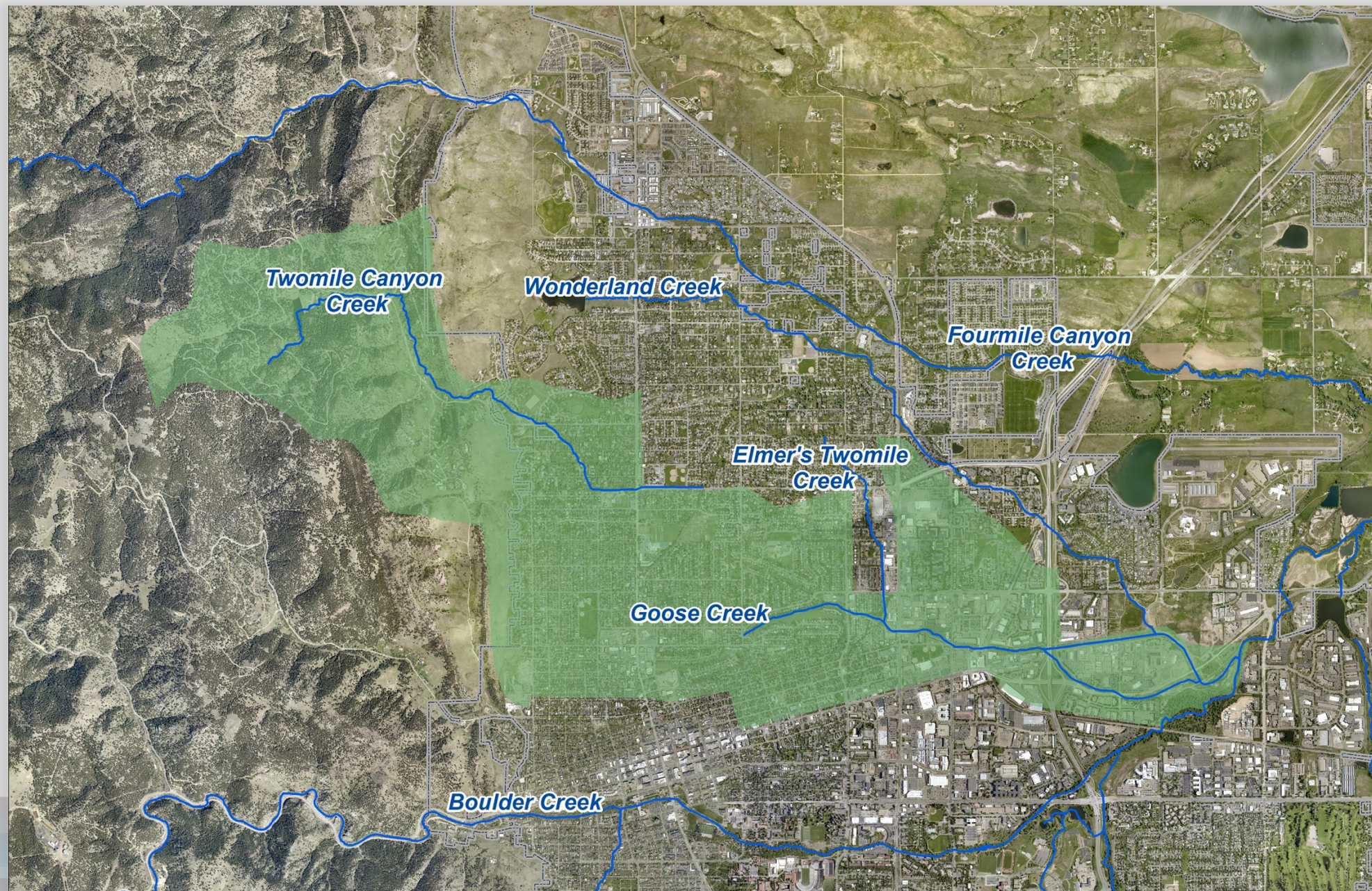


# Upper Goose Creek and Twomile Canyon Creek

## Flood Mitigation Plan Alternatives Report

April 28, 2023

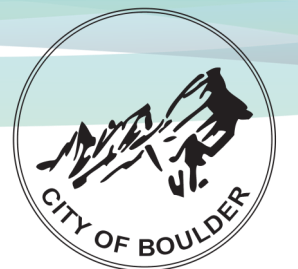


Prepared By:

In Cooperation With:

**ICON**  
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**MHFD**  
MILE HIGH FLOOD DISTRICT

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April 28, 2023

Mr. Brandon Coleman, P.E.  
City of Boulder Public Works  
Storm and Flood  
Engineering Project Manager  
1739 Broadway  
Boulder, CO 80302

**RE: Upper Goose Creek and Twomile Canyon Creek – Flood Mitigation Plan - Alternatives Report**

Dear Mr. Coleman:

ICON Engineering, Inc. is pleased to submit the Upper Goose Creek and Twomile Canyon Creek – Flood Mitigation Plan – Alternatives Report.

We would like to acknowledge the projects team's assistance in the preparation of this study. This report could not have been prepared without input from yourself, and other stakeholders.

We believe this report will provide a solid framework for the continuing phases of this project.

We appreciate the opportunity to prepare this report and look forward to working with you on future projects.

Sincerely,

**ICON ENGINEERING, Inc.**



Craig D. Jacobson, P.E., CFM  
Principal



Brian LeDoux, P.E., CFM  
Project Manager

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Appendix A – Alternative Selection Memorandum
Appendix B – Alternative Benefit Cost Analysis Memorandum
Appendix C – Alternative Scoring Memorandum
Appendix D – Recommended Plan Memorandum
Appendix E – Public Comments
Appendix F – Wetland and Habitat Evaluations

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

## 0.0 EXECUTIVE SUMMARY

### 0.1 PURPOSE AND OBJECTIVE

The purpose of this study is to analyze the existing drainage conditions within the Upper Goose and Twomile Canyon Creek floodplain, develop alternative drainageway planning concepts to mitigate flood damages, and prepare a conceptual design of recommended flood mitigation improvements. The information in this plan will support the City of Boulder, Mile High Flood District (MHFD) and others in the prioritization and implementation of improvements to increase stormwater resiliency, reduce potential damages due to flooding, and improve the condition of the Upper Goose Creek and Twomile Canyon Creek corridors in combination of other City-wide objectives.

### 0.2 PROJECT AREA DESCRIPTION

The study area extends from Twomile Canyon and Goose Creeks confluence near Folsom Street to the upstream City of Boulder limits just north of Linden Avenue for Twomile Canyon Creek, and to the North Boulder Park for Upper Goose Creek. The study area is located in Sections 24 and 25 of Township 1 North, Range 71 West, and Sections 19, 20, 29 and 30, Township 1 North, Range 70 West.

### 0.3 HYDROLOGIC AND HYDRAULIC ANALYSIS

Two previous reports completed as part of the Upper Goose Creek and Twomile Canyon Creek Flood Study Mapping Update project detail the hydrologic and hydraulic conditions of the project area. Hydrologically and hydraulically the project area is very complex. Upstream portions of the watershed are steep and uninhabited, while just downstream is a densely populated urban area where Twomile Canyon Creek exhibits more unconfined, alluvial fan type flow patterns. There are few areas upstream of the City of Boulder to locate improvements which would detain or slow flows, and downstream these improvements have to contend with high land values and existing infrastructure. Additionally, there is a frequent threat of wildfires and the resulting damage to vegetation as well as massive sedimentation which can greatly impact systems downstream. The hydrologic and hydraulic analysis are summarized in Sections 3 and 4 below.

### 0.4 ALTERNATIVE ANALYSIS

The City retained ICON Engineering, Inc. (ICON) to evaluate potential alternatives to help alleviate future flooding along Upper Goose and Twomile Canyon Creek. ICON's Alternative Selection Memorandum is included as **Appendix A**. This analysis contains a detailed description of the data and models used to determine the improvement alternatives which would improve flood conveyance along Upper Goose and Twomile Canyon Creek. Once all potential alternatives were developed, ICON performed a benefit cost analysis (BCA) along with a detailed description of the methodologies used to determine the benefit cost ratios associated with the improvements. The complete memo for BCA analysis can be found in **Appendix B**. In addition to the BCA analysis, each alternative was scored based on how well they met the goals of primary mitigation needs, community values and budget feasibility. The complete memo

for Alternative Scoring is included in **Appendix C**. These composite scores generally led to the recommended mitigation plan improvements based upon highest point total for each reach.

### 0.5 PUBLIC PROCESS

An extensive public process was completed in order to help formulate the flood mitigation alternatives addressed in this study. Three open house meetings, a flood mitigation alternatives workshop, and a Water Resources Advisory Board (WRAB) meeting have been conducted to obtain public input on mitigation alternatives. Additional public outreach was completed in December 2022 and March 2023 to inform the public how the input was incorporated into the recommended plan.

### 0.6 RECOMMENDED PLAN

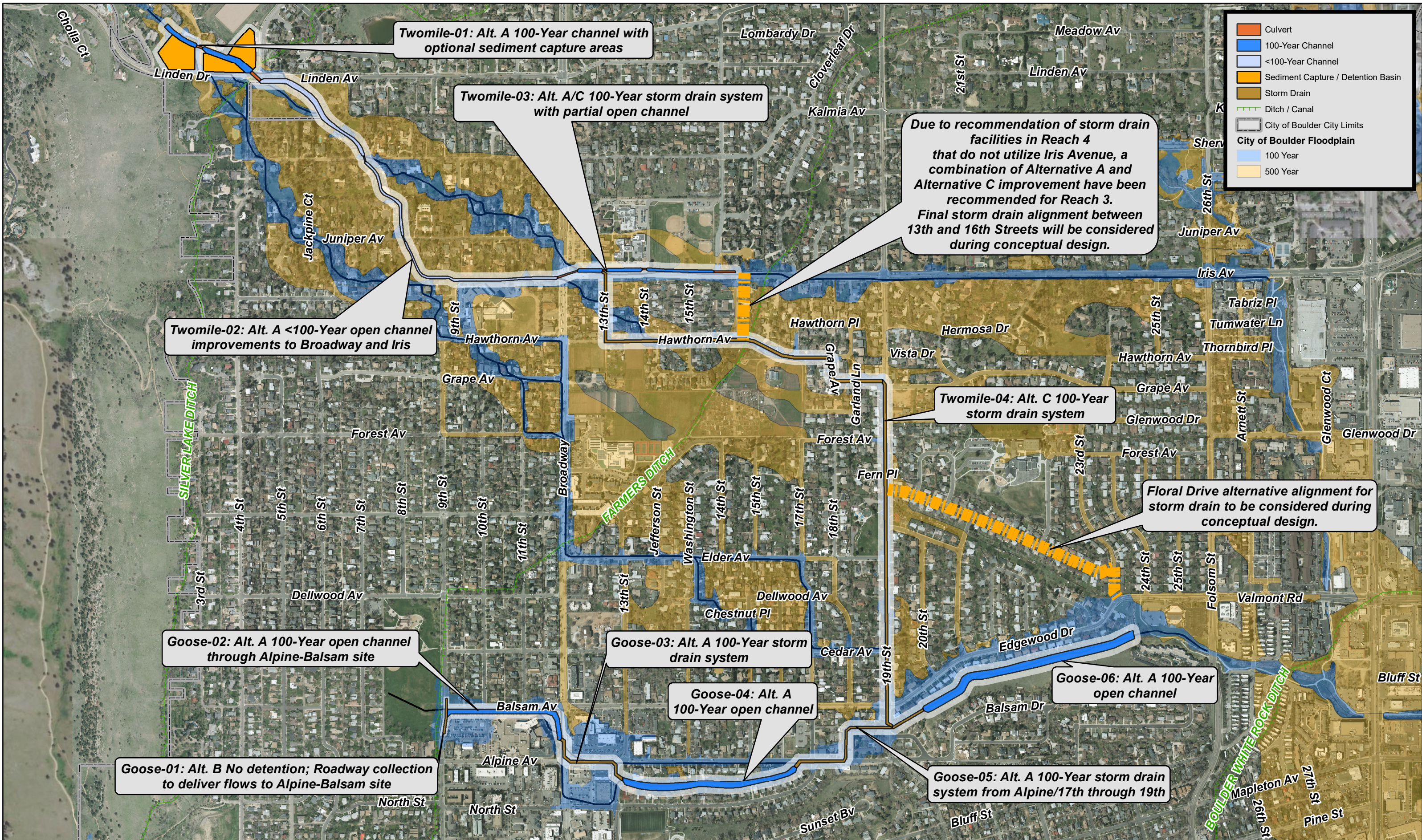
An overview of the Recommended Plan for flood mitigation in the Upper Goose Creek and Twomile Canyon Creek areas is depicted in **Figure 0-1**. The following mitigation elements are included:

**Table 0-1: Estimated Cost of Recommended Plan**

Recommendation	Cost
1. <b>Goose-01:</b> Alt. B Roadway collection to deliver flows to Alpine-Balsam site	\$500,000
2. <b>Goose-02:</b> Alt. A 100-Year capacity open channel through Alpine-Balsam site	\$1,000,000
3. <b>Goose-03:</b> Alt. A 100-Year capacity storm drain system	\$1,200,000
4. <b>Goose-04:</b> Alt. A 100-Year capacity open channel	\$2,400,000
5. <b>Goose-05:</b> Alt. A 100-Year capacity storm drain system from Alpine/17 <sup>th</sup> through 20 <sup>th</sup> Street	\$2,200,000
6. <b>Goose-06:</b> Alt. A 100-Year capacity open channel	\$12,000,000
7. <b>Twomile-01:</b> Alt. A 100-Year capacity channel improvements; new Spring Valley Drive and Linden Avenue culverts with optional sediment capture areas (Alt. C)	\$3,500,000
8. <b>Twomile-02:</b> Alt. A Less Than 100-Year channel capacity improvement; new Kalmia Avenue, Juniper Avenue, and Broadway culverts; channel to Broadway and Iris	\$10,300,000
9. <b>Twomile-03:</b> Alt. C 100-Year capacity storm drain outfall system with partial open channel	\$7,100,000
10. <b>Twomile-04:</b> Alt. C 100-Year capacity storm drain outfall system	\$3,000,000
<b>Total Cost of Recommended Plan</b>	<b>\$43,200,000</b>

### 0.7 CONCEPTUAL DESIGN

The next step for this mitigation plan is conceptual design of the recommended alternatives following approval of this Alternatives Report by City Council. The conceptual design will focus on the feasibility and ideal alignments of the recommended alternatives. If 100-year flood protection is determined to be not feasible, the conceptual design will prioritize high hazard zone mitigation in place of 100-year capacity.



	Culvert
	100-Year Channel
	<100-Year Channel
	Sediment Capture / Detention Basin
	Storm Drain
	Ditch / Canal
	City of Boulder City Limits
	City of Boulder Floodplain
	100 Year
	500 Year

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

## 1.0 INTRODUCTION

### 1.1 PLANNING PROCESS

The Upper Goose Creek and Twomile Canyon Creek watershed was greatly impacted by a flood in September of 2013. A post-flood open house was held on October 17, 2013 to provide flood recovery information and gather public comments about the extent of the floodwaters and the damages sustained.

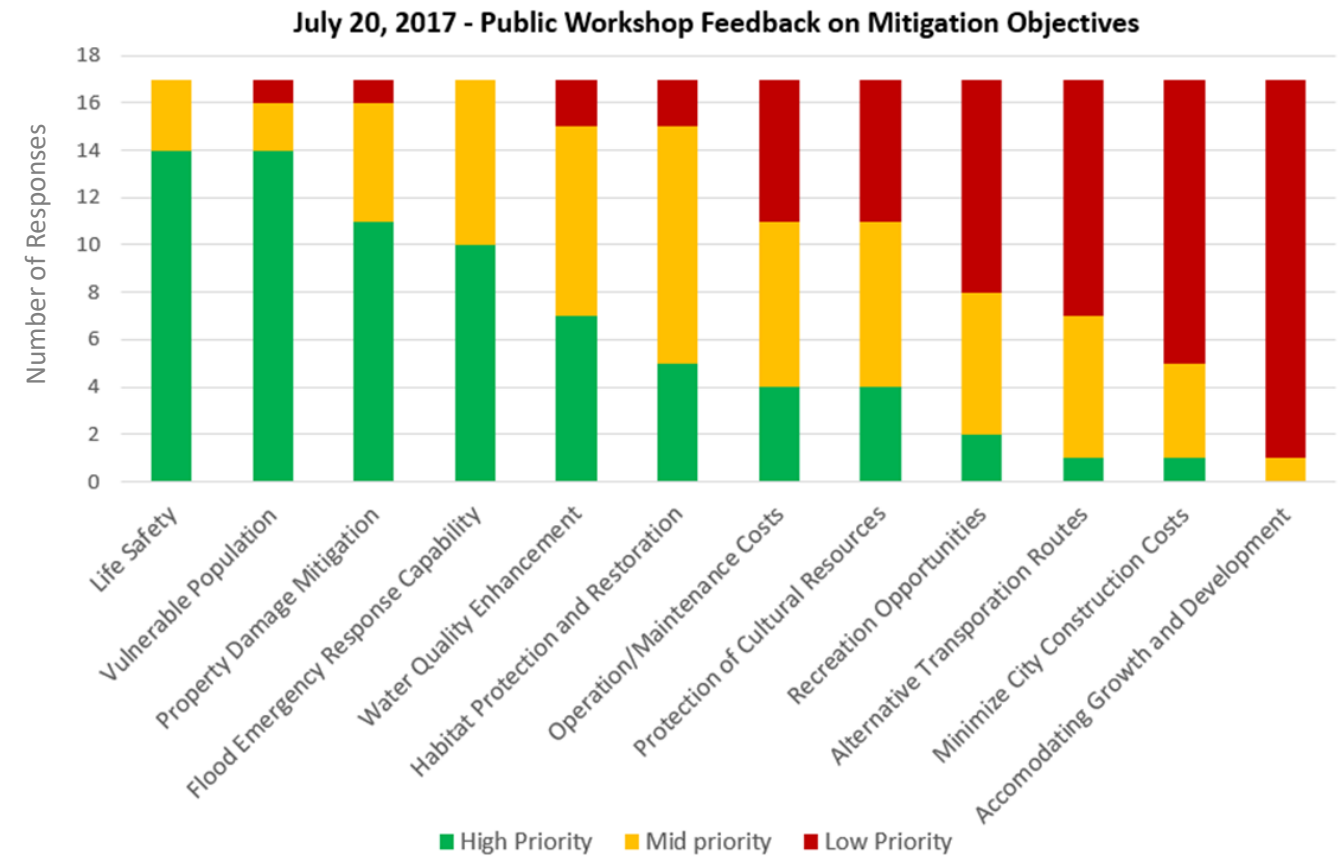
The City was working on the floodplain mapping study for Upper Goose and Twomile Canyon Creek when the September 2013 flood event occurred. The mapping study included an extensive public process with open house meetings and WRAB public hearings. The mapping study was accepted by City Council on July 28, 2015, deemed effective by FEMA on August 18, 2016, and forms the foundation for this flood mitigation plan. The email list that was developed for the mapping study was also used to notify people about the mitigation plan and people have had the option to join or leave the list throughout the planning process.



An open house was held on April 12, 2017 to provide the community with City-wide flood planning and mitigation information. This public open house was also the official “kick-off” to the flood mitigation planning process and provided the public an opportunity to discuss problem areas and provide ideas for consideration.

A workshop was held on July 13, 2017, to collaborate with community members on mitigation strategies. A presentation was given that highlighted the development and flood history for Twomile Canyon and Upper Goose Creek and described several different mitigation strategies that could be considered. Table-top discussions were arranged and facilitated by City staff to brainstorm options, evaluate priorities, and capture the residents’ preferred flood mitigation strategies. When asked to rank the flood and greenways objectives, workshop participants provided input as shown in **Figure 1-1**.

Figure 1-1: Flood Mitigation Workshop Participants’ Ranking of Objectives



Workshop participants also provided opinions on different mitigation strategies. From that input, the most preferred mitigation strategy was channel and culvert improvements. Detention/sediment capture was also highly rated by most participants. There were mixed opinions about the roadway conveyance and use of underground, piped storm drainage alternatives. The no action alternative was not favored. The ratings of the different mitigation strategies are illustrated on the graphs on the following page.

During a table-top exercise, workshop participants collaborated in small teams to determine which mitigation strategies they thought would be most appropriate or desired in different locations along the drainageways. The most preferred suggestions included:

- Detention/sediment capture north of Linden Ave, north of Kalmia Ave. and at North Boulder Park
- Culvert improvements where Twomile Canyon Creek crosses Broadway
- Roadway conveyance along Linden Ave. and Iris Ave.
- Channel improvements for Twomile Canyon Creek between Spring Valley Drive and Iris Ave.
- Channel and/or piped storm drainage improvements along Upper Goose Creek between North Boulder Park and 19th St.

A map showing the results of this table-top exercise is included with the public input in **Appendix E**.

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

On March 19, 2018, a public open house was held to present information on several different mitigation alternatives. On that same day, the alternatives were also presented to the Water Resources Advisory Board (WRAB). Comments were received through email and an on-line questionnaire was also developed to capture public feedback. In general, over 450 emails and responses were received, including responses to an online questionnaire organized by sections of the drainageway (or 'reaches') to inform respondents of downstream impacts and encourage site specific feedback.

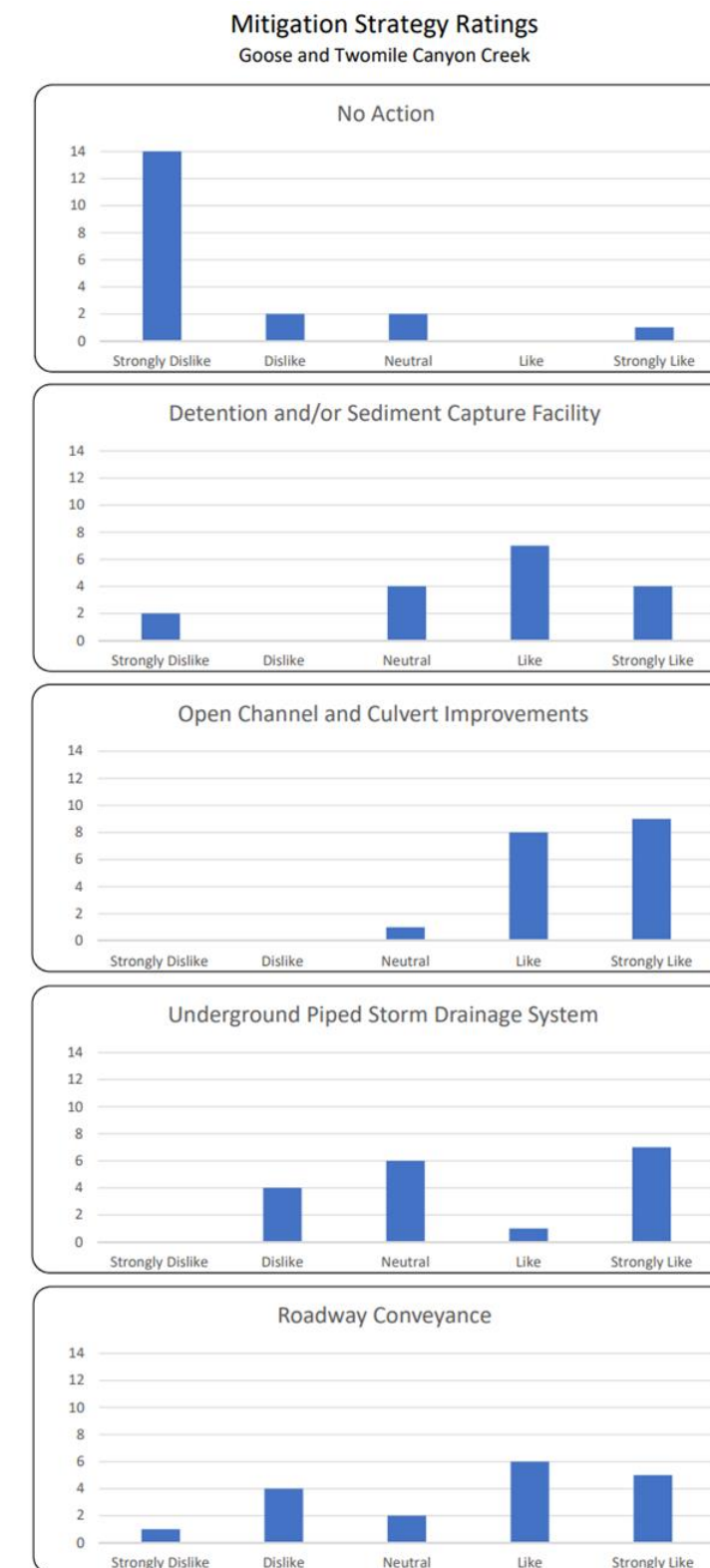
For Twomile Canyon Creek reaches, favored alternatives included 'no action' and alternatives that would direct floodwaters east on Iris Avenue to discharge into Elmer's Twomile Canyon Creek. For Goose Creek, the questionnaire feedback favored detention at North Boulder Park and 100-year containment within storm drains upstream of 19th Street. Downstream of 19th Street, channel improvement alternatives were generally not preferred.

In addition, over 800 individual comments were received through the questionnaire. Many of the comments related to 100-year flood containment both in favor of and against, though most responses expressed concern about private property impacts from 100-year flood containment. In addition, comments from Reach 1, the most upstream area of Twomile Canyon Creek, included suggestions for new alternatives not included on the questionnaire.

Comments received at the open house, the WRAB meeting and through the questionnaire are compiled in **Appendix E**.

After receiving and compiling the public input, ICON proceeded with an initial screening of the alternatives. Those alternatives deemed to have sufficient support and benefit were then evaluated further. Next came a Benefit Cost Analysis of every viable alternative for each reach of Upper Goose Creek and Twomile Canyon Creek. Then the benefit cost rating became part of the overall alternative score along with 11 other factors. The Alternative Development, Benefit Cost and Scoring processes are each discussed in more detail in Section 5. Finally, a recommended plan was identified based upon the resulting scoring for each alternative. This process is discussed in detail in Section 6.

Figure 1-2: Responses from the May 24, 2018 Open House





# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

The proposed alternative recommendations were presented to the public at a virtual meeting on December 7<sup>th</sup>, 2022 and at an in-person open house on March 1<sup>st</sup>, 2023. The recommendations were then presented to WRAB on March 20, 2023 and go before City Council on May 18, 2023.

**Table 1-1: Timeline Summary of the Public Process**

Date	Meeting
Oct. 24, 2013	Post-Flood Open House
April 12, 2017	City-wide Flood Open House
July 13, 2017	Flood Mitigation Workshop
March 19, 2018	Flood Mitigation Plan Open House and WRAB Public Meeting
March 1-April 9, 2018	Questionnaires Open for Public Comment
Dec. 7, 2022	Virtual Information Meeting
March 1, 2023	In-person Open House Information Meeting
March 20, 2023	WRAB Meeting (Voted 5-0 to recommend approval of plan)
May 18, 2023	City Council Meeting

A compilation of public comments is included in **Appendix E**.

## 1.2 MAPPING AND SURVEYS

Elevation data for the study area was provided by the City of Boulder. The topographic mapping included the City of Boulder’s 2013 Light Detection and Ranging (LiDAR) data. In addition, survey collected as part of the previous hydraulic study and as-built construction drawings were also incorporated in the analysis. No new mapping or survey was performed as part of this analysis.

## 1.3 DATA COLLECTION

In addition to GIS data and other City resources, previous studies were reviewed during the process of developing this mitigation plan. The following is a list of these studies:

- *Storm Drainage Pilot Planning Study* – Denver Regional Council of Governments, 1969
- *Major Drainageway Planning Study - Boulder and Adjacent County Drainageways “Phase A”*, Greenhorne and O’Mara, 1984.
- *Major Drainageway Planning Study - Boulder and Adjacent County Drainageways “Phase B”*, Greenhorne and O’Mara, 1987.
- *Upper Goose Creek and Twomile Canyon Creek Floodplain Mapping Study (Approved by FEMA, 2016)* ICON Engineering, Inc., 2015.

- *Comprehensive Flood and Stormwater Utility Master Plan*, URS, 2004.
- *Pine Brook Dam and Reservoir, Hydrologic/Hydraulic Data*, TCB|AECOM, 2005.
- *City of Boulder Stormwater Master Plan*, HDR Engineering, 2007.
- *Greenways Master Plan*, City of Boulder, 2011.
- *Rainfall-Runoff Analysis for September 2013 Flood in the City of Boulder, Colorado*, Wright Water Engineers, Inc., 2014.
- *City of Boulder 2016 Stormwater Master Plan*, HDR, 2016.
- *Boulder Valley Comprehensive Plan*, City of Boulder, 2017.
- *City of Boulder Alpine-Balsam Vision Plan*, Mithun, 2017.
- *Conceptual Utility and Drainage to Support City of Boulder; Alpine-Balsam Area Plan* – Wilson & Company, 2018.
- *Alpine-Balsam, Core Team Workshop 4 Packet*, Civitas, 2018.
- *Geotechnical and Hydrologic Engineering Investigation for North Boulder Park, Boulder, Colorado*, Martinez Associates, 2019.

## 1.4 ACKNOWLEDGEMENTS

This report was completed with the support and input from various individuals at the City of Boulder, the Mile High Flood District (MHFD) and ICON Engineering Inc. The key participants in the development of this plan are summarized below.

**Table 1-2: Key Contributors to the Flood Mitigation Plan**

Project Member	Affiliation
Katie Knapp, P.E., CFM	City of Boulder, Greenways Coordinator / Engineering Project Manager
Brandon Coleman, P.E.	City of Boulder, Engineering Project Manager
Debbie Fisher, P.E., CFM, CPESC	City of Boulder, Senior Project Manager
Sara DeGroot, P.E., CFM, ENV SP	City of Boulder, Senior Civil Engineer
Christin Shepherd, P.E., CFM	City of Boulder, Flood & Wetland Administrator
Laurel Olsen-Horen, CFM	City of Boulder, Flood & Greenways Specialist
Jim Watt, P.E., CFM	Mile High Flood District, Project Manager
Craig Jacobson, P.E., CFM	ICON Engineering Inc., Principal
Brian LeDoux, P.E., CFM	ICON Engineering Inc., Project Manager

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

## 2.0 STUDY AREA DESCRIPTION

### 2.1 PROJECT AREA

The Twomile Canyon Creek drainage basin originates in the mountains west of Boulder near Pine Brook Hill Fire Station. The upper portion of the drainage basin is narrow, steep and rocky with a well-defined channel. The creek enters the City of Boulder and flows through a residential area near Spring Valley Road. Under normal flows, water is diverted into the Silver Lake ditch near the Linden Ave. and Wonderland Hill Ave. intersection. The South Juniper Lateral returns water into the creek near Foothills Elementary School. The rocky creek bed is approximately three to four feet wide and ends on the west side of the intersection of Broadway and Iris. East of this intersection, water flows through a small ditch that runs along the north side of Iris and into a storm sewer. The storm sewer discharges into Elmer's Two Mile Park, which flows into Goose Creek, just south of Valmont Road.

The Upper Goose Creek drainage basin is primarily composed of residential and commercial development and is located just south of Twomile Canyon Creek. During minor storm events, runoff is collected in storm sewers and conveyed to a concrete lined channel at 19th St. and Tyler Rd. During major storm events, water naturally drains to the east side of North Boulder Park located on 9th St. From here to 19th St., floodwaters head east, along Balsam Ave., Alpine Ave. and through backyard areas, because there is no defined stream channel within this portion of the drainage basin. The concrete lined channel starts at 19th St. and continues for approximately 270 feet before becoming a more natural, vegetated channel. The stream channel runs south of and parallel to Edgewood Dr. which also carries flood waters. From approximately 600 feet upstream (west) of Folsom, Goose Creek has been improved to convey the 100-year storm event. The width of the channel is as large as 25 feet with 6 to 15-foot high channel walls.

At the turn of the century, much of the land along Twomile Canyon and Goose Creek was used for farming and agriculture. As demand for housing increased from the 1960's to the 1980's, dense residential development started to spread north from central and south Boulder, closely resembling the urban landscape we see today. Development has altered historic channels, stormwater flow paths, runoff characteristics, and surface water quality. Most of the development within the Twomile Canyon and Goose Creek floodplains occurred prior to the City's adoption of floodplain regulations and drainage system requirements, and therefore does not conform to current development standards. There are limited drainage and flood control easements across private properties along these creeks.

The project area is illustrated in **Figure 2-1**.

### 2.2 SOILS

According to the Soil Survey of Boulder County Area, Colorado (United States Department of Agriculture Soil Conservation Service in cooperation with Colorado Agriculture Experiment Station (1975)), the land within the Upper Goose Creek and Twomile Canyon Creek watersheds is comprised of the following soil classifications: Fern Cliff-Allens Park-Rock Outcrop Complex (FcF), Juget-Rock Outcrop Complex (JrF), Payton-Juget (PgE), Godvale Rock Outcrop Complex (GrF), Pinata-Rock Outcrop Series (PrF), Colluvial Land (Cu), Sixmile Stony Loam (SmF), Baller Stony Sandy Loam (BaF), Terrace Escarpments (Te), Nederland Series (NdD), Valmont Cobbly Clay Loam (VcC), and Loveland Soils (Lv).

The upper portion of the watershed is predominantly Juget-Rock outcrop complex (JrF), Payton-Juget (PgE) and Fern Cliff-Allens Park-Rock Outcrop Complex (FcF), with Godvale Rock Outcrop Complex (GrF), and Pinata-Rock Outcrop Series (PrF) further east. These soils, consist of stony sandy loam, gravely sandy loam and gravely loamy sand along with steep rock outcrops with exposed bedrock. The runoff potential is slow to rapid and the erosion potential is high.

Further east, the watershed has bands of Colluvial Land (Cu), Sixmile Stony Loam (SmF), Baller Stony Sandy Loam (BaF), and Terrace Escarpments (Te). These soils vary widely in depth, texture, color, and stoniness due to the runoff from adjacent slopes that these lands receive. Most of the area has stones and cobbles on the surface. Runoff is rapid and the erosion hazard is high.

The central and lower parts of the watershed contain Nederland Series (NdD), Valmont Cobbly Clay Loam (VcC), and Loveland Soils (Lv). These are deep, well-drained soils that formed on old high terraces and alluvial fans. The soils developed on loamy alluvium that contains many cobblestones and other stones. These soils have moderate permeability and roots can penetrate to a depth of 60 inches or more. These areas have many stones and cobblestones on the surface. Runoff is slow to medium and the erosion hazard is slight to moderate.

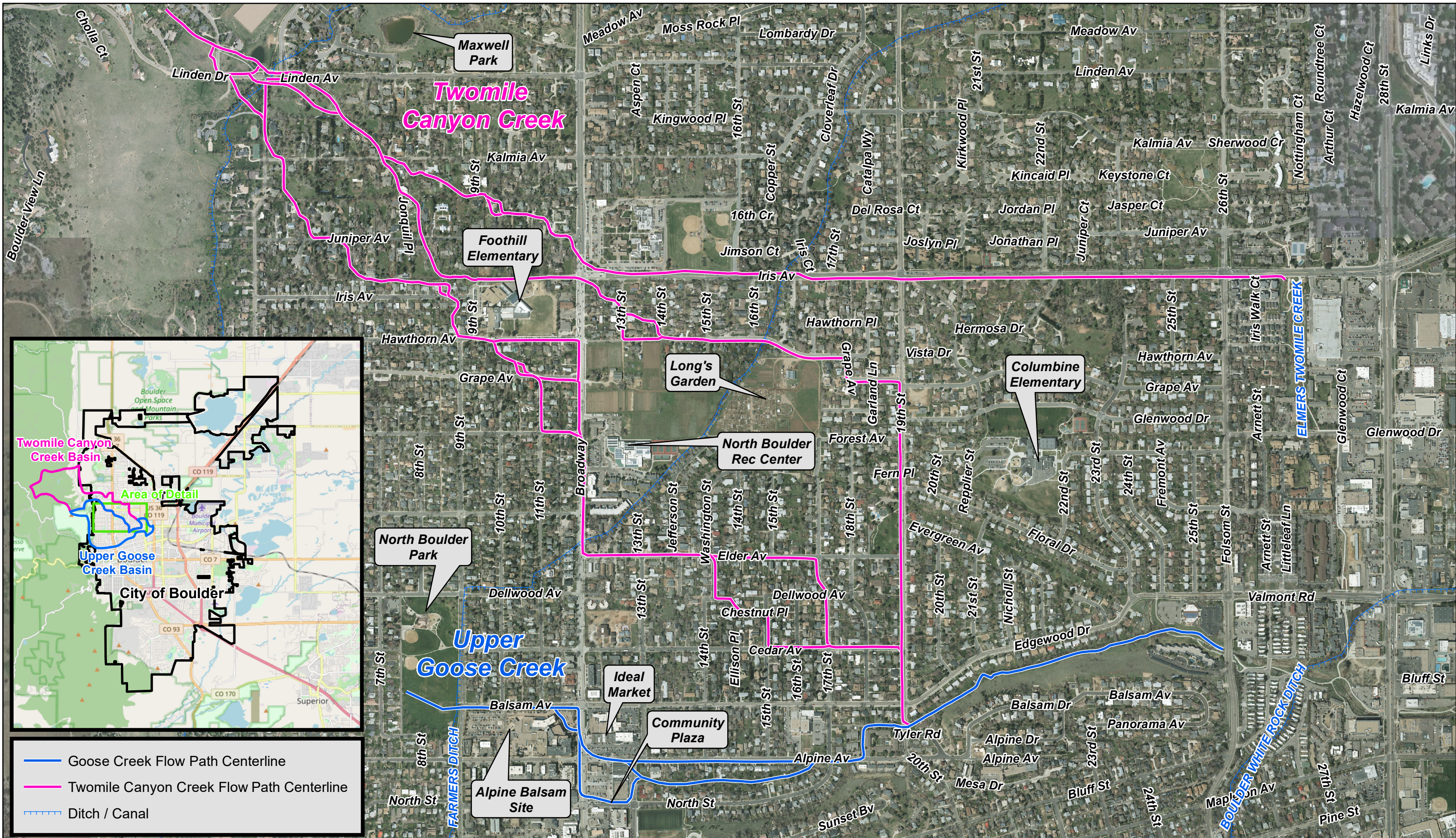
Soil types are illustrated in **Figure 2-2**.

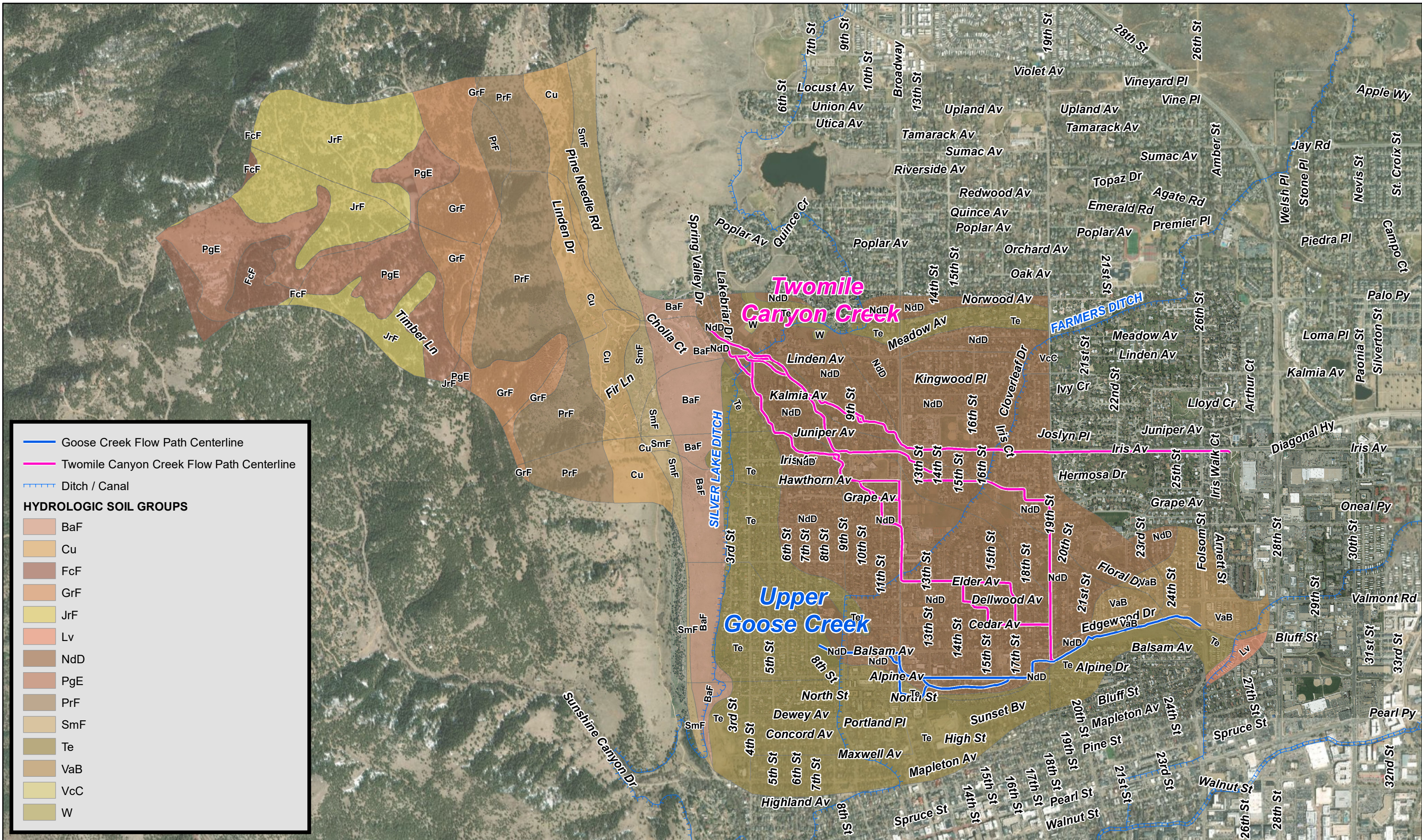
### 2.3 LAND USE

Upstream of the City limits, the lands within the Twomile Canyon and Goose Creek watersheds has been preserved as City Open Space or are sparsely developed. Within the City limits, the majority of property within the watershed is comprised of low density, residential zoning districts (RE, RL-1 and RL-2). Density intensifies towards Alpine Avenue to the south and Folsom Avenue to the east where property is zoned Mixed and High Residential (RM-1 and 2, RH-3, 4 and 5) as well as Commercial (BT-1 and BC-2). The land areas zoned Public (P) contain Iris Fields, City of Boulder departments, North Boulder Rec Center and the Alpine Balsam property.

Notable community features within the watershed include North Boulder Park, the Alpine-Balsam site, Long's Gardens, North Boulder Recreation Center, Maxwell Park, Columbine and Foothill Elementary Schools, and Farmer's Ditch.

Land use and notable community features are illustrated in **Figure 2-3**.





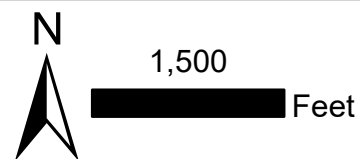
— Goose Creek Flow Path Centerline  
— Twomile Canyon Creek Flow Path Centerline  
--- Ditch / Canal

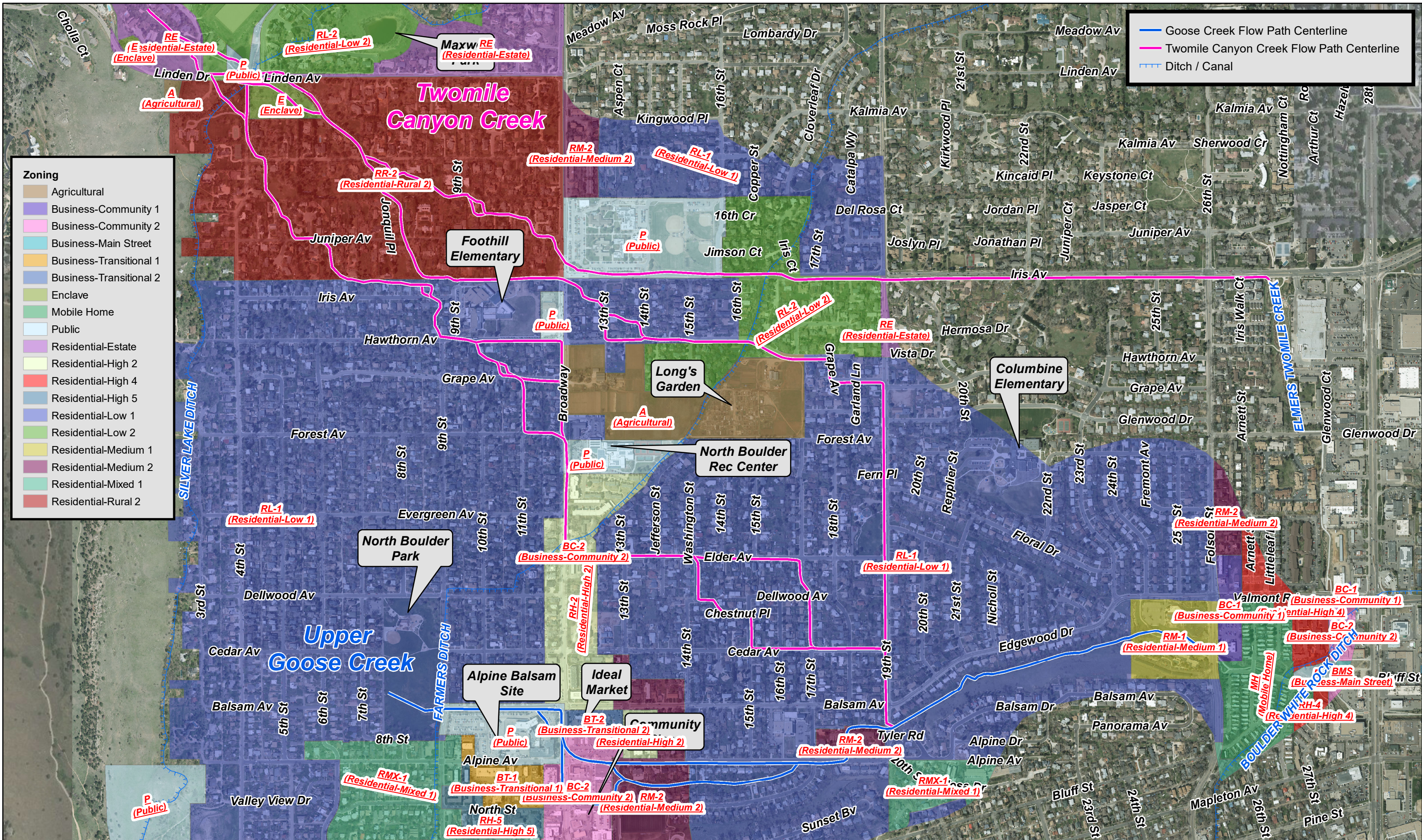
**HYDROLOGIC SOIL GROUPS**

BaF
Cu
FcF
GrF
JrF
Lv
NdD
PgE
PrF
SmF
Te
VaB
VcC
W



**Upper Goose Creek and Twomile Canyon Creek  
 Flooding Mitigation Plan - Alternatives Report**  
 Figure 2-2: Soils Map

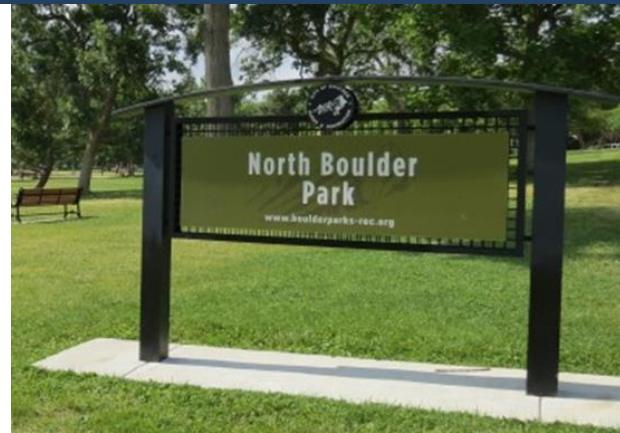




# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

## North Boulder Park

The site of Boulder’s first ever 10k race, North Boulder Park has seen its share of Olympians, cyclists, and outdoor enthusiasts. The park is situated along 9th street between Dellwood Avenue and Alpine Avenue and features baseball diamonds, sports fields, picnic areas, nature play, mini mountain bike trail, ping pong table and a fountain immortalized in not one but two songs.



## Long’s Gardens

Founded in 1905 by J.D. Long, Long’s Gardens is a third generation, family owned and operated iris farm on North Broadway. Long’s Gardens showcases iris plants, farm animals, antique farm equipment, tours and historical relevance. JD’s granddaughter, Catherine Long Gates, and her husband Dennis Gates carry on the family business today. In 2012, Catherine won the “Inspiring Individual” award at the REAL (Recognizing Everything About Local) Award Ceremony, sponsored by Boulder Magazine. Upon accepting the award, Catherine delivered a moving speech: “What’s more local than a plant?” she asked the crowd. “We should all be more like plants—rooted, taking what comes, whether rain, snow or sun.”



## Community Gardens

Growing Gardens is a Boulder-based non-profit organization that manages more than 535 individual community garden plots across eleven locations in Boulder County. Their mission is to enrich the lives of the community through sustainable urban agriculture. Growing Gardens leases the east 11 acres of Long’s Gardens and runs various farm programs, including the Community Gardens, Cultiva Youth Project, the Children’s Peace Garden, Able Garden and greenhouse.



## FOOTHILL ELEMENTARY

Foothill Elementary is a neighborhood school located on Broadway and Hawthorn Avenue and has over 500 students in attendance. The school was damaged during the 2013 flood.



## Maxwell Park

Maxwell Park is a neighborhood park featuring a small lake with an unpaved walking path. The park provides unstructured, hand-on exploration of tall grasses and lake wildlife including fish and riparian animals.



## Alpine-Balsam

In December of 2015, the City of Boulder purchased 8.8 acres of property, which is the entire Boulder Community Health property on Broadway, between Alpine and Balsam. This purchase kicked off a multi-year planning process to guide redevelopment of the site, which the City hopes to utilize in a manner that best benefits the community.



# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

## **Columbine Elementary School**

Columbine Elementary School is a neighborhood school with over 500 students in attendance. The school also offers free and tuition preschool classes in addition to K-5th grades.



## **North Boulder Recreation Center**

The North Boulder Recreation Center is a 50,000-square foot recreation center located on Broadway just north of Elder Avenue. Many local residents utilize the facility for recreation, sport, child care and swimming activities. The North Boulder Recreation Center is also one of three disaster shelter locations designated by the City Manager.



## **Farmer's Ditch**

Farmer's Ditch runs approximately eight miles from the north side of Boulder Creek to Boulder reservoir. Completed in 1862, the Farmer's Ditch was the first source of water for most of Boulder. Long's Gardens took its water from both Farmers and Silver Lake Ditches, with Everett Long serving as president of both.



## **2.4 FLOOD HISTORY**

The City of Boulder is highly susceptible to flash flooding because it sits near the mouths of several canyons in the foothills. In 1894, damaging floods were experienced in late May, during the time of spring runoff, when a heavy and constant spring rain was pinned against the western mountains by an upslope wind condition, dropping 5 to 8.54 inches of rain during that period (Floods in Boulder County, Colorado, A Historical Investigation; Sherry D. Oaks; 1982). During this event, the crest of the water on Sixth Street reached twelve feet and nearly every bridge along Boulder Creek was washed out. It is estimated that discharge in Boulder Creek was between 12,000 and 13,600 cfs during this event.

Significant flooding has also occurred in Boulder in 1896, 1906, 1909, 1916, 1921, 1938, 1969, and most recently, in September of 2013. The Boulder Creek peak discharges during the major flood events have ranged from 2,500 cfs to 13,000 cfs, and most of the storms occurred in either May or June. In 1909, flooding along Twomile Canyon Creek resulted in two deaths. Flooding in Boulder County typically occurs as a result of snowmelt combined with heavy spring rainfall. However, record setting rains were widespread across Boulder from Sept. 9 to 13, 2013 due to a moist tropical air mass from the Gulf of Mexico that was displaced into the region by air coming in from the south. An upper-level high-pressure system locked this storm against the mountains to the west, and rain fell for about a week. 17.6 inches of rain fell over a three-day period, making 2013 the wettest year on record in Boulder.

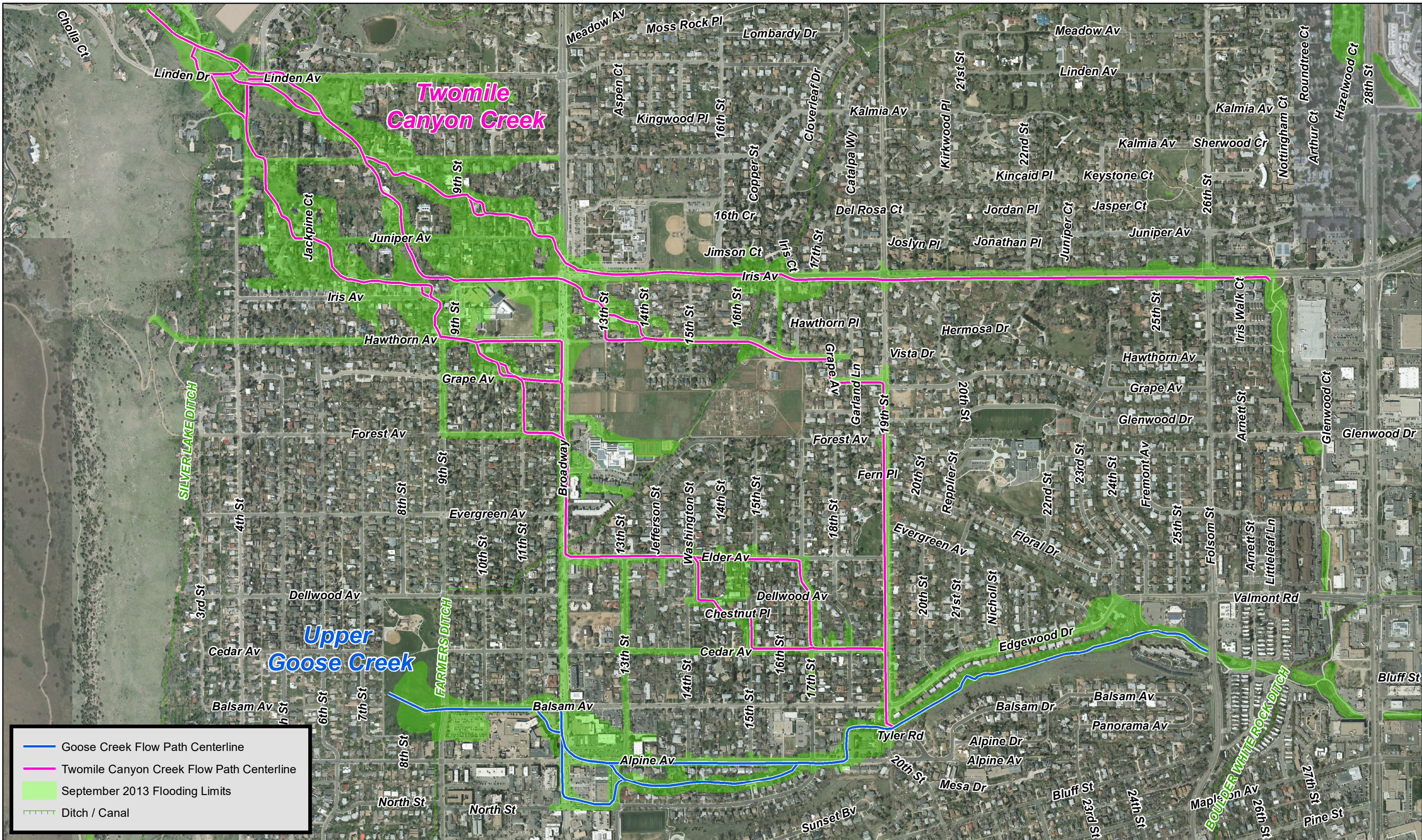
### **September 2013 Flooding**





During the September 2013 event, NOAA/NWS reported that 'worst case' 24-hour, 72-hour, and 7-day precipitation totals in many parts of the Boulder Creek watershed had annual exceedance probabilities on the order of 1/1,000 (0.1 percent), which is a 1,000-year rainfall event. The precipitation lasted from September 9 to September 15, 2013, with the most intense rainfall in the watershed occurring on September 11 and 13, when more than 6 inches of rain fell over a 24-hour period in many locations, including downtown Boulder (A *September to Remember*; Urban Drainage and Flood Control District, 2014).

During the 2013 storm, channels and culverts along Twomile Canyon Creek were filled with rocks and debris which had been transported from the canyon upstream. The alluvial nature of the watershed, and already limited conveyance capacity of the channel, caused widespread, overland flooding and sediment deposition. On Sept. 11, 2013, a car got trapped in a mudslide at the intersection of Linden Dr. and South Cedar Rd., near Twomile Canyon Creek; two of the occupants tried to escape but did not survive. **Figure 2-4** illustrates the estimated 2013 flooding extents as provided by the City of Boulder.



**2013 flooding damage at Spring Valley Road and Linden Avenue**

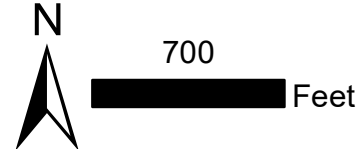


	Goose Creek Flow Path Centerline
	Twomile Canyon Creek Flow Path Centerline
	September 2013 Flooding Limits
	Ditch / Canal



**Upper Goose Creek and Twomile Canyon Creek  
Flooding Mitigation Plan - Alternatives Report**

Figure 2-4: 2013 Flooding





# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

According to *A September to Remember*, "...the maximum 24-hour rainfall was approximately 8 inches within the Twomile Canyon and Goose Creek watersheds, correlating to a rainfall return period of greater than 1,000 years.

Wright Water Engineers prepared a "Rainfall-Runoff Analysis for the September 2013 Flood in the City of Boulder, Colorado", which was publicly released in Sept. of 2014. According to this study, during the 2013 flood, precipitation depths and intensities generally increased from west to east with total rainfall from Sept. 11-13 ranging 9.8 inches to 10.3 inches. It is estimated that the rainfall return periods the Twomile Canyon and Goose Creek drainageways received ranged from a 50- to a greater than 100-year event for the worst case 2-hour duration.

To determine runoff during the September 2013 event, Wright Water analyzed the City's inundation mapping. According to the inundation maps, the runoff during the event was generally contained with the 100-year floodplain boundary, with the following notable exceptions:

- Upstream of Broadway, there were extensive overflows to the north and south of the Twomile Canyon Creek drainage.
- Broadway was inundated with flows from both Twomile Canyon Creek and Goose Creek.
- Downstream of Broadway, overflows from the south of Twomile Canyon Creek continued in a southwesterly direction until its confluence with Goose Creek. Flows were conveyed through various streets such as Elder Avenue, 13th Street, Cedar Avenue, and 17th Street, none of which are within the FEMA effective 100-year floodplain.
- From Broadway to the confluence with Goose Creek, there was relatively little flow within the FEMA effective 100-year floodplain for Twomile Canyon Creek. The debris flow and abrupt change in the stream flow path at the mouth of the canyon resulted in widespread street and overland flooding in urban areas east of Broadway.

Twomile Canyon Creek is an example of an alluvial fan within an urban area. There was significant debris clogging culverts and rerouting flows overland. Landslides occurred in the steep slopes of Twomile Canyon and resultant debris traveled downstream causing street and overland flooding west of Broadway.

### **Damage Analysis from the 2013 Flood**

After the September 2013 flood, the City of Boulder commissioned a study to analyze the source of and amount of damage caused by the flood. The results are a compilation of data obtained via an online survey and from claims submitted for FEMA for reimbursement. In the Twomile Canyon and Goose Creek watersheds, it is estimated that the total amount of damages exceeded \$39,000,000. The primary sources of damage were a result of flooding from local drainage, especially in the Twomile Canyon Creek watershed. It is estimated that approximately \$5,000,000 in damage was caused in the 100-year floodplain and \$5,700,000 in damage was caused in the 500-year floodplain (outside of the 100-year floodplain). The remainder of the damage amount, approximately \$28.3 million, was outside of the designated floodplains.

### **2.5 ENVIRONMENTAL ASSESSMENT**

A survey was completed in 2010 along many of the Boulder Creek tributary reaches to update the aquatic habitat inventory. This inventory results are presented in the following table. The survey data sheets are included in **Appendix F**.

*Table 2-1: Summary of 2010 Habitat Survey*

Category	Twomile Canyon Creek	Upper Goose Creek
Vegetation Structure	Good to Very Good	Poor to Good
Native Plant Habitat	Good to Very Poor	Poor
Bird Habitat	Poor	Poor
Aquatic Habitat	Fair	Marginal

#### **Wetlands**

Twomile Canyon Creek is a narrow, intermittent stream that flows southward out of steep canyon and into alluvial flat lands. According to the City's "Functional Evaluation Summaries for Individual Wetlands", included in **Appendix F**, the wetlands located along Twomile Canyon Creek are characterized by a generally narrow active channel and small ponds. Water supply is supported by Silver Lake Ditch and local seepage off the hillside. The maximum water depth is approximately 5 feet in the ponds and 1 foot in the channel. The wetlands along the channel are covered completely in vegetation comprised of cottonwood, and mixed herbaceous trees and shrubs.

Goose Creek begins at North Boulder Park and traverses west to its confluence with Boulder Creek. According to the City's "Functional Evaluation Summaries for Individual Wetlands", included in **Appendix F**, the Goose Creek wetlands in the study area are characterized as a narrow channel that mostly carries stormwater runoff. The maximum water depth is approximately 2 feet. Between 65 and 75 percent of this wetland is covered by vegetation which is comprised of crack willows and cattails.

The geohydrologic information indicates groundwater recharge or discharge are possible for both creeks. The effectiveness of the function is limited by bedrock outcrops, the narrow channel, and intermittent flows.

### **2.6 PREVIOUS STUDIES AND MASTER PLANS**

The Boulder Valley Comprehensive Plan (BVCP), the Comprehensive Flood and Stormwater Utility Master Plan (CFS), the Mile High Flood District (MHFD) (formerly the Urban Drainage and Flood Control District (UDFCD)) Drainage Criteria Manual and the Greenways Master Plan all contain policies related to floodplain preservation, development, and mitigation. These documents guide flood mitigation master planning. Previous master plans, floodplain mapping studies and mitigation planning documents were also reviewed for this mitigation plan as described below.

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

## ***Boulder Valley Comprehensive Plan***

The following applicable policies are included in the BVCP:

### **3.18 Hazardous Areas**

Hazardous areas that present a danger to life and property from flood, forest fire, steep slopes, erosion, unstable soil, subsidence or similar geological development constraints will be delineated, and development in such areas will be carefully controlled or prohibited.

### **3.21 Preservation of Floodplains**

Undeveloped floodplains will be preserved or restored where possible through public land acquisition of high hazard properties, private land dedication and multiple program coordination. Comprehensive planning and management of floodplain lands will promote the preservation of natural and beneficial functions of floodplains whenever possible.

### **3.22 Flood Management**

The City and County will protect the public and property from the impacts of flooding in a timely and cost-effective manner while balancing community interests with public safety needs. Recognizing that the impact of climate change on the magnitude and frequency of significant flood events is not yet known, the City and County will continue to monitor the effects of climate change on floodplain delineation and management and amend regulation and management practices as needed for the purpose of protecting life and property.

The City and County will manage the potential for floods by implementing the following guiding principles: a) Preserve floodplains b) Preparation for floods c) Help people protect themselves from flood hazards d) Prevent unwise uses and adverse impacts in the floodplain e) Seek to accommodate floods, not control them.

In addition, the City and County will prepare for, respond to and manage flood recovery by implementing multi-hazard mitigation programs and projects, preparing flood response and recovery plans and regulating the siting and protection of critical facilities in floodplains. The city seeks to manage flood recovery by protecting critical facilities in the 500-year floodplain and implementing multi-hazard mitigation and flood response and recovery plans.

### **3.23 Non-Structural Approach**

The City and County will seek to preserve the natural and beneficial functions of floodplains by emphasizing and balancing the use of non-structural measures with structural mitigation. Where drainageway improvements are proposed, a non-structural approach should be applied wherever possible to preserve the natural values of local waterways while balancing private property interests and associated cost to the City.

### **3.24 Protection of High Hazard Areas**

High hazard areas are the areas of the floodplain with the greatest risk to loss of life due to floodwater velocity. The City will prevent redevelopment of significantly flood-damaged properties in high hazard areas. The City will prepare a plan for property acquisition and other forms of mitigation for flood-damaged and undeveloped land in high-hazard flood areas. Undeveloped high hazard flood areas will be retained in their natural state whenever possible. To reduce risk and loss, riparian corridors, natural ecosystems, wildlife habitat and wetlands will be protected in these areas. Trails or other open recreational facilities may be feasible in certain areas.

### **3.25 Larger Flooding Events**

The City and County recognize that floods larger than the 100-year event will occur resulting in greater risks and flood damage that will affect even improvements beyond those constructed to current flood protection standards. The City and County will seek to better understand the impact of larger flood events and evaluate context appropriate, cost-effective policies and floodplain management strategies to address these risks.

### **3.26 Protection of Water Quality**

Water quality is a critical health, economic and aesthetic concern. The City and County have been protecting, maintaining and improving water quality and overall health within the Boulder Valley watersheds as a necessary component of existing ecosystems and as a critical resource for the human community. The City and County will continue to reduce point and nonpoint sources of pollutants, protect and restore natural water systems and conserve water resources. Special emphasis will be placed on regional efforts, such as watershed planning, and priority will be placed on pollution prevention over treatment.

## ***Comprehensive Flood and Stormwater Utility Master Plan***

The CFS contains the following guiding principles for flood management:

1. Preserve Floodplains (Preservation)
2. Be Prepared for Floods (Preparedness)
3. Help People Protect Themselves from Flood Hazards (Education)
4. Prevent Adverse Impacts and Unwise Uses in the Floodplain (Regulation)
5. Seek to Accommodate Floods, Not Control Them (Mitigation)

More detail about each of these guiding principles can be found in Chapter 3 of the CFS. The fifth principal, as listed above, is directly related to mitigation and, in the CFS, more completely states:

- Seek to accommodate floods, not control them through planned and monitored system maintenance, nonstructural flood proofing, opening non-containment corridors, overbank land shaping to train flood waters, and limited structural measures at constrained locations. Possible tools for implementation include:

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

- o Update mitigation master plans to emphasize nonstructural measures.
- o Re-evaluate mitigation priorities to eliminate bottlenecks, acquire land to avoid channel improvements, provide non-structural overbank grading, target limited flood protection improvements for high hazards, and research alternative mitigation approaches.
- o Assess any need for structural improvements with evaluation of multiple alternatives.
- o Focus on mitigating high hazard locations citywide and give priority to areas of the greatest risk.

**Urban Drainage and Flood Control District (UDFCD; now the Mile High Flood District (MHFD)) Urban Storm Drainage Criteria Manual**

The UDFCD Urban Storm Drainage Criteria Manual contains the following basic policies:

- The major drainageway system shall be capable of conveying water without flooding buildings and shall remain relatively stable during a 100-year flood.
- Public safety is fundamental to the major drainageway system.
- Public acceptance of the major drainageway system depends on a multitude of factors such as public perception of flood protection, channel aesthetics, right-of-way, open space preservation, and channel maintenance.
- Identify areas with potential for recreational use.
- Consider environmental impacts and benefits and examine the advantages and disadvantages.
- Open channels are more desirable than underground conduits in urban areas because they are closer in character to natural drainageways and offer multiple use benefits.
- Consider two-stage channels. In some cases, it may be desirable to balance the 100-year flow between a formal channel and the adjacent floodplain.

**Greenways Master Plan**

The Greenways Program in the City of Boulder was an outgrowth of the Boulder Creek Corridor Project. It was created on the basis of recognition that stream corridors are a vital link in the larger environmental system and that each stream is a natural and cultural resource. The purpose of the Greenways Program is to extend the stewardship of the City of Boulder to the important riparian areas along the tributaries of Boulder Creek. The objectives of the Greenways Program include:

- Protect and restore riparian, floodplain, and wetland habitat
- Enhance water quality
- Mitigate storm drainage and floods
- Provide alternative modes of transportation routes or trails for pedestrians and bicyclists

- Provide recreation opportunities
- Protect cultural resources

To date, there have been no improvements along Twomile Canyon Creek which facilitate the Greenways Program purpose and objectives. Considering the narrow channel of the creek and the development constraints, there have been no opportunities to construct pedestrian or bicycle facilities within the City limits along this stream reach. Downstream of Folsom Avenue, Goose Creek has been significantly improved to contain a 100-year flood event including a multi-use path. As residential areas were developed upstream of Folsom Avenue, Goose Creek was established in a narrow channel and stormwater pipes that do not contain a 100-year event.

Implementation of the recommendations included in this flood mitigation plan will aid in mitigating storm drainage and floods and help to restore riparian, floodplain, and wetland habitat in certain areas along the creeks.

**Floodplain Mapping Study**

The regulatory floodplain maps for Twomile Canyon and Goose Creeks were updated in 2015 by ICON Engineering, Inc. The updated floodplain mapping established base flood elevations using detailed methods and incorporated improvements and changes along the drainageways. **Figure 2-5** illustrates the 500-year floodplain, 100-year floodplain, conveyance zone and high hazard zone delineated by the mapping study. The number of structures located in each floodplain zone are shown in the table below.

**Table 2-2: Structure Count within Floodplain Zones**

Flood Zone	Number of Structures
500-year Floodplain	843*
100-year Floodplain	759*
Conveyance Zone	77
High Hazard Zone	6

\* Accounts for shallow flooding outside of regulatory floodplain

**Major Drainageway Master Plans**

The drainageway infrastructure in the study area was constructed in the 1950's and 1960's as the neighborhood was expanding and becoming denser.

A storm drainage pilot planning study for the North Boulder Major Drainageways was completed by the Denver Regional Council of Governments in 1969. For Twomile Canyon Creek, this plan called for detention upstream of Linden Avenue, open channel along the historic channel alignment between Linden Avenue and Broadway, and a culvert from Broadway to the historic confluence with Goose Creek. For Upper Goose Creek, this plan called for open channel from 13<sup>th</sup> Street to Alpine Avenue, a culvert from Alpine Avenue to 19<sup>th</sup> Street, and open channel from 19<sup>th</sup> Street to the confluence with Twomile Canyon Creek. With the exception to a small sediment capture facility

upstream of Linden Avenue on Twomile Canyon Creek, no improvements from the 1969 plan were constructed in the study area.

A Major Drainageway Master Plan was developed in 1987 by Greenhorn & O'Mara that identified flood mitigation improvements for Twomile Canyon and Goose Creeks. The most notable of which was the recommendation to purchase and demolish homes along Edgewood Drive, thereby providing 100-year containment for Goose Creek between 19th Street and Folsom Street. Public opposition resulted in abandoning this recommendation and investigating other alternatives (see Love and Associates 1990 memorandum below). No other improvements from the 1987 plan were constructed in the study area.

### ***Goose Creek Mitigation Studies***

In 1990, Love and Associates revisited the 1987 Greenhorn & O'Mara study to evaluate mitigation alternatives from North Boulder Park to Folsom Street. Recommendations from this plan included detention at North Boulder Park, a trapezoidal channel from 13th to 17th Street, enlarged box culverts and reducing flows in Edgewood Drive by increasing channel size and lowering street elevations along 19th Street, Edgewood Drive and Balsam Street. None of the proposed recommendations were constructed.

In 2016, ICON Engineering, Inc. analyzed channel conveyance options along Goose Creek from 19th Street to Folsom Street. From the 2016 study, channel improvements were recommended that would remove on the order of 30 homes from the 100-year floodplain.

## **2.7 PREVIOUSLY COMPLETED PROJECTS**

No major flood mitigation projects have been completed on Upper Goose Creek or Twomile Canyon Creek. A small sediment capture facility that partially reflects the detention as presented in the 1969 storm drainage pilot planning study now exists on Twomile Canyon Creek upstream of Linden Avenue. Minor storm sewer systems have been completed throughout the study area but do not exist to the extent as presented in the previous master plans for major storm events.

Following the 2013 flooding event, major sediment cleanup was completed in the upper reaches of Twomile Canyon Creek. There was significant sediment deposition in the area around Linden Avenue including within the existing sediment capture facility. The Twomile Canyon Creek channel in the area upstream of Linden Avenue was re-built to approximate the pre-storm conditions. However, no major flood mitigation improvement projects were completed as part of the 2013 flooding event recovery.

## **2.8 STREAM ASSESSMENT**

A stream assessment by the City of Boulder for Upper Goose Creek and Twomile Canyon Creek has not been completed at this time. It is expected that typical erosion, debris and sedimentation issues will be identified and incorporated into the typical maintenance program for the study area. As some of these issues are on private property, maintenance easements should be acquired prior to any activities by the City.



# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

## 3.0 HYDROLOGIC ANALYSIS

### 3.1 PREVIOUS STUDIES

Hydrologic information for Twomile Canyon Creek and Upper Goose Creek was previously included as part of the May 1987 Flood Hazard Area Delineation (1987 FHAD) for Boulder and Adjacent County Drainageways prepared by Greenhorne & O'Mara, Inc. and the Upper Goose Creek and Twomile Canyon Creek Flood Mapping Study Update Hydrology Verification Report prepared by ICON Engineering in February 2012. The hydrologic and hydraulic information presented in the 1987 FHAD was originally prepared by the MSM/SP Group (Greiner Engineering Services) as part of the original Flood Insurance Study update. In the 1987 FHAD, hydrology was presented for the 10-, 50-, and 100-year events. Equivalent discharges are shown in the 2002 Flood Insurance Study (2002 FIS), which also presented 500-year discharges. Excerpts from the 1987 FHAD and 2002 FIS are included in Appendix A of the Upper Goose Creek and Twomile Canyon Creek Flood Mapping Study Update Hydrology Verification Report. **Table 3-1** below includes the Effective Conditions drainage areas and associated discharges as developed by the 1987 FHAD and 2002 FIS.

**Table 3-1: Effective Conditions Discharges**

Location	SWMM Element	Effective DA (sq. mi.)	Effective Conditions (1987 FHAD / 2002 FIS)			
			10-Year (cfs)	50-Year (cfs)	100-Year (cfs)	500-Year (cfs)
<b>Twomile Canyon Creek</b>						
Linden Avenue	JUNCT_601	1.40	210	540	710	1430
North Broadway Street	JUNCT_602	1.68	210	675	890	1800
Confluence with Goose Creek	JUNCT_603	2.19	360	840	1120	2000
<b>Goose Creek</b>						
Balsam Avenue	JUNCT_701	0.48	260	520	620	1000
19th Street	JUNCT_702	1.28	700	1320	1600	2450
Upstream of Confluence with Twomile Creek	JUNCT_703	1.32	670	1270	1590	2400
Downstream of Folsom Street	JUNCT_704	3.63	1050	2100	2680	4300

#### Overview of Methodology and Approach

As mentioned above, the 2012 hydrologic verification report supported the floodplain mapping changes. From this previous information, changes were made to the model including conversion to a newer one (CUHP v1.3.3) and incorporation of EPA-SWMM 5.0 features. Adjustments to drainage basins and land use were made per discussions with the project sponsors. Rainfall distribution remained unchanged from prior studies. One-hour rainfall values and corresponding peak discharges are shown in the following tables and figures.

Drainage basin delineations are shown in **Figure 3-1**, next page, and areas are compared in **Table 3-2** below. Differences in basin area between the Effective Conditions and the Duplicate Effective Conditions can be attributed to digitizing of the original basins from the 1987 FHAD map.

**Table 3-2: Drainage Basin Areas**

Basin	Drainage Basin Area (mi <sup>2</sup> )		
	1987FHAD Effective Conditions	Duplicate Effective Conditions	Corrected Effective Conditions
601	1.40	1.38	1.38
602	0.28	0.28	0.21
603	0.51	0.56	0.36
701	0.48	0.43	0.43
702	0.80	0.86	0.98
703	0.04	0.07	0.07
704	0.12	0.12	0.12
<b>Total</b>	<b>3.63</b>	<b>3.70</b>	<b>3.55</b>

**Table 3-3: Percent Impervious**

Basin	% Impervious		
	1987 FHAD Effective Conditions	Corrected Effective Conditions	% Difference
601	7.0	6.1	-13%
602	25.0	30.1	20%
603	41.0	40.7	-1%
701	27.0	25.3	-6%
702	42.0	41.5	-1%
703	28.0	33.8	21%
704	41.0	48.2	18%

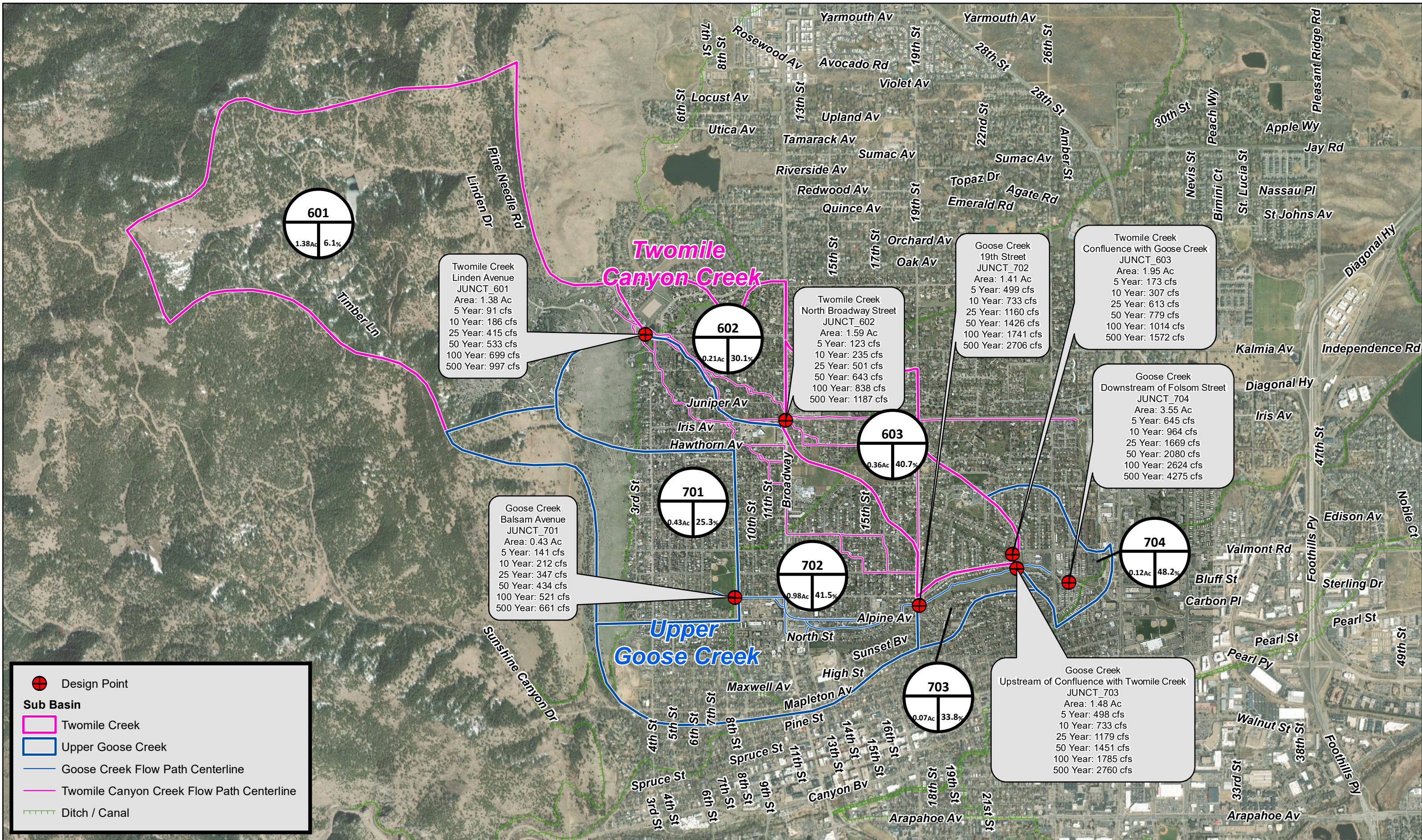
**Table 3-3** identifies the 1987 FHAD Effective Conditions impervious values, the Corrected Effective Conditions impervious values based on the revisions described above, and difference between the two conditions.

**Table 3-4** below includes the 1-hour rainfall depths for all drainage basins in the project area. The City of Boulder's Design and Construction Standards also provide rainfall intensity values for use within the City's jurisdiction. These rainfall values compare very well to those developed for this study and have been added to the bottom of the Rainfall Depth table for reference; however, for this study the sub-basin specific rainfall values have continued to be used for consistency with the Effective Conditions discharges.

**Table 3-4: 1 Hour Rainfall Values**

Basin	1-Hour Rainfall (in)					
	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR
601	1.35	1.60	1.95	2.20	2.45	3.05
602	1.38	1.65	2.02	2.30	2.55	3.19
603	1.40	1.70	2.05	2.30	2.65	3.27
701	1.35	1.65	2.00	2.30	2.55	3.19
702	1.39	1.70	2.02	2.30	2.60	3.21
703	1.41	1.70	2.06	2.30	2.65	3.27
704	1.42	1.70	2.08	2.40	2.65	3.34
COB	1.37	1.79	2.05	2.24	2.49	n/a

Based on the hydrologic analysis presented in the 2012 report and discussions with project sponsors, the Corrected Effective Conditions discharges, following the calibration efforts, were utilized in the Upper Goose Creek and Twomile Canyon Creek flood mapping study update. These peak discharges are presented below in **Figure 3-1**



## 4.0 HYDRAULIC ANALYSIS

### 4.1 EVALUATION OF EXISTING FACILITIES

Hydraulic information for Twomile Canyon Creek and Upper Goose Creek was previously produced as part of the May 1987 Flood Hazard Area Delineation (1987 FHAD) for Boulder and Adjacent County Drainageways prepared by Greenhorne & O'Mara, Inc. This hydraulic information was then significantly updated as part of the Upper Goose Creek and Twomile Canyon Creek Flood Mapping Study Update Hydraulic Report prepared by ICON Engineering in August 2015. As with the Hydrology modeling, there are several contributing factors that were investigated to determine the locations and extent of hydraulic modeling and the resulting flood hazard areas.

#### Mapping

Topographic LiDAR data from 2013 along with building footprint information was provided by the City of Boulder. Topographic data was used for cross section station and elevation data and surface information for the hydraulic modeling efforts. The building footprint information was used to create areas of blocked obstruction in both the FLO-2D (2D) and HEC-RAS (1D) models.

#### FLO-2D Modeling

A 2D FLO-2D hydraulic model was developed to determine the major flow paths along Twomile Canyon Creek. These major flow paths were used as a roadmap to develop the 1D HEC-RAS hydraulic model. Peak discharge values as determined by the 2D FLO-2D model were used as the basis for the major split flow distributions in the 1D HEC-RAS model.

#### Storm Sewer Analysis

Portions of the storm sewer systems – where pipes are 24" or larger - along the Upper Goose Creek and Twomile Canyon Creek (Iris Avenue) were evaluated for capacity. The estimated capacity was then reduced by 10% to reflect a typical blockage factor. The resulting capacity of the storm sewer system was then subtracted from the surface flows in the 1D HEC-RAS model in order to account for storm sewer capacity when modeling the adjacent floodplain.

#### HEC-RAS Modeling

As previously noted, a 1D HEC-RAS hydraulic model was developed based on flow paths as identified by the 2D FLO-2D model and as observed during the September 2013 flooding event. Peak discharges identified by the FLO-2D model were used in the HEC-RAS model. Parameters used within the HEC-RAS hydraulic model are discussed below. HEC-RAS model reports, cross sections, floodplain and conveyance zone data can be found in the 2015 report. Ultimately this 1D HEC-RAS model was utilized to determine the regulatory floodplain for Upper Goose Creek and Twomile Canyon Creek as completed in the 2015 LOMR.

#### Channel Crossing Structures

Channel crossing structures were included in the HEC-RAS model at all crossing structure locations. Debris blockage was incorporated into all crossing structures to reflect the recommended blockage factor at each crossing. Detailed discharge values for all reaches of Upper Goose Creek and Twomile Canyon Creek can be found in the 2015 report.

### 4.2 FLOOD HAZARDS

Floodplain delineation for Upper Goose Creek and Twomile Canyon Creek was completed for the 2015 ICON report and Letter of Map Revision (LOMR). Effective floodplains based on the 2015 ICON flood mapping update and LOMR are illustrated in **Figure 2-5**. The resulting flood hazard zone designations are discussed in detail below.

#### Zone AE with BFEs and 100-year shallow flooding

The HEC-RAS model results were delineated to develop the 100-year (Zone AE) floodplain and associated Base Flood Elevations (BFEs). Floodplain delineation and BFE placements were based on 1-foot topographical mapping developed from the 2013 LiDAR data provided by the City of Boulder.

There are extensive reaches of HEC-RAS modeling that result in vertically extended cross sections. For areas of vertically extended cross sections that averaged spill depths less than 0.5 feet, no shallow flooding zone was shown and the 100-year floodplain delineation was limited to the outer limits of the HEC-RAS cross sections. For vertically extended cross sections that averaged spill depths greater than 0.5 feet but less than 1.0 feet, Zone X shallow flooding zones were developed based on anticipated shallow flooding.

#### Zone AO

Areas with HEC-RAS cross sections that are vertically extended along the main flow path are indicative of locations where flow will diverge and continue overland along a different path. This flow is generally shallow and spread out by nature, typical of a FEMA Zone AO shallow flooding designation. For areas with cross section extensions greater than 0.5 feet in depth, shallow flooding zones were added to the flood map. For areas with an average overland flow depth between 1.0 feet and 1.5 feet, a Zone AO (1 foot) designation was used. For areas with an average overland flow depth between 1.5 feet and 2.5 feet, a Zone AO (2 foot) designation was used. In most cases average flow depths were estimated using supplemental hydraulic calculations along the more dominant route for the overland flow.

Foothill Elementary School is located west of Broadway, between Hawthorne Avenue and the Twomile Canyon Creek main channel. The school did experience flood damage during the September 2013 flood. Although this building is located off line of the major flow paths, pockets of potential shallow flooding for average flow depths exceeding 1-foot have been estimated based on the FLO-2D models and reflect a Zone AO (1 foot) designation. A similar approach



was used for shallow flooding in areas both east and west of the school where flow depths averaged less than 1.0 foot and have been designated as a Zone X (shaded) area.

## Conveyance Zone

Conveyance zones throughout the major flow paths were developed based on a 0.5 foot rise criteria. For flow paths along City of Boulder streets, the conveyance zone encroachment was generally limited to the right-of-way on each side of the roadway. No additional optimization of the conveyance zone was completed provided the encroachment limited the conveyance zone to within the City of Boulder right-of-way. For conveyance zones within channels or other low-lying areas, the conveyance zone was optimized in greater detail to maximize the 0.5 foot rise criteria. For minor split flow reaches where the full discharge could be carried within the dominant flow path and still meet the 0.5 foot rise criteria, a conveyance zone was not developed.

## Zone X (500-year)

The Zone X floodplain for Upper Goose Creek is based on the HEC-RAS cross sections and corresponding water surface elevations. Areas where the 500-year floodplain is significantly different from the 100-year floodplain have been delineated as Zone X and are shown on the floodplain work maps.

The Zone X floodplain for Twomile Canyon Creek is based on the FLO-2D model results for the 500-year event. As discussed with the project team and FEMA representatives, the 500-year floodplain extents from the FLO-2D model were limited to areas of 0.25 feet of depth or greater. The Zone X floodplain (including coverage from the Zone X extents identified by the 100-year modeling as discussed above) was then delineated according to the FLO-2D limits.

## High Hazard Area

For Goose Creek, the high hazard areas were delineated based on depth and product of depth and velocity values per the City of Boulder Criteria. Areas of 100-year floodplain depth equal to or greater than 4.0 feet, and/or areas where the depth multiplied by the velocity is equal or greater than 4.0 feet per second were shown as high hazard. All depth and velocity values were taken from the HEC-RAS model and interpolated using GIS software. The resulting depth and velocity rasters were then used to determine areas that satisfy the high hazard criteria. For the Twomile Canyon Creek, high hazard potential was reviewed from the HEC-RAS floodplain modeling, as well as a high hazard interpolation at individual grid cells in the FLO-2D model. Due to the nature of flooding in Twomile Canyon Creek, City staff elected to only map the proposed high hazard zone in areas where both the 1D HEC-RAS and 2D FLO-2D indications were coincident.

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

## 5.0 ALTERNATIVE ANALYSIS

### 5.1 ALTERNATIVE DEVELOPMENT AND SELECTION PROCESS

Typically, flood mitigation plans are developed to adequately convey a 100-year storm event and comply with the policies of the Boulder Valley Comprehensive Plan, the Comprehensive Flood and Stormwater Utility Master Plan and the MHFD Drainage Criteria Manual. This plan began by examining every option for the entire reach of Upper Goose and Twomile Canyon Creek. These options were then presented at several public meetings over the course of three years, including open houses and Water Resource Advisory Board (WRAB) meetings. All of the summary results and comments from these meetings are presented in the full memo in **Appendix A**.

#### Alternative Descriptions

Each alternative analyzed as part of this study utilized one or more methods to convey stormwater through the selected reach. These general stormwater conveyance methods are:

- **100-year channel** – An open channel designed to convey the 100-year flood event. A typical project would include: right-of-way acquisition to construct the improvements, channel grading and stabilization measures, designation of a bankfull (low flow) channel for frequent conveyance, grading in the banks for additional flood capacity. Open channels are designed to perform over a full spectrum of flows and have freeboard to protect structures or carry flows beyond design capacity. Open channels often accompany public access



through trail systems, which can also double as maintenance access. Open channels can improve water quality through wetland development and wildlife habitat creation and connectivity, following City green space goals. Stream maintenance is often performed as part of the MHFD's stream maintenance program. A **less than 100-year channel** would serve similar functions as a 100-year channel, only at a lower conveyance capacity. Limitations include the need to build or modify crossing structures such as bridges or culverts.

- **Detention** – A water storage site on a river or stream designed to delay the flow of water and reduce the peak discharge. These projects entail many of the same elements as channel improvements, such as acquiring land, mass grading and freeboard, except in a more compact area. Many of the same benefits are found as well, such as recreation, water quality and habitat improvements. Limitations in this area relate to land acquisition, and area impacted. There are few locations where detention would provide enough benefit to be feasible and these would generally require large dam facilities which are undesirable in open spaces or upstream of urban areas.



- **Storm Drain** – These are a traditional pipe and inlet system used to capture water and convey it underground to a point downstream with capacity to accept flows. A project of this type will require significant amounts of work within the road and associated rights-of-way, limited easements are necessary, but inconvenience to neighborhoods and businesses is high. Space will limit capacity, though there is often some room for water quality improvements. There is an increase in life safety but not in habitat.



- **Roadway Conveyance** – This method takes advantage of the capacity to be found within existing rights-of-way, using the roadway as conveyance channel. Some reconfiguration is required for most areas, which may limit parking and could close areas to traffic during larger storms. Maintenance costs can be reduced, but there are few chances for water quality or habitat improvements. Introduction of high hazard areas and flooding where not previously located are notable issues with roadway conveyance. It should be noted that during a severe flood event, using the roads as conveyance may cause them to become impassable to emergency personnel.

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

**Sediment Capture** – This method is substantially similar to a detention pond, but with the goal of capturing sediment rather than large volumes of water. As such, construction is similar but usually on a smaller scale. Benefits include reduction of sediment impact to downstream facilities and thus maintenance, and possible incorporation of habitat or recreation opportunities. The challenges are that this alone does not improve issues related to water depths such as damage to buildings from flooding.



## ***Detention in Boulder County***

Detention alternatives within Boulder County and at the Boulder County complex near Iris and Broadway were reviewed and presented to Boulder County staff during a meeting on June 25th, 2018. As discussed, new storm water detention upstream of the City of Boulder limits would require approximately five new dam/detention facilities to provide storage for the 100-year event down to the capacity of the downstream drainageway. Due to steep topography in this area, all five dams would be expected to range in size from 3 to 19.3 acre-feet, with all five likely to fall under state jurisdictional status due to the dam heights. In addition, impacts to private property, transportation and roadways, and viewsapes could be considerable. To date, a formal response from Boulder County regarding their assessment and thoughts behind these alternatives has not been received. Based on land use impacts and high costs, new detention upstream of the City of Boulder limits was chosen to not be pursued further.

The flood storage that exists within the Pine Brook Reservoir was reviewed as a detention alternative. However, only a relatively small portion of the Twomile Canyon Creek basin is located upstream of the reservoir; therefore, added detention at Pine Brook Reservoir had a relatively minor benefit on peak flood attenuation within the City of Boulder. Based on this, a detention alternative within Pine Brook Reservoir was not pursued further.

The area along Twomile Canyon Creek just upstream of Linden Avenue and Spring Valley Drive is owned by the City of Boulder. The site does not provide for significant storage volume for a detention facility, but the location was reviewed as a sediment capture facility. The sediment capture facility would function similar to the current sediment capture facility in this location but would be expanded including a second embankment upstream of Spring Valley Drive.

## ***Detention at the Boulder County Complex (NE corner of Iris & Broadway)***

The original detention concept for the Boulder County Complex at the north east corner of Iris Avenue and Broadway included detention options for both the ballfields on the east side of the property as well as the location of the current Boulder County offices. The project team found the potential to acquire the building site alone for detention to be unlikely due to the high value of the property. Therefore, detention here was removed from consideration. However, should the portion of the parcel that includes the County offices be redeveloped in the future, the option to include detention could be reconsidered if other mitigation measures are not yet complete. The ballfields on the east side of the property have been retained as an alternative for detention consideration. The detention alternative will reduce the footprint available for ballfields, but the area could still function as fields.

## ***Community Plaza and Ideal Market Commercial Area***

The City of Boulder met with representatives of the Community Plaza and Ideal Market commercial area to discuss major redevelopment efforts of the commercial area. Extent and timing of any redevelopment of the area is unknown at this time. Furthermore, the alternative of an open channel, while being a potential focus point of a redevelopment, would also likely reduce the developable footprint of the area. For this reason, the

## **Initial Alternative Screening**

Flood mitigation alternatives at the following areas have been adjusted based on an initial screening that reviewed feasibility, public support, level of mitigation, and greenways objectives.

### **Long's Garden Property along Twomile Canyon Creek**

Following public input, all stormwater improvements with the potential to impact the Long's Garden property and gardens have been removed from consideration. Additional alternatives have been developed east of Broadway maintaining construction around the Longs Garden property.

### **Alpine Condominiums Property along Upper Goose Creek**

Following public input, all alternatives resulting in acquiring the Alpine Condominiums have been removed from consideration. Current alternatives consider an underground storm drain across the property. Should the Alpine Condominiums area undergo a significant redevelopment in the future, the option to daylight flood mitigation measures at this location should be a consideration.

### ***100-Year Open Channel***

Following public input, along with significant project costs, several reaches of 100-year channel conveyance have been removed from consideration where acquisition and removal of a large number of privately held residential structures would be required. This was particularly evident along Twomile Canyon Creek, west of Broadway.

open channel alternatives between Broadway and 13th Street along Upper Goose Creek were removed from consideration. Should the Community Plaza and Ideal Market commercial area redevelop in the future, the option to daylight flood mitigation could be considered.

### ***Roadway Conveyance on Twomile Canyon Creek west of Broadway***

A roadway conveyance mitigation approach west of Broadway had originally not been moved forward based on public input from the July 2017 public workshop, with open channel favored over roadway conveyance. However, this alternative was incorporated into the alternatives for further evaluation based on comments received in the 2018 questionnaire which requested that roadway conveyance be investigated further in place of major changes to the existing Twomile Canyon Creek channel.

### **Alternatives for Further Evaluation**

Following the public process, feedback incorporation and initial screening, the alternatives for additional analysis for the Upper Goose Creek and Twomile Canyon Creek Flood Mitigation Plan were consolidated and are summarized in **Table 5-1** (Twomile Canyon Creek) **Table 5-2** (Upper Goose Creek), and **Figure 5-1**.

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

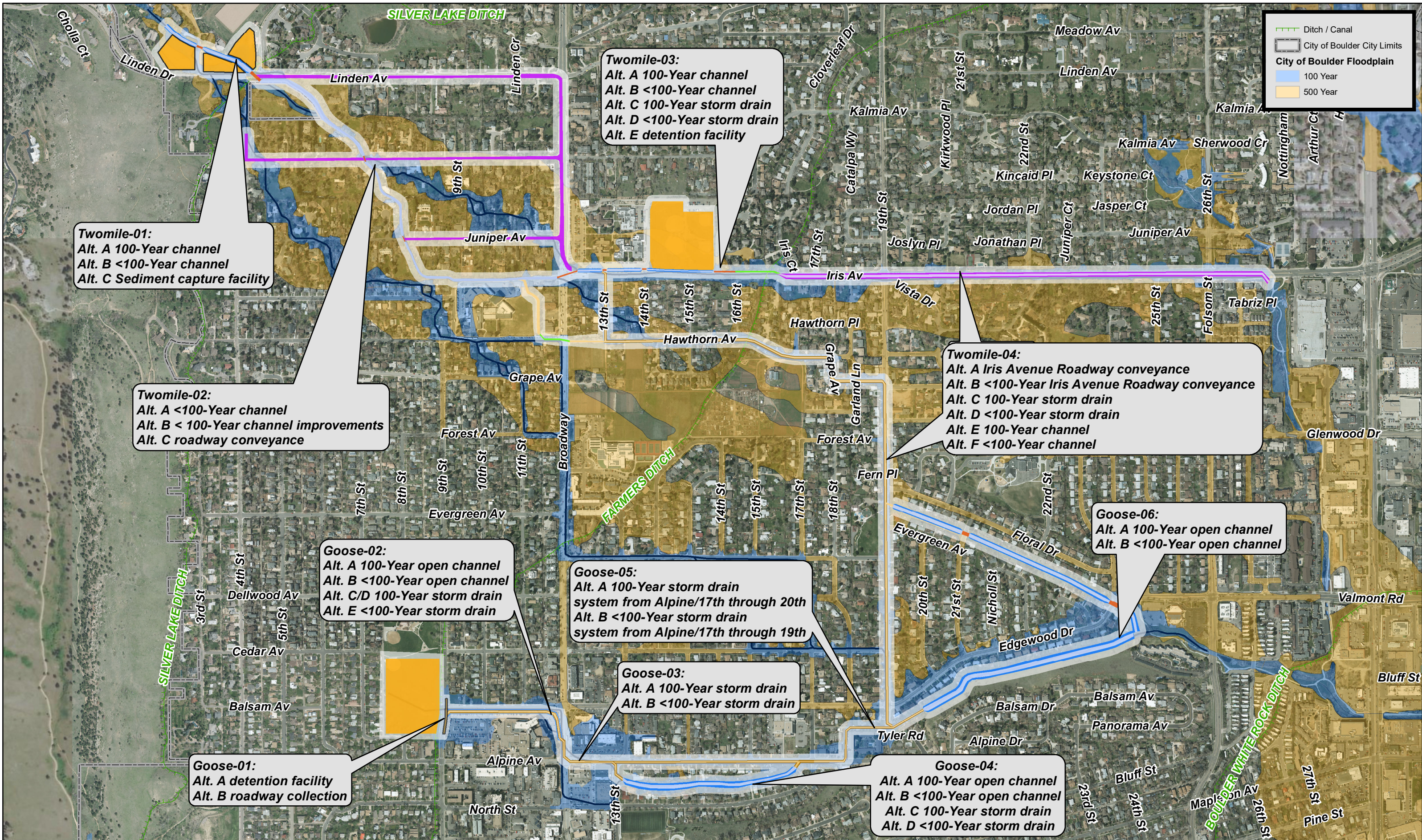
**Table 5-1: Twomile Canyon Creek Alternatives for Further Evaluation Summary**

Reach	Reach Description	Alt	Mitigation Measure	Cost	Project Benefits (pro)	Project Issues (con)
Twomile-01	City Limits to Linden Avenue	A	100-Year channel improvements; new Spring Valley Drive and Linden Avenue culverts	\$2.5M	<ul style="list-style-type: none"> <li>Reduces spill flow out of Twomile Canyon Creek</li> <li>Reduces overtopping of roadways</li> </ul>	<ul style="list-style-type: none"> <li>May require removal of mature trees</li> <li>Does not address sediment capture</li> <li>Channel work requires drainage easements</li> </ul>
Twomile-01	City Limits to Linden Avenue	B	Less Than 100-Year channel improvements; new Spring Valley Drive and Linden Avenue culverts	\$1.6M	<ul style="list-style-type: none"> <li>Reduces spill flow out of Twomile Canyon Creek</li> <li>Reduces overtopping of roadways</li> </ul>	<ul style="list-style-type: none"> <li>May require removal of mature trees</li> <li>Does not address sediment capture</li> <li>Channel work requires drainage easements</li> <li>Does not contain 100-year event</li> </ul>
Twomile-01	City Limits to Linden Avenue	C	Enlarge existing sediment capture facility	\$1.0M	<ul style="list-style-type: none"> <li>Reduces sedimentation impact downstream</li> <li>Existing City ownership of sediment capture facility footprint</li> <li>Can be constructed independent of other improvements</li> </ul>	<ul style="list-style-type: none"> <li>Change in natural sediment transport</li> <li>May require removal of mature trees</li> <li>Embankment may impact view scape</li> <li>Impacts Open Space Mountain Parks land</li> <li>No significant reduction in flood risk</li> </ul>
Twomile-02	Linden Avenue to Broadway	A	Less Than 100-Year channel improvements; new Kalmia Avenue, Juniper Avenue, and Broadway culverts; channel to Broadway and Iris	\$10.3M	<ul style="list-style-type: none"> <li>Reduces spill flow out of Twomile Canyon Creek</li> <li>Reduces overtopping of roadways</li> <li>Follows existing channel alignment</li> <li>Opportunity for underpass at Broadway</li> </ul>	<ul style="list-style-type: none"> <li>Requires some structure acquisition</li> <li>Requires extensive drainage easements</li> <li>Requires Iris or 13th Street alternatives</li> </ul>
Twomile-02	Linden Avenue to Broadway	B	Less Than 100-Year channel improvements; new Kalmia Avenue, Juniper Avenue, and Broadway/Hawthorn Avenue culverts; channel to Broadway and Hawthorn	\$14.1M	<ul style="list-style-type: none"> <li>Reduces spill flow out of Twomile Canyon Creek</li> <li>Reduces overtopping of roadways</li> <li>More efficient connection to downstream channel</li> <li>Opportunity for underpass at Broadway</li> </ul>	<ul style="list-style-type: none"> <li>Not as feasible for Broadway underpass</li> <li>Requires some structure acquisition</li> <li>Requires extensive drainage easements</li> <li>Requires downstream improvements</li> </ul>
Twomile-02	Linden Avenue to Broadway	C	Roadway conveyance along Linden, Kalmia and/or Juniper to Broadway	\$4.6M	<ul style="list-style-type: none"> <li>Captures spill flow out of Twomile Canyon Creek</li> <li>Utilizes existing roadway corridors</li> </ul>	<ul style="list-style-type: none"> <li>Conveys flood risk into areas without previous risk</li> <li>Possible utility conflicts</li> <li>Increases surface flow within Broadway</li> <li>Life safety and emergency access concerns with street flooding</li> </ul>
Twomile-03	Broadway to 19th Street	A	100-Year channel improvements; new 13th Street, 14th Street culverts, culvert from 16th Street through Farmer's Ditch; Iris Avenue Roadway Improvements for surface flow	\$8.4M	<ul style="list-style-type: none"> <li>Conveys flood flows to Elmer's Twomile</li> <li>Less property acquisition than southern alignments</li> </ul>	<ul style="list-style-type: none"> <li>Major impact to Iris Avenue</li> </ul>
Twomile-03	Broadway to 19th Street	B	Less Than 100-Year channel improvements; new 13th Street, 14th Street culverts, culvert from 16th Street through Farmer's Ditch; Iris Avenue Roadway Improvements for surface flow	\$5.7M	<ul style="list-style-type: none"> <li>Conveys flood flows to Elmer's Twomile</li> <li>Less property acquisition than southern alignments</li> </ul>	<ul style="list-style-type: none"> <li>Major impact to Iris Avenue</li> <li>Does not contain 100-year event</li> </ul>
Twomile-03	Broadway to 19th Street	C	100-Year storm drain outfall system	\$7.10M	<ul style="list-style-type: none"> <li>Utilizes existing City Right-of-Way</li> <li>Provides for local drainage along 13th Street</li> </ul>	<ul style="list-style-type: none"> <li>Requires downstream improvements</li> <li>Does not impact Iris Avenue</li> <li>Susceptible to clogging</li> </ul>
Twomile-03	Broadway to 19th Street	D	Less Than 100-Year storm drain outfall system	\$5.0M	<ul style="list-style-type: none"> <li>Utilizes existing City Right-of-Way</li> <li>Provides for local drainage along 13th Street</li> </ul>	<ul style="list-style-type: none"> <li>Requires downstream improvements</li> <li>Does not impact Iris Avenue</li> <li>Susceptible to clogging</li> </ul>
Twomile-03	Broadway to 19th Street	E	Detention facility within the Boulder County Complex at Broadway and Iris (ballfields only)	\$2.2M	<ul style="list-style-type: none"> <li>Reduces downstream discharges</li> <li>Utilizes publicly owned property</li> <li>Retain or re-purpose park uses</li> </ul>	<ul style="list-style-type: none"> <li>Impact to existing park uses</li> <li>May require removal of mature trees</li> <li>Embankment may impact view scape</li> </ul>
Twomile-04	19th Street to Elmer's Twomile Creek	A	Iris Avenue Roadway Improvements for surface flow	\$3.1M	<ul style="list-style-type: none"> <li>Conveys flood flows to Elmer's Twomile</li> </ul>	<ul style="list-style-type: none"> <li>Major impact to Iris Avenue</li> <li>Life safety and emergency access concerns with street flooding</li> </ul>
Twomile-04	19th Street to Upper Goose Creek	B	Less Than 100-Year Iris Avenue Roadway Improvements for surface flow	\$1.6M	<ul style="list-style-type: none"> <li>Conveys flood flows to Elmer's Twomile</li> </ul>	<ul style="list-style-type: none"> <li>Major impact to Iris Avenue</li> <li>Life safety and emergency access concerns with street flooding</li> <li>Does not contain 100-year event</li> </ul>
Twomile-04	19th Street to Upper Goose Creek	C	100-Year storm drain outfall system	\$3.0M	<ul style="list-style-type: none"> <li>Utilizes the 19th Street Right-of-Way</li> <li>Does not require open channel construction</li> </ul>	<ul style="list-style-type: none"> <li>Does not remove Twomile Canyon Creek discharge from Goose Creek between 19th and historical confluence</li> <li>Susceptible to clogging</li> </ul>
Twomile-04	19th Street to Upper Goose Creek	D	Less Than 100-Year storm drain outfall system	\$2.0M	<ul style="list-style-type: none"> <li>Utilizes the 19th Street Right-of-Way</li> <li>Does not require open channel construction</li> </ul>	<ul style="list-style-type: none"> <li>Does not remove Twomile Canyon Creek discharge from Goose Creek between 19th and historical confluence</li> <li>Susceptible to clogging</li> <li>Does not contain 100-year event</li> </ul>
Twomile-04	19th Street to Upper Goose Creek	E	100-Year channel improvements; new 21st Street and Edgewood Drive culverts	\$2.8M	<ul style="list-style-type: none"> <li>Provides open channel connectivity to Goose Creek</li> <li>May reduce groundwater issues in local area</li> </ul>	<ul style="list-style-type: none"> <li>Requires significant land acquisition</li> <li>May require removal of mature trees</li> <li>Places channel in backyards</li> </ul>
Twomile-04	19th Street to Upper Goose Creek	F	Less Than 100-Year channel improvements; new 21st Street and Edgewood Drive culverts	\$2.0M	<ul style="list-style-type: none"> <li>Provides open channel connectivity to Goose Creek</li> <li>May reduce groundwater issues in local area</li> </ul>	<ul style="list-style-type: none"> <li>Requires significant land acquisition</li> <li>May require removal of mature trees</li> <li>Places channel in backyards</li> </ul>

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

**Table 5-2: Upper Goose Creek Alternatives for Further Evaluation Summary**

Reach	Reach Description	Alt	Mitigation Measure	Cost	Project Benefits (pro)	Project Issues (con)
Goose-01	North Boulder Park to 9th Street	A	Detention facility within North Boulder Park; new 9th Street culvert	\$3.0M	<ul style="list-style-type: none"> <li>Reduces downstream discharges</li> <li>Reduces overtopping of 9th Street</li> <li>Retain or re-purpose park uses</li> </ul>	<ul style="list-style-type: none"> <li>Impact to existing park uses</li> <li>May require removal of mature trees</li> <li>Embankment may impact view scape</li> </ul>
Goose-01	North Boulder Park to 9th Street	B	No detention; Roadway collection to deliver flows to Alpine-Balsam site	\$0.5M	<ul style="list-style-type: none"> <li>Provides flooding protection for the Alpine-Balsam site</li> <li>Does not impact North Boulder Park</li> <li>Reduces flooding on Balsam Avenue</li> </ul>	<ul style="list-style-type: none"> <li>No reduction in discharges</li> <li>Concentrates discharges onto the Alpine-Balsam site</li> <li>May require roadway reconfiguration</li> </ul>
Goose-02	9th Street to Broadway	A	100-Year open channel through Alpine-Balsam site	\$1.0M	<ul style="list-style-type: none"> <li>Provides flooding protection for the Alpine-Balsam site</li> <li>Reduces flooding on Balsam Street</li> <li>Aligns with the Alpine-Balsam Master Plan</li> <li>Provides open channel habitat / green infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>Final configuration of Alpine-Balsam site unknown</li> <li>Requires more room than storm drain system</li> </ul>
Goose-02	9th Street to Broadway	B	Less Than 100-Year open channel through Alpine-Balsam site	\$0.8M	<ul style="list-style-type: none"> <li>Provides flooding protection for the Alpine-Balsam site</li> <li>Reduces flooding on Balsam Street</li> <li>Aligns with the Alpine-Balsam Master Plan</li> <li>Provides open channel habitat / green infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>Final configuration of Alpine-Balsam site unknown</li> <li>Requires more room than storm drain system</li> <li>Does not contain 100-year event</li> </ul>
Goose-02	9th Street to Broadway	C	100-Year storm drain through Alpine-Balsam site (detained flow)	\$0.7M	<ul style="list-style-type: none"> <li>Provides flooding protection for the Alpine-Balsam site</li> <li>Reduces flooding on Balsam Street</li> <li>Aligns with the Alpine-Balsam Master Plan</li> </ul>	<ul style="list-style-type: none"> <li>Final configuration of Alpine-Balsam site unknown</li> <li>Susceptible to clogging</li> </ul>
Goose-02	9th Street to Broadway	D	100-Year storm drain through Alpine-Balsam site (full flow)	\$1.1M	<ul style="list-style-type: none"> <li>Provides flooding protection for the Alpine-Balsam site</li> <li>Reduces flooding on Balsam Street</li> </ul>	<ul style="list-style-type: none"> <li>Final configuration of Alpine-Balsam site unknown</li> <li>Susceptible to clogging</li> </ul>
Goose-02	9th Street to Broadway	E	Less Than 100-Year storm drain through Alpine-Balsam site (full flow)	\$0.9M	<ul style="list-style-type: none"> <li>Provides flooding protection for the Alpine-Balsam site</li> <li>Reduces flooding on Balsam Street</li> </ul>	<ul style="list-style-type: none"> <li>Final configuration of Alpine-Balsam site unknown</li> <li>Susceptible to clogging</li> <li>Does not contain 100-year event</li> </ul>
Goose-03	Broadway to 13th Street	A	100-Year storm drain system	\$1.2M	<ul style="list-style-type: none"> <li>Utilizes existing Right-of-Way</li> <li>Does not require property acquisition</li> <li>Provides local drainage along Broadway and Alpine Avenue</li> </ul>	<ul style="list-style-type: none"> <li>Construction disruption to busy business corridor</li> <li>Susceptible to clogging</li> </ul>
Goose-03	Broadway to 13th Street	B	Less Than 100-Year storm drain system	\$0.9M	<ul style="list-style-type: none"> <li>Utilizes existing Right-of-Way</li> <li>Does not require property acquisition</li> <li>Provides local drainage along Broadway and Alpine Avenue</li> </ul>	<ul style="list-style-type: none"> <li>Construction disruption to busy business corridor</li> <li>Susceptible to clogging</li> </ul>
Goose-04	13th Street to 17th Street	A	100-Year open channel	\$2.4M	<ul style="list-style-type: none"> <li>Provides additional open channel habitat</li> <li>Enhances existing drainage path</li> <li>Green infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>Requires extensive drainage easement acquisition</li> <li>Disruptive to residential back-yards</li> </ul>
Goose-04	13th Street to 17th Street	B	Less Than 100-Year open channel	\$1.2M	<ul style="list-style-type: none"> <li>Provides additional open channel habitat</li> <li>Enhances existing drainage path</li> <li>Green infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>Requires extensive drainage easement acquisition</li> <li>Disruptive to residential back-yards</li> <li>Does not contain 100-year event</li> </ul>
Goose-04	13th Street to 17th Street	C	100-Year storm drain system	\$3.1M	<ul style="list-style-type: none"> <li>Utilizes existing Right-of-Way</li> <li>Does not require property acquisition</li> <li>Provides local drainage along Alpine Avenue</li> </ul>	<ul style="list-style-type: none"> <li>Does not address overland flow in existing flow path</li> <li>Susceptible to clogging</li> </ul>
Goose-04	13th Street to 17th Street	D	Less Than 100-Year storm drain system	\$2.0M	<ul style="list-style-type: none"> <li>Utilizes existing Right-of-Way</li> <li>Does not require property acquisition</li> <li>Provides local drainage along Alpine Avenue</li> </ul>	<ul style="list-style-type: none"> <li>Does not address overland flow in existing flow path</li> <li>Susceptible to clogging</li> <li>Does not contain 100-year event</li> </ul>
Goose-05	17th Street to 20th Street	A	100-Year storm drain system from Alpine/17th through 20th	\$2.2M	<ul style="list-style-type: none"> <li>Utilizes some existing Right-of-Way</li> <li>Does not require Alpine Condos removal</li> <li>Provides local drainage adjacent to Alpine Condos</li> </ul>	<ul style="list-style-type: none"> <li>Requires drainage easement acquisition</li> <li>Disruptive to Alpine Condo property (construction)</li> <li>Susceptible to clogging</li> </ul>
Goose-05	17th Street to 20th Street	B	Less Than 100-Year storm drain system from Alpine/17th through 19th	\$1.6M	<ul style="list-style-type: none"> <li>Utilizes some existing Right-of-Way</li> <li>Does not require Alpine Condos removal</li> <li>Provides local drainage adjacent to Alpine Condos</li> </ul>	<ul style="list-style-type: none"> <li>Requires drainage easement acquisition</li> <li>Disruptive to Alpine Condo property (construction)</li> <li>Susceptible to clogging</li> <li>Does not contain 100-year event</li> </ul>
Goose-06	20th Street to 24th Street	A	100-Year Open channel	\$12.0M	<ul style="list-style-type: none"> <li>Provides additional open channel habitat</li> <li>Enhances existing drainage path</li> <li>Green infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>Requires extensive drainage easement acquisition</li> <li>Disruptive to residential back-yards</li> <li>Requires tall retaining walls on south bank</li> </ul>
Goose-06	20th Street to 24th Street	B	Open channel (sizing per previous study recommending a "5-Year" improvement; exceeds 5-Year with detained flow and/or Twomile improvements)	\$5.7M	<ul style="list-style-type: none"> <li>Provides additional open channel habitat</li> <li>Enhances existing drainage path</li> <li>Green infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>Requires extensive drainage easement acquisition</li> <li>Disruptive to residential back-yards</li> <li>Requires tall retaining walls on south bank</li> <li>Does not contain 100-year event</li> </ul>



# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

## 5.2 ALTERNATIVE BENEFIT COST ANALYSIS

As part of the Benefit Cost Analysis, ICON prepared a cost estimate for each viable alternative. These can be found as part of the Memorandum in **Appendix B**. In order to determine flood mitigation benefits of any alternative, a complete evaluation of the properties, existing, and proposed flood hazards must be undertaken. This process is described in detail below. A summary of Benefit Cost Analysis is included in **Table 5-3**.

### Flood Inundation Analysis

For Twomile Canyon Creek, the FLO-2D hydraulic models that were developed for the 2015 LOMR were utilized to estimate flooding in both existing and proposed conditions. These models were then modified with the selected alternatives to obtain estimates of the proposed conditions flooding extents and inundation depths. For Upper Goose Creek, the effective conditions 1D HEC-RAS models were utilized to estimate flooding in both existing and proposed conditions.

For both Twomile Canyon Creek and Upper Goose Creek, proposed condition models were only developed for design storm intervals that exceeded the expected capacity of the alternative. That is, for a 100-year capacity alternative, only the 500-year model was utilized to evaluate flooding potential beyond the capacity of the improvement. All other more frequent events were assumed to be contained within the proposed alternatives and flooding would not inundate adjacent properties and buildings.

### Building Dataset

A GIS building dataset was obtained from the City of Boulder encompassing the area of this study. This dataset included basic information on each structure including a building type and a ground elevation value. This City of Boulder information was then cut down to just the structures that are located within the effective condition Zone AE or Zone X (shaded) floodplains. This reduction resulted in 1,030 structures identified for potential flooding impacts and damage/benefit calculations.

A second GIS data set was obtained from Boulder County Assessor in January 2019. These two data sets were merged, which resulted in a series of attributes for each individual structure that is potentially impacted by flooding. These attributes include building type, finished size (both basement and non-basement areas), and car storage size (i.e. garage). This information was further evaluated such that each structure was assigned a specific structure type to be used within the flooding damage calculations. Additionally, the City of Boulder provided floodproofing data for applicable structures within the project area, which was integrated into the structure data and utilized in the flood depth calculations as applicable.

### Damage Assessment Approach

A damage assessment was completed for existing and proposed conditions to determine the potential benefits of implementing a flood mitigation alternative. This analysis was limited to calculating damages related to building and content value. Additional damages such as displacement costs and loss of function impacts and non-traditional

damages (landscaping and agricultural equipment, outbuildings, vehicles, traffic function and public safety or loss of life) were not included in this analysis. Inclusion of items such as these would only increase overall project benefits. The approach to assessing damages throughout the basin typically followed FEMA Benefit-Cost-Analysis (BCA) guidance, with modifications to best consider the unique landscape within the watershed. The approach to the BCA is detailed in the BCA Memorandum included in **Appendix B**.

### Annualized and Present Value Damages

Total damages (TD) to each structure for the 10-, 50-, 100- and 500-year events were annualized to estimate the expected damages per year. Expected annualized damages (EAD) were used to estimate the total damages that would be expected over project lifetime. The present value (PV) of damages represents the total damage value over the life of the project in current day value. The standard FEMA discount rate of 7% and a useful life of a major drainage system of 50-years were used for these calculations. Complete calculations are provided in the BCA Memorandum in **Appendix B**.

### Benefit Cost Ratio

The benefit cost ratio is the benefit value divided by the mitigation costs. A ratio of less than 1 indicates a project with costs that exceed the benefits, while a ratio greater than 1 indicates a project with costs that are less than the benefits. The resulting benefit cost ratios are summarized in **Table 5-3**.

Mitigation alternatives presented here with a benefit cost ratio of less than one are not cost effective with respect to flood damage mitigation. However, if non-flood damage benefits (ex. sediment and/or debris capture with associated reduced clean-up efforts) can be realized from these projects, their inclusion into the recommended plan may still be warranted.

Based on the full project comparisons, there was no substantial difference between the 100-year improvements and the less than 100-year improvements in terms of the benefit cost ratio, and both ratios are well above a value of one. Therefore, the conclusion reached was that it may be appropriate to develop a recommended plan that utilizes a combination of alternatives to best correlate with other community values. However, the resulting plan of some 100-year improvements and some less than 100-year improvements would require further review of overall floodplain impacts.



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**Table 5-3: Damage and Benefit-Cost Calculation Summary**

Reach ID	Existing Conditions Damages					Annualized Damage (\$)	Present Value of Damage Over Project Life (\$)	Mitigation Alternative	Proposed Mitigation								
	Number of Structures Flooded				Total Number of Structures in Regulatory Floodplain				Number of Structures Flooded				Present Value of				
	10-Year Event	50-Year Event	100-Year Event	500-Year Event					10-Year Event	50-Year Event	100-Year Event	500-Year Event	Annualized Damage (\$)	Project Life (\$)	Benefit Value (\$)	Mitigation Cost (\$)	Benefit Cost Ratio
Twomile-01	2	7	7	11	16	\$207,489	\$2,863,497	A	0	3	4	6	\$88,887	\$1,226,708	\$1,636,789	\$2,500,000	0.7
								B	0	3	4	6	\$88,887	\$1,226,708	\$1,636,789	\$1,600,000	1.0
Twomile-02	200	252	261	274	316	\$5,623,443	\$77,607,707	A	0	159	201	228	\$1,923,254	\$26,542,336	\$51,065,372	\$10,300,000	5.0
								B	0	159	201	228	\$1,923,254	\$26,542,336	\$51,065,372	\$14,100,000	3.6
								C	52	152	202	213	\$3,372,045	\$46,536,733	\$31,070,974	\$4,596,808	6.8
Twomile-03	185	237	250	267	329	\$3,603,998	\$49,737,867	A	0	0	0	194	\$141,691	\$1,955,436	\$47,782,431	\$8,400,000	5.7
								B	0	144	172	207	\$1,176,654	\$16,238,702	\$33,499,164	\$5,700,000	5.9
								C	0	0	0	194	\$141,691	\$1,955,436	\$47,782,431	\$7,123,149	6.7
								D	0	144	172	207	\$1,176,654	\$16,238,702	\$33,499,164	\$5,003,365	6.7
								E	--	--	--	--	--	--	\$5,750,000.0	\$2,200,000	2.6
Twomile-04	77	141	159	196	263	\$3,078,641	\$42,487,549	A	0	0	0	96	\$117,971	\$1,628,090	\$40,859,459	\$3,100,000	13.2
								B	0	86	129	169	\$1,219,831	\$16,834,572	\$25,652,978	\$1,600,000	16.0
								C	0	0	0	96	\$117,971	\$1,628,090	\$40,859,459	\$3,000,000	13.6
								D	0	86	129	169	\$1,219,831	\$16,834,572	\$25,652,978	\$2,000,000	12.8
								E	0	0	0	169	\$169,283	\$2,336,235	\$40,151,314	\$2,800,000	14.3
								F	0	97	131	178	\$1,353,001	\$18,672,426	\$23,815,123	\$2,000,000	11.9
<b>Twomile Total</b>	<b>464</b>	<b>637</b>	<b>677</b>	<b>748</b>	<b>924</b>	<b>\$12,513,571</b>	<b>\$172,696,620</b>										
Goose-01	0	0	0	0	0	\$0	\$0	A	0	0	0	0	\$0	\$0	\$2,400,000	\$3,000,000	0.8
								B	0	0	0	0	\$0	\$0	\$0	\$500,000	0.0
Goose-02	2	6	7	7	9	\$93,080	\$1,284,570	A	0	0	0	2	\$1,394	\$19,239	\$1,265,331	\$1,000,000	1.3
								B	0	3	4	4	\$34,726	\$479,247	\$805,323	\$800,000	1.0
								C	0	0	0	2	\$1,394	\$19,239	\$1,265,331	\$700,000	1.8
								D	0	0	0	2	\$1,394	\$19,239	\$1,265,331	\$1,100,000	1.2
								E	0	3	4	4	\$34,726	\$479,247	\$805,323	\$900,000	0.9
Goose-03	2	2	3	3	3	\$196,365	\$2,709,985	A	0	0	0	2	\$9,452	\$130,443	\$2,579,542	\$1,200,000	2.1
								B	0	2	2	2	\$119,138	\$1,644,199	\$1,065,786	\$900,000	1.2
Goose-04	7	15	20	22	26	\$388,326	\$5,359,193	A	0	0	0	16	\$15,893	\$219,335	\$5,139,858	\$2,400,000	2.1
								B	0	15	20	22	\$181,085	\$2,499,103	\$2,860,089	\$1,200,000	2.4
								C	0	0	0	16	\$15,893	\$219,335	\$5,139,858	\$3,100,000	1.7
								D	0	15	20	22	\$181,085	\$2,499,103	\$2,860,089	\$2,000,000	1.4
Goose-05	5	10	15	19	22	\$480,057	\$6,625,151	A	0	0	0	3	\$15,636	\$215,789	\$6,409,362	\$2,200,000	2.9
								B	0	3	4	10	\$181,495	\$2,504,762	\$4,120,389	\$1,600,000	2.6
Goose-06	13	30	37	44	46	\$522,218	\$7,206,997	A	0	0	0	3	\$21,572	\$297,704	\$6,909,294	\$12,000,000	0.6
								B	0	3	3	17	\$135,221	\$1,866,156	\$5,340,842	\$5,700,000	0.9
<b>Goose Total</b>	<b>29</b>	<b>63</b>	<b>82</b>	<b>95</b>	<b>106</b>	<b>\$1,680,047</b>	<b>\$23,185,897</b>										
<b>Full Project</b>																	
100-Year Improvements*	493	700	759	843	1030	\$14,193,618	\$195,882,517	100-Year	0	162	205	550	\$2,335,749	\$32,235,081	\$163,647,436	\$43,100,000	3.8
Less Than 100-Year Improvements								Less Than 100-Year	0	418	539	665	\$5,060,290	\$69,835,785	\$126,046,732	\$33,200,000	3.8

\*100-Year improvements not presented west of Broadway along Twomile Canyon Creek due to prohibitive property acquisition costs

## 5.3 ALTERNATIVE SCORING

### Scoring Matrix

A project scoring matrix was created to identify and rank the multitude of potential projects identified throughout the watershed. The scoring matrix distinguishes three major categories – primary mitigation needs, community values, and budget feasibility. The categories were developed based upon the main concerns each alternative would address. These broadly represent: danger to people and property from floodwaters; matters prioritized by residents and business but unrelated to flood damages; and lifetime costs and benefits of each project. These were prioritized by the group comprised of City of Boulder, MHFD and ICON staff members, as informed by several public comment sessions, with safety issues being the most important, and community and budget items sharing equal value.

Each major category was broken into objectives, each of which was assigned a weight (value) and a score, typically between 0 and 5. There were a total of 12 sub-objectives across the 3 categories. These objectives and values were informed by the public process as well as staff member experiences.

Early in 2020, ICON, MHFD and City staff completed independent scoring efforts. If there was a spread in scores of more than three points, a group consensus was developed for these instances through discussions and voting. The project team determined that the average score rounded to the nearest whole number would be the approach for all scoring instances where there had not been a previously determined group consensus. A project's total score was determined by multiplying the weight by the score, and then summing the results, with the highest overall score ranked as the highest priority for inclusion into the recommended plan. Projects were scored based on a possible total of 100 points. This section presents a brief overview of the scoring process, complete details are presented in the Alternative Scoring Memorandum in **Appendix C**. The scoring matrix is included in **Table 5-4**.

### Primary Mitigation Needs

Primary Mitigation needs was given the greatest weight making up a possible 50 of 100 points, 50% of the total achievable points. The primary mitigation needs category contains mitigation objectives to improve overall life safety, reduced flood risk on infrastructure and properties, protection or enhancement of environmental conditions, and resiliency with respect to adaptation and longevity.

### Community Values

Community Values were incorporated into the scoring system at a weight of half of the primary mitigation needs, or 25 of 100 possible points. The community values category contains non-stormwater related objectives also determined to be critical to the community, including: protection of cultural resources, preservation or enhancement of recreation activities, preservation or enhancement of alternative transportation means, and feasibility and community impacts.

### Budget Feasibility

Budget Feasibility was incorporated into the ranking system at a weight of half of the primary mitigation needs, or 25 of 100 possible points. The budget feasibility evaluation scores the overall cost of the project, the benefit-cost-ratio (BCR), and expected maintenance of each project.

### Total Value and Rankings

The scoring and associated point value per weighting for each of the 12 sub-objectives were then totaled for each alternative. This total score was then used to rank the alternatives relative to each individual reach, drainage, and for the overall watershed. The scoring matrix in **Table 5-4** below includes all scores, weighted values, totals, and rankings. This information has been used to develop the recommended flood mitigation plan.

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Table 5-4: Scoring Summary

Reach	ID	Project Description	Primary Mitigation Needs (50%)										Community Values (25%)								Budget Feasibility (25%)								Total Value and Rankings							
			Life Safety		Property Damage Mitigation		Water Quality Enhancement		Habitat Protection and Restoration		Project Resiliency		Total Value (50pts)	Protection of Cultural Resources		Recreational Opportunities		Alternative Transportation		Feasibility / Impacts		Total Value (25pts)	Project Benefit (\$)	Project Cost (\$)	Benefit - Cost Ratio (BCR)	Project Cost		Benefit - Cost Ratio		Project Maintenance		Total Value (25pts)	Total Value (100 Points)	Reach Rank	Drainage Rank	Watershed / Overall Rank
			Score	Value (15pts)	Score	Value (15pts)	Score	Value (5pts)	Score	Value (5pts)	Score	Value (10pts)		Score	Value (5pts)	Score	Value (10pts)	Score	Value (5pts)	Score	Value (5pts)					Score	Value (10pts)	Score	Value (10pts)	Score	Value (5pts)					
Goose-01	A	Detention facility within North Boulder Park; new 9th Street culvert	4	12	4	12	4	4	2	2	3	6	36	2	2	1	2	3	3	3	3	10	\$2,400,000	\$3,000,000	0.8	3	6	1	2	2	2	10	56	1	11	18
Goose-01	B	No detention; Roadway collection to deliver flows to Alpine-Balsam site	2	6	2	6	1	1	0	0	1	2	15	2	2	2	4	2	2	4	4	12	\$0	\$500,000	0.0	5	10	0	0	3	3	13	40	2	17	34
Goose-02	A	100-Year open channel through Alpine-Balsam site	5	15	4	12	4	4	4	4	4	8	43	2	2	4	8	4	4	4	4	18	\$1,265,331	\$1,000,000	1.3	4	8	2	4	3	3	15	76	1	1	1
Goose-02	B	Less Than 100-Year open channel through Alpine-Balsam site	3	9	3	9	3	3	3	3	3	6	30	2	2	3	6	3	3	5	5	16	\$805,323	\$800,000	1.0	5	10	2	4	3	3	17	63	2	3	6
Goose-02	C	100-Year storm drain through Alpine-Balsam site (detained flow)	5	15	4	12	1	1	0	0	1	2	30	2	2	2	4	2	2	3	3	11	\$1,265,331	\$700,000	1.8	5	10	2	4	3	3	17	58	4	8	14
Goose-02	D	100-Year storm drain through Alpine-Balsam site (full flow)	5	15	4	12	1	1	0	0	2	4	32	2	2	2	4	2	2	4	4	12	\$1,265,331	\$1,100,000	1.2	4	8	2	4	3	3	15	59	3	6	9
Goose-02	E	Less Than 100-Year storm drain through Alpine-Balsam site (full flow)	3	9	3	9	1	1	0	0	1	2	21	2	2	2	4	1	1	5	5	12	\$805,323	\$900,000	0.9	5	10	1	2	3	3	15	48	5	14	29
Goose-03	A	100-Year storm drain system	5	15	4	12	1	1	0	0	2	4	32	3	3	2	4	2	2	4	4	13	\$2,579,542	\$1,200,000	2.1	4	8	3	6	3	3	17	62	1	4	7
Goose-03	B	Less Than 100-Year storm drain system	3	9	3	9	1	1	0	0	1	2	21	2	2	2	4	1	1	4	4	11	\$1,065,786	\$900,000	1.2	5	10	2	4	3	3	17	49	2	12	24
Goose-04	A	100-Year open channel	5	15	5	15	4	4	4	4	4	8	46	2	2	3	6	2	2	2	2	12	\$5,139,858	\$2,400,000	2.1	3	6	3	6	3	3	15	73	1	2	2
Goose-04	B	Less Than 100-Year open channel	3	9	3	9	3	3	3	3	3	6	30	2	2	3	6	1	1	3	3	12	\$2,860,089	\$1,200,000	2.4	4	8	3	6	3	3	17	59	2	6	9
Goose-04	C	100-Year storm drain system	5	15	4	12	1	1	0	0	2	4	32	2	2	2	4	2	2	4	4	12	\$5,139,858	\$3,100,000	1.7	3	6	2	4	3	3	13	57	3	10	17
Goose-04	D	Less Than 100-Year storm drain system	3	9	3	9	1	1	0	0	1	2	21	2	2	2	4	2	2	5	5	13	\$2,860,089	\$2,000,000	1.4	4	8	2	4	3	3	15	49	4	12	24
Goose-05	A	100-Year storm drain system from Alpine/17th through 20th	5	15	5	15	2	2	0	0	2	4	36	2	2	2	4	2	2	1	1	9	\$6,409,362	\$2,200,000	2.9	3	6	3	6	3	3	15	60	1	5	8
Goose-05	B	Less Than 100-Year storm drain system from Alpine/17th through 19th	3	9	3	9	1	1	0	0	1	2	21	2	2	2	4	1	1	2	2	9	\$4,120,389	\$1,600,000	2.6	4	8	3	6	3	3	17	47	2	15	30
Goose-06	A	100-Year Open channel	4	12	5	15	3	3	3	3	4	8	41	2	2	2	4	2	2	2	2	10	\$6,909,294	\$12,000,000	0.6	1	2	1	2	3	3	7	58	1	8	14
Goose-06	B	Open channel (sizing per previous study recommending a "5-Year" improvement; exceeds 5-Year with detained flow and/or Twomile improvements)	2	6	3	9	3	3	3	3	3	6	27	2	2	2	4	1	1	3	3	10	\$5,340,842	\$5,700,000	0.9	2	4	1	2	3	3	9	46	2	16	31
Twomile-01	A	100-Year channel improvements; new Spring Valley Drive and Linden Avenue culverts	5	15	4	12	4	4	4	4	4	8	43	2	2	4	8	3	3	3	3	16	\$1,636,789	\$2,500,000	0.7	3	6	1	2	3	3	11	70	1	1	3
Twomile-01	B	Less Than 100-Year channel improvements; new Spring Valley Drive and Linden Avenue culverts	3	9	3	9	3	3	3	3	3	6	30	2	2	3	6	2	2	4	4	14	\$1,636,789	\$1,600,000	1.0	4	8	2	4	3	3	15	59	2	4	9
Twomile-01	C	Enlarge existing sediment capture facility	2	6	2	6	4	4	4	4	3	6	26	3	3	2	4	2	2	5	5	14	\$0	\$1.0M	0.0	4	8	0	0	2	2	10	50	3	12	23
Twomile-02	A	Less Than 100-Year channel improvements; new Kalmia Avenue, Juniper Avenue, and Broadway culverts; channel to Broadway and Iris	3	9	4	12	3	3	3	3	3	6	33	2	2	3	6	3	3	2	2	13	\$51,065,372	\$10,300,000	5.0	1	2	4	8	3	3	13	59	1	4	9
Twomile-02	B	Less Than 100-Year channel improvements; new Kalmia Avenue, Juniper Avenue, and Broadway/Hawthorn Avenue culverts; channel to Broadway and Hawthorn	3	9	3	9	3	3	3	3	3	6	30	2	2	3	6	3	3	2	2	13	\$51,065,372	\$14,100,000	3.6	1	2	3	6	3	3	11	54	2	8	19
Twomile-02	C	Roadway conveyance	2	6	4	12	0	0	0	0	1	2	20	2	2	2	4	1	1	4	4	11	\$31,070,974	\$4,596,808	6.8	3	6	4	8	4	4	18	49	3	13	24
Twomile-03	A	100-Year channel improvements; new 13th Street, 14th Street culverts, culvert from 16th Street through Farmer's Ditch; Iris Avenue Roadway Improvements for surface flow	3	9	4	12	4	4	3	3	4	8	36	2	2	3	6	3	3	2	2	13	\$47,782,431	\$8,400,000	5.7	2	4	4	8	3	3	15	64	1	3	5
Twomile-03	B	Less Than 100-Year channel improvements; new 13th Street, 14th Street culverts, culvert from 16th Street through Farmer's Ditch; Iris Avenue Roadway Improvements for surface flow	2	6	3	9	3	3	2	2	3	6	26	2	2	2	4	2	2	3	3	11	\$33,499,164	\$5,700,000	5.9	2	4	4	8	3	3	15	52	3	9	20
Twomile-03	C	100-Year storm drain outfall system	4	12	5	15	1	1	0	0	2	4	32	2	2	2	4	2	2	3	3	11	\$47,782,431	\$7,123,149	6.7	2	4	4	8	3	3	15	58	2	7	14
Twomile-03	D	Less Than 100-Year storm drain outfall system	2	6	3	9	1	1	0	0	1	2	18	2	2	2	4	2	2	4	4	12	\$33,499,164	\$5,003,365	6.7	2	4	4	8	3	3	15	45	5	16	32
Twomile-03	E	Detention facility within the Boulder County Complex at Broadway and Iris (ballfields only)	3	9	3	9	2	2	1	1	2	4	25	2	2	2	4	2	2	3	3	11	\$5,750,000	\$2,200,000	2.6	3	6	3	6	3	3	15	51	4	10	21
Twomile-04	A	Iris Avenue Roadway Improvements for surface flow	2	6	3	9	0	0	0	0	2	4	19	2	2	2	4	1	1	3	3	10	\$40,859,459	\$3,100,000	13.2	3	6	5	10	4	4	20	49	4	13	24
Twomile-04	B	Less Than 100-Year Iris Avenue Roadway Improvements for surface flow	1	3	2	6	0	0	0	0	1	2	11	2	2	2	4	1	1	3	3	10	\$25,652,978	\$1,600,000	16.0	4	8	5	10	4	4	22	43	6	17	33
Twomile-04	C	100-Year storm drain outfall system	3	9	4	12	1	1	0	0	2	4	26	2	2	3	6	3	3	3	3	14	\$40,859,459	\$3,000,000	13.6	3	6	5	10	3	3	19	59	2	4	9
Twomile-04	D	Less Than 100-Year storm drain outfall system	2	6	3	9	1	1	0	0	1	2	18	2	2	2	4	2	2	4	4	12	\$25,652,978	\$2,000,000	12.8	3	6	5	10	3	3	19	49	4	13	24
Twomile-04	E	100-Year channel improvements; new 21st Street and Edgewood Drive culverts	3	9	4	12	4	4	4	4	4	8	37	2	2	2	4	3	3	1	1	10	\$40,151,314	\$2,800,000	14.3	3	6	5	10	3	3	19	66	1	2	4
Twomile-04	F	Less Than 100-Year channel improvements; new 21st Street and Edgewood Drive culverts	2	6	2	6	3	3	3	3	2	4	22	2	2	2	4	2	2	2	2	10	\$23,815,123	\$2,000,000	11.9	3	6	5	10	3	3	19	51	3	10	21

## 6.0 RECOMMENDED PLAN

### 6.1 PLAN DESCRIPTION

Based on the Alternative Scoring memorandum, the top scoring alternatives for each reach were generally selected for the recommended plan. The total score for each alternative and the relative ranking of each alternative within the reach, drainage and watershed were summarized previously in **Table 5-4**. The recommended plan is summarized below and illustrated in **Figure 6-1**.

- Goose-01: Alt. B Roadway collection to deliver flows to Alpine-Balsam site
- Goose-02: Alt. A 100-Year capacity open channel through Alpine-Balsam site
- Goose-03: Alt. A 100-Year capacity storm drain system
- Goose-04: Alt. A 100-Year capacity open channel
- Goose-05: Alt. A 100-Year capacity storm drain system from Alpine/17th through 20th Street
- Goose-06: Alt. A 100-Year capacity open channel
- Twomile-01: Alt. A 100-Year capacity channel improvements; new Spring Valley Drive and Linden Avenue culverts with optional sediment capture areas (Alt. C)
- Twomile-02: Alt. A Less Than 100-Year channel capacity improvement; new Kalmia Avenue, Juniper Avenue, and Broadway culverts; channel to Broadway and Iris
- Twomile-03: Alt. C 100-Year capacity storm drain outfall system with partial open channel
- Twomile-04: Alt. C 100-Year capacity storm drain outfall system

Three of the recommended alternatives were ranked as the second highest scoring alternatives for the designated project reach but were chosen for the recommended plan in place of the top scoring alternative. For the **Goose-01** reach, the roadway collection alternative has been recommended in place of the detention facility in North Boulder Park. The reason for this is the significant impacts on the park if a detention facility were constructed. However, the option for detention should be considered if a future large scale redevelopment of the park is considered. This issue is addressed in additional detail below. For the **Twomile-03** reach, the storm drain outfall system with partial open channel has been recommended in place of the 100-Year open channel that connected to Iris Avenue. The driving reason for this recommendation is to avoid the alignment that routes flood flows to Iris Avenue roadway and ultimately Elmer's Twomile, which was a much lower scoring alternative in part due to the flood impacts on Iris Avenue. For the **Twomile-04** reach, the storm drain outfall system has been recommended in place of the 100-Year open channel. The project team determined that despite the high score of the open channel, the introduction of a flooding channel and the associated flood hazard into an area that currently does not have a regulatory floodplain or high hazard areas is not a preferred approach.

Both **Twomile-03** and **Twomile-04** have alternative alignments available for the recommended storm drain systems. These alternative alignments are illustrated in **Figure 6-1**. The final recommended alignment will be determined during conceptual design efforts. The **Twomile-03** alternative open channel should also be designed in a manner that can keep the roadways functional for emergency personnel in larger events.

### North Boulder Park Detention

This plan recommends the implementation of the roadway collection alternative in 9<sup>th</sup> Street in order to capture and deliver flood flows to the Alpine Balsam site. The alternative for a detention facility within North Boulder Park is to be considered for implementation if a future large scale redevelopment of the park is completed. Redevelopment of North Boulder Park would allow the integration of the detention facility such that desired uses within the park are compatible with the temporary storage of stormwater. Based on this constraint for implementation of detention in North Boulder Park, downstream flood mitigation projects designed prior to a North Boulder Park redevelopment should not rely on peak discharge reduction from a detention facility and should be designed based on full (non-detention) discharges along Goose Creek.

### Other mitigation plan measures not specific to a location

#### Habitat Improvements

Protecting streams and enhancing wildlife habitat are important values of the community. Therefore, habitat improvements should be considered in addition to the recommended flood mitigation measures. Within the city limits, the majority of creek channels are located on private property. Property owners can work on their own or in conjunction with city staff to assess stream and riparian areas and identify habitat improvements such as:

- Removal of noxious weeds and non-native species
- Removal of hazardous trees
- Addition of native plants
- Water quality enhancements

#### Implement non-structural methods

This alternate includes items currently implemented as part of the City's floodplain management program and flood preparation activities and includes:

- flash flood forecasting and warning systems
- flood hazard education programs
- development of evacuation plans
- flood insurance
- floodproofing of structures
- floodplain regulation enforcement

Non-structural methods should be considered as an interim solution until the mitigation plan is implemented, and continued after implementation, as they are not a "stand alone" alternate.

# UPPER GOOSE CREEK AND TWOMILE CANYON CREEK FLOOD MITIGATION PLAN - ALTERNATIVES REPORT

## Property Acquisition

The City has a program in place to purchase properties located in flood prone areas, and particularly in the high hazard flood zone when there is a willing seller. Opportunity-based property acquisition is a key element of the floodplain management program given the City’s interest in working with a willing seller. The property acquisition program, in conjunction with flood mitigation improvements has been very successful over the years and has resulted in over one hundred structures no longer being in the high hazard floodplain. Specific property acquisition was not an alternative analyzed by this project, but should be considered as an interim solution or as a supplement to the recommended plan in locations where a willing seller is identified.

## Conceptual Design

The next step for this mitigation plan is conceptual design of the recommended alternatives following approval of this Alternatives Report by City Council. The conceptual design will focus on the feasibility and ideal alignments of the recommended alternatives. If 100-year flood protection is determined to be not feasible, the conceptual design will prioritize high hazard zone mitigation in place of 100-year capacity.

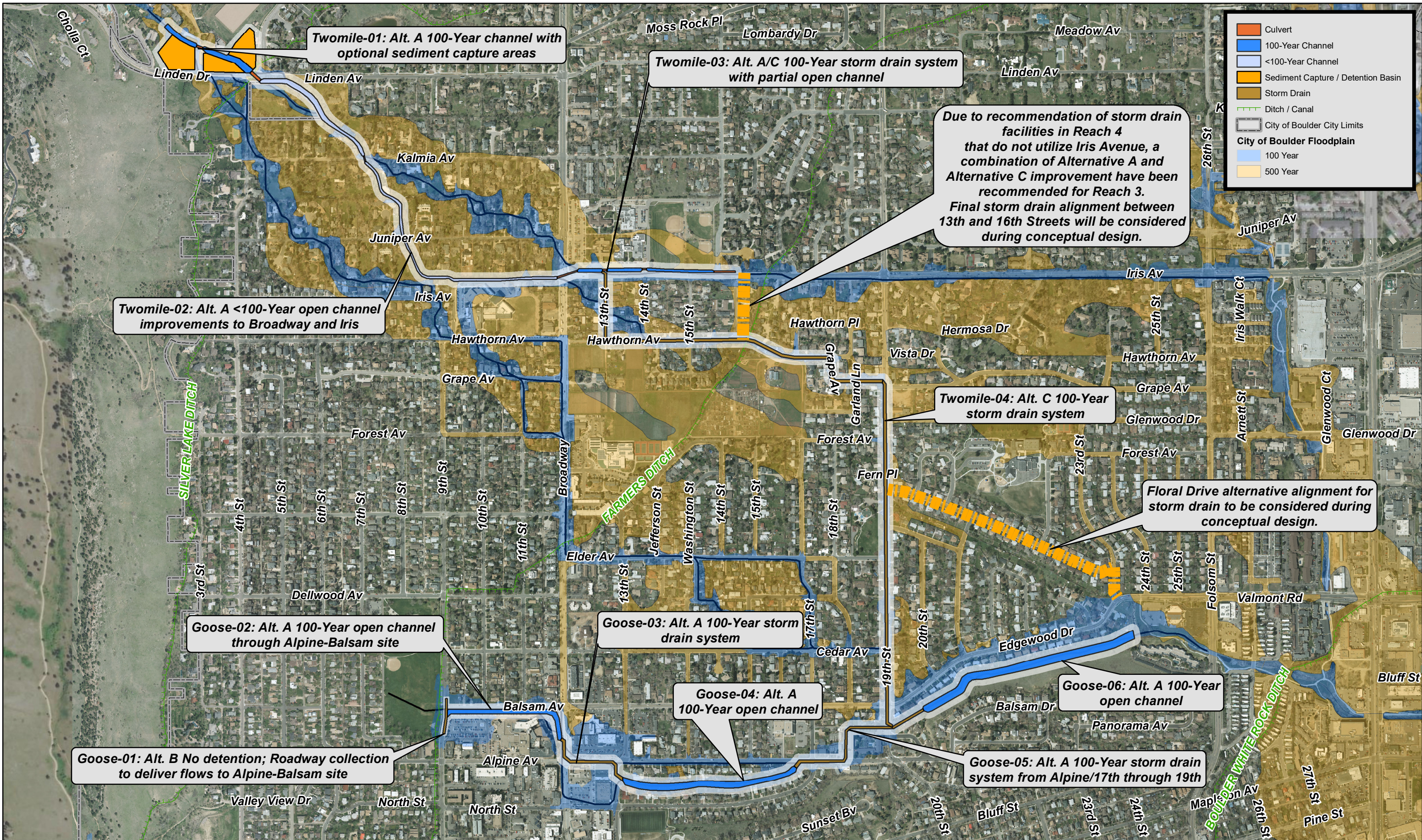
### 6.2 BENEFIT COST ANALYSIS

As noted above, a BCR should be above 1 for a project to proceed forward. For this project three exceptions are made to this rule. Goose Reach 1, Goose Reach 6 and Twomile Reach 1 have BCR’s below 1, however, the selected alternatives Goose Reach 6 and Twomile Reach 1 received the highest score for that reach overall. These scores included mitigation and community values in addition to budgetary considerations. Thus, while these projects might not be ideal, they are the best candidates for improving the issues in their area. Additionally, these projects are necessary components in the full recommended plan for flood mitigation.

The full recommended plan for Upper Goose Creek and Twomile Canyon Creek has a benefit cost ratio of 3.8, despite three individual projects that have a ratio of less than 1. As a composite recommended plan the benefits exceed the costs by nearly a factor of 4.

**Table 6-1: Benefit Cost Ratio of Recommended Plan**

Recommendation	Benefit	Cost	Benefit Cost Ratio
1. <b>Goose-01:</b> Alt. B Roadway collection to deliver flows to Alpine-Balsam site	\$0	\$500,000	0.0
2. <b>Goose-02:</b> Alt. A 100-Year open channel through Alpine-Balsam site	\$1,265,331	\$1,000,000	1.3
3. <b>Goose-03:</b> Alt. A 100-Year storm drain system	\$2,579,542	\$1,200,000	2.1
4. <b>Goose-04:</b> Alt. A 100-Year open channel	\$5,139,858	\$2,400,000	2.1
5. <b>Goose-05:</b> Alt. A 100-Year storm drain system from Alpine/17th through 19th	\$6,409,362	\$2,200,000	2.9
6. <b>Goose-06:</b> Alt. A 100-Year open channel	\$6,909,294	\$12,000,000	0.6
7. <b>Twomile-01:</b> Alt. A 100-Year channel (with optional sediment capture areas)	\$1,636,789	\$3,500,000	0.5
8. <b>Twomile-02:</b> Alt. A Less Than 100-Year channel improvements	\$51,065,372	\$10,300,000	5.0
9. <b>Twomile-03:</b> Alt. C 100-Year storm drain outfall system	\$47,782,431	\$7,100,000	6.7
10. <b>Twomile-04:</b> Alt. C 100-Year storm drain outfall system	\$40,859,459	\$3,000,000	13.6
<b>Total Cost of Recommended Plan for 100-year improvements</b>	<b>\$163,647,438</b>	<b>\$43,200,000</b>	<b>3.8</b>



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# APPENDIX A - ALTERNATIVE SELECTION MEMORANDUM



# APPENDIX B – ALTERNATIVE BENEFIT COST ANALYSIS MEMORANDUM

# APPENDIX C - ALTERNATIVE SCORING MEMORANDUM

# APPENDIX D – RECOMMENDED PLAN MEMORANDUM

# APPENDIX E – PUBLIC COMMENTS

# APPENDIX F – WETLAND AND HABITAT EVALUATIONS