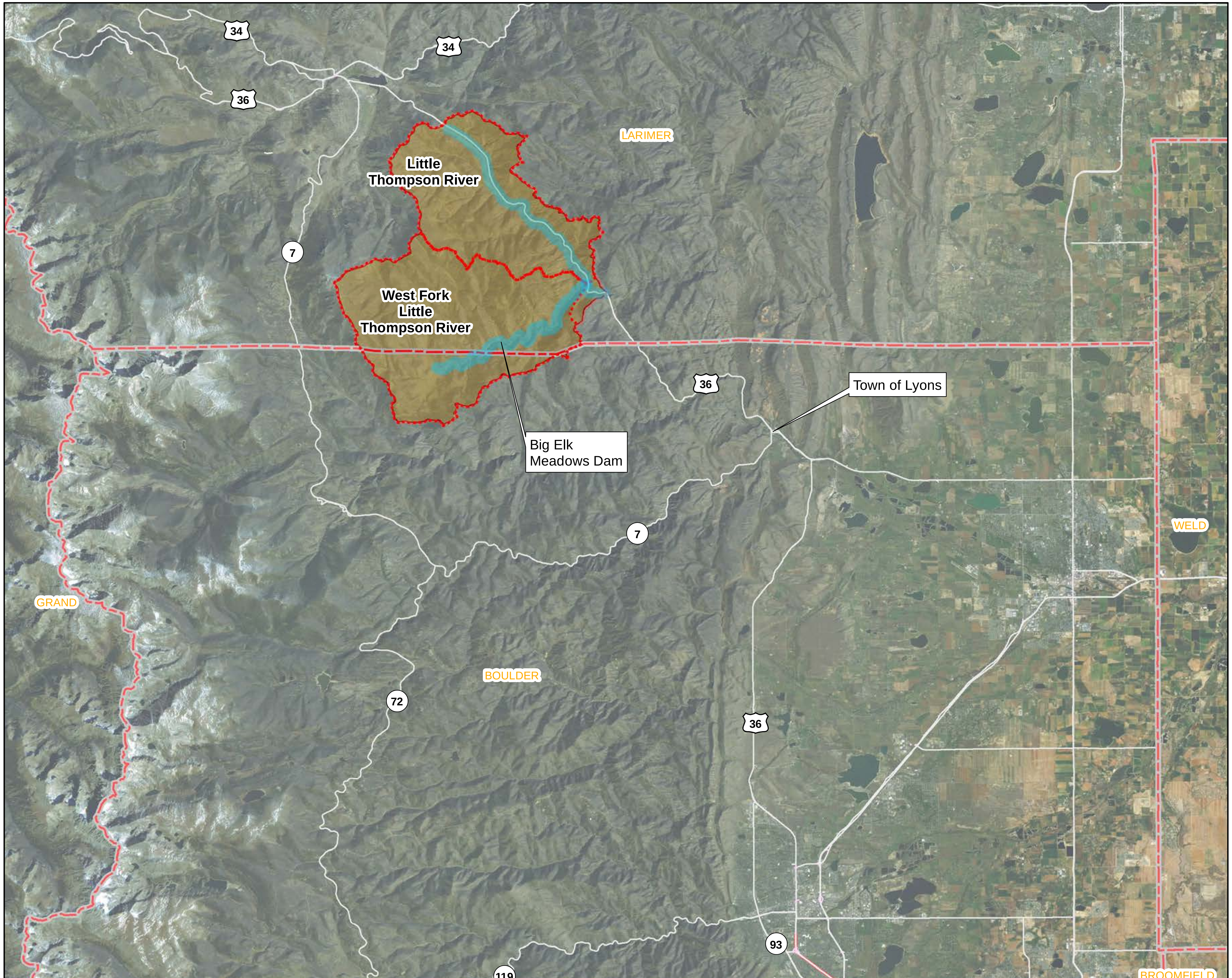
Appendix B
Hydrologic Analysis and Parameters

Figures

Tables

Appendix B
Hydrologic Analysis and Parameters

Figures



VICINITY MAP

LEGEND

- Study Reach
- Little Thompson River Watershed
- Sub-Watershed Boundary
- Counties
- Interstate
- US and State Highway

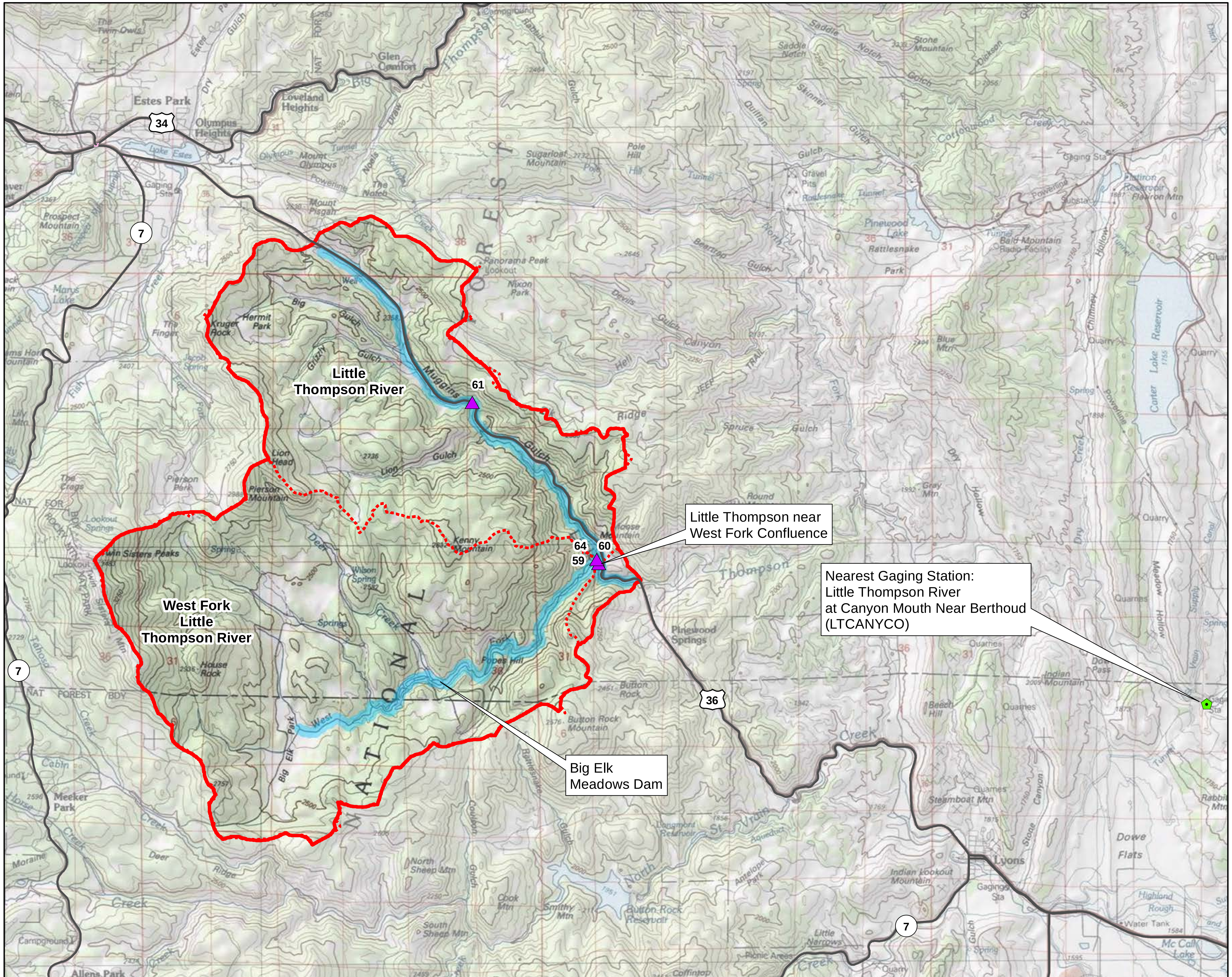
N

0 0.75 1.5 3 Miles

1 in = 3 miles

FIGURE B-1
Vicinity and Watershed Map

CDOT Flood Recovery Hydrologic Evaluation



VICINITY MAP

LEGEND

- Paleoflood Evaluation Point
- Stream Gage
- Study Reach
- Sub-Watershed Boundary
- Little Thompson Watershed

0 0.75 1.5 3 Miles

1 in = 1.5 miles

FIGURE B-2
Little Thompson Physical-Based Evaluation and Gage Locations

CDOT Flood Recovery Hydrologic Evaluation

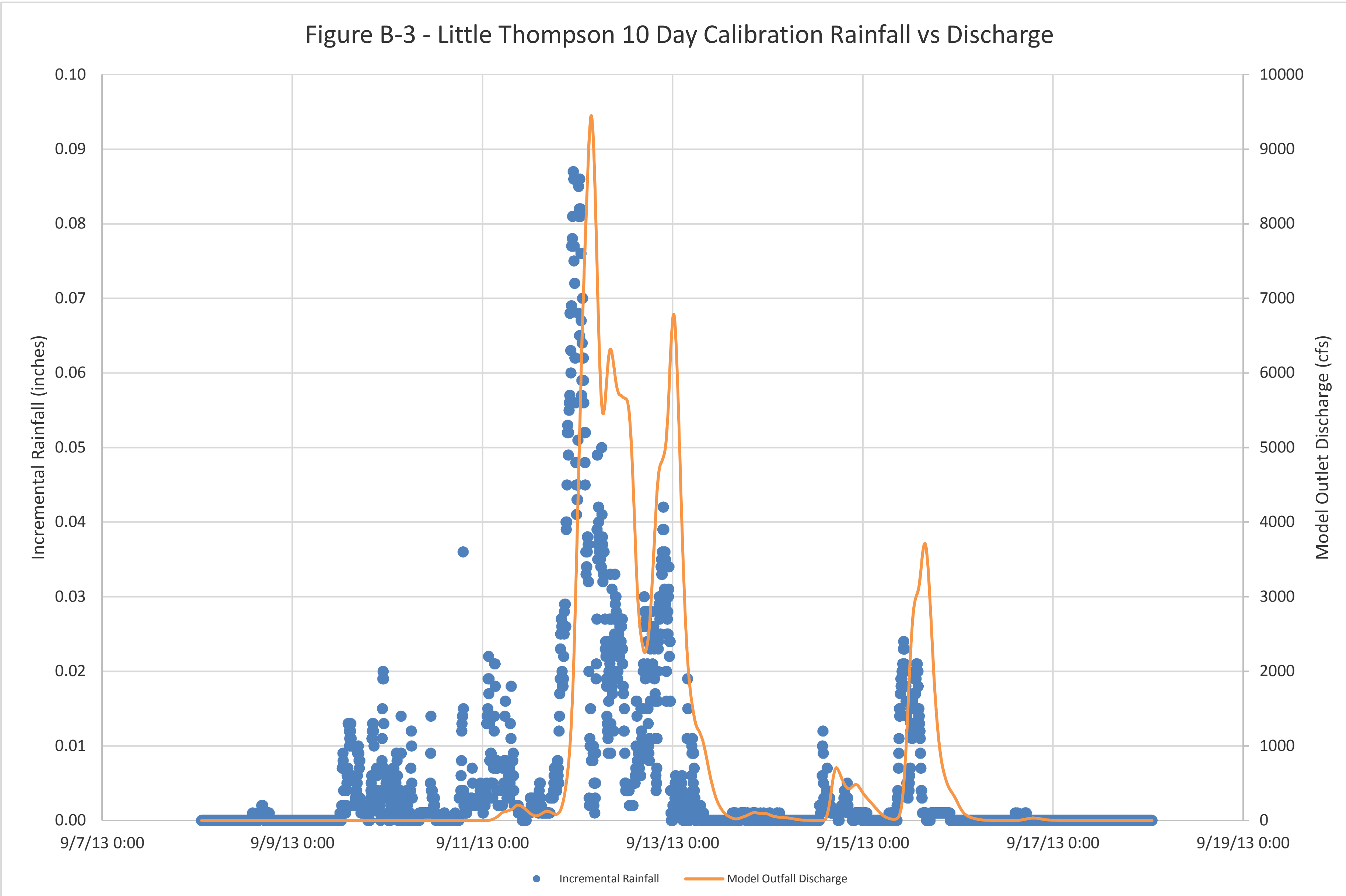
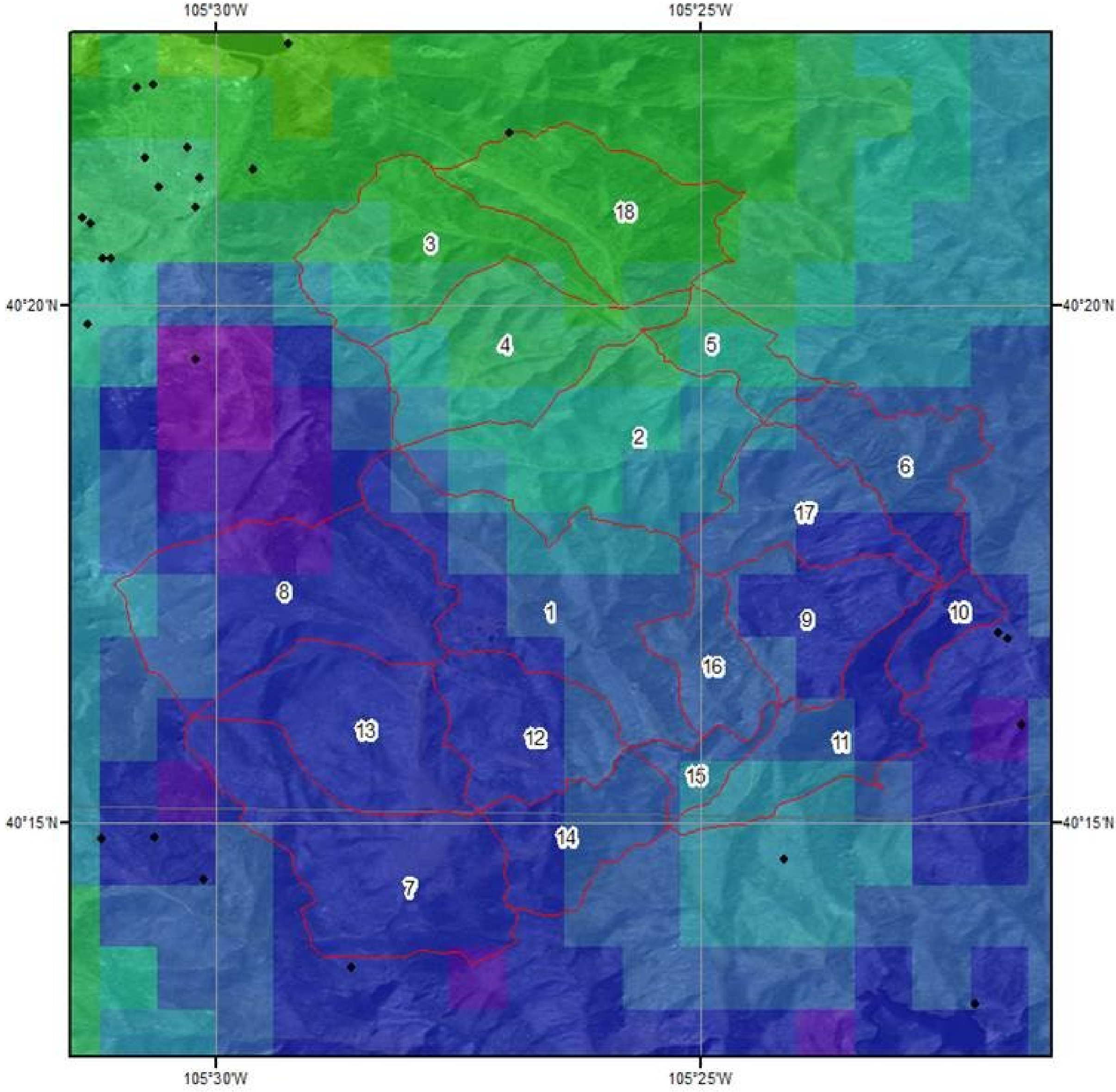


Figure B-3 - Little Thompson 10 Day Calibration Rainfall vs Discharge
Incremental Rainfall (inches)
Model Outlet Discharge (cfs)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
9/7/13 0:00
9/9/13 0:00
9/11/13 0:00
9/13/13 0:00
9/15/13 0:00
9/17/13 0:00
9/19/13 0:00
Incremental Rainfall
Model Outfall Discharge

Figure B-4 - AWA 10 Day Precipitation



Total 10-day Precipitation (in)
Sept 8, 2013 - Sept 17, 2013
SPAS #1302

Note: Raw rainfall data provided by AWA is located in the Digital Data CD attached to this report.

Gauges

◆ 1302 Stations

Miles: 0, 0.5, 1, 2

Kilometers: 0, 1.25, 2.5, 5

Precipitation (inches)

0.13 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
19.01 - 20.00
20.01 - 21.00

01/07/2014

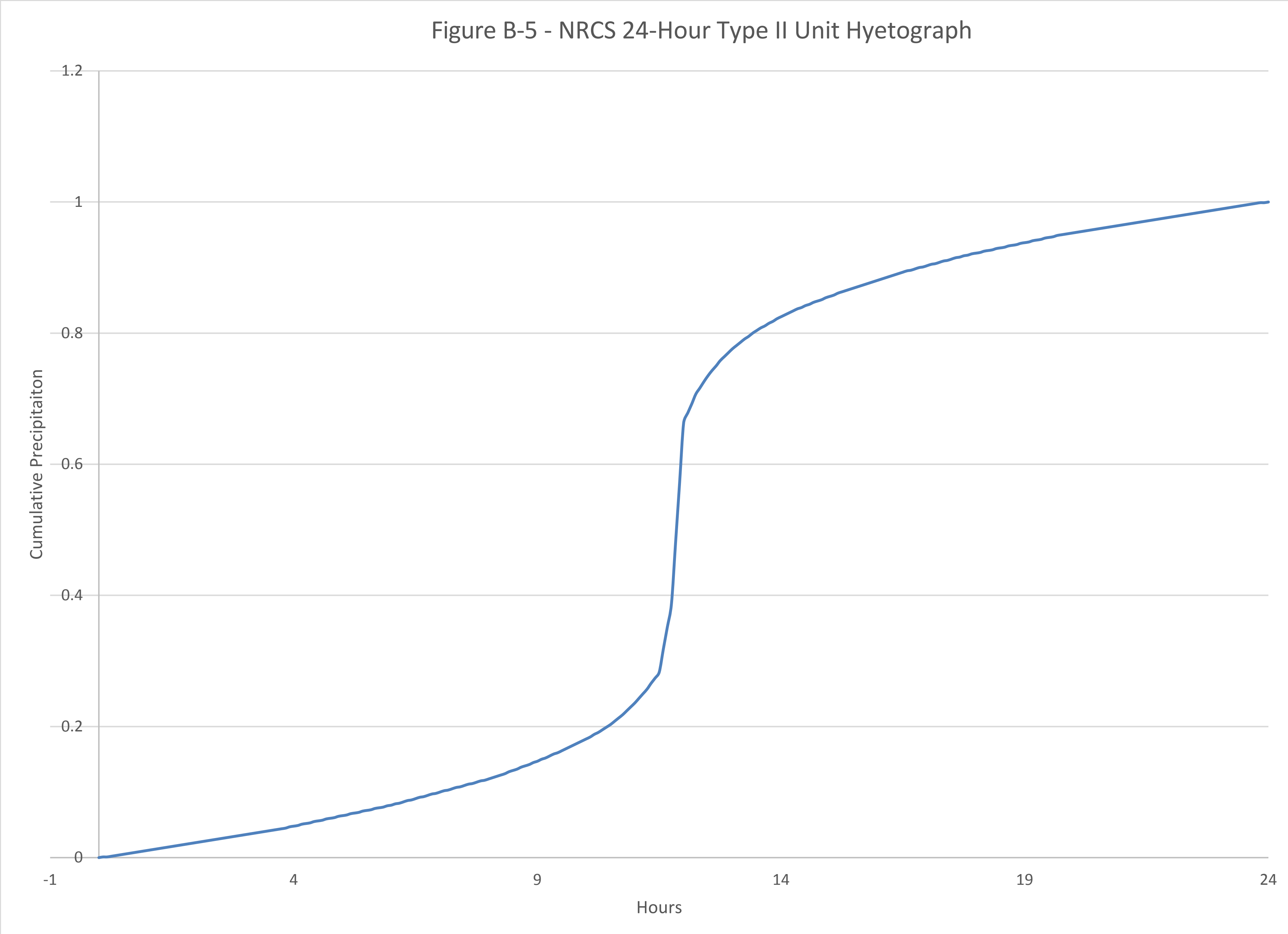
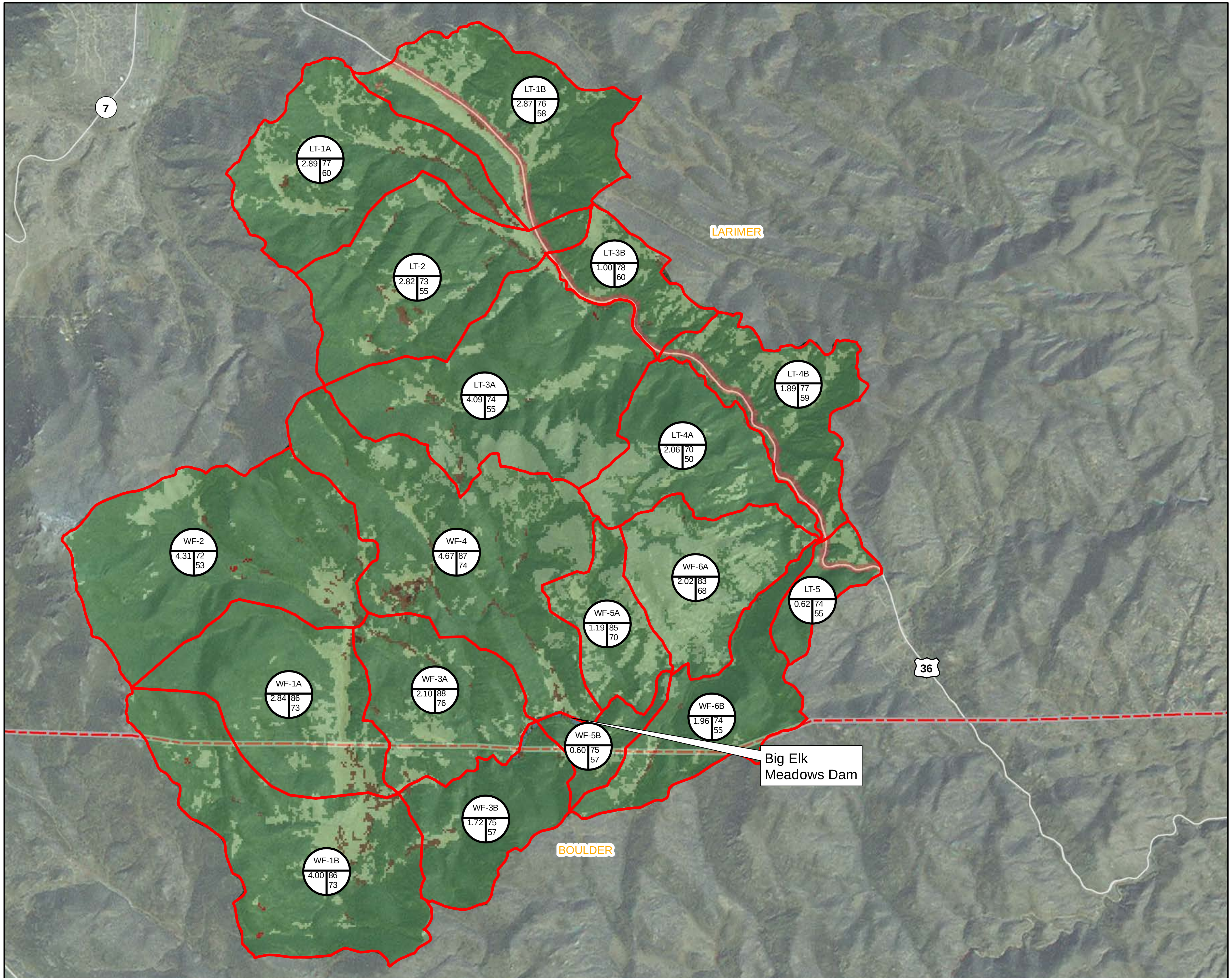


Figure B-5 - NRCS 24-Hour Type II Unit Hyetograph
Cumulative Precipitaiton
1.2
1
0.8
0.6
0.4
0.2
0
-1
4
9
14
19
24
Hours



VICINITY MAP

LEGEND

Little Thompson Sub-Basins

Land Use

- Open Water
- Developed Open Space
- Developed, Low Intensity
- Deciduous Forest - Oak / Aspen
- Shrub/Brush
- Grassland/Pasture
- 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 0.25 0.5 1 Miles

1 in = 1 miles

FIGURE B-6
Land Use Map

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.

VICINITY MAP

LEGEND

Little Thompson Sub-Basins

Hydrologic Soil Group
- A
- B
- C
- D
- Water

Counties

N

0 0.5 1 Miles

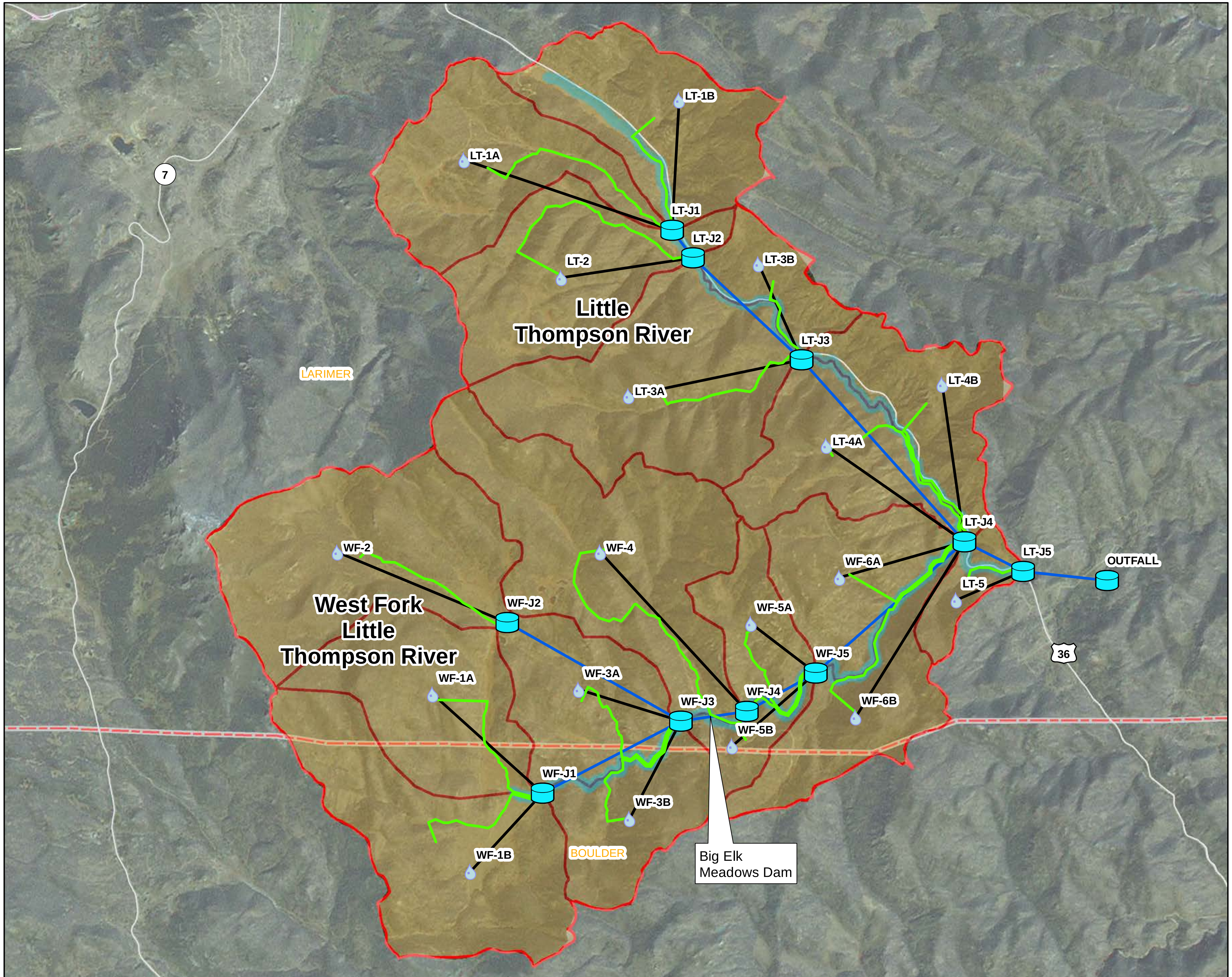
1 in = 1 miles

FIGURE B-7

Soil Data Map

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.



VICINITY MAP

LEGEND

- Model Precipitation Gage
- Sub-Watershed Routing
  - Basin Connection
  - Reach Segment
- Model Junctions
- Study Reach
- Little Thompson Sub-Basins
- Flow Paths to Sub-Basin Centroid
- Little Thompson River Watershed
- Counties

0 0.25 0.5 1 Miles

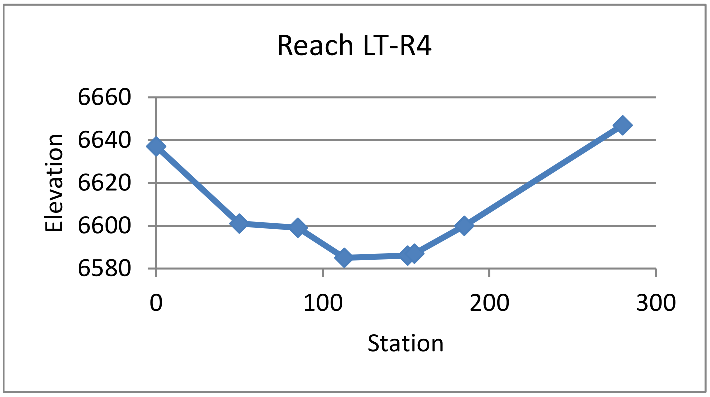
1 in = 1 miles

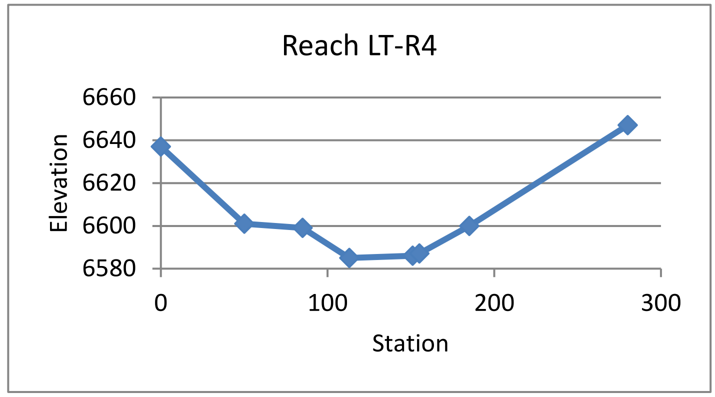
FIGURE B-8
Connectivity Map

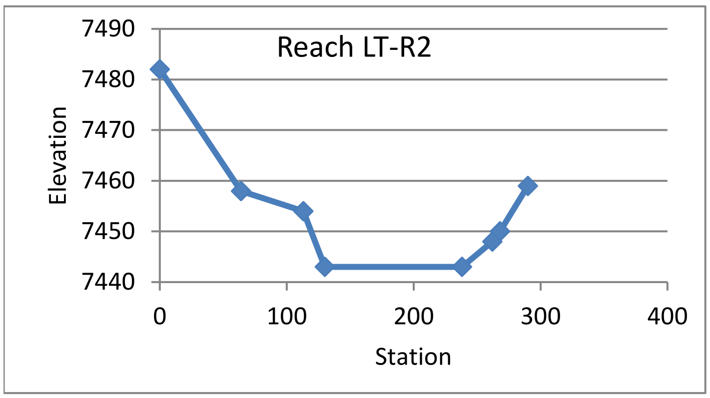
CDOT Flood Recovery Hydrologic Evaluation

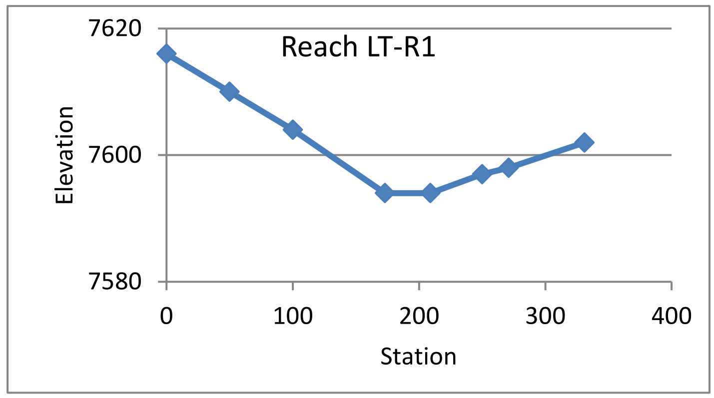
CH2MHILL.

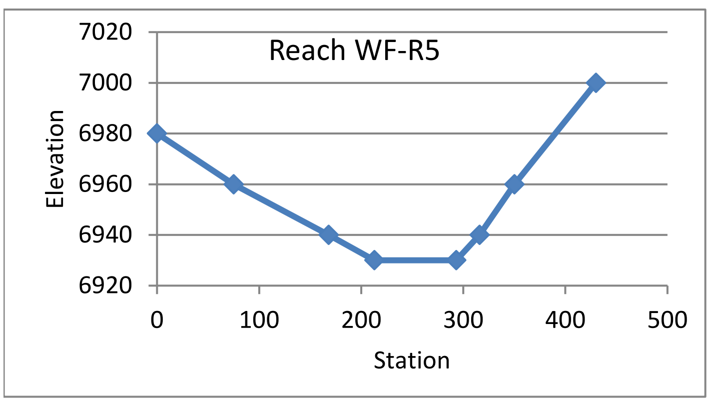
Figure B-9 - Muskingum-Cunge Eight-Point Routing Cross Sections











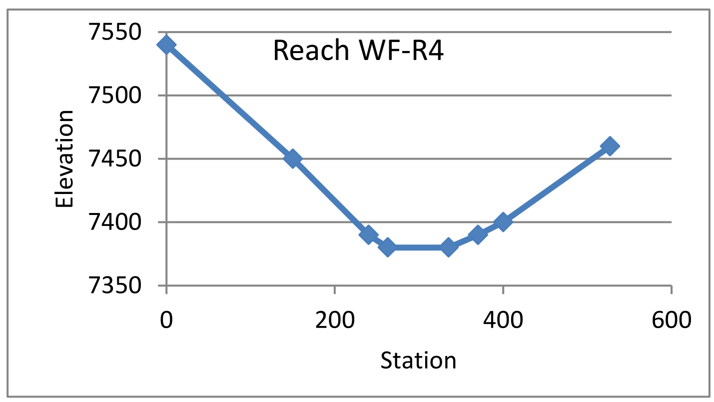
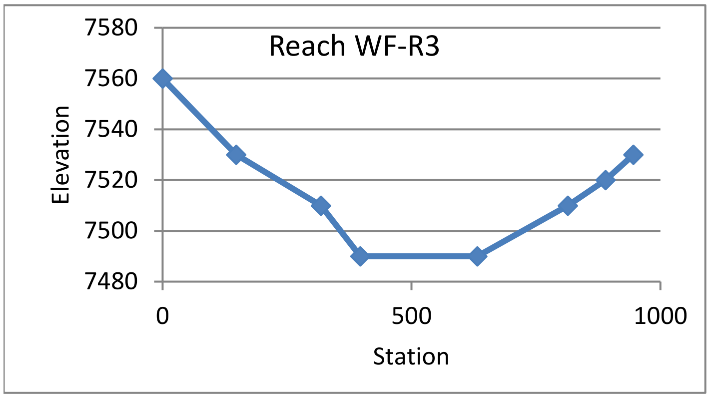
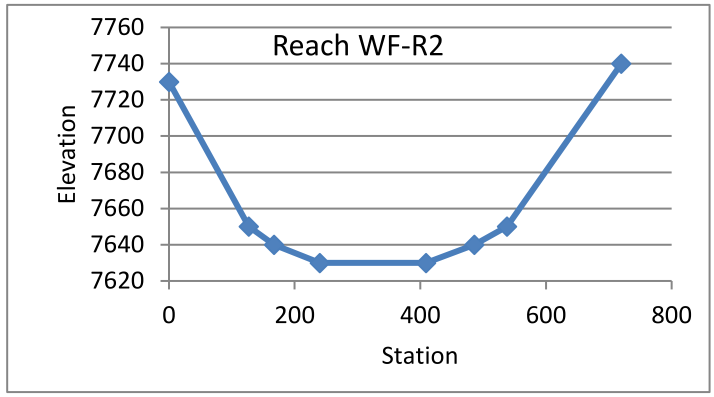
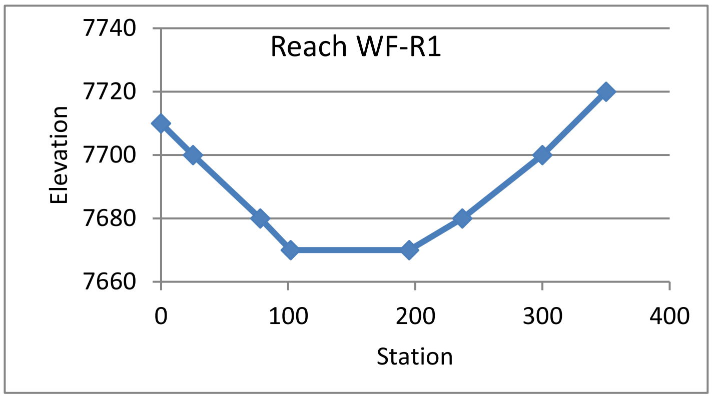


Figure B-9 - Muskingum-Cunge Eight-Point Routing Cross Sections (Continued)







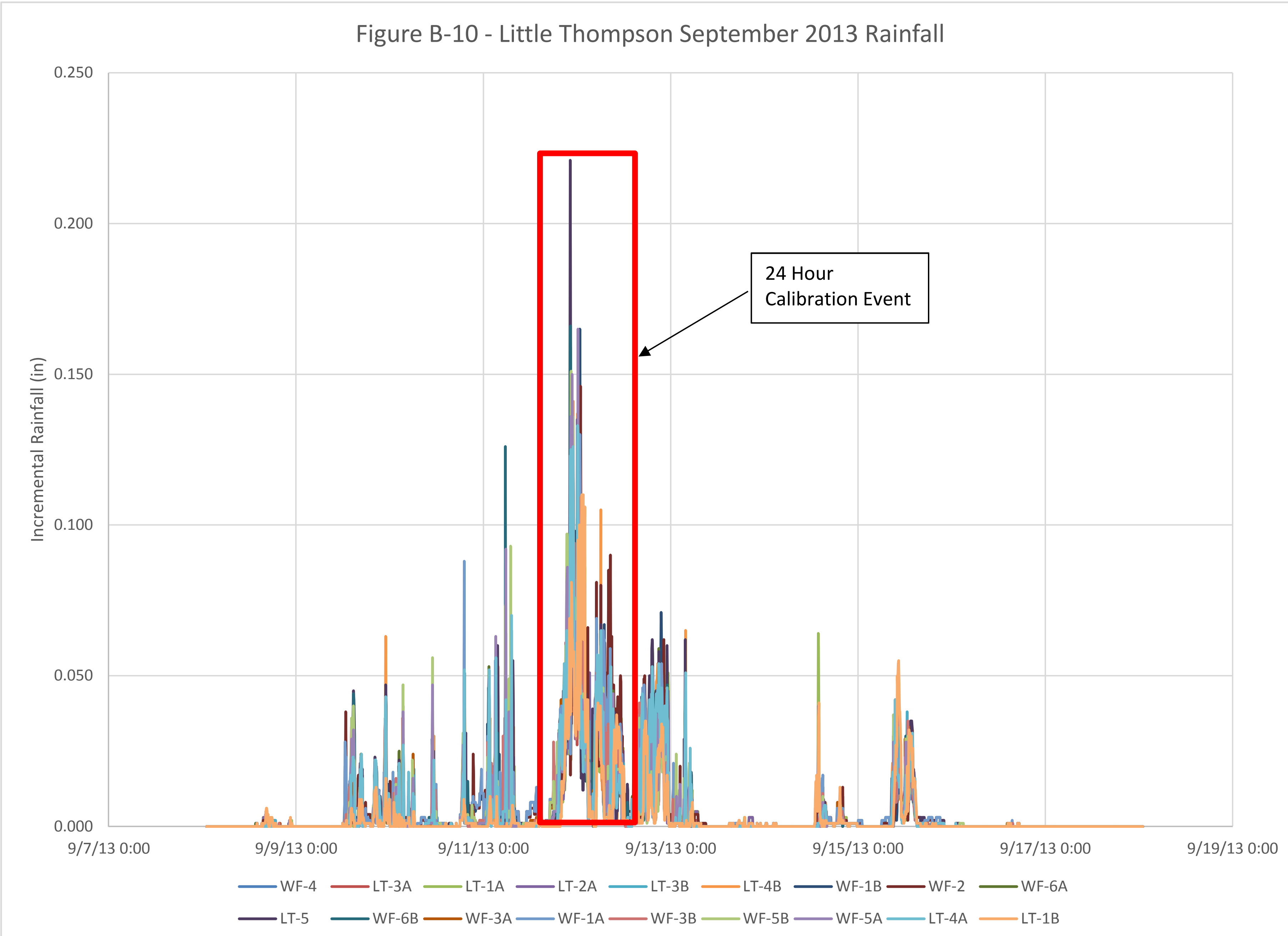


Figure B-10 - Little Thompson September 2013 Rainfall
Incremental Rainfall (in)
0.250
0.200
0.150
0.100
0.050
0.000
9/7/13 0:00
9/9/13 0:00
9/11/13 0:00
9/13/13 0:00
9/15/13 0:00
9/17/13 0:00
9/19/13 0:00
24 Hour Calibration Event
WF-4
LT-3A
LT-1A
LT-2A
LT-3B
LT-4B
WF-1B
WF-2
WF-6A
LT-5
WF-6B
WF-3A
WF-1A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

Figure B-11 - LT-J3

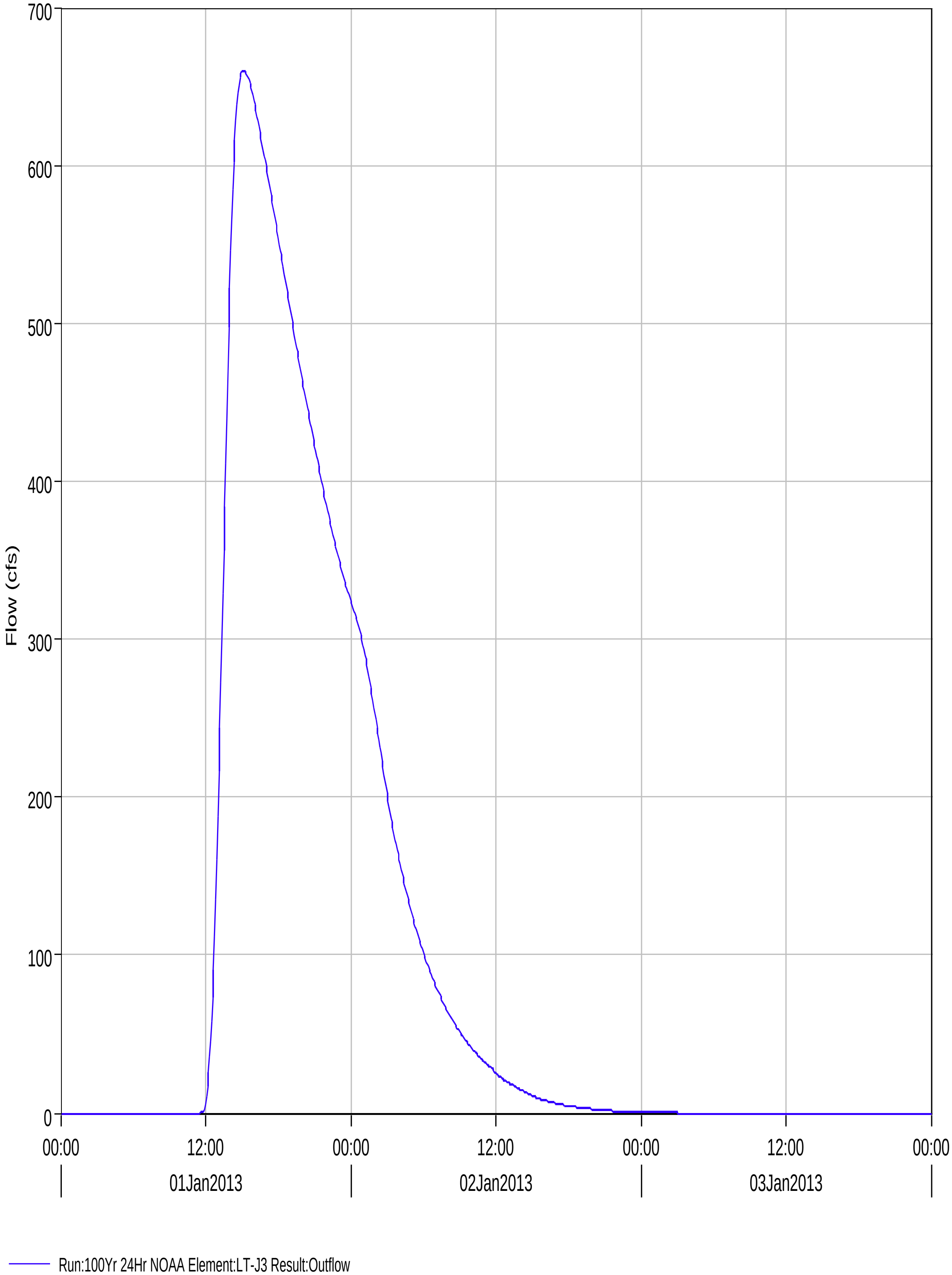
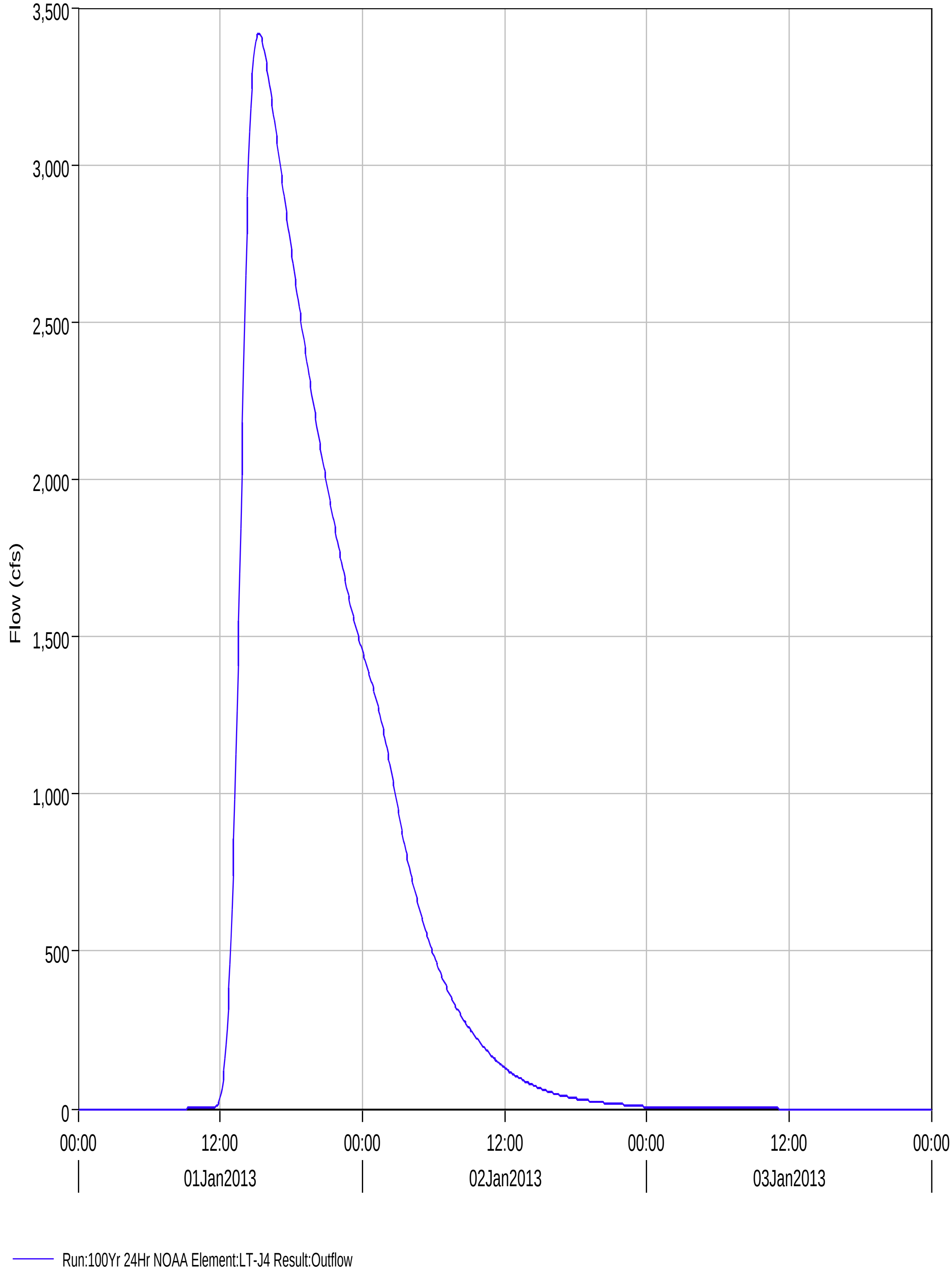


Figure B-11 - LT-J4



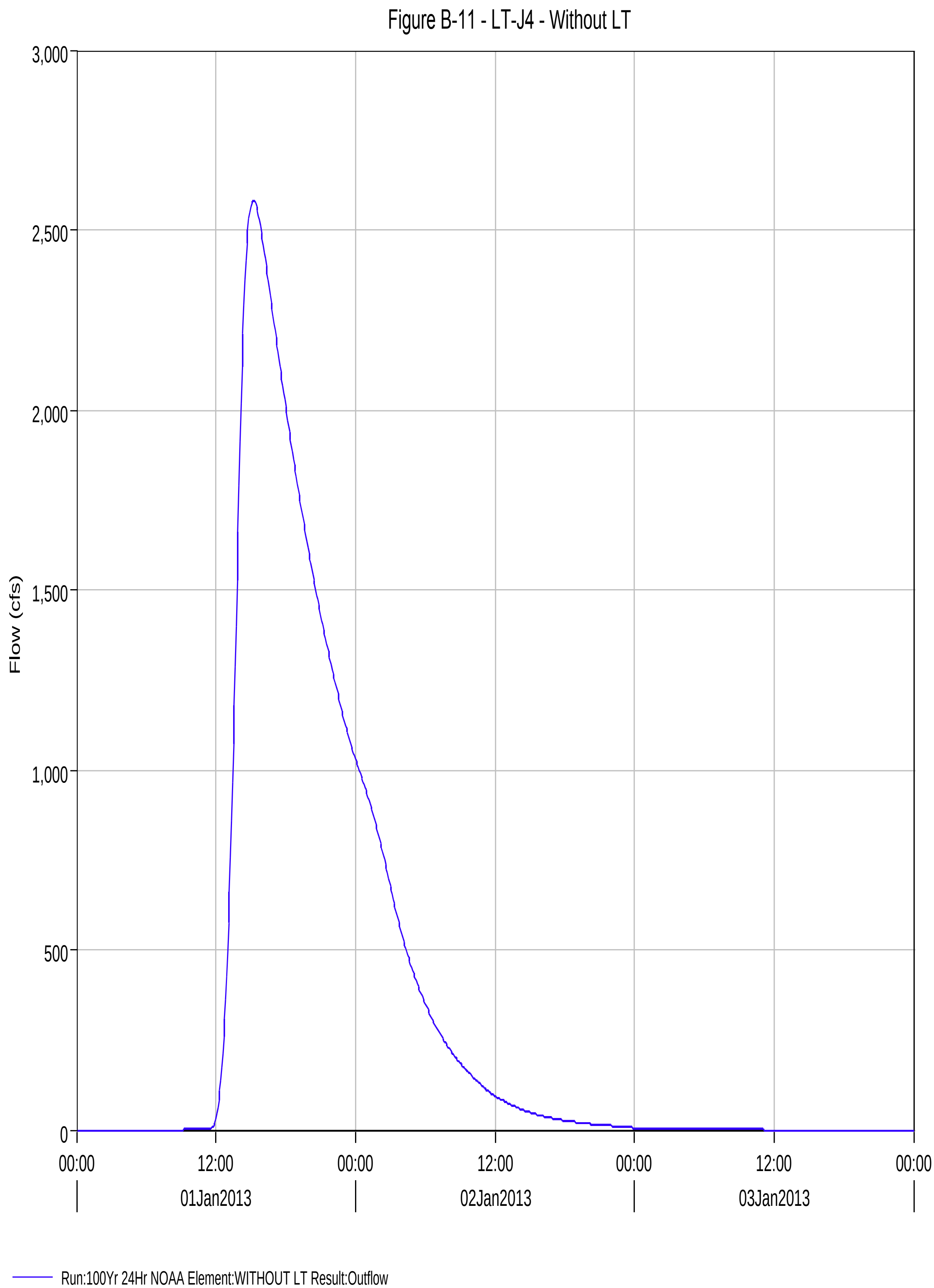


Figure B-11 - LT-J4 - Without LT
Flow (cfs)
3,000
2,500
2,000
1,500
1,000
500
0
00:00
12:00
00:00
12:00
00:00
12:00
00:00
01Jan2013
02Jan2013
03Jan2013
Run:100Yr 24Hr NOAA Element:WITHOUT LT Result:Outflow

Figure B-11 - LT-J4 - Without WF

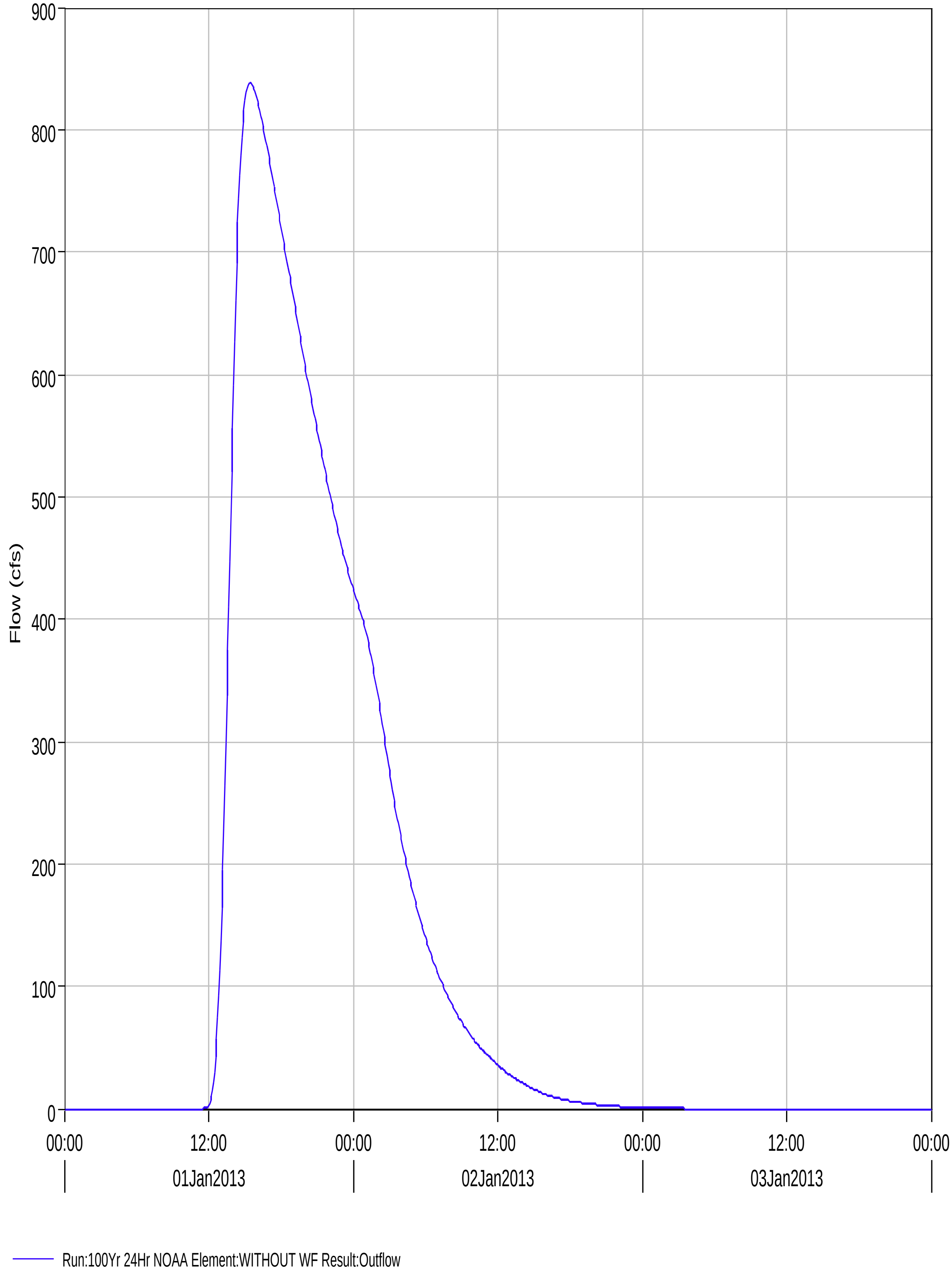


Figure B-11 - WF-J4

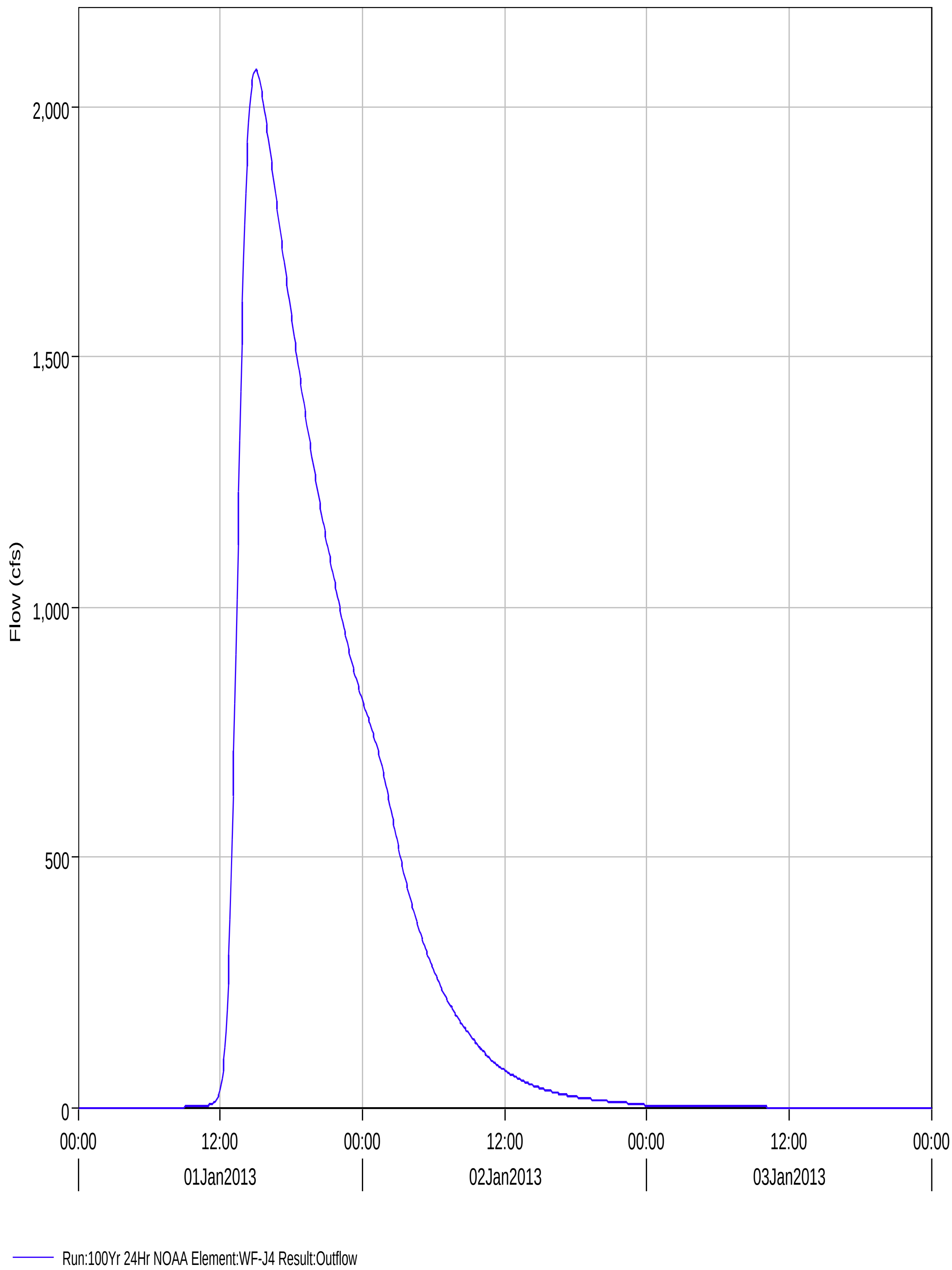
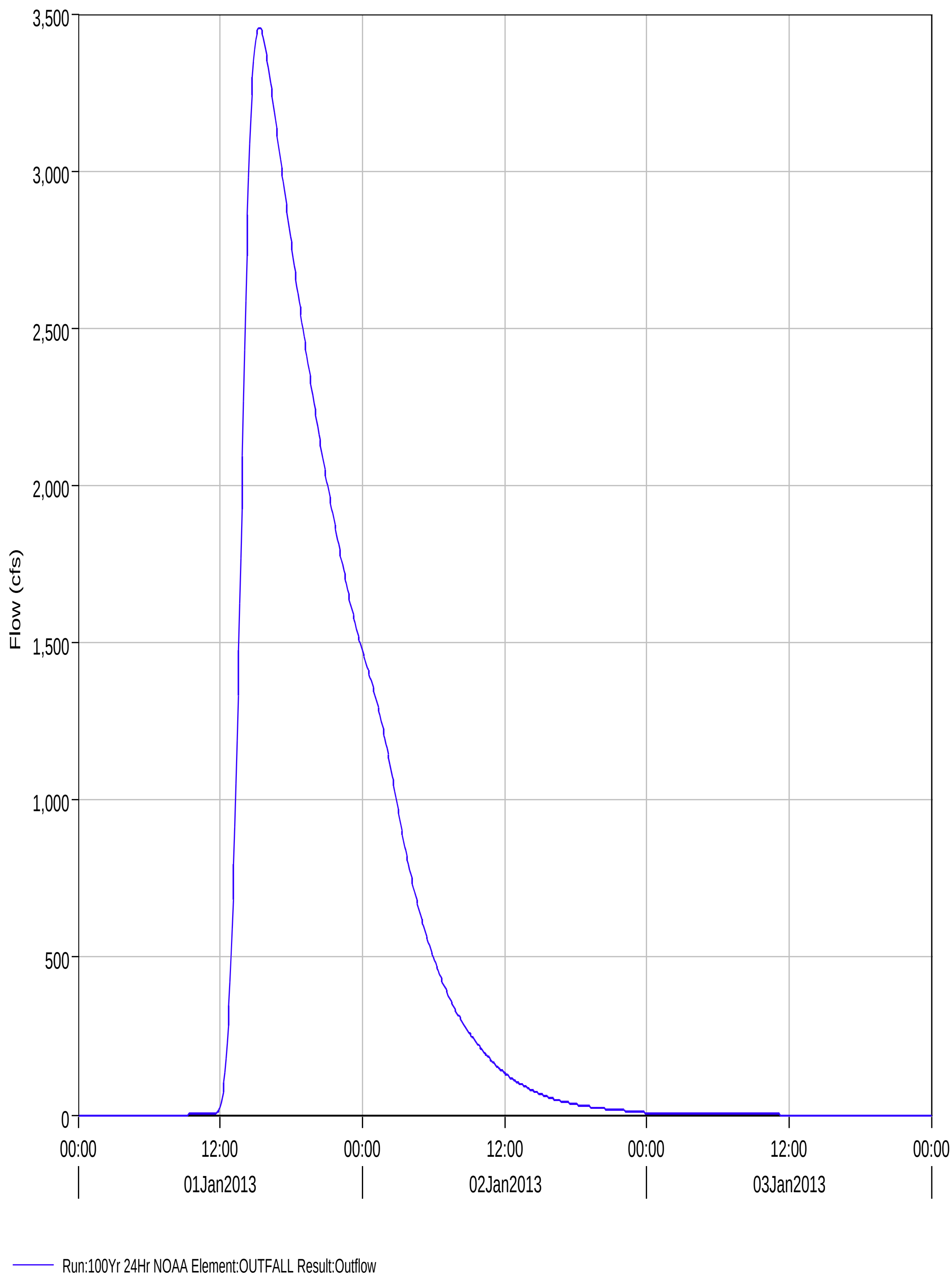


Figure B-11 - OUTFALL



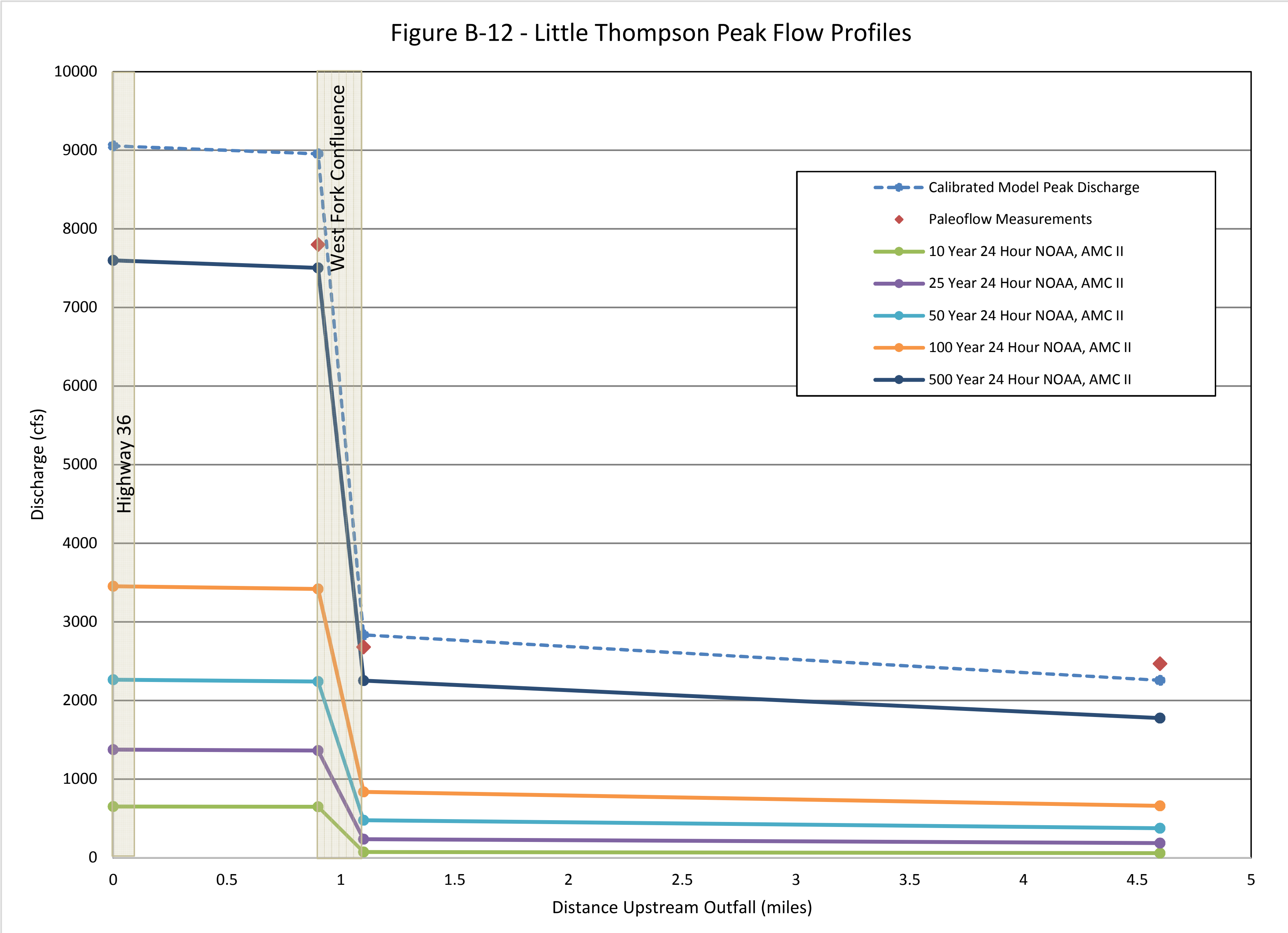


Figure B-12 - Little Thompson Peak Flow Profiles
Discharge (cfs)
Distance Upstream Outfall (miles)
Highway 36
West Fork Confluence
Calibrated Model Peak Discharge
Paleoflow Measurements
10 Year 24 Hour NOAA, AMC II
25 Year 24 Hour NOAA, AMC II
50 Year 24 Hour NOAA, AMC II
100 Year 24 Hour NOAA, AMC II
500 Year 24 Hour NOAA, AMC II
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

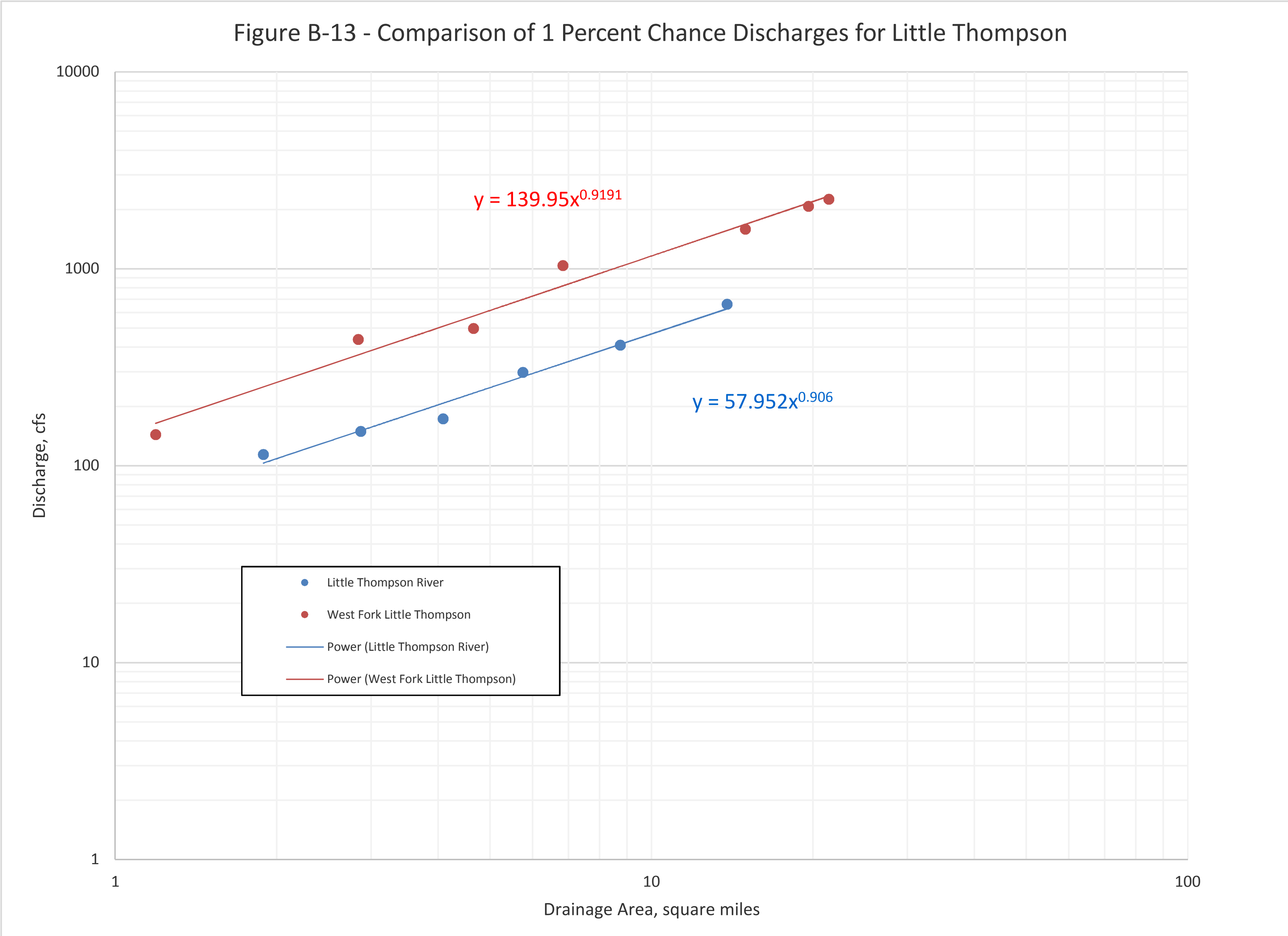
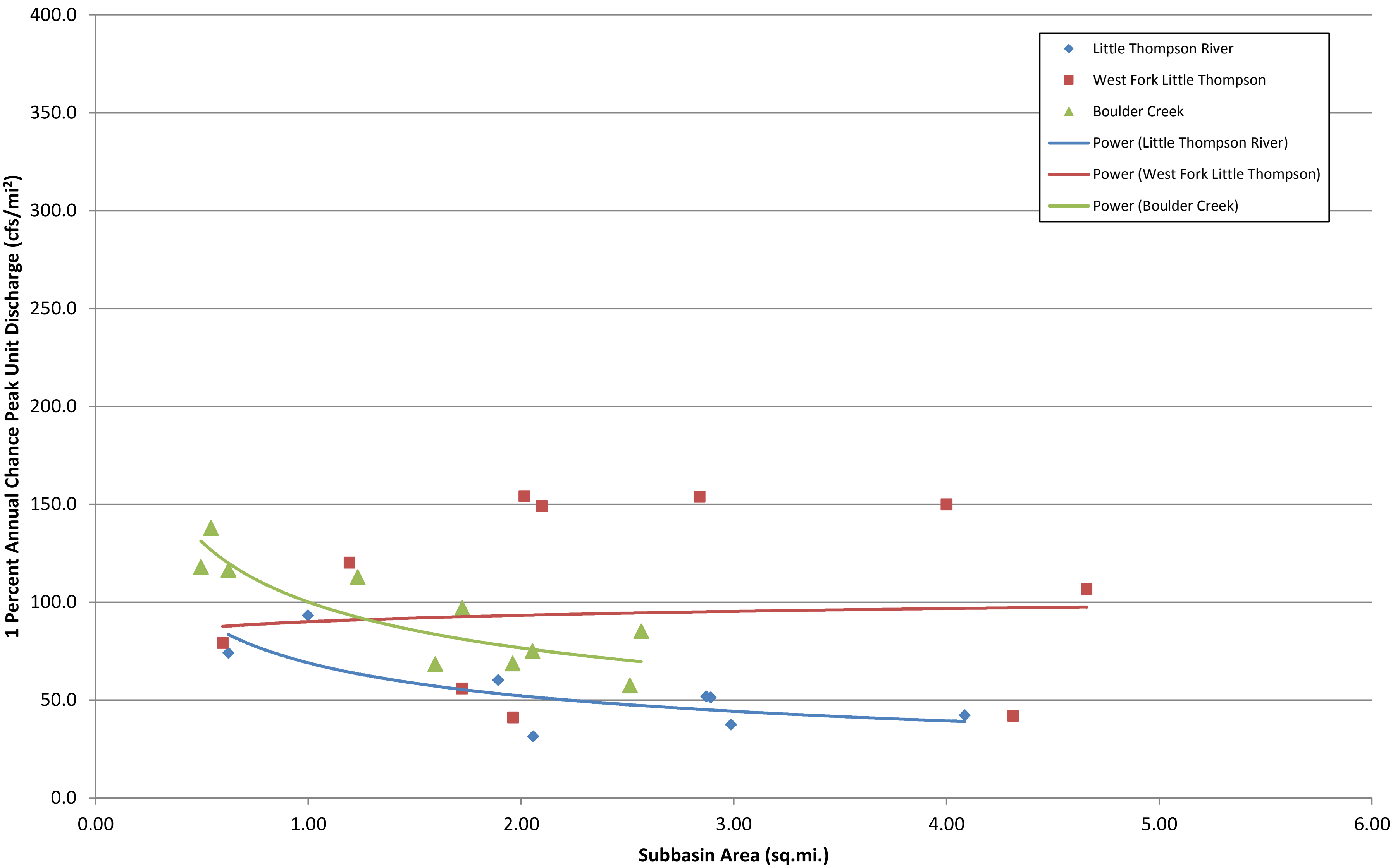


Figure B-13 - Comparison of 1 Percent Chance Discharges for Little Thompson
y = 139.95x^0.9191
y = 57.952x^0.906
10000
1000
100
10
1
Discharge, cfs
1
10
100
Drainage Area, square miles
Little Thompson River
West Fork Little Thompson
Power (Little Thompson River)
Power (West Fork Little Thompson)

Figure B-14 - 1 Percent Annual Chance Peak Unit Discharge vs. Subbasin Area



Appendix B
Hydrologic Analysis and Parameters

Tables

Table B-1 - Little Thompson Basin Area

Basin ID	Area *mi²*
LT-1A	2.9
LT-1B	2.9
LT-2	3.0
LT-3A	4.1
LT-3B	1.0
LT-4A	2.1
LT-4B	1.9
LT-5	0.6
WF-1A	2.8
WF-1B	4.0
WF-2	4.3
WF-3A	2.1
WF-3B	1.7
WF-4	4.7
WF-5A	1.2
WF-5B	0.6
WF-6A	2.0
WF-6B	2.0

Table B-2 - Little Thompson River NOAA 24 hour rainfall depths (inches)

		NOAA Atlas 14 - Rainfall Depths (in)					Predictive Model Adjusted Rainfall Depths (in)				
Basin ID	24 hour September 2013 Total Precip.	10 year 24 hr Precip.	25 year 24 hr Precip.	50 year 24 hr Precip.	100 year 24 hr Precip.	500 year 24 hr Precip.	10 year *	25 year*	50 year*	100 year*	500 year*
LT-1A	6.0	2.4	3.1	3.8	4.5	6.6	2.3	3.0	3.6	4.3	6.3
LT-1B	5.8	2.5	3.2	3.9	4.6	6.8	2.4	3.1	3.7	4.4	6.5
LT-2A	6.4	2.5	3.2	3.9	4.6	6.7	2.4	3.1	3.7	4.4	6.4
LT-3A	6.8	2.6	3.3	4.0	4.7	6.8	2.5	3.1	3.8	4.5	6.5
LT-3B	6.3	2.6	3.4	4.0	4.8	7.0	2.5	3.2	3.8	4.6	6.6
LT-4A	7.1	2.7	3.4	4.1	4.9	7.0	2.5	3.2	3.9	4.6	6.6
LT-4B	7.0	2.7	3.4	4.1	4.9	7.1	2.5	3.3	3.9	4.7	6.7
LT-5	7.3	2.7	3.5	4.2	4.9	7.1	2.6	3.3	4.0	4.7	6.7
WF-1A	8.2	2.6	3.4	4.0	4.8	6.9	2.5	3.2	3.8	4.5	6.5
WF-1B	8,4	2.7	3.4	4.0	4.8	6.8	2.5	3.2	3.8	4.5	6.5
WF-2	8.4	2.6	3.4	4.0	4.8	6.9	2.5	3.2	3.8	4.6	6.6
WF-3A	8.1	2.6	3.4	4.0	4.8	6.8	2.5	3.2	3.8	4.5	6.5
WF-3B	8.1	2.7	3.4	4.1	4.8	6.8	2.5	3.2	3.8	4.5	6.5
WF-4	7.7	2.6	3.3	4.0	4.8	6.8	2.5	3.2	3.8	4.5	6.5
WF-5A	7.2	2.7	3.4	4.1	4.8	6.9	2.5	3.2	3.9	4.6	6.6
WF-5B	7.3	2.7	3.4	4.1	4.8	6.9	2.5	3.2	3.9	4.6	6.6
WF-6A	7.3	2.7	3.4	4.1	4.9	7.0	2.5	3.2	3.9	4.6	6.6
WF-6B	7.2	2.7	3.5	4.1	4.9	7.0	2.6	3.3	3.9	4.6	6.7

*Depth Area Ajustment Factor of 0.95 was applied to NOAA Atlas 14 rainfall data. These depths were used in conjunction with the SCS Type II distribution in the predictive model.

Table B-3 - Dimensionless Values of Cumulative Rainfall for NRCS Type II Storm

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 - Little Thompson Lag Time Parameters for the Predictive Model

Basin ID	Kn	L *mi*	Lc *mi*	S *ft/mile*	TLAG *hours*
LT-1A	0.15	3.6	2.3	370	2.5
LT-1B	0.15	2.7	1.4	150	2.2
LT-2	0.15	3.1	2.7	450	2.4
LT-3A	0.15	3.6	1.8	400	2.3
LT-3B	0.15	2.3	0.9	770	1.4
LT-4A	0.15	3.4	2.3	990	2.1
LT-4B	0.15	3.2	1.8	170	2.5
LT-5	0.15	1.8	0.8	750	1.2
WF-1A	0.15	4.3	1.9	490	2.0
WF-1B	0.15	3.7	1.6	560	2.1
WF-2	0.15	3.4	1.7	690	2.0
WF-3A	0.15	3.0	1.9	200	2.4
WF-3B	0.15	2.6	1.9	390	2.1
WF-4	0.15	5.3	3.3	320	3.3
WF-5A	0.15	2.9	1.7	180	2.4
WF-5B	0.15	1.2	1.5	730	1.3
WF-6A	0.15	2.4	1.5	1340	1.5
WF-6B	0.15	4.1	2.6	280	2.8

Table B-5 - Little Thompson 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-6 - Little Thompson Curve Numbers

Basin ID	Calibrated CN *AMC III*	Predictive CN *AMC II*	Hydrologic Condition
LT-1A	77	60	Fair
LT-1B	76	58	Fair
LT-2	73	55	Fair
LT-3A	74	55	Fair
LT-3B	78	60	Fair
LT-4A	70	50	Fair
LT-4B	77	59	Fair
LT-5	74	55	Fair
WF-1A	86	73	Poor
WF-1B	86	73	Poor
WF-2	72	53	Fair
WF-3A	88	76	Poor
WF-3B	75	57	Fair
WF-4	87	74	Poor
WF-5A	85	70	Poor
WF-5B	75	57	Fair
WF-6A	83	68	Poor
WF-6B	74	55	Fair

Table B-7
Model Results Summary

		Calibrated 24 hour			NOAA Design Storms: 10-percent			4-percent			2-percent			1-percent			0.2-percent		
Hydrologic Element	Drainage Area (sq mi)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/sq mi)	Volume (in)
LT-1A	2.9	430	150	2.8	16	5.6	0.12	46	16	0.32	88	30	0.56	150	52	0.90	380	130	2.1
LT-1B	2.9	500	170	2.7	14	4.8	0.10	43	15	0.29	86	30	0.52	150	52	0.85	400	140	2.0
LT-2	3.0	450	150	2.8	8.1	2.7	0.06	29	9.6	0.20	61	20	0.40	110	38	0.68	320	110	1.7
LT-3A	4.1	690	170	3.2	13	3.3	0.07	46	11	0.23	96	23	0.43	170	42	0.72	480	120	1.8
LT-3B	1.0	240	240	3.5	10	10	0.17	30	30	0.40	56	56	0.68	93	93	1.1	230	230	2.3
LT-4A	2.1	330	160	3.0	3.2	1.6	0.03	14	6.7	0.14	32	16	0.30	65	32	0.55	210	100	1.5
LT-4B	1.9	310	170	3.3	14	7.3	0.16	38	20	0.39	70	37	0.67	110	60	1.0	280	150	2.3
LT-5	0.62	150	240	3.8	3.4	5.5	0.10	12	20	0.28	26	42	0.51	46	75	0.83	130	200	2.0
LT-J1	5.8	930	160	2.8	30	5.2	0.11	89	16	0.31	170	30	0.54	300	52	0.87	780	140	2.1
LT-J2	8.8	1400	160	2.8	37	4.3	0.09	120	13	0.27	230	27	0.49	410	47	0.81	1100	130	1.9
LT-J3	14	2300	160	2.9	58	4.2	0.09	190	13	0.27	380	27	0.49	660	48	0.80	1800	130	1.9
LT-J4	43	9000	210	4.0	650	15	0.28	1400	32	0.54	2200	52	0.84	3400	79	1.2	7500	170	2.5
LT-J5	44	9100	210	4.0	650	15	0.27	1400	31	0.54	2300	52	0.84	3500	79	1.2	7600	170	2.5
LT-R1	5.8	930	160	2.8	30	5.2	0.11	89	16	0.31	170	30	0.54	300	52	0.87	780	140	2.1
LT-R2	8.8	1400	160	2.8	37	4.3	0.09	120	13	0.27	230	27	0.49	410	47	0.81	1100	130	1.9
LT-R3	14	2300	160	2.9	58	4.2	0.09	190	13	0.27	380	27	0.49	660	48	0.80	1800	130	1.9
LT-R4	43	9000	210	4.0	650	15	0.28	1400	32	0.54	2200	52	0.84	3400	79	1.2	7500	170	2.5
WF-1A	2.8	870	310	5.8	110	40	0.57	210	73	0.98	310	110	1.4	440	150	1.9	830	290	3.5
WF-1B	4.0	1300	330	6.0	160	40	0.59	290	73	1.0	430	110	1.4	600	150	1.9	1100	280	3.5
WF-2	4.3	970	220	4.4	13	2.9	0.06	45	10	0.20	97	23	0.40	180	42	0.68	530	120	1.7
WF-3A	2.1	630	300	5.8	91	43	0.69	160	75	1.10	230	110	1.6	310	150	2.1	570	270	3.8
WF-3B	1.7	420	240	4.6	10	5.8	0.12	30	17	0.32	57	33	0.55	96	56	0.87	240	140	2.0
WF-4	4.7	1000	220	4.7	130	29	0.60	240	52	1.00	360	77	1.5	500	110	2.0	940	200	3.6
WF-5A	1.2	300	250	4.7	34	28	0.48	66	55	0.87	100	84	1.3	140	120	1.8	280	240	3.3
WF-5B	0.60	160	270	4.2	4.3	7.2	0.12	14	24	0.33	28	46	0.57	47	79	0.9	120	210	2.0
WF-6A	2.0	600	300	4.8	64	32	0.41	130	66	0.78	210	100	1.2	310	150	1.6	640	320	3.2
WF-6B	2.0	320	160	3.3	8.0	4.1	0.10	24	12	0.28	47	24	0.50	81	41	0.81	210	110	1.9
WF-J1	6.8	2200	320	5.9	270	40	0.58	500	73	0.99	740	110	1.4	1000	150	1.9	2000	290	3.5
WF-J2	4.3	970	220	4.4	13	2.9	0.06	45	10	0.20	97	23	0.40	180	42	0.68	530	120	1.7
WF-J3	15	4000	270	5.2	370	25	0.39	690	46	0.71	1100	72	1.1	1600	110	1.5	3300	220	2.9
WF-J4	20	5000	260	5.1	500	26	0.44	930	47	0.78	1400	73	1.1	2100	110	1.6	4100	210	3.0
WF-J5	21	5400	250	5.0	540	25	0.43	1000	47	0.77	1600	73	1.1	2300	110	1.6	4500	210	3.0
WF-R1	6.8	2200	320	5.9	270	40	0.58	500	73	0.99	740	110	1.4	1000	150	1.9	2000	290	3.5
WF-R2	4.3	970	220	4.2	13	2.9	0.06	45	10	0.20	97	23	0.40	180	42	0.68	530	120	1.7
WF-R3	15	4000	270	5.2	370	25	0.39	690	46	0.71	1100	72	1.1	1600	110	1.5	3300	220	2.9
WF-R4	20	5000	260	5.1	500	26	0.44	930	47	0.78	1400	73	1.1	2100	110	1.6	4100	210	3.0
WF-R5	21	5400	250	5.0	540	25	0.43	1000	47	0.77	1600	73	1.1	2300	110	1.6	4500	210	3.0
Without LT	25	6200	240	4.8	600	24	0.41	1100	45	0.74	1800	70	1.1	2600	100	1.5	5300	210	2.9
Without WF	18	2800	160	2.9	74	4.2	0.09	240	13	0.27	480	27	0.49	840	47	0.79	2300	130	1.9
OUTFALL	44	9100	210	4.0	650	15	0.27	1400	31	0.54	2300	52	0.84	3500	79	1.2	7600	170	2.5

Appendix C
Project Correspondence and Response to Review Comments

Meeting Minutes
Response to CDOT and CWCB Review Comments (April 2014)
Response to Public Review Comments (August 2014)

Appendix C
Project Correspondence and Response to Review Comments

Meeting Minutes

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

<u>CH2M Hill</u>

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 10th. 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.

<u>Jacobs</u>

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

Appendix C
Project Correspondence and Response to Review Comments

Response to CDOT and CWCB Review Comments

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.

Appendix C
Project Correspondence and Response to Review Comments

Response to Public Review Comments

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.

Appendix D
Digital Data

GIS Shapefiles
AWA Rainfall Data
HEC-HMS Calibrated Hydrologic Model
HEC-HMS Predictive Hydrologic Model