Flood Hazard Area Delineation

Plum Creek
East Plum Creek
West Plum Creek

PREPARED FOR:

Urban Drainage and
Flood Control District

Douglas County

NOVEMBER 2019

PREPARED BY:

Enginuity Engineering Solutions
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ACKNOWLEDGEMENTS

ENGINEERING TEAM

The following team members were a part of the preparation of this report:

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SPONSOR TEAM

The following team members sponsored this work:

Shea Thomas, PE – Watershed Services Manager (UDFCD)

Terri Fead, PE – Project Manager (UDFCD)

Morgan Lynch, PE, CFM – Project Manager (UDFCD)

Brad Robenstein, PE – Douglas County

SUBMITTAL LETTER

November 1, 2019

Urban Drainage and Flood Control District
Morgan Lynch, P.E.
Project Manager – Master Planning
2480 W. 26th Avenue, Suite 156B
Denver, Colorado 80211-5304

RE: Flood Hazard Area Delineation Report for Plum Creek, East Plum Creek and West Plum Creek

Dear Ms. Lynch:

Enginuity Engineering Solutions is pleased to submit this Flood Hazard Area Delineation (FHAD) study and associated analysis for the Urban Drainage and Flood Control District (District) and Douglas County. The analysis includes detailed hydraulic modeling and mapping of 14.7 miles along Plum Creek, East Plum Creek and West Plum Creek from Chatfield State Park to the District boundary. In addition to the hydraulic and floodplain mapping update, an erosion and channel migration zone analysis was also included as part of the study.

We also want to express our gratitude to our partners from Douglas County and the District. It was a joy to work with you on this project.

Sincerely,

Gerald Blackler, PE, PhD

Project Manager
Enginuity Engineering Solutions

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1. INTRODUCTION

1.1. Authorization

On May 5, 2015, the Urban Drainage and Flood Control District (UDFCD) contracted with Enginuity Engineering Solutions, LLC (Enginuity) to provide both a Major Drainageway Planning (MDP) study and Flood Hazard Area Delineation (FHAD) study for Plum Creek, West Plum Creek, and East Plum Creek. The FHAD is being prepared in conjunction with UDFCD and Douglas County. The project was authorized under Agreement No. 15-01.29, Major Drainageway Plan for and Flood Hazard Area Delineation for Plum Creek, West Plum Creek and East Plum Creek. Amendment No.1, 15-01.29A, was issued on June 22, 2015, for additional studies on Erosion Hazard Zones (EHZs) to be included in the MDP.

1.2. Purpose and Scope

The purpose of this study is to provide updated hydraulic information along Plum Creek, and portions of East Plum Creek and West Plum Creek in the UDFCD and Douglas County boundaries. The revised hydraulic analysis is based on updated hydrology developed in the September 2016 MDP. The FHAD includes updated hydraulic analyses and floodplain mapping for 11.1 miles of Plum Creek, 3.9 miles of East Plum Creek, and 2.8 miles of West Plum Creek. The results presented in this report will provide updated flood hazard information for problem identification and informed decision making relative to safety, property damage, and development. The UDFCD and Douglas County drainage criteria as well as FEMA flood mapping guidelines were followed in developing the hydrologic and hydraulic calculations associated with this study.

Hydrologic and hydraulic information along East, West, and Plum Creek was originally developed by Howard, Needles, Tammen, and Bergendorff, for the Federal Insurance Administration (FIA) in July 1978. Additional hydrologic and hydraulic analysis of East Plum Creek was completed by J.F. Sato and Associates, Inc. for the Federal Emergency Management Agency (FEMA) in August 1985. This hydrologic and hydraulic information formed the basis of the pre-countywide Flood Insurance Study (FIS) dated January 5, 1996, and of subsequent master planning efforts.

In November 2001 and July 2003, WRC Engineering Inc., (WRC Engineering) completed the Outfall Systems Planning (OSP) Alternatives Evaluation Phase A and Preliminary Design Phase B Reports, respectively. WRC Engineering also completed the FHAD in November 2001. A second FHAD developed by ICON Engineering, Inc. (ICON Engineering) was completed in August 2004. The FHAD covered the lower portions of East Plum Creek and the upper portions of Plum Creek. The WRC Engineering and ICON Engineering used the hydrologic information from the 1996 FIS to complete the updated hydraulic and floodplain mapping analyses that were eventually incorporated into the September 30, 2005, countywide FIS revision for Douglas County.

Upstream of the ICON Engineering study, a separate FHAD study for a portion of East Plum Creek was originally completed by CH2M HILL in 2007 and amended in 2013. This FHAD was sponsored by the Town of Castle Rock. This study was incorporated into the March 16, 2016, Physical Map Revision (PMR) of the Douglas County FIS.

This FHAD is the first study for Plum Creek, East Plum Creek, and West Plum Creek that uses updated hydrology that is different than the published FIS flow rates. Although the previous studies include portions of East, West, and Plum Creek, this study is the first comprehensive FHAD and MDP to update and delineate the flood hazard areas for the entire study area.

The following tasks are being completed as part of this FHAD:

- Obtain most recent mapping and Geographic Information System (GIS) data.
- Review and incorporate recent FEMA approved Letters of Map Revision (LOMR) into the hydraulic modeling.
- Collection and evaluation of available reports and studies on existing drainage facilities, zoning and land ownership plans, current and future land use plans and other drainage related information.
- Coordination and meetings with the project stakeholders.
- Performance of a site investigation to identify major drainage structures, existing problem locations and hydraulic parameters.
- Estimation of the flooding potential to properties along the drainageways.
- Development of water surface profiles along the drainageways.
- Definition of floodplain boundaries and floodway boundaries along the drainageways.
- Preparation of the electronic FHAD documentation.
- Assessment of Channel Migration Zones (CMZ).

1.3. Planning Process

The FHAD planning process followed for this project generally included the following tasks:

- Collection and evaluation of available reports and studies on existing drainage facilities, zoning and land ownership plans, current and future land use plans, soils information and other drainage related information;
- Coordination and meetings with the project stakeholders;

- Performance of a site investigation to identify major drainage structures, existing problem locations and hydraulic parameters;
- Review of the previously completed hydrologic analyses for the existing and proposed basin conditions;
- Estimation of the flooding potential to properties along the drainageways;
- Evaluation of the hydraulic capacity of the existing drainage system and facilities;
- Development of water surface profiles and floodplain boundaries along the drainageways;
- Creation of a FHAD report.

Input from both the project stakeholders and the public are important components of the FHAD planning process. Meeting minutes from all meetings held during this phase of the project can be found in Appendix A. Meeting dates and pertinent topics related to this study are described in more detail below:

- **May 12, 2015 - Project Kickoff Meeting**: The project scope was introduced, and project stakeholders were identified. Additional topics discussed included the available existing information including the ongoing survey, selection of the channel thalweg as the centerline vs. a model baseline for the hydraulic model, inclusion of the new Airport Boulevard Bridge that has been designed but not built, and how to quantify existing and future conditions for the large, mostly undeveloped 322 square mile watershed.
- **July 28, 2015 - Progress Meeting**: Team discussed the preliminary FHAD development including preliminary floodplain delineations, model development, and floodway analysis.
- **January 11, 2016 - Public Meeting:** A public meeting was held in Sedalia to engage residents and interested parties.
- **April 14th, 2016 - Comments and FHAD Draft Discussion**: Team discussed the comments and a change to the centerline.

1.4. Mapping and Surveys

GIS layers were obtained from the UDFCD and Douglas County. These layers include aerial imagery, roads, rail roads, parks, and parcel data. Topography was obtained from the 2014 Denver Regional Council of Governments (DRCOG) that includes a 2.5-foot Digital Elevation Model (DEM) for the entire study area. Contour data at 2-foot and 10-foot intervals was developed for this project. Additionally, a ground survey was conducted at major bridges and drop structures along East, West, and Plum Creek in May of 2015 specifically used to supplement the regional LiDAR for this FHAD effort. Mapping for this project is in NAVD 88 (vertical) and NAD 1983 State Plane Colorado Central (horizontal projected coordinate system).

1.5. Data Collection

Drainage studies, as-built plans for storm improvements, and regional detention facilities were requested and gathered from local agencies. The studies in **Table 1** were used as references for this study. **Section 6 – References** lists all reference used in developing the FHAD report.

Table 1: Data Collection Summary

Title	Date	Author
Flood Hazard Area Delineation: Plum Creek Watershed	November 2001	WRC Engineering, Inc.
Plum Creek Watershed: Outfall Systems Planning Alternatives Evaluation Report Phase A	November 2001	WRC Engineering, Inc.
Plum Creek Watershed: Outfall Systems Planning Preliminary Report Phase B	July 2003	WRC Engineering, Inc.
Flood Hazard Area Delineation: Plum Creek and East Plum Creek	August 2004	ICON Engineering, Inc.
Flood Insurance Study, Douglas County, Colorado and Incorporated Areas	September 30, 2005	Federal Emergency Management Agency
East Plum Creek Watershed Baseline Hydrology Report	November 2007	CH2M Hill
East Plum Creek Watershed Master Plan Improvements	February 2009	CH2M Hill
Airport Road over Plum Creek Bridge Replacement Project Hydraulic Report	July 2013	Muller Engineering Company, Inc.
East Plum Creek Flood Hazard Area Delineation	August 2013	CH2M Hill
Airport Road over Plum Creek Bridge Replacement Project Construction Plans	December 2014	Muller Engineering Company, Inc.
Plum Creek Channel Improvements Project, Floodplain Study – Titan Rd. to Airport Rd.	March 21, 2015	Muller Engineering Company, Inc.
Flood Insurance Study, Douglas County, Colorado and Incorporated Areas	March 16, 2016	Federal Emergency Management Agency
Major Drainageway Plan: Plum Creek, West Plum Creek, East Plum Creek	September 2016	Enginuity Engineering Solutions

1.6. Acknowledgements

This report was prepared with cooperation from the project sponsors (UDFCD and Jefferson County). Participants of this study are listed below in **Table 2**.

Table 2: Project Sponsors and Participants

Participant Name	Organization	Title
Shea Thomas, PE	UDFCD	Program Manager
Morgan Lynch, PE	UDFCD	Project Manager
Brad Robenstein, PE	Douglas County	Project Manager
Gerald Blackler, PE, PhD	Enginuity	Project Manager
Sarah Houghland, PE, CFM	Enginuity	Project Engineer
Colin Barry, CFM	Enginuity	Project Engineer

2. STUDY AREA DESCRIPTION

2.1. Project Area

The study area is in Douglas County, and the UDFCD boundary as shown in **Figure 1**. The watershed for the east, west, and main branches of Plum Creek drains mostly forested land that is mixed with agriculture and medium to light development, with most of the development areas located near where East Plum Creek drains through Castle Rock, Colorado. The watershed is 321 square miles. The headwaters of East Plum Creek begin at the Palmer Lake divide north of Monument, Colorado, and the West Plum Creek headwaters originate west of Perry Park, Colorado. East and West Plum Creek confluence near Sedalia, Colorado to form Plum Creek, which then drains into Chatfield Reservoir, where the creek confluences with the South Platte River. The project area for this study is bound 4,000 feet upstream of the UDFCD Boundary line on East Plum Creek, the UDFCD line on West Plum Creek, and the downstream boundary is Chatfield Reservoir. The project area has not changed since the last analysis because the effective FEMA peak discharges are the values that are still being used for this study. A more detailed discussion is included in **Section 3 – Hydrology**. The project area has a rich history tied to the beginnings of Colorado, and today serves as one of the widest and longest riparian corridors in Douglas County.

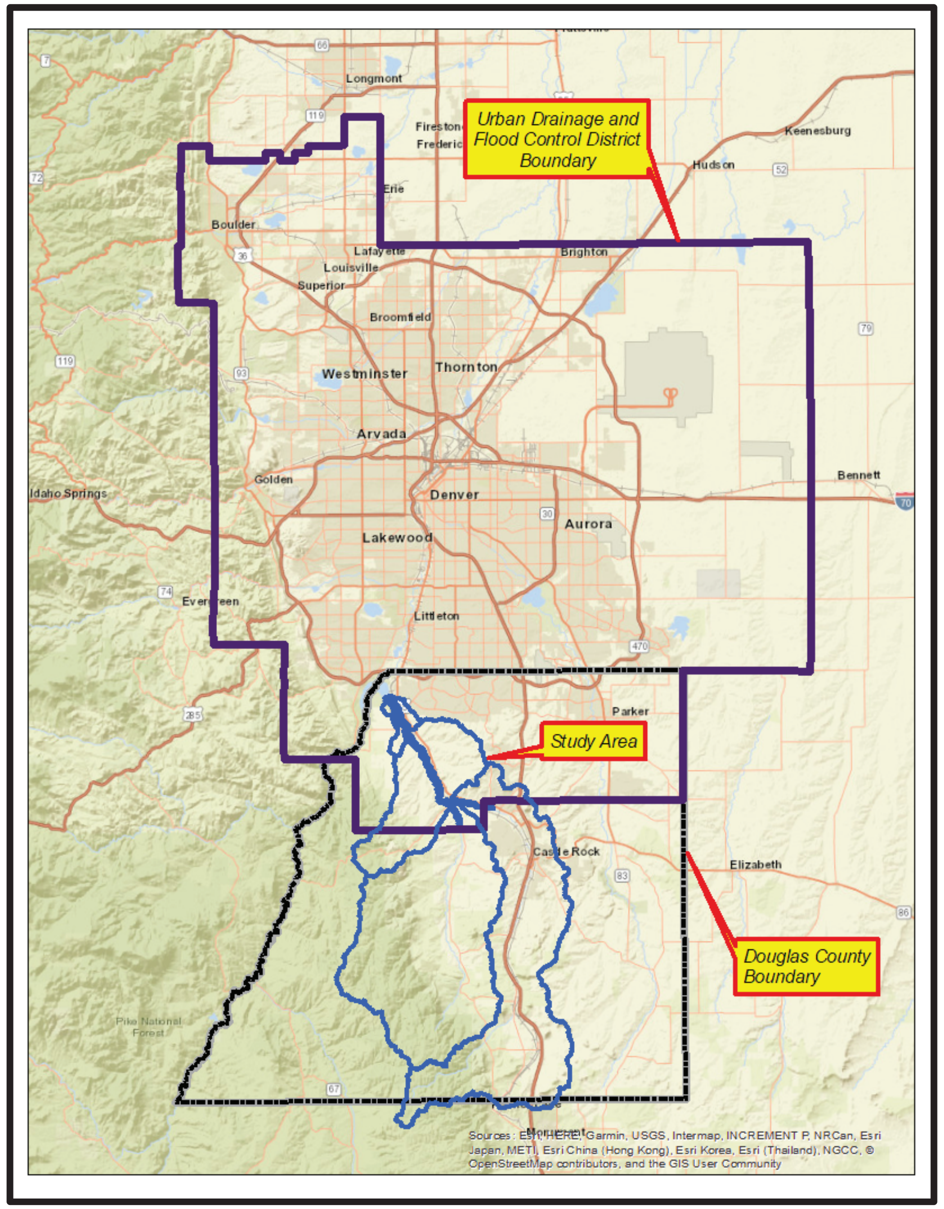

Figure 1: Vicinity Map

The Plum Creek drainages were once hunting grounds for the Arapahoe and Cheyenne tribes. Around 1858, the William Green Russel Party from Auraria, Colorado (the now Auraria Campus in downtown Denver) found some "color" or flakes of gold in the stream at the headwaters of Cherry Creek. This resulted in a staked claim for present day Castle Rock, Colorado that is adjacent to East Plum Creek. The largest change to the Plum Creek corridor before the 20th century was the D&RG Railroad built along East Plum Creek in 1871. Lumbering of the western foothills and mining of a lava rock known as Rhyolite was the economic basis for solidifying small towns and villages such as Sedalia and Louviers, Colorado. Louviers was built by the Dupont Company in 1907 for dynamite production and mining. Today, the town of Louviers remains in the same layout designed by the Dupont Executives in the early 1900s.

Today, the east, west, and mainstem of Plum Creek serve as a wildlife and riparian semi-urban corridor that connects to the Chatfield State Park and Reservoir. Preservation of Plum Creek's ecological habitat and untouched natural beauty are important to local communities while the preservation of the expansive floodplain for conveyance of rare, but potentially catastrophic flood events are important to the safety of local residences and business that back up to the corridor.

The prominent land use and soils within the entire Plum Creek Watershed are Type D (Low infiltration and High Runoff Potential) and Type B (Moderate Infiltration and Moderate to Low Runoff Potential) hydrologic soils overlaid with evergreen forest and grassland land use classifications.

2.2. Land Use

Only three percent of the watershed area is considered developed as either low, medium, or high intensity development. When developed open space is accounted for, the total land use area with any type of development is nine percent of the total watershed area.

For this study, the future and existing hydrologic conditions are considered to be the same. Even large changes in development near Interstate 25 or Santa Fe Drive would not change the annual peak flow estimates. This is because the watershed's peak flow rates are predominately controlled by the 300 plus square miles of tributary area upstream of any local development. The peak flow rates are unchanged when land use lower in the watershed is adjusted for future development. The upstream watershed is unlikely to change drastically; it consists of open forests and grassland, and no known large scale planned developments for the upper watershed are in progress. **Table 3** presents the computed land use and soil areas for the entire 321 square mile watershed. The composite imperviousness is approximately 1 percent while the computed Curve Number (CN) based on guidance in the TR-55 manual is around 69 to 70. **Table 3** summarizes the results of this classification estimate.

Table 3: Land Use and Soils Occupying Plum Creek Watershed

Hydrologic Soil Rating	Land Use Description	Area Occupied (Square Miles)
D	Pasture/Hay	0.03
C	Barren Land (Rock/Sand/Clay)	0.03
B	Pasture/Hay	0.06
B	Barren Land (Rock/Sand/Clay)	0.06
C	Emergent Herbaceous Wetlands	0.08
C	Woody Wetlands	0.19
B	Open Water	0.22
C	Cultivated Crops	0.33
B	Cultivated Crops	0.36
D	Grassland/Herbaceous	0.44
D	Mixed Forest	0.52
D	Woody Wetlands	0.55
C	Developed, Medium Intensity	0.58
B	Developed High Intensity	0.66
C	Developed, Low Intensity	1.07
C	Evergreen Forest	1.90
D	Developed, Open Space	1.93
B	Developed, Medium Intensity	2.37
B	Emergent Herbaceous Wetlands	2.59
C	Developed, Open Space	2.81
C	Deciduous Forest	2.89
B	Woody Wetlands	3.03
D	Shrub/Scrub	3.47
D	Deciduous Forest	3.58
B	Developed, Low Intensity	5.59
B	Deciduous Forest	8.51
C	Shrub/Scrub	13.55
B	Developed, Open Space	13.94
C	Grassland/Herbaceous	16.86
B	Evergreen Forest	24.27
B	Shrub/Scrub	56.30
B	Grassland/Herbaceous	74.45
D	Evergreen Forest	77.56
	Total =	**320.78**

2.3. Reach Descriptions

The entire Plum Creek Corridor is a well-established riparian zone with steep vertical bluffs and a highly active meandering sandy bed channel. Throughout the floodplain corridor there are well established cottonwood trees and large bushels of willow plants along the bank. The sandy channel is composed of decomposed lava rock and rhyolite with the banks consisting of clay and clay loam like material with many fines and clay deposits. Outcrops of wetlands and ineffective flow areas exist along the wide floodplains for both east, west, and the main branches of Plum Creek. In this report, the East and West Plum Creek branches are designated as single reaches, while the mainstem of Plum Creek from the confluence at Sedalia to its termination in Chatfield Reservoir is divided into separate reach descriptions, as discussed below. **Figure 2** Study Area Map is included to graphically show the study limits and reach breaks. **Table 4** Major Roadway Crossings is included on the following page, and the table provides a summary of the different crossings in the study area.

2.3.1 EAST PLUM CREEK

East Plum Creek Study Reach E1 begins at the UDFCD boundary and ends at the confluence with West Plum Creek near Sedalia. There are only two major crossings through this reach, which is the Highway 67 bridge from Sedalia and the BNSF Railroad in the upper portion of the reach. The corridor is defined by steep eroding bluffs that are scattered with pines and some bushes. Between the bluffs and the meandering channel, are grassy terraces that contain willows, wheat grasses, and a mix of large trees including cotton woods and western willows. There are few grade control structures on this reach. The meandering channel is somewhat stable for portions and then cuts into large bluffs causing mass wasting of the banks and hazardous erosion zones for structures perched on top of the bluffs' flat lands.

2.3.2 WEST PLUM CREEK

West Plum Creek Reach W1 begins approximately 1.75 miles downstream of the UDFCD boundary and ends at the confluence with Plum Creek near Sedalia. West Plum Creek runs parallel to North Perry Park Road until it intersects with Highway 67 near the confluence with East Plum Creek. As with East Plum Creek, the corridor is defined by steep eroding bluffs that are scattered with pines and some bushes. Between the bluffs and the meandering channel are grassy terraces that contain willows, wheat grasses, and a mix of large trees including cotton woods and western willows. The meandering channel is somewhat stable for portions and then cuts into large bluffs around outside meanders.

2.3.3 PLUM CREEK

The mainstem of Plum Creek begins approximately 9.6 miles upstream of Chatfield Reservoir at the confluence of East and West Plum Creek reaches. The mainstem of Plum Creek is similar in riparian habitat and creek morphology as East and West Plum Creek, however, the mainstem of Plum Creek has a larger floodplain width and a wider meander of the low flow channel. The geo-morphology in the lower reaches are stable to quasi stable, while the upper reaches are in the process of stabilization by transporting volumes of soil from the banks to the stream bed until a stable slope is reached.

Reach M1 - Chatfield Reservoir to Titan Road: The lower portions of Plum Creek can be characterized as a stable to quasi stable sandy bed stream with a light armoring layer of 2 to 3 inch minus gravels in the main channel. Sediment in the banks range from course sand near the stream to fine sand with some silt in the overbanks. According to the Schumm Model of Channel Evolution, the lowest portions of Plum Creek appear to be class V (Stable) with a history of aggredated material in the main channel and a multi terraced floodplain that has been widened over time and during large flood events, such as the historic flood of June 1965.

Reach M2 - Titan Road to Airport Road: Bank and stream classifications change moving upstream. Approximately a few miles above Titan Road, Plum Creek converges into a class IV (degradation and widening) where the stream is still stabilizing and taking material from the banks. Further up the main channel is representative of a class III (degradation), where bank failures are observed on more vertical banks and channel migration out of the bank (avulsion) is more likely to occur and appears to be present at some small crossing locations.

Reach M3 - Airport Road to the East and West Plum Creek Confluence: The upper reaches of the mainstem have a more well-defined channel and banks through the corridor. The stream armoring layer of the main channel consists of courser cobbles to gravel, indicative of a steeper gradient, and the banks are vegetated grassy banks instead of deposited sands and silts. The floodplain terrace quickly rises in height, compared to the gradual increase in the lower reaches and consists of dryer soils with shrubs and small grasses intermixed with large trees. The floodplain vegetation is less dense and tall in the upper reach as well.

2.4. Flood History

The most damaging flood that has been recorded on Plum Creek occurred in June of 1965, when a series of convective storms formed over the watershed and produced intense rainstorms mixed with hail and some reports of funnel clouds. During this storm, the one gauging station on Plum Creek near Louviers was destroyed, however, reports indicate a change from 150 to 154,000 cfs occurred in less than 3 hours. This is the largest ever recorded discharge for this gage, with the next lower annual peak discharge being around 4,400 cfs. The 1965 flood is the historic flood event for Plum Creek, surpassing all other known floods by over 30 times. The estimated 150,000 cfs that is published for the Louviers gage greatly skews the flood frequency curve even though it's treated as an outlier. No other annual peaks come close to the magnitude and duration of this historic event that washed out I-25 over East Plum Creek and destroyed the Rio Grande and BNSF Railroad bridges over Plum Creek.

Table 4: Major Roadway Crossings

Drainageway	Roadway	Structure Type	Structure ID
Plum Creek	Trail Crossing	Bridge	8
	Titan Road	Bridge	7
	Main Street	Bridge	6
	Airport Road	Bridge	5
	Old Railroad Bridge	Bridge	4
	CR-20/Rio Grande Avenue	Bridge	3
West Plum Creek	Highway 67	Bridge	2
East Plum Creek	Highway 67	Bridge	1
	Maintenance Road Crossing	Box Culverts	18
	AT&SF Railroad	Bridge	17

2.5. Environmental Assessment

The Plum Creek Watershed is considered by the Colorado Division of Wildlife to be one of the ten most important areas for conserving wildlife and habitat diversity in the State of Colorado (WRC 2000). It is home to several rare or endangered species, such as the Prebles Meadows Jumping Mouse. The grasslands in addition to the forested and riverine wetlands are a prime habitat for small mammals and endangered species. Areas of Plum Creek that contain a base flow or remain inundated on a yearly basis provide habitat for several endangered fishes, including the Common Shiner, Brassy Minnow, Iowa Darter, and the Northern Red Belly Dace.

2.5.1 WETLAND AND RIPARIAN ZONES

A desktop review of wetland areas was completed based on National Wetland Inventory (NWI) data and aerial photography. The entire corridor consists of freshwater forest and shrub wetlands with riverine wetlands delineated in the main channel. Riverine wetlands can be as confined as 10-30 foot and as wide as a few hundred feet, while the freshwater forests can span a few thousand feet where the well-established floodplain has been widened by the meandering low flow channel and historic floods.

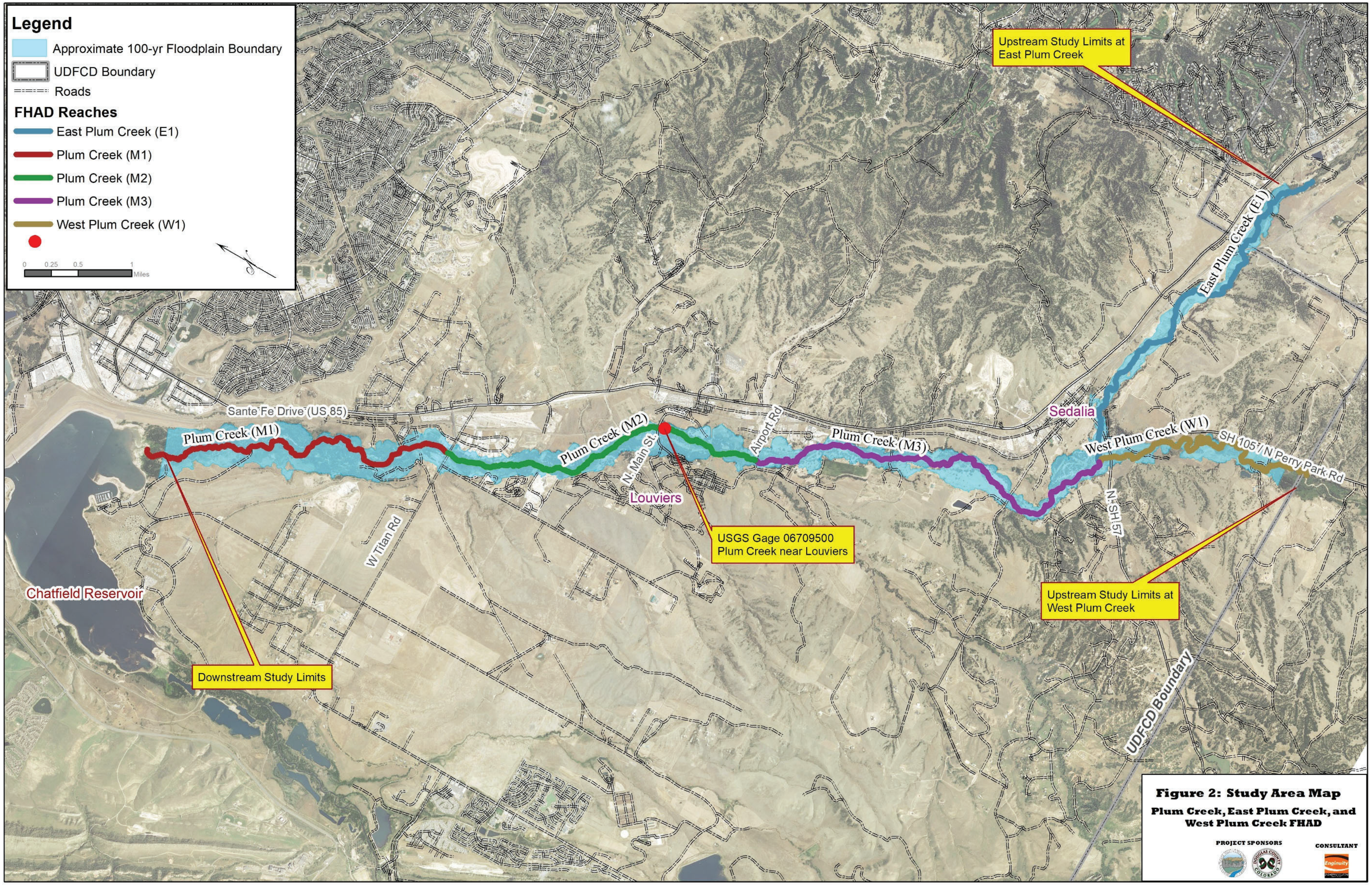

Figure 2: Study Area Map

2.5.2 FLORA, FAUNA AND THREATENED AND ENDANGERED SPECIES

In the lower reaches of Plum Creek, the ecological habitat is well connected with a continuous stream that has few, if any, large vertical drops or eroding banks. In these reaches, many frogs, toads, and birds are observed along with deer and coyote prints. This abundance of wildlife indicates a healthy stream environment in both the channel and terraced floodplains. As one progresses higher in the reaches of East and West Plum Creek, the floodplain and stream connectivity are reduced by more vertical banks, although these banks are still vegetated, some are being eroded near the channel.

A desktop review was completed to identify the potential presence of Federal and State listed threatened and endangered species as well as State species of concern, which are collectively referred to as special status species. The United States Fish and Wildlife Service (USFWS), and Natural Diversity Information Source (NDIS, a division of CDOW) websites were researched to determine if suitable habitat for any special status species was present within the study area. A summary of the protected species found during this research are discussed below:

- Prebles Meadows Jumping Mouse: The Preble's meadow jumping mouse (Preble's or PMJM) is a small mammal approximately 9 inches in length with large hind feet adapted for jumping, a long bicolored tail (which accounts for 60% of its length), and a distinct dark stripe down the middle of its back which is bordered on either side by gray to orange-brown fur. The east, west, and mainstem branches of Plum Creek are well established habitats for the PMJM and are included in the County's Prebles Jumping Mouse Habitat Conservation Plan.
- The Pawnee montane skipper (Hesperia leonardus montana) is a rare butterfly that occurs only on the Pikes Peak Granite Formation in the South Platte River drainage system in Colorado, involving portions of Jefferson, Douglas, Teller, and Park Counties. Because of the limited habitat and range of the species, unexpected environmental, random events could have a major deleterious effect on the population.
- The bald eagle (Haliaeetus leucocephalus), our national bird, is the only eagle unique to North America. The bald eagle's scientific name signifies a sea (halo) eagle (aeetos) with a white (leukos) head. Bald eagles are found throughout most of North America, from Alaska and Canada to northern Mexico. The lower portions of Plum Creek near Chatfield Reservoir are considered a winter forage area for the Bald Eagle. Currently there are no bald eagle nests or roosts mapped within the study area, however, the waterbodies within and adjacent to the study area may supply bald eagles with prey during winter months.
- Ute ladies'-tresses is a perennial herb with erect, glandular-pubescent stems 12-60 cm tall arising from tuberous-thickened roots. Basal leaves are narrowly linear, up to 1 cm wide and 28 cm long, and persist at the time of flowering. The species occurs in Colorado, Idaho, Montana, Nebraska, Nevada, Utah, Washington, and Wyoming.

3. HYDROLOGIC ANALYSIS

3.1. Overview

For this study, the hydrologic results have not been updated from earlier analyses based upon further evaluation. The peak flow rates that were originally developed by Howard, Needles, Tammen, and Bergendorff, for the Federal Insurance Administration (FIA) in July 1978 and the additional hydrologic and hydraulic analysis of East Plum Creek completed by J.F. Sato and Associates, Inc. for the Federal Emergency Management Agency (FEMA) in August 1985 that formed the basis of the pre-countywide FIS dated January 5, 1996, will continue to be used.

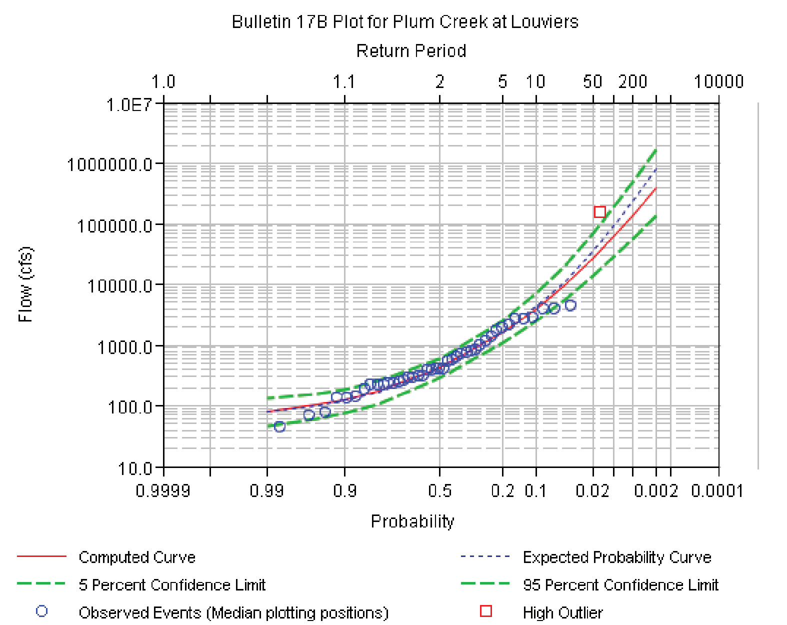

Figure 3: Flood Frequency Graph of a Bulletin 17B Analysis for USGS Gage 06709500 - Plum Creek near Louviers

For this report, the currently reported peak discharge values are considered adequate for existing and future conditions because of the following reasons:

- Peak flood flows are dominated by the 300 plus square mile tributary drainage area above Castle Rock, Douglas County, and any planned development. Therefore, development in the local watershed does not control the rare flood events used for a flood hazard area delineation. However, these local developments do impact frequent flows that control sediment supply and transport.
- There is no recent history or indication that the flood flows in the FIS are inaccurate or under accounting for peak flow events.
- The USGS Gage for Plum Creek near Louviers does not include a recorded annual peak flow exceeding 4,300 cfs aside from the outlying the 1965 flood event. Over 43 years of record do not contain a flow event greater than the 10-year FIS flow when outliers are eliminated.
- A statistical analysis using the Bulletin 17b method and the HEC-SSP program show the 100-year FIS flow within the confidence intervals for the gage at Titan Road.

3.2. Design Rainfall

Design rainfall used in the 1996 pre-county wide FIS analysis applied the Soils Conservation Service (SCS) Type IIA storm distribution with 24-hour rainfall depths. With a total drainage area of 321 square miles, and area reduction factors as described in the National Oceanic and Atmospheric Administrations (NOAA) Rainfall Atlas for the Western US were applied to the 24-hour rainfall depths to make an average rainfall depth across the watershed. Design rainfall depths used in the 1996 FIS are not specifically discussed in the document.

Although WRC's 2001 study used the Colorado Urban Hydrograph Procedure (CUHP) and the analysis subdivided small watersheds within the UDFCD Boundary, the peak flows along Plum Creek were calibrated to the 1996 FIS so that the larger watershed was accounted for. The 2005 county wide FIS incorporated the 2001 WRC study, but the hydrology did not change while the hydraulic modeling and floodplain mapping were updated. Since the 2001 WRC hydrology was calibrated to the 1996 FIS values, there is no difference in peak flows. The two methods (1996 pre-countywide FIS versus 2001 WRC/2005 countywide FIS) of rainfall can be substantial; however, this difference is not known since the 2001 WRC analysis was calibrated to the 1996 FIS values.

Table 5 presents the 24-hour design rainfall depths for Louviers, Colorado from the most recent NOAA Atlas 14, available via the Precipitation Frequency Data Server (PFDS) maintained by NOAA and the 2-hour total rainfall depths used in WRC's 2001 analysis, which only included the 10-, 50-, and 100-year storm intervals.

Table 5: Rainfall Depths

Return Period	24-hour Point Rainfall at Louviers, CO from the most Recent PFDS (inches)	2-hour Total Rainfall Depths from WRC (2001) (inches)
2-Year	1.96	-
5-Year	2.48	-
10-Year	2.94	1.80
25-Year	3.62	-
50-Year	4.18	2.42
100-Year	4.77	2.74
500-Year	6.27	-

3.3. Sub Watershed Characteristics

The prominent land use and soils within the entire Plum Creek Watershed are Type D (Low infiltration and High Runoff Potential) and Type B (Moderate Infiltration and Moderate to Low Runoff Potential) hydrologic soils overlaid with evergreen forest and grassland land use classifications. Only three percent of the watershed area is considered developed as either low, medium, or high intensity development. When developed open space is accounted for, the total land use area with any type of development is nine percent of the total watershed area.

For this study, the future and existing hydrologic conditions are considered equal. Even large changes in development near Interstate 25 or Santa Fe Drive would not change the annual peak flow estimates. This is because the peak flood flows resulting from the 300 plus square miles upstream of any local development and are unchanged when land use lower in the watershed is adjusted. The upstream watershed is unlikely to change drastically; it consists of open forests and grassland and there is no known large scale planned developments for the upper watershed. Table 2-1 presents the computed land use and soil areas for the entire 320 square mile watershed. The composite imperviousness is approximately 1 percent while the computed Curve Number (CN) based on guidance in the TR-55 manual is around 69 to 70.

3.4. Hydrograph Routing

Routing of hydrographs from sub-basins is not explicitly discussed in the 2005 or 1996 FIS, however, it is deduced that the routing including Muskingum or Muskingum-Cunge routing schemes that would allow for attenuation of the flood hydrograph as it travels through Plum Creek. This is evident by the decreasing peak discharges from Louviers Avenue to the downstream limit of the detailed study. Routing within the 2001 WRC study followed the standard kinematic wave routing recommended by UDFCD, which can lag the flood wave in time but does not contain the mathematics that will produce attenuation of the peak. However, since it was calibrated to the original FIS, attenuation of the flood wave was accounted for through model calibration.

3.5. Previous Studies

The most pertinent hydrologic studies for this area are the:

- 1996 FIS
- 2001 Baseline Hydrology by WRC
- 2005 FIS (unchanged from 1996 FIS)
- 2007 Baseline Hydrology for East Plum Creek

The 2007 Baseline Hydrology by CH2M HILL is the only published hydrology that differs from the FIS, as all other baseline studies were calibrated back to the 1996 FIS. CH2M HILL (2007) applied the SCS Unit Hydrograph method with 24-hour rainfall distributions and area reduction factors for the East Plum Creek Watershed upstream of Castle Rock, Colorado. Generally, the results from CH2M HILL's analysis are within 10 percent of the FIS published flows. The main difference in peak flows occurs as the flood wave progresses downstream. CH2M HILL applied the kinematic wave for hydrologic routing, which does not attenuate peak flows as the flood wave progresses downstream, while the FIS applied a routing scheme that attenuates flows as the flood wave passes through the wide flood channel of Plum Creek. This study finds that the routing scheme in the 1996 and subsequently modeled 2005 FIS is appropriate for the size and geometry of the Plum Creek flood channel and remains with the 2005 published flows for the portions of East Plum Creek that are mapped as part of this FHAD.

3.6. Results of Analysis

This study is based on hydrology presented in the 2005 FIS. The methodology included in the 2005 FIS was reviewed in addition to other studies from CH2M HILL and WRC. There are no observed reasons from prior flood events or from review of the 2005 FIS methodology that necessitates an adjustment to the 2005 FIS flows at the time of this study. A statistical analysis including 43 years of annual peak data on Plum Creek indicate that the 100-year FIS flows fall within the lower band of confidence intervals for the USGS gauge near Louviers Avenue (North Main Street). If the 1965 flood event is removed from the data set, the 100-year FIS flows are considerably reduced, however, it is not appropriate to completely remove the 1965 flood event from the statistical analysis but instead to perform the outlier test and handle the outlier according to methodology in Bulletin 17B published by the USGS. **Table 6** presents the flow rates applied for this study while **Table 7** presents the computed flood frequency results for the gage near Louviers, Colorado.

Table 6: Peak Flow Rates

	Return Interval (Years)	10	50	100	500
Location	**Drainage Area (square miles)**	**Flow in Cubic Feet Per Second**			
Plum Creek					
Downstream Limit	317	14,190	28,730	38,590	69,460
Titan Road	314	14,150	28,800	38,710	69,680
USGS Gage 067069500 (Louviers Avenue/North Main Street)	302	14,430	29,130	39,100	70,380
West Plum Creek					
Upstream Limit to Confluence with East Plum Creek	135	2,450	11,740	19,210	32,500
East Plum Creek					
At Confluence with West Plum Creek to Douglas County Boundary	142	6,020	12,460	16,650	27,730

Table 7: Bulletin 17B Analysis on USGS Gage near Louviers, Colorado

Percent Chance of Exceedence	Return Interval (Years)	Computed Flow Values (cfs)	5% Confidence Interval	95% Confidence Interval
0.2	500	382,039	1,675,609	134,333
0.5	200	136,522	482,777	55,597
1	100	61,905	186,004	28,149
2	50	27,681	70,725	14,030
5	25	9,276	19,207	5,394
10	10	3,927	6,997	2,506
20	5	1,588	2,487	1,086
50	2	415	596	283

4. HYDRAULIC ANALYSIS

4.1 General

A Flood Hazard Area Delineation (FHAD) has been completed for the mainstem of Plum Creek and portions of East and West Plum Creeks within Douglas County and the UDFCD Boundaries. The purpose of the FHAD mapping is to identify areas, structures, and property which have the potential of being inundated by the 100-year flood event. In addition to the FHAD mapping, floodways have been defined along each of the drainageways to establish the portion of the channel that must remain free of obstruction to allow for conveyance of the 100-year flood without significant increases in water surface elevation. While the Federal Emergency Management Agency (FEMA) uses the 1.0-foot floodway as part of the Flood Insurance Study (FIS), the 0.5-foot floodway was utilized in this study per Colorado Water Conservation Board (CWCB) regulations.

4.2 Evaluation of Existing Facilities

The 10-, 50-, 100-, and 500-year water surface elevations were determined using the U.S. Army Corps of Engineer's step backwater program HEC-RAS, Version 5.0.3. Cross-section data was developed from the 2014 LiDAR Digital Elevation Model (DEM), which had a processed DEM resolution of 2.5 feet between cells. Estimates of channel and overbank roughness were made from aerial photographs, field observations, and soils and materials data available from the USGS and NRCS. Manning's 'n' values ranged from 0.025 to 0.045 in the channel and from 0.035 to 0.12 in the overbank areas. Blocked obstructions and ineffective flow locations were utilized to account for large structures and flow conveyance paths around structures.

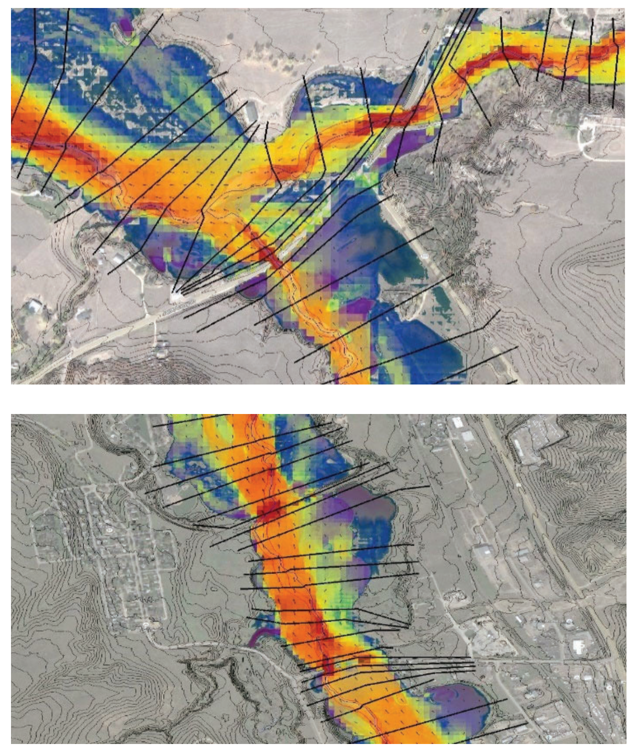

Figure 4: HEC-RAS 2D Hydraulic Model Images

HEC-RAS 2D was used to confirm ineffective flow areas around structures and through the 14 miles of stream lengths studied.

4.2.1 HEC-RAS MODEL DEVELOPMENT

The HEC-RAS model developed for this project calculated water surface elevation profiles for the 10-, 50-, 100-, and 500-year flood events. As discussed in Section 3 – Hydrologic Analysis, future and existing conditions are the same, making for a single HEC-RAS plan and model run. All flows were modeled as steady state within the HEC-RAS program. Cross-sections were placed at an average of no more than 500 feet apart based on the channel thalweg, and graphical representations of all cross-sections are located in **Appendix C**.

Additionally, a 2-Dimensional (2-D) hydraulic analysis of the 100-year flows was performed using the HEC-RAS 2D Beta (Version 5.0 Released for Limited use in October 2014). The 2-D hydraulic model confirmed section placement perpendicular to both the center line and floodplain in addition to effective and ineffective flow locations around structures. In **Figure 4** to the right, the top image presents the 2-D analysis for Highway 67 over East and West Plum Creek at the confluence. Notice the effective flow areas on the expansion of East Plum Creek as it approaches the confluence. This type of additional analysis allows for a complete and representative 1D hydraulic model that requires adjustments of in-effective flow and expansion coefficients to properly model expansion and contractions.

4.2.2. HYDRAULIC MODELING OF STRUCTURES

Along East, West, and the Mainstem of Plum Creeks there are a range of hydraulic structures from small pedestrian and private crossings to large bridges supporting multi-lane highways. A few drop structures are located along Plum Creek and East Plum Creek, however, the size of the drops compared to the 100-year flood depths are minimal. A cross section upstream and downstream of each drop was still included in the analysis. All structure data, including drop structures, were input into the HEC-RAS model based on the May 2015 survey data collected as part of this project in conjunction with the 2014 LiDAR data used for cutting cross sections across the reach. Bridges with piers were modeled using the momentum equation and appropriate drag coefficients. All structures were modeled with the pressure-weir option turned on within the bridge hydraulic model options to ensure proper modeling of overtopping flows. A summary of structures is included in **Table 8**.

4.2.3 SURVEY DATA

The bridge and culvert crossings in the HEC-RAS model were constructed from ground survey data provided by UDFCD. The structure survey data were acquired in May 2015. All elevations are referenced to the NAD83 and NAVD88 datums. The structures in this document are numbered 1 through 18. The structure number of a given bridge/culvert has been included in the HEC-RAS model in the description bar in the Bridge Culvert Data Editor for that structure. LiDAR data for the cross sections was collected from the Denver Regional Council of Governments (DRCOG) and USGS, which included 2.5-foot resolution Raster Files from the processed LiDAR. These raster surfaces were combined to make one large surface for the study area. All contours and surfaces are in the NAD83 and NAVD88 datums.

4.2.4 DEVELOPMENT OF MANNING'S N VALUES

Roughness values to account for hydraulic friction losses within HEC RAS were established by site visits, materials data, and aerial photography. A composite Manning's Roughness for the channel and overbanks was computed for each cross section to appropriately account for friction losses. Photographs and site observations are compared with published data on Manning's Roughness Coefficients in the US Geological Survey Water Supply Paper 1849 and 2339 and from Chow's Open Channel Hydraulics. In general, the following classification of topography and roughness are applied:

- Main Channel (Braided with Sandy Gravel Bottom), 0.025 < n < 0.030
- Main Channel (Moderately Confined with Riffles), 0.030 < n < 0.040
- Main Channel (Sandy Bed Outcrops and Mixed Vegetation), 0.035 < n < 0.045
- Overbank near Channel (Wheat Grasses, Willows, and Moderate Understory), 0.05 < n < 0.06
- Overbank near Channel (Short Grasses, sandy coverage), 0.025 < n < 0.035
- Overbank near Channel (Wetland Cattails, Medium Dense Brush), 0.070 < n < 0.12
- Far Overbank (Mixed Trees with Tall Grasses in Between), 0.085< n < 0.12
- Far Overbank (trees, brushes, grasses, and moderately dense understory), 0.050 < n < 0.065
- Far Overbank (Light Trees, Short Grasses, Sandy Bottom), 0.035 < n < 0.045
- Far Overbank with light grasses and Sandy Bottom, 0.04 < n < 0.055
- Far Overbank (Sandy bottom and well-established brush), 0.045 < n < 0.055

The images on the next few pages (**Figures 5** to **14**) document the land use and vegetative characteristics for each Manning's n value presented above.

Figure 5: Plum Creek Main Channel Braided with Sandy Bottom (0.025<n<0.030)

Figure 6: Plum Creek Main Channel Moderately Confined with Riffles (0.030<n<0.040)

Figure 8: Plum Creek Main Channel Sandy Bed Outcrops Mixed with Vegetation (0.035<n<0.045)

Figure 7: Plum Creek Main Channel Overbank near Channel Wheat Grasses, Willows, and Moderate Understory (0.050<n<0.060)

Figure 9: Plum Creek Main Channel Overbank near Channel with Wetlands, Grasses, and Medium Dense Brush (0.070<n<0.12)

Figure 10: Plum Creek Main Channel Overbank near Channel Short Grasses and Sandy Coverage (0.025<n<0.035)

Figure 11: Plum Creek Main Channel Far Overbank with Mixed Trees and Tall Grasses (0.025<n<0.030)

Figure 12: Plum Creek Main Channel Far Overbank with Trees, Brushes, Grasses, and Moderately Dense Understory (0.050<n<0.065)

Figure 14: Plum Creek Main Channel Far Overbank with Light Trees, Short Grasses and Sandy Bottom (0.035<n<0.045)

Figure 13: Plum Creek Main Channel Far Overbank with Light Grasses, Sandy Bottom (0.040<n<0.050)

4.2.5 FLOODWAY ANALYSIS

The 0.5-foot floodway modeling was also completed using HEC-RAS version 5.0.3. The equal conveyance reduction method was used to achieve floodway encroachments that were less than the maximum allowable surcharge of 0.5-foot. The Floodway Data Table is included in **Appendix D**, and the floodway delineation is included on the hydraulic work map in **Appendix E**.

4.2.6 RESULTS OF HYDRAULIC ANALYSIS

The hydraulic analysis in this study produced mapping extents of the 100-year floodplain that are wider than the current published flood hazard zones. This is due to more refined roughness values in the overbanks and updated topography. In total, 38 structures are now located within the updated floodplain compared to 17 structures that were located within the floodplain before this study was conducted. **Figure 15** shows which structures are located in the 100-yr floodplain.

4.3 Flood Hazards

The results of the floodplain analysis are displayed in the Floodplain and Floodway Data Tables in **Appendix D**, the hydraulic work maps included in **Appendix E,** and the flood profiles in **Appendix F.** A summary of flood hazards is provided here by reach. **Figure 15** shows structures that are in the 100-year floodplain.

A Channel Migration Zone (CMZ) was also delineated for this study. The CMZ is used to predict areas at risk for future channel erosion due to natural fluvial processes. By delineating the CMZ, it is possible to reduce the damage to property and risk to human life by understanding that creeks are in constant motion across the landscape. The CMZ also allows for a focused approach to mitigating the degradation along the channel that naturally occurs over time. More information regarding the CMZ analysis is included **Appendix G**. The Drainage Problem Areas figure included in **Appendix C** shows the CMZ along with the structures in the 100-yr floodplain and the Drainage Problem Areas from the MDP.

4.3.1 EAST PLUM CREEK

Flood hazards on East Plum Creek are minimal. The one structure that overtops during the 10-year and larger events is a private maintenance road downstream from the BNSF Railroad Bridge at Station 16441.47. Where Highway 67 crosses East Plum Creek just upstream of the confluence, there is two buildings on the northeast side of the highway that is close to the 100-year floodplain. There are sheds or storage facilities identified as structures in the floodplain. Additionally, the property appears to have equipment within the floodplain that is likely to be inundated during the 100-year flood event.

4.3.2 WEST PLUM CREEK

The Highway 67 bridge just upstream of the confluence with East Plum Creek overtops during the 100-year flood event but passes the 50-year and smaller flood events. The overtopping appears to be contained within the top of the road near the bridge as the highway slopes east to west and has a sag vertical curve above the highway. Downstream of the bridge, East Plum Creek spills into West Plum Creek for the 100-year and larger events before they confluence with

Plum Creek. There are also four buildings immediately upstream of the Highway 67 bridge that are in the 100-year floodplain.

4.3.3 PLUM CREEK

Reach M1: Chatfield Reservoir to Titan Road: The pedestrian trail bridge near the confluence with Chatfield reservoir overtops for all flood events. The Titan Road Bridge over Plum Creek overtops on the left (west) abutment where there is a spill location. This depth of overtopping would make the bridge un-passable during the 100 year and larger floods. Immediately downstream of the bridge, there are a series of structures within the floodplain and the floodway. These structures are also shown to be within the current effective floodplain and floodway.

Reach M2: Titan Road to Airport Road: Between Titan Road and Airport Road there many structures in the floodplain. The Main Street bridge that provides access from Santa Fe Drive to the Town of Louviers overtops between the 10- and 50-year flood events. The overtopping is contained within the sag vertical curve of the roadway alignment; however, somewhat frequent overtopping can be expected at this bridge. Citizens in Louviers do have a secondary exit across Plum Creek via Airport Road. Downstream of Main Street bridge there is a pond that is within the 100-year floodplain. The pond's embankment is higher than the 100-year floodplain, however, would be at some risk from erosion and scour during these high flows. The new bridge over Airport Road safely passes the 100-year flood event with 4-feet of freeboard and overtops on the east side during the 500-year flood flows.

Reach M3: Airport Road to East and West Plum Creek Confluence: The Highway 20/Rio Grande Avenue bridge overtops for the 500-year event but passes the other flood events. The Old Railroad Bridge the bridge overtops during the 10-year event and overtops by approximately 8 feet during the 100-year event. There are multiple structures located in the 100-year floodplain within this reach as well.

Table 8: Bridge Overtopping Summary for East, West, and Plum Creek

Stream	Location	Structure ID Number	Station	Type	Approx. Total Span (ft)	10-Year Overtopping Depth (ft)*	100-Year Overtopping Depth (ft)*
East Plum Creek	Highway 67	1	1883.36	Bridge	167	None	None
East Plum Creek	Maintenance Road D/S of Railroad	18	16441.47	Box Culverts		4.77	8.56
East Plum Creek	AT&SF Railroad	17	16607.95	Bridge	148	None	None
Plum Creek	Trail Crossing	8	1666	Bridge	90	5.53	6.63
Plum Creek	Titan Road	7	18657.58	Bridge	249	None	5.80
Plum Creek	Main Street	6	30661.66	Bridge	200	None	3.89
Plum Creek	Airport Road	5	36402.45	Bridge	333.5	None	None
Plum Creek	Old Railroad Bridge	4	44016.99	Bridge	53.5	6.17	8.45
Plum Creek	CR-20/Rio Grande Avenue	3	51591.94	Bridge	317	None	None
West Plum Creek	Highway 67	2	728.60	Bridge	66	None	5.22

*Overtopping depths calculated by subtracting water surface elevation from the lowest point of overtopping.

4.4 Previous Analyses: Comparison with Effective Flood Insurance Study

A comparison was made between the information presented in the FHAD and the effective Flood Insurance Study (FIS) for Douglas County. In general, the 100-year floodplain Base Flood Elevations (BFEs) are higher than the effective study and consequently wider, encompassing a larger inundated area during the 100-year flood flows. The FHAD also includes approximately 9,000 feet of additional floodplain mapping for Plum Creek. The FHAD mapping now extends to Chatfield Reservoir while the effective FIS mapping stops approximately 9,000 feet upstream. Areas where the FHAD mapping is wider than the effective FIS mapping include:

- Plum Creek Reach 1 – Downstream of Titan Road
- Plum Creek Reach 2 – Multiple isolated areas between Titan Road and Airport Road
- Plum Creek Reach 3 – For this reach the floodplain is generally slightly wider over the full length
- East Plum Creek – For areas generally upstream of the crossings
- West Plum Creek – Multiple isolated areas upstream of Highway 67

Differences between the effective mapping and the flood hazard delineations presented in this FHAD can be attributed to more using detailed topographic data and minor differences in modeling techniques that were used for this analysis. The 2004 FHAD (ICON 2004) placed cross sections immediately at the bridge deck while this study modeled bridge and structures according to the HEC-RAS technical manual (USACE 2010), which requires that the upstream and downstream cross sections be at the toe of the embankment and that internal cross sections are used to model the bridge face. This study also models contractions and expansions of topography with ineffective flows and appropriate contraction and expansion coefficients. Additionally, this study has more frequent placements of cross sections when compared to previous studies and has a more refined analysis and variations of overbank roughness values for each section.

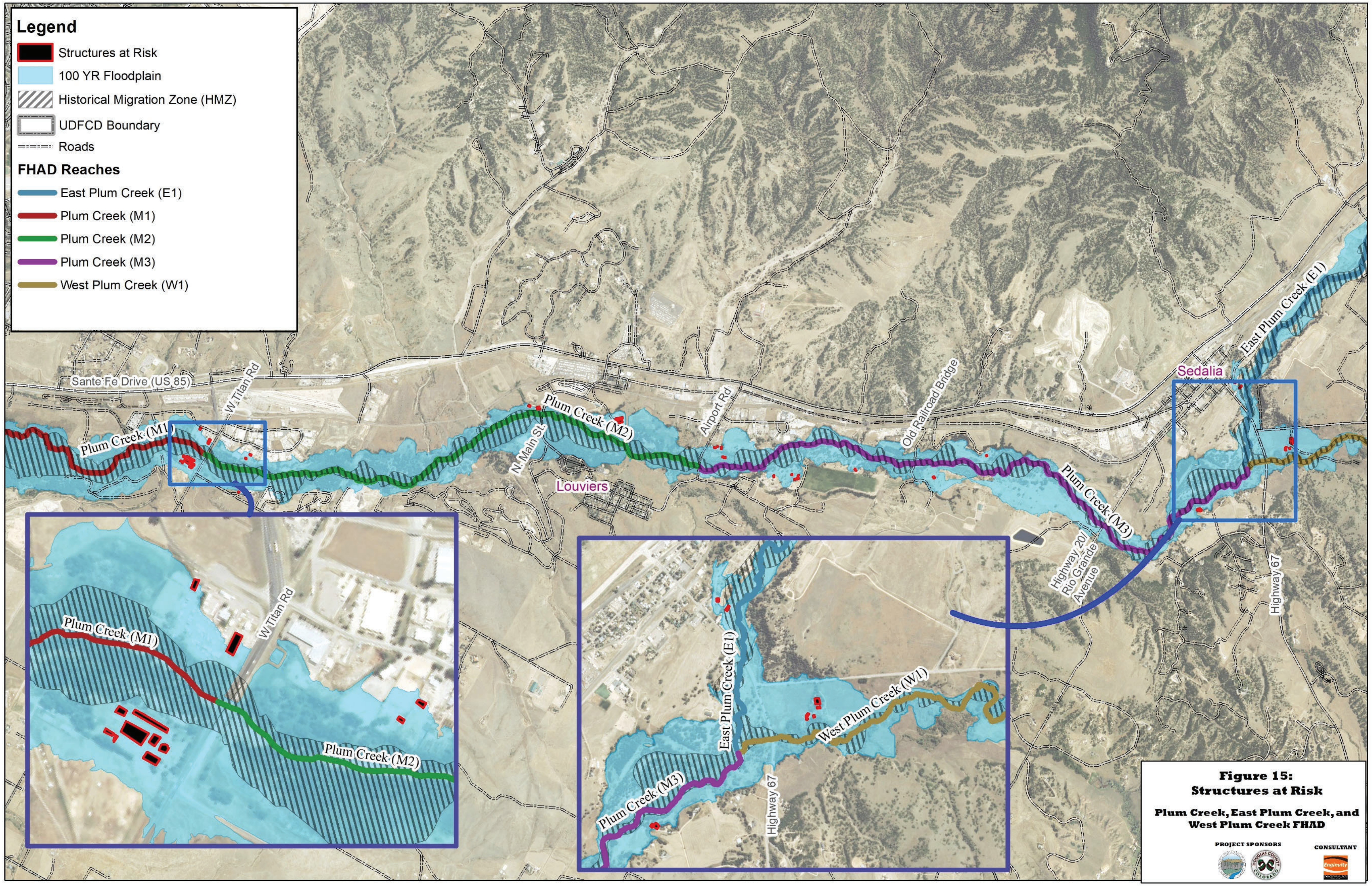

Figure 15: Structures at Risk

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