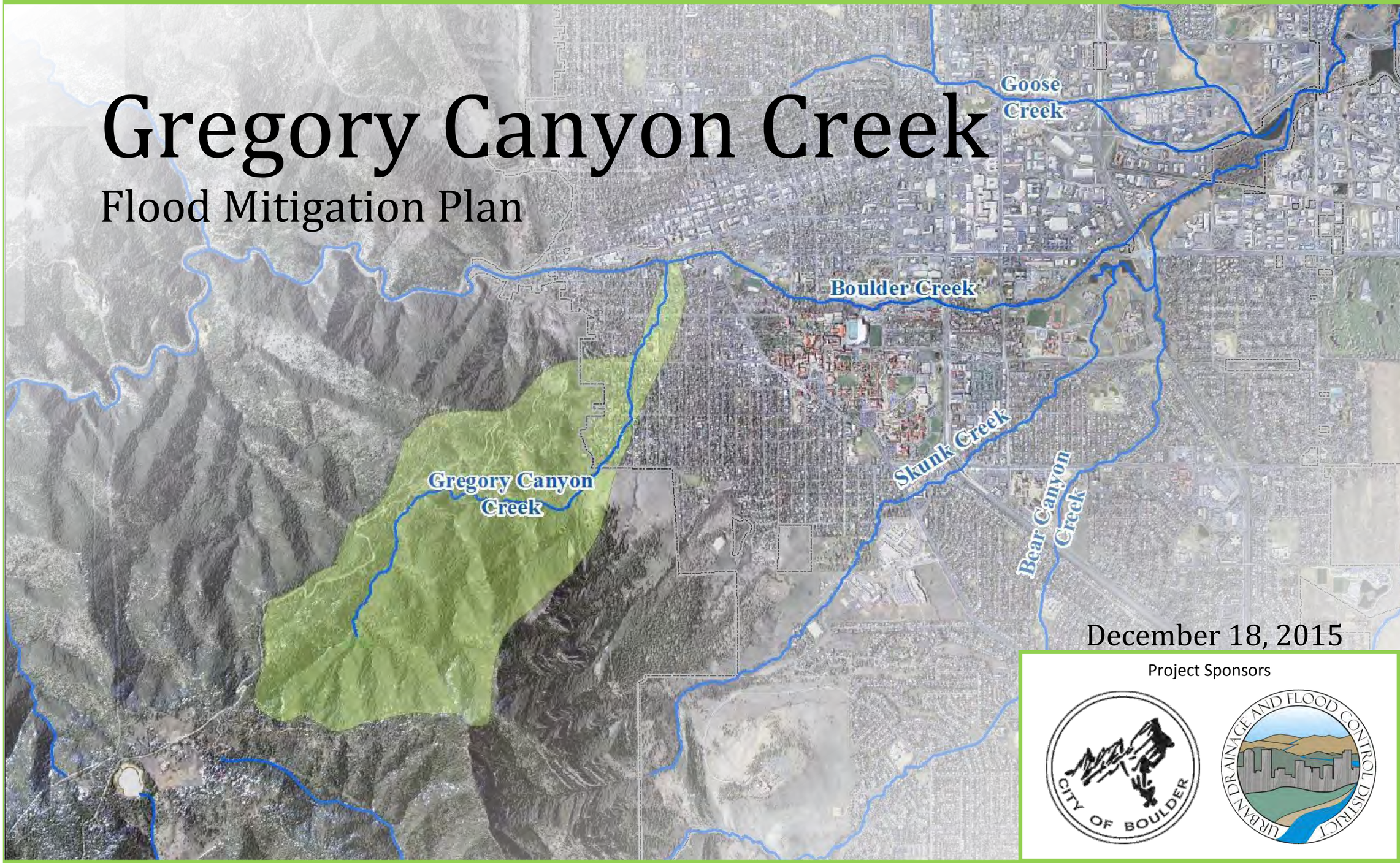
Gregory Canyon Creek

Flood Mitigation Plan



December 18, 2015

Project Sponsors

CITY OF BOULDER

URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

TABLE OF CONTENTS

EXECUTIVE SUMMARY

PURPOSE AND OBJECTIVE

The purpose of this study is to analyze the existing drainage conditions within the Gregory Canyon Creek floodplain, develop alternative drainageway planning concepts to mitigate flood damages, and prepare a conceptual design of the recommended flood mitigation plan selected by the Project Sponsors.

The information in this plan will support the City of Boulder and others in the prioritization and implementation of improvements to reduce potential damages due to flooding and improve the condition of Gregory Canyon Creek. It will also be beneficial in completing grant applications and securing funding for future projects.

PROJECT AREA DESCRIPTION

The study area, shown on the Vicinity Map, extends from the confluence of Gregory Canyon Creek and Boulder Creek to the upstream city limits just south of Flagstaff Road. The study is located in part of Section 36, Township 1 North, Range 71 West, and a small part of Section 1 Township 1 South, Range 71 West.

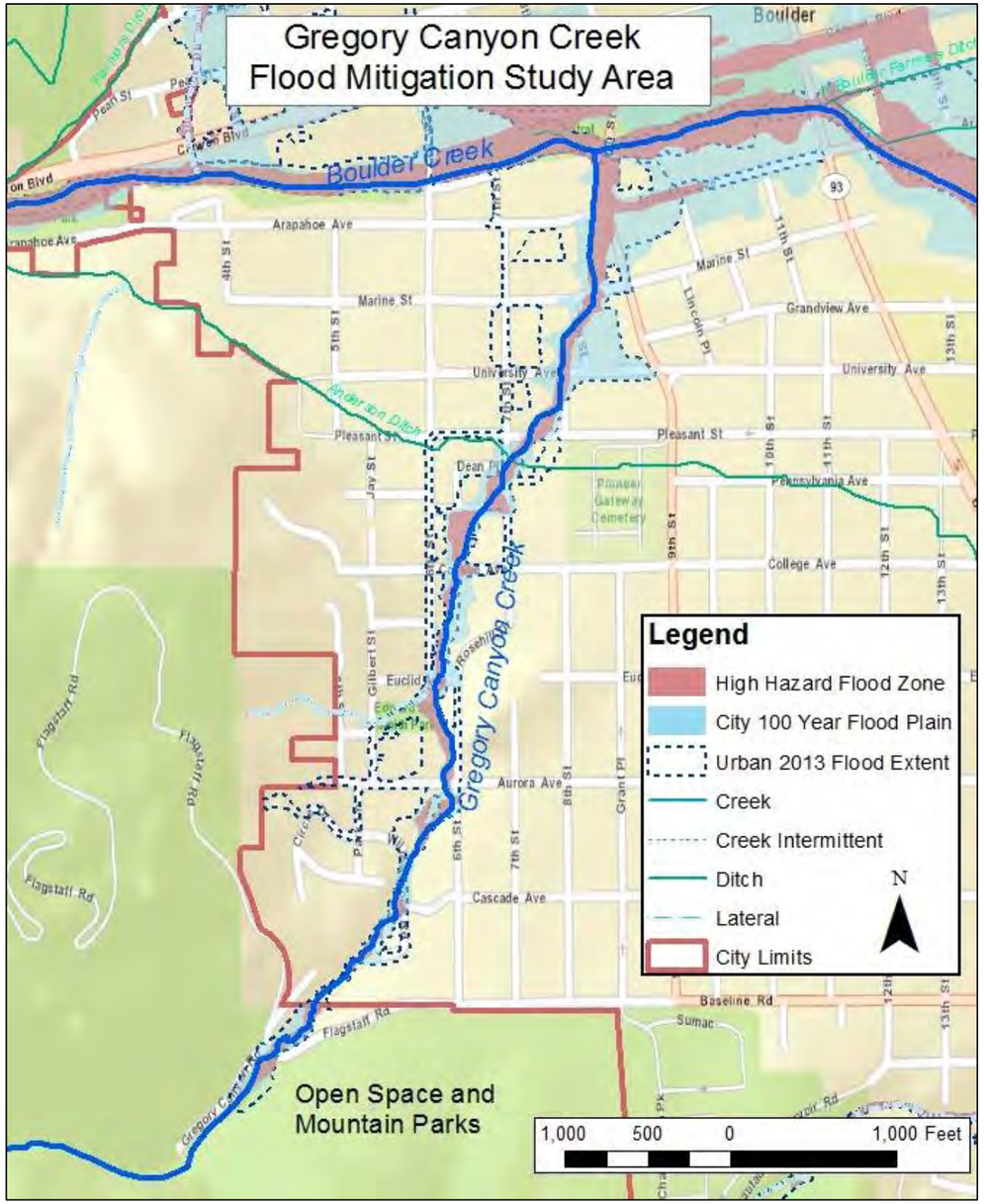
ALTERNATIVE ANALYSIS

The city retained CH2M to evaluate potential alternatives to help alleviate future flooding along Gregory Canyon Creek. CH2M's Alternative Analysis Memorandum is included as **Appendix A**. This analysis contains a detailed description of the data and models used to determine the improvements which would help flood conveyance along Gregory Canyon Creek. Culverts were evaluated for existing conditions, the size required to convey a 10-year event, and the maximum size that could feasibly be constructed without impacting existing buildings. The intent of the analysis was to identify various types of improvements which could be constructed along the creek corridor, assess the costs and benefits associated with each improvement, and include an engineer's recommendation.

The alternatives analysis also includes 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 following table summarizes the results of the BCA completed to assess the different alternatives:

Benefit Cost Analysis Summary

Alternative	*Benefit Cost Ratio*
10-year culvert improvements	2.67
10-year culvert improvements with street conveyance improvements	1.52
Maximum size culvert improvements	1.78
Maximum size culvert improvements with street conveyance improvements	1.28



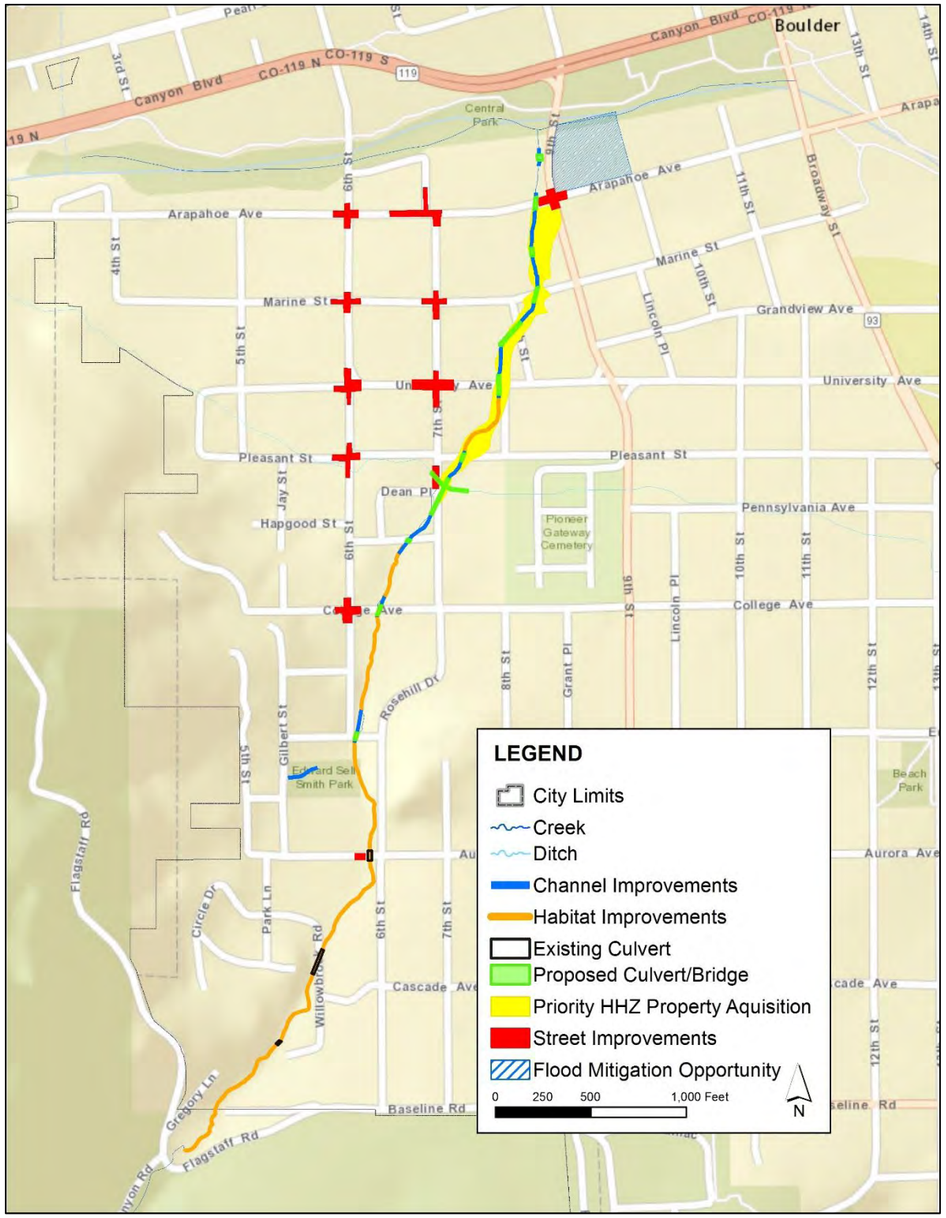
RECOMMENDED PLAN

The Recommended Plan is depicted in the image to the right, with a more detailed illustration in **Section 6**. The following elements are included:

	Recommendation	Cost
1.	Culvert and Channel Improvements: Replace culverts to convey the 10-year storm. Provide a pedestrian bridge at Pennsylvania Ave. and a vehicular bridge at the Highland City Club entrance.	$9,924,400
2.	Road Improvements: Implement flood conveyance modifications in conjunction with other roadway construction.	$2,102,200
3.	Provide in-line sediment trap structure upstream of Culvert C1 (Willowbrook Rd.).	$86,100
4.	Assess stream and riparian areas and implement habitat improvements	TBD
5.	Pipe the Anderson Ditch to the east of 7th St.	$43,400
6.	Relocate the sanitary sewer manhole and pipes currently located within the "Gregory Gulch".	$164,600
7.	Add new storm drainage inlets on Willowbrook Rd. to help capture floodwaters that overtop the culvert.	$147,600
8.	Investigate installing grates above culverts.	TBD
9.	Property Acquisition: Continue acquiring high hazard zone properties, focusing on the properties identified as priority structures.	$7,631,100
10.	Evaluate additional flood mitigation opportunities with the development of the Civic Area Plan.	TBD
11.	Non-Structural Methods: Continue to implement non-structural measures and encourage property owners to prepare for floods and protect their properties and themselves.	N/A
	Total:	**$20,099,400**

CONCEPTUAL DESIGN

Conceptual design drawings were developed based on the Recommended Plan and are included as **Appendix E**. These drawings are intended to depict a long-range plan for future flood mitigation projects and show the general extents and nature of the proposed improvements. The conceptual design drawings are not intended for construction use. Prior to the construction of any improvements, a complete design will be required and construction documents developed. In addition to the conceptual design drawings, CH2M completed a Conceptual Design Memorandum to document design criteria, the results of the hydraulic analysis and the refinement of the benefit cost analysis. The Conceptual Design Memorandum is included as **Appendix B**.



Recommended Plan

SECTION 1–INTRODUCTION

PLANNING PROCESS

The September 2013 flood greatly impacted the Gregory Canyon Creek watershed. A post-flood open house was held on October 14, 2013 to provide flood recovery information and gather public comments about the extent of the floodwaters and the damages sustained. The community expressed a strong desire for flood mitigation improvements along Gregory Canyon Creek, so this mitigation plan was initiated by the City of Boulder and the Urban Drainage and Flood Control District.

One area that was severely damaged by the September 2013, was Pennsylvania Ave., where flood waters washed out the roadway around the existing culvert. Prior to repairing the roadway, different repair options were considered and presented to the public for input:

Alternative 1: Replace the existing culvert and rebuild the roadway.

Alternative 2: Remove the culvert and damaged roadway above the creek, close the road to through traffic, and build a pedestrian bridge over the creek.

Alternative 3: Remove the culvert and construct a new roadway with a significantly larger culvert or a vehicular bridge over the creek.

Pennsylvania Ave. Flood Damage

An open house was held on February 6, 2014 and a website was created with an online survey to gather input on the Pennsylvania Ave. repair alternatives. Alternative 2, replacing the culvert with a pedestrian bridge received a high level of public support. On May 22, 2014 the Greenways Advisory Committee considered the Pennsylvania Ave. flood repair alternatives and recommended the immediate implementation of Alternative 1 with further evaluation of the other alternatives as part of this Gregory Canyon Creek Flood Mitigation Plan. The public input received about the Pennsylvania Ave. alternatives is included in the public comments (**Appendix C**).

The engineering consultant team, CH2M, was selected to help with the development of the flood mitigation alternatives and mitigation plan. An open house to officially "kick-off" the flood mitigation planning process was held on June 12, 2014. The purpose of this public open house was to identify problem areas and collect ideas for future flood mitigation projects.

After reviewing previous studies, master plans and policies, flood mitigation alternatives were developed and assessed. Due to the existing development along the creek, it was determined that improvements to accommodate a 100-year flood event would not be feasible, but improvements along the creek could be constructed which would facilitate flows from a 10-year event. Improvements to culverts that could convey events greater than a 10-year event were also assessed. Each culvert was evaluated for existing conditions, the size required to convey a 10-year event, and the maximum size that could feasibly be constructed without impacting existing buildings. The primary categories of alternatives initially evaluated included:

- Improvements along the creek channel
- Improvements to facilitate flow outside of the creek channel (roadway conveyance)
- Property acquisition
- Detention facilities

On October 20, 2014, a public open house was held to present the potential alternatives, or categories of improvements, that had been developed. On that same day, the first public meeting with the Water Resources Advisory Board (WRAB) was held. Comments received at the open house and the WRAB meeting were assimilated and the mitigation plan was further refined based on these comments, where feasible and practical. The WRAB recommended that city staff facilitate the organization of smaller neighborhood groups to help identify and discuss mitigation options for more localized areas of the creek.

In February of 2015, staff conducted three site walks along the Gregory Creek Drainage. The first of these walks included city staff from the Stormwater, Road Maintenance and Drainageway Maintenance departments. Two walks with residents in the area were then conducted in order to obtain their feedback and suggestions related to the proposed alternatives. The comments received from city staff and residents were assimilated and reviewed and then submitted to the consultants to incorporate suggestions, where feasible.

A benefit cost analysis was performed to analyze the alternatives. The following four primary alternatives were analyzed:

- 10-year culvert improvements
- 10-year culvert improvements with street conveyance improvements
- Maximum size culvert improvements
- Maximum size culvert improvements with street conveyance improvements

An Engineer's Recommended Plan was developed by CH2M based on the benefit cost analysis, feedback from public meetings, project stakeholders, staff input and preliminary discussions with WRAB. The Engineer's Recommended Plan to minimize the identified flooding issues along Gregory Canyon Creek includes improvements that would accommodate a 10-year storm event. The complete Alternative Analysis Memorandum with the Engineer's Recommended Plan is included in **Appendix A**.

City of Boulder staff assessed the Engineer's Recommended Plan and developed a Staff Recommended Plan, incorporating input from the public, maintenance considerations and observations from the 2013 flood event. The Staff Recommended Plan included the 10-year culvert improvements included in the Engineer's Recommended Plan, but modified some of the recommendations for channel improvements, eliminating some of the improvements between Euclid and College and including continuous channel improvements between University and Arapahoe. The Staff Recommended plan also included roadway improvements, recommending that they be incorporated with future roadway construction projects in order to be more cost effective. In addition, a pedestrian bridge was recommended at Pennsylvania Ave. instead of a box culvert and a vehicular bridge was recommended at the entrance to the Highland School property. The Staff Recommended Plan also included sediment traps to enhance water quality, habitat improvements, piping a section of the Anderson

Ditch, a sanitary sewer relocation, new drainage inlets, possible grates installed over culverts, a prioritization for property acquisition and non-structural methods such as emergency warning systems, flood education and private property flood protection.

An open house was held on March 30, 2015 to present the alternatives, the Engineer's Recommended Plan and a draft of Staff's Recommended Plan. Feedback from the open house was used to refine the staff recommendations. The Staff Recommended Plan was presented to WRAB on April 27, 2015. WRAB unanimously recommended that the Gregory Canyon Creek Flood Mitigation Plan be finalized based on the Staff Recommended Plan and then presented to City Council for acceptance.

Following the recommendation from WRAB, draft conceptual design drawings were developed based on the Staff Recommended Plan. All property owners directly impacted by the proposed improvements were contacted and city staff met with individuals and small groups of property owners to receive feedback on the draft conceptual design drawings. The draft conceptual design drawings were revised to incorporate comments and concerns received from property owners, to the greatest extent possible. Input from property owners and City Council, and the engineering analysis conducted during the development of the conceptual design drawings resulted in additional refinements to the Staff Recommended Plan, including:

- A proposed sediment trap at Smith Park was eliminated because existing site grades are too steep to make it feasible.
- A proposed sediment trap upstream of Aurora Ave. was eliminated because the existing channel is much lower than the existing street elevation, so maintenance would be difficult.
- The proposed sediment trap upstream of 7th St. was eliminated due to property owner concerns.
- The replacement of the private culvert at 705 Willowbrook was removed from the recommended plan because private property improvements were being implemented in this area to protect properties against flood damages and therefore the replacement would provide little benefit.

The Final Recommended Plan incorporates these revisions and is included in **Section 6**. The plan was accepted by the Boulder City Council On Dec. 1, 2015.

The following table summarizes the public process:

Date	Meeting
Oct. 14, 2013	Post-Flood Open House
Feb. 6, 2014	Pennsylvania Ave. Open House
May 22, 2014	Pennsylvania Ave. GAC Public Hearing
June 12, 2014	Flood Mitigation Plan Open House
Oct. 20, 2014	Flood Mitigation Plan Open House and WRAB Public Hearing
Feb. 2015	Flood Mitigation Plan Group Site Walks
Mar. 30, 2015	Flood Mitigation Plan Open House
April 27, 2015	Flood Mitigation Plan WRAB Public Hearing
July-Sept. 2015	Flood Mitigation Plan Individual Property Owner Meetings
Dec. 1, 2015	Flood Mitigation Plan City Council Public Hearing

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

MAPPING AND SURVEYS

Elevation data for the Study Area was provided by the City of Boulder. The topographic mapping included 2013 Light Detection and Ranging (LiDAR) data that was sponsored by FEMA and collected after the September 2013 flood event. In addition, survey collected as part of previous hydraulic studies or as-built construction drawings was also incorporated in the analysis. No new mapping or survey was performed as part of this analysis.

DATA COLLECTION

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

- *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.
- *Flood Hazard Area Delineation Boulder and Adjacent County Drainageways* Greenhorne and O'Mara, 1987
- *Hydraulic Mitigation Analysis - Gregory Canyon Creek High Hazard Zone Reanalysis – Mini - Master Plan,* Belt Collins West, 2009.
- *LOMR Determination - Gregory Canyon Creek LOMR Determination Data Reconciliation (Approved by FEMA, 2010)*, Belt Collins West, 2010.
- *Hydraulic Mitigation Analysis - Gregory Canyon Creek Mitigation Analysis,* WH Pacific, 2012.
- *Alternative Analysis - Pennsylvania Avenue Flood Repair / Improvement Alternative Analysis,* City of Boulder, 2014.

ACKNOWLEDGEMENTS

This report was completed with the support and input from various individuals at the City of Boulder, the Urban Drainage and Flood Control District (UDFCD) and CH2M. The key participants in the development of this plan are shown in the following table:

Project Contributors

Project Team Members	Affiliation	Role
Katie Knapp	City of Boulder	Project Manager
Annie Noble	City of Boulder	Principle Engineer for Flood and Greenways
Christin Shepherd	City of Boulder	Civil Engineer I / GIS Analyst
Laurel Olsen-Horen	City of Boulder	Flood and Greenways Specialist
Kristin Dean	City of Boulder	Utilities Planner
Shea Thomas	UDFCD	Sr. Project Engineer
Alan Turner	CH2M	Project Manager
Morgan Lynch	CH2M	Project Engineer
Frans Lambrechtsen	CH2M	Staff Engineer

SECTION 2–STUDY AREA DESCRIPTION

PROJECT AREA

Gregory Canyon Creek originates in City of Boulder Open Space. From the city limits at Flagstaff Road to its confluence with Boulder Creek, Gregory Canyon Creek is approximately 1.8 miles in length and ranges in elevation from approximately 5727 feet to 5360 feet USGS. The watershed associated with this creek is approximately 1.9 square miles.

The upper part of the watershed is south of the city limits. Upslope areas are covered with a variety of rock outcroppings, thick residual soils on bedrock, and thicker debris, alluvium, and slope wash deposits that are vegetated with grasses, trees, and shrubs. Deeper soils and wetland vegetation are found on alluvial deposits adjacent to streams. A well-defined channel is visible upstream of Flagstaff Road. The Gregory Canyon trail is located along this section of the creek.

Gregory Canyon Creek Upstream of City Limits

Within the city limits, the creek generally flows to the northeast through developed neighborhoods, crossing both public and private land. Throughout this area, the creek is mostly confined in narrow channels, due to fairly dense residential development, and conveyed under streets through culverts.

Gregory Canyon Creek North of University Ave.

Residential development along Gregory Canyon Creek began as early as 1890 in areas closer to the center of the city and peaked between the 1950's and 1960's as development moved closer to Baseline Rd. Development has altered historic channels, stormwater flow paths, runoff characteristics, and surface water quality. Most of the development within the Gregory Canyon Creek floodplain 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 currently only a few drainage and flood control easements across the private properties located along this creek.

SOILS

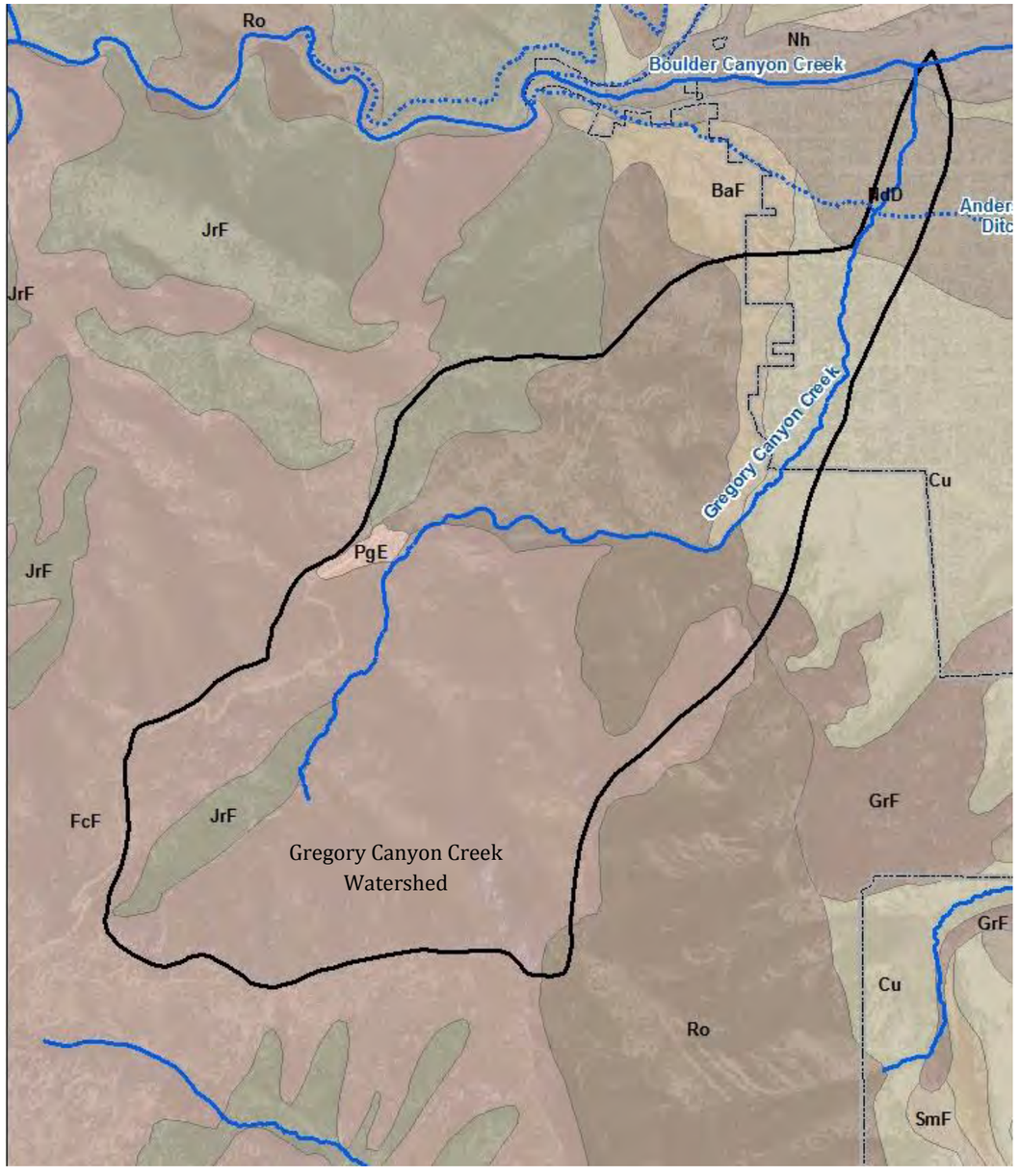
According to the Soil Survey of Boulder County Area, Colorado (United States Department of Agriculture Soil Conservation Service in cooperation with Colorado Agriculture Experiment Station (1975)), the land within the Gregory Canyon Creek watershed is comprised of the following soil classifications: Fern Cliff-Allens Park-Rock Outcrop Complex (FcF), Juget-Rock Outcrop Complex (JrF), Rock Outcrop (Ro), Payton-Juget (PgE), Godvale Rock Outcrop Complex (Gfr), Colluvial Land (Cu), Baller Stony Sandy Loam (BaF), Nederland Series (NdD), and the Niwot Series (Nh).

The upper portion of the watershed is predominantly Fern Cliff-Allens Park-Rock Outcrop Complex (FcF) and Juget-Rock outcrop complex (Jrf). These soils, consist of stony sandy loam, gravely sandy loam and rock outcrops on mountain side slopes. The runoff potential is medium to rapid and the erosion potential is high.

The central part of the watershed contains Rock Outcrop (Ro), Payton-Juget (PgE), and Godvale Rock Outcrop Complex (Gfr). Steep rock outcrops with exposed bedrock dominate. Pockets of gravely, loamy sand allow roots to penetrate to depths of 40 to 60 inches or more. These areas provide prime habitat for wildlife.

Further down in the watershed, where Gregory Canyon Creek crosses Flagstaff Road, Colluvial Land (Cu) is the predominant soil type until transitioning into the NdD soils at the Columbia Cemetery and Flatirons School. Cu soils vary widely in depth, texture, color, and stoniness due to the runoff from adjacent slopes that these lands receive. Most area of Colluvial land have stones and cobbles on the surface. The erosion hazard associated with Cu soils is high. The Nederland series (NdN) is made up of 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 on this soil and the hazard is slight. A band of Baller Stony Sandy Loam (BaF) exists along the western city limits in the lower watershed. These soils are shallow and well drained with rapid permeability, high erosion hazard and rapid runoff potential

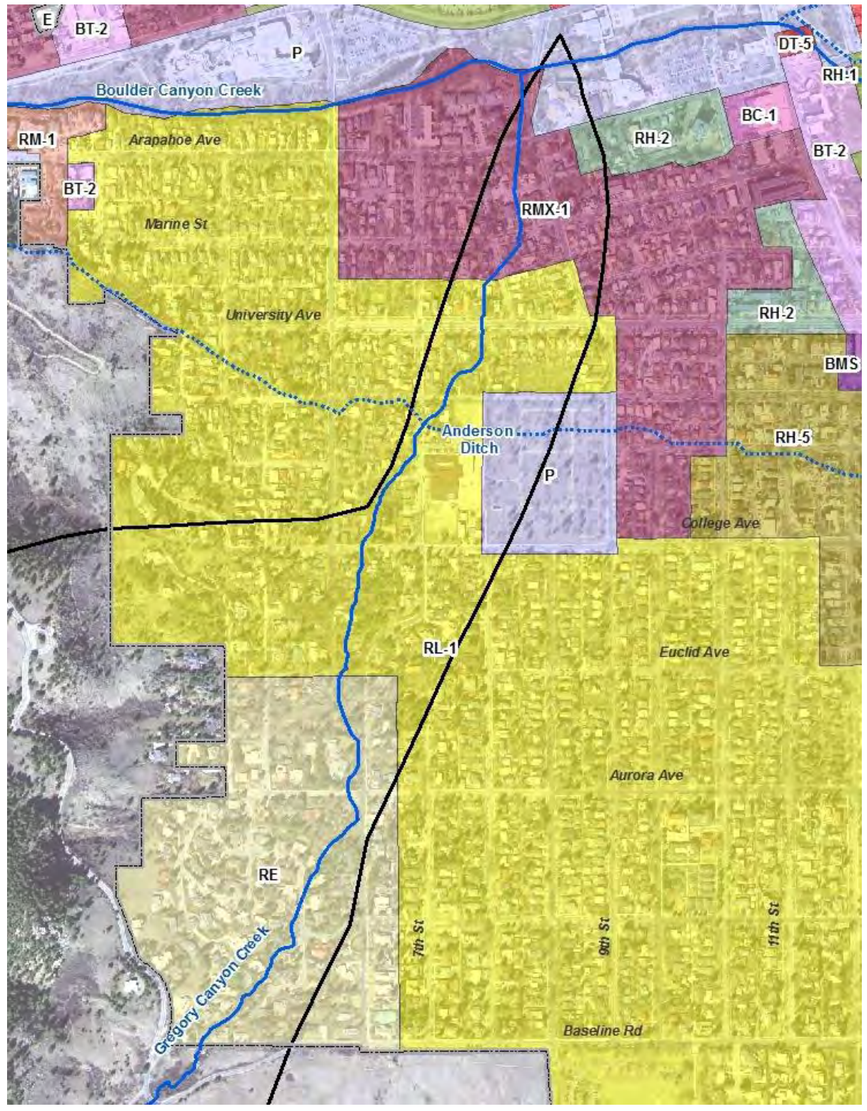
Niwot Series (Nh) soils are located at the confluence with Boulder Creek. The Niwot series is made up of deep, somewhat poorly drained soils that are shallow over gravelly sand. These soils formed on low terraces and bottom lands in loam alluvium. Niwot soils have moderate permeability. Roots can penetrate to a depth of 60 inches or more and the seasonal high water table is at a depth of between 6 and 18 inches. Niwot soils are typically found on stream terraces and bottoms. Runoff is slow on these soils and the erosion hazard is slight except for back cutting near channels. Because of their position in the landscape, these soils are frequently flooded and have seasonal high water table.



Soils Map

LAND USE

Upstream of the city limits, the lands within the Gregory Canyon Creek watershed have been preserved as city Open Space. Within the city limits, the majority of the property within the watershed is comprised of low density, residential zoning districts (RE and RL-1). Density intensifies at approximately 6th St. and Marine where property is zoned RMX-1 (Residential-Mixed 1). The land areas zoned Public (P) contain the Columbia Cemetery and the East Senior Center.



Zoning Map

Notable landmarks within the watershed include the Highlands School, Hannah Barker House, Columbia Cemetery, Anderson Ditch, Flatirons Elementary School, and Smith Park.

HIGHLANDS SCHOOL

Built in 1891, the Highlands School (885 Arapahoe Ave.) was Boulder's fourth permanent school. Situated at the confluence of Gregory Canyon Creek and Boulder Creek, the school was constructed on an elevated area to protect it from flooding. During the 100-year flood of 1894, the school was unscathed while much of the town was substantially damaged. The school closed in the 1960's due to the opening of numerous other schools in the Boulder Valley School District. The school was placed on the National Register of Historic Places in December of 1978. That same year, the new owners set a course to restore and preserve the exterior while creating a luxurious interior space. The building is now home to high-end offices and the Highland City Club.

Highlands School

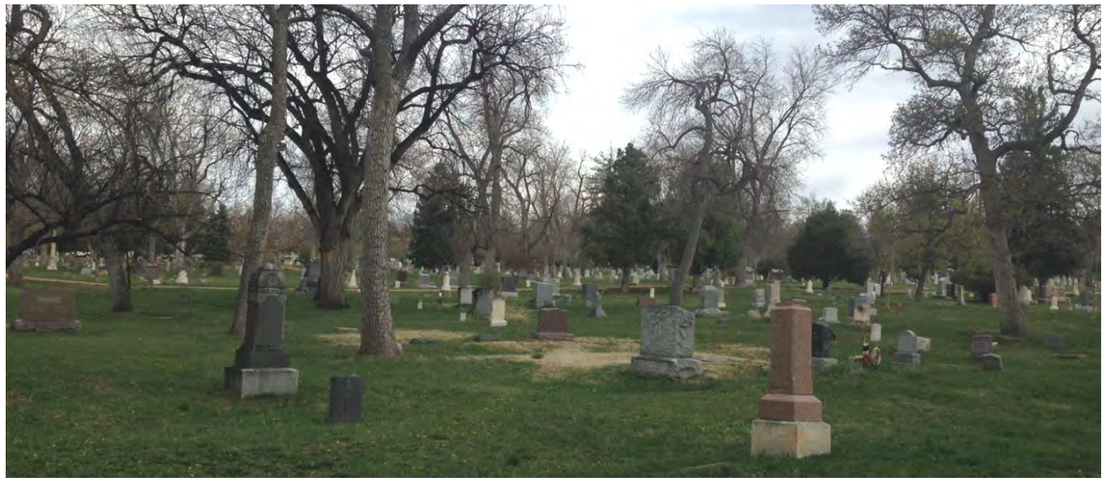
HANNAH BARKER HOUSE

One of the oldest buildings in Boulder, the Hannah Barker House, is located across the street from the historic Highlands School at 800 Arapahoe Ave. The house was originally built in 1875 by Caleb and Carrie Stowell, and is historically significant because of its association with Hannah Connell Barker, a prominent pioneer woman, civic leader, philanthropist and business woman. She was also one of the first female teachers in Boulder. The house is currently being restored by Historic Boulder, Inc., who purchased the property in 2010.

Hannah Barker House

COLUMBIA CEMETERY

Columbia Cemetery is located west of 9th St. between Pleasant St. and College Ave. The ten-acre tract of land was bought in 1870 by the Columbia Lodge #14 A.F. & A.M. ("Ancient Free and Accepted Masons") from Marinus G. Smith and his wife, Anna. Marinus Smith was also instrumental in constructing the Anderson Ditch which flows through the northerly portion of the cemetery. After many years of financial difficulty and various owners, the cemetery became the responsibility of the City of Boulder Parks and Recreation Department in 1966. The cemetery was placed on the National Register of Historic Places in 1997. Today, approximately 6,500 people are interred in the cemetery.



Columbia Cemetery

THE ANDERSON DITCH

In 1860, Jonas Anderson and Marinus Smith dug the Anderson Ditch, which diverted water from Boulder Creek and then wound through the neighborhoods west of Broadway, over University Hill, and past Green Mountain Cemetery. Anderson and Smith were instrumental in bringing the university to Boulder and raised more than $16,000 in 1876 for this endeavor. This was the same year that that territory of Colorado became a state. Today, one-third of the Anderson Ditch rights are owned by CU Boulder and almost all of the remaining two-thirds are owned by the City of Boulder.

Anderson Ditch at 7th St.

FLATIRONS ELEMENTARY SCHOOL

Flatirons Elementary School

Flatirons Elementary School is located at 1150 7th St. on a 4.26 acre parcel bordered to the east by Columbia Cemetery, to the west by 7th St., to the south by College Ave. and to the north by Pleasant St. The Anderson Ditch runs along with northerly edge of the school property and Gregory Canyon Creek is to the west, on the opposite side of 7th St. Aside from the cemetery, the school is surrounded by single-family homes. The school was first constructed in 1956 and is a 43,857 square foot facility. The school has classes for students in kindergarten through 5th grade.

SMITH PARK

Smith Park is a 1.12 acre neighborhood park located on the east side of Gilbert St. This land was donated to the City of Boulder in 1963 by Mildred Cromley Smith as a memorial for her late husband, Edward Sell Smith, for whom the park was later named. The park includes a small play structure, picnic tables and seating areas. Natural areas surround the park providing areas for wildlife. An unnamed tributary stream flows through the park and joins Gregory Canyon Creek immediately downstream of the park.

Smith Park

FLOOD HISTORY

Boulder is highly susceptible to flash flooding because it sits near the mouths of 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. Historical accounts of the 1894 flood attribute flood damage near the Highlands School to Gregory Creek, which had also caused significant damage to homes and property many upstream locations. 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. 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. 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.

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 Gregory Canyon Creek were filled with rocks and debris which had been transported from erosion in the steep, mountainous portions of the watershed, thus significantly reducing the conveyance capacity. Due to the undersized main channel and the plugged culverts, the streets served as the major drainage flow paths for Gregory Canyon Creek.

Street flooding at 7th St. and Arapahoe Ave., Sept. 2013

Sept. 2013 Approximate Flooding Extents

According to A September to Remember, "…the maximum 24-hour rainfall was approximately 8 inches within the Gregory Canyon Creek watershed. The rainfall was greater in the lower part of the watershed, with a maximum 24-hour rainfall return period between 500 and 1,000 years. There are no stream gages on Gregory Canyon Creek, so a peak flow was not estimated…Damages to property and transportation and drainage infrastructure in the watershed were severe…Gregory Canyon Creek dramatically demonstrated the urban drainage principle that every urban area has an initial and major drainage system whether or not actually planned and designed".

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 Gregory Canyon Creek drainage way ranged from a 40-50 year event for the worst case 2-hour duration. However, according to the Wright Water report, while the short-duration intensities reported are lower than those assumed in the 100-year design storm, "the rocky soils and shallow bedrock in the upper sub-watersheds limit infiltration, and intense periods of rainfall later in the event, when soils were saturated, produced significant runoff and debris flows." Because of the significant amount of rocks, sediment and debris blocking the culverts along Gregory Canyon Creek, the extent of flooding in September 2013 was beyond what would be normally mapped for a 25-50-year "clear water" flood.

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:

- The culvert at Willowbrook Rd. was clogged with debris, causing floodwaters to run down the roadway and "Gregory Gulch" to Aurora St.
- Smith Park, which is outside of the 100-year floodplain saw flooding due to the flood flows along the unnamed tributary that crosses Gilbert St. and flows through the park.
- West of the intersection of Aurora and 6th St., hillside flows ran down Aurora Ave., Circle Dr. and Park Lane.
- At the intersection of College Ave. and 6th St., flood waters went north along 6th St. and then turned east and flowed along Pleasant St.
- Downstream of Pleasant St., flood waters continued north down 7th St. to Boulder Creek and spread throughout the area between 7th St. and 9th St.

The Anderson Ditch also runs across the Gregory Canyon Creek watershed and may have also contributed to the widespread flooding along Gregory Canyon Creek downstream of Pleasant St.

Along the creek, many culverts became partially or mostly clogged with rocks, sediment, and debris which forced the floodwaters to leave the stream banks and flow down the streets. A landslide occurred below Flagstaff Rd. and sent rocks and debris downhill. The storm sewer system and sanitary sewer systems were also overwhelmed due to the flood waters and elevated groundwater.

Damage Analysis from the 2013 Flood

After the September 2013 flood, the city 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 also of claims submitted for FEMA for reimbursement. In the Gregory Canyon Creek watershed, it is estimated that the total amount of damages exceeded just over $7,000,000. The primary sources of damage we a result of major drainageway flooding, groundwater infiltration, and local drainage flooding. It is estimated that approximately $1,941,000 in damage was caused in the 100 year floodplain, $2,473,800 in damage was caused in the 500 year floodplain, and the remainder was outside of the designated floodplains.

Environmental Assessment

A survey was completed in 2010 along many of the Boulder Creek tributary reaches to update the aquatic habitat inventory. This inventory found the aquatic habitat along Gregory Canyon Creek to be in fair to poor condition. From Boulder Creek to College Ave., the native plant habitat was evaluated as being poor, but the overall vegetative structure was found to be excellent to good. Bird species richness in this stream reach were determined to be poor to very poor. South of College Ave. to the city limits at Baseline Rd., native plants are considered to be in good condition, with the vegetative structure being very good. Bird species richness is very good to good within this stream reach. The survey data sheet is included in **Appendix C**.

Wetlands

Gregory Creek is a steep, rocky intermittent stream that flows northward along the eastern edge of a Pierre shale bedrock formation and drains into Boulder Creek. According to the city's "Functional Evaluation Summaries for Individual Wetlands", included in **Appendix C**, the wetlands located along Gregory Creek east of Mountain Parks and south of Boulder Creek are characterized by a generally narrow active channel with a fairly steep gradient. Precipitation in the foothills to the west supports seasonal flows in the creek.

The maximum water depth is approximately 1.5 feet. Ninety percent of this wetland is covered by vegetation with five percent comprised of bare ground and five percent in water. The wetland vegetation is fairly dense along the creek and consists of narrowleaf cottonwood and mixed herbaceous trees and shrubs.

The geohydrologic map indicates groundwater recharge or discharge are possible. The effectiveness of the function is limited by impermeable bedrock near the surface, the narrow channel, and intermittent flows.

Previous Studies and Master Plans

The Boulder Valley Comprehensive Plan (BVCP), the Comprehensive Flood and Stormwater Utility Master Plan ("CFS"), 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.

BOULDER VALLEY COMPREHENSIVE PLAN
The following applicable policies are included in the BVCP:

3.19 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.

3.20 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. The city and county will manage the potential for floods by implementing the following guiding principles: a) Preserve floodplains b) Be prepared 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. 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.

3.21 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.

3.22 Protection of High Hazard Areas
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. Compatible uses of riparian corridors, such as natural ecosystems, wildlife habitat and wetlands will be encouraged wherever appropriate. Trails or other open recreational facilities may be feasible in certain areas.

3.23 Larger Flooding Events
The city recognizes that floods larger than the 100-year event will occur resulting in greater risks and flood damage that will affect even improvements constructed with standard flood protection measures. The city will seek to better understand the impact of larger flood events and consider necessary floodplain management strategies including the protection of critical facilities.

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:
  - Update mitigation master plans to emphasize nonstructural measures.
  - 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.
  - Assess any need for structural improvements with evaluation of multiple alternatives.
  - Focus on mitigating high hazard locations citywide and give priority to areas of the greatest risk.

URBAN DRAINAGE AND FLOOD CONTROL DISTRICT (UDFCD) DRAINAGE CRITERIA MANUAL
The UDFCD 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 objects 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 few improvements along Gregory 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. Recreationally, there is a trail that follows this tributary up a fairly steep incline through Chautauqua Park and then beyond and which is located within the Boulder Open Space and Mountain Parks lands. Additionally, Smith Park is located to the west of the main Gregory Canyon Creek Channel, but it has a small tributary that runs through it and which connects to the creek just below Euclid Ave. and 6th St.

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 with creek.

MAJOR DRAINAGEWAY MASTER PLAN

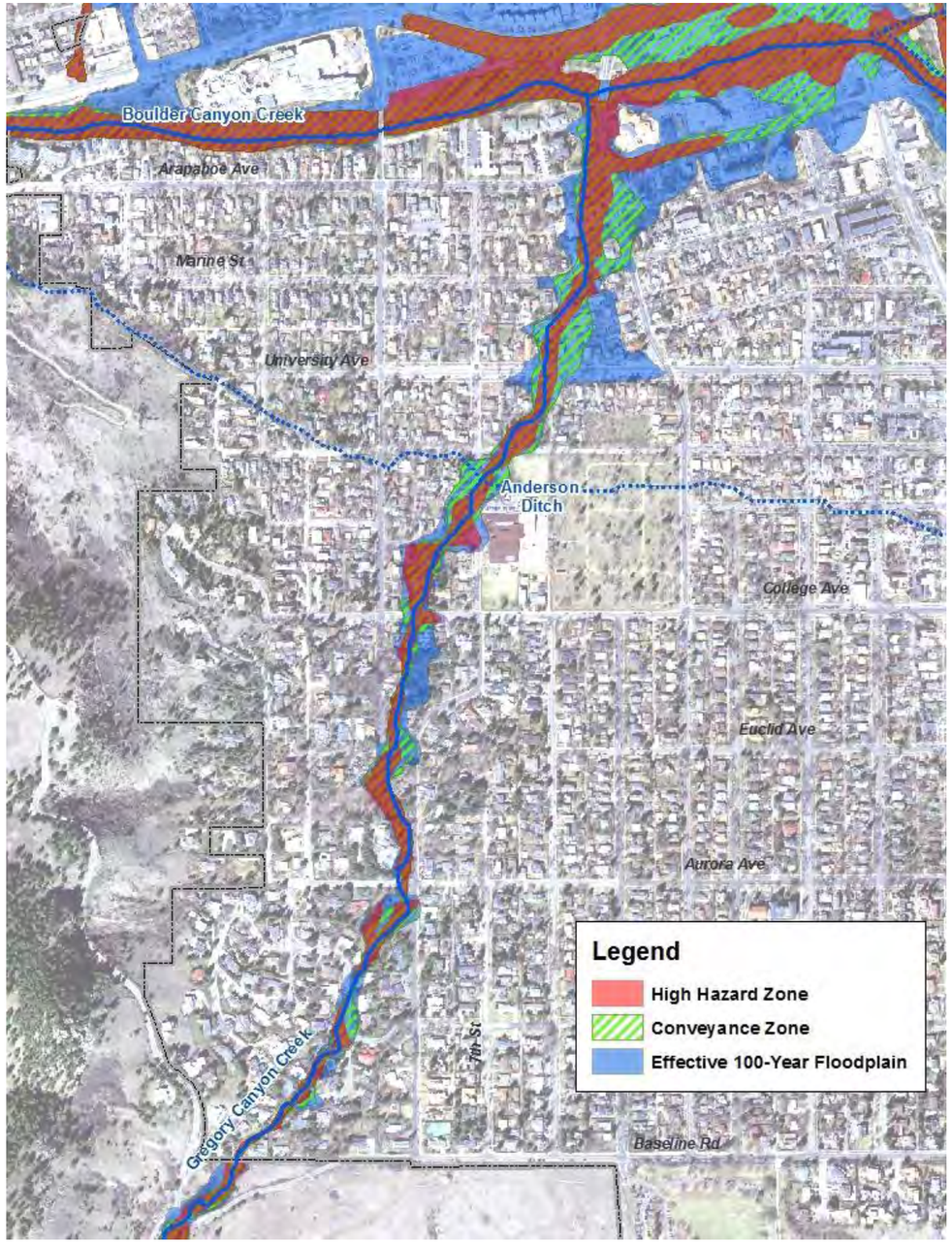
A Major Drainageway Master Plan was developed in 1987 by Greenhorn & O'Mara that identified flood mitigation improvements for Gregory Canyon Creek. Following the Master Plan, the following channel and culvert improvement projects were constructed:

- Culvert replacement at Willowbrook Rd. (1996)
- Channel widening, drop structure installation and rip-rap protection upstream of Aurora Ave. (1995)
- Culvert replacement at Aurora Ave. (1995)
- Culvert replacement at Pleasant St. (1995)
- Channel grading, tree removal and drop structures installed between Pleasant St. and University Ave. (1995)
- Channel grading and drop structure installation between Pennsylvania Ave. and 7th St.

FLOODPLAIN MAPPING STUDY

The floodplain maps for Gregory Canyon Creek were updated in 2010 (Belt Collins West, 2010). The updated floodplain mapping established base flood elevations using detailed methods and incorporated improvements and changes along Gregory Canyon Creek. The figure to the right shows the 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:

Flood Zone	Number of Structures
100-year Floodplain	98
Conveyance Zone	63
High Hazard Zone	32



Floodplain Map

GREGORY CANYON CREEK MITIGATION STUDIES

During the floodplain mapping analysis in 2010, several properties were newly identified as being within the high hazard flood zone. Prior to the adoption of the floodplain maps, a Mini-Master Plan was conducted to investigate the feasibility of mitigation options to remove the newly identified high hazard zone properties from the high hazard zone. None of the proposed projects identified in the Mini-Master Plan were implemented because the benefit to cost ratios did not justify moving forward and funding was allocated to other projects.

A Mitigation Analysis was conducted in 2012 to further investigate improvement options to remove structures from the high hazard zone. This analysis focused solely on high hazard zone modifications and did not assess improvements to reduce flood damages from more frequent storm events. The analysis did not identify any improvements that would be financially feasible compared to the benefits of the proposed work and concluded that purchasing properties, deconstructing structures and converting property to open space would be the best policy for flood mitigation along Gregory Canyon Creek.

BOULDER CIVIC AREA PLAN

In July of 2015, Boulder City Council adopted a new Civic Area Master Plan for the Boulder Civic Area (BCA). A phased implementation of the plan is taking place concurrent with the Gregory Canyon Creek Flood Mitigation Plan. The existing flood risks to the West Senior Center site have been recognized and an evaluation of potential flood mitigation work has been recommended as part of the BCA planning process.

SECTION 3-HYDROLOGIC ANALYSIS

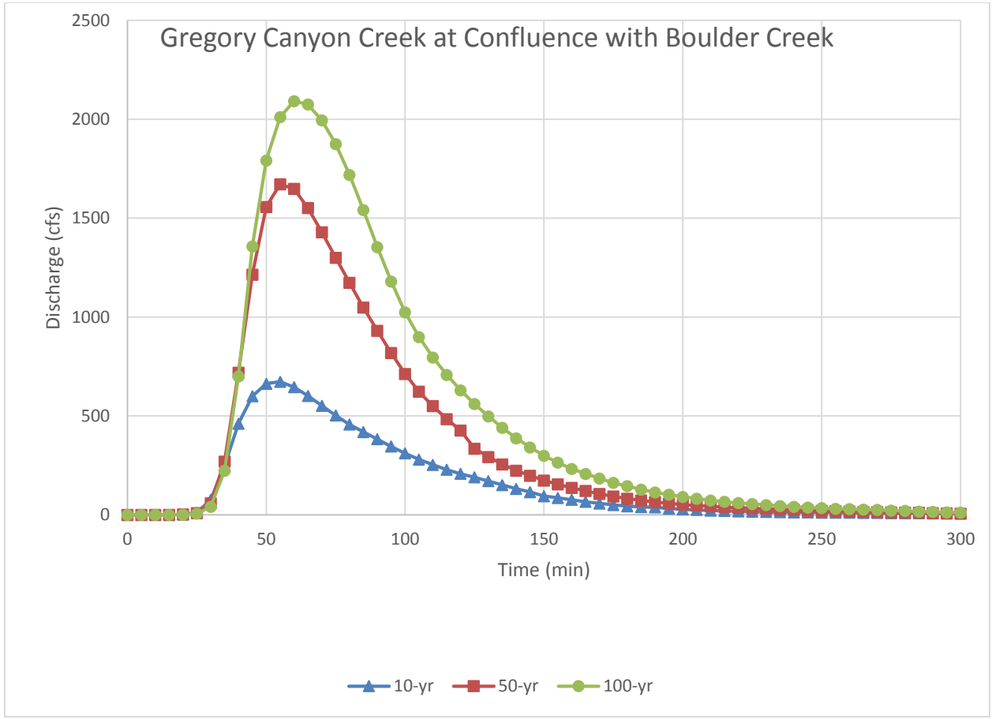
A hydrologic analysis was not performed as part of this master plan. The information used in this master plan was derived from the previous hydrologic analysis performed for Gregory Canyon Creek. To date, one report has been published documenting the hydrology of Gregory Canyon Creek. The hydrologic study is described in detail in the following subsections and is referenced in the current Boulder County Flood Insurance Study (FIS) as the source for the FEMA effective hydrology.

PREVIOUS STUDIES

In accordance with an agreement with Urban Drainage and Flood Control District (UDFCD), the City of Boulder, and Boulder County, Greenhorne & O'Mara, Inc., completed a Major Drainageway Planning Study – Boulder and Adjacent County Drainageways for 11 drainageways in the Boulder area, including Gregory Canyon Creek, dated May 1987. As a part of the study, Greenhorne & O'Mara completed future conditions hydrology for the 2-, 5-, 10-, 50-, and 100-year storm events. The Colorado Urban Hydrograph Procedure (CUHP) was used to determine the runoff hydrographs for each storm event. These hydrographs were then routed through the US Army Corp of Engineers (USACE) Hydrologic Engineering Center (HEC) model, HEC-1. It was documented in the report that the rainfall data reflected the 1982 guidelines stated in the Urban Storm Drainage Criteria Manual. The study watershed for Gregory Canyon Creek was approximately 2.29 square miles with a 100-year peak discharge of 2,092 cfs at the confluence with Boulder Creek. The peak discharges from this study are documented in the current FEMA FIS, dated December 18, 2012, and have been the basis for each subsequent study completed for the City of Boulder for Gregory Canyon Creek.

SUMMARY OF PEAK DISCHARGES

Hydrographs from the CUHP and HEC-1 analysis (Greenhorne & O'Mara, 1987) were extracted from output for use in the two – dimensional hydraulic analysis that was performed as part of this study.



The FEMA effective flows identified in the 2010 Letter of Map Revision (LOMR) (Belt Collins West, 2010) were used for the one – dimensional Hydrologic Engineering Center River Analysis System (HEC-RAS) hydraulic modeling. A summary of the discharges used in this study are shown below:

Peak Discharge for Gregory Canyon Creek (cfs)

Location	10-yr	50-yr	100-yr	500-yr
Confluence with Boulder Creek (XS 10 – XS 180)	673	1672	2092	3700
University Ave (XS 190 – XS 318)	600	1504	1900	3300
College Ave (XS 330 – XS 455)	495	1286	1700	3000
Willowbrook Road (XS 460 – XS 600)	400	1060	1450	2600

SECTION 4-HYDRAULIC ANALYSIS

EVALUATION OF EXISTING FACILITIES

The existing conveyance infrastructure within the project area was evaluated using the HEC-RAS version 4.1.0 and FLO-2D to determine the capacity of the infrastructure. In addition, EPA-SWMM version 5.0 was used to evaluate the capacity of the 7th Street culvert and to analyze the storm drain system on Willowbrook Road

The FEMA effective HEC-RAS hydraulic model was used as the baseline hydraulic condition for this analysis. This model was updated based on crossing information that was gathered on a site walk performed on July 17, 2014. The topography of Gregory Canyon Creek had been altered slightly by the storm event in September 2013, however it was agreed that the topography reflected in the 2010 LOMR was the best information available. City of Boulder Staff collected measurements for each public crossing. The majority of crossing infrastructure gathered in the field was reflected in the baseline study, however several crossings were updated to reflect current field conditions.

The geometry for the crossings was updated in the HEC-RAS model to reflect the conditions identified in the field maintaining the blockage assumption that was applied to the baseline hydraulic model. This was done by reducing the area of the crossing by the assumed percent blockage. These changes to the crossings had negligible impacts to the split flow reach and the model as a whole. A comparison between the Effective Model (2010 Floodplain Study Geometry) and the updated Existing Conditions Models (Updated Geometry) is depicted in the table to the right. No other changes were made to the baseline model to create the existing conditions HEC-RAS model for the purpose of this analysis.

FLO-2D Evaluation

During the September 2013 storm event, many residents along the Gregory Canyon Creek corridor witnessed flows along streets adjacent to Gregory Canyon Creek. To get a better understanding of the flow distribution outside the limits of the channel corridor, CH2M HILL developed a two-dimensional hydraulic model, using the FLO-2D V2009 model. A grid was built using 2013 LiDAR data provided by the City of Boulder for the project area. Manning's N values were adjusted based on the surrounding land use as recommended by the documentation in the FLO-2D reference, see the table below for all Manning's N assumptions for the FLO-2D hydraulic model.

Manning's N Documentation

Land use Description	Manning's N Value
Developed, Medium Intensity	0.7
Developed, Low Intensity	0.8
Open Space	0.6
Grassland	0.35
Forested Area	0.4
Developed Open Space	0.25
Streets	0.02

Location	Percent Blockage Assumption	2010 Floodplain Study Geometry	Updated Geometry
Flagstaff Rd	50%	73.2" diameter	54" diameter
Private Drive at Old Baseline Road	100%	23" diameter	--
Pedestrian Bridge at Willowbrook Road Cul-de-sac	0%	Not Modeled	--
Private Drive at NW Corner of Willowbrook Road Cul-de-sac (705 Willowbrook Road)	50%	52.8" diameter	--
Private Drive at West Side of Willowbrook Road (777 Willowbrook Road)	50%	120" x 60" bridge	--
Willowbrook Road	50%	108" x 60" box culvert	--
Pedestrian Bridge at Willowbrook Road	0%	Not Modeled	--
Private Drive 550 Aurora	0%	192" x 84" box culvert	--
Aurora Crossing #1	0%	36" diameter	--
Aurora Crossing #2	0%	60" x 120" box culvert	--
Euclid Avenue	100%	48" diameter	--
College Avenue	50%	62.4 "x 72" arch culvert	72" x 78" arch culvert
Private Drive Wood Bridge DS of College Avenue	75%	Open Area = 77.4 sq. ft.	--
Pennsylvania Avenue	50%	56.4" x 36" arch culvert	--
7th Street	50%	48" diameter	--
Weir Split Flow Box DS of Anderson Ditch	0%	Not Modeled	--
704 Pleasant Street Patio	30%	66" x 34.8" arch culvert	--
Pleasant Street	20%	96" x 48" arch culvert	--
University Avenue	50%	72" x 60" arch culvert	--
8th street and Alley	50%	66" x 38.4" arch culvert	--
810 Marine Street	50%	48" x 36" box culvert	75" x 54" box culvert
Marine Street	50%	96" x 48" box culvert	104" x 48" box culvert
Alley Between Marine and Arapahoe	50%	62.4" x 42" arch culvert	--
Arapahoe Avenue	50%	120" x 36" box culvert	108" x 36" box culvert
Private Driveway To Old School	50%	42" diameter	48" diameter

A summary of the HEC- 1 peak discharges and their approximate location in the two – dimensional analysis are located in the table below.

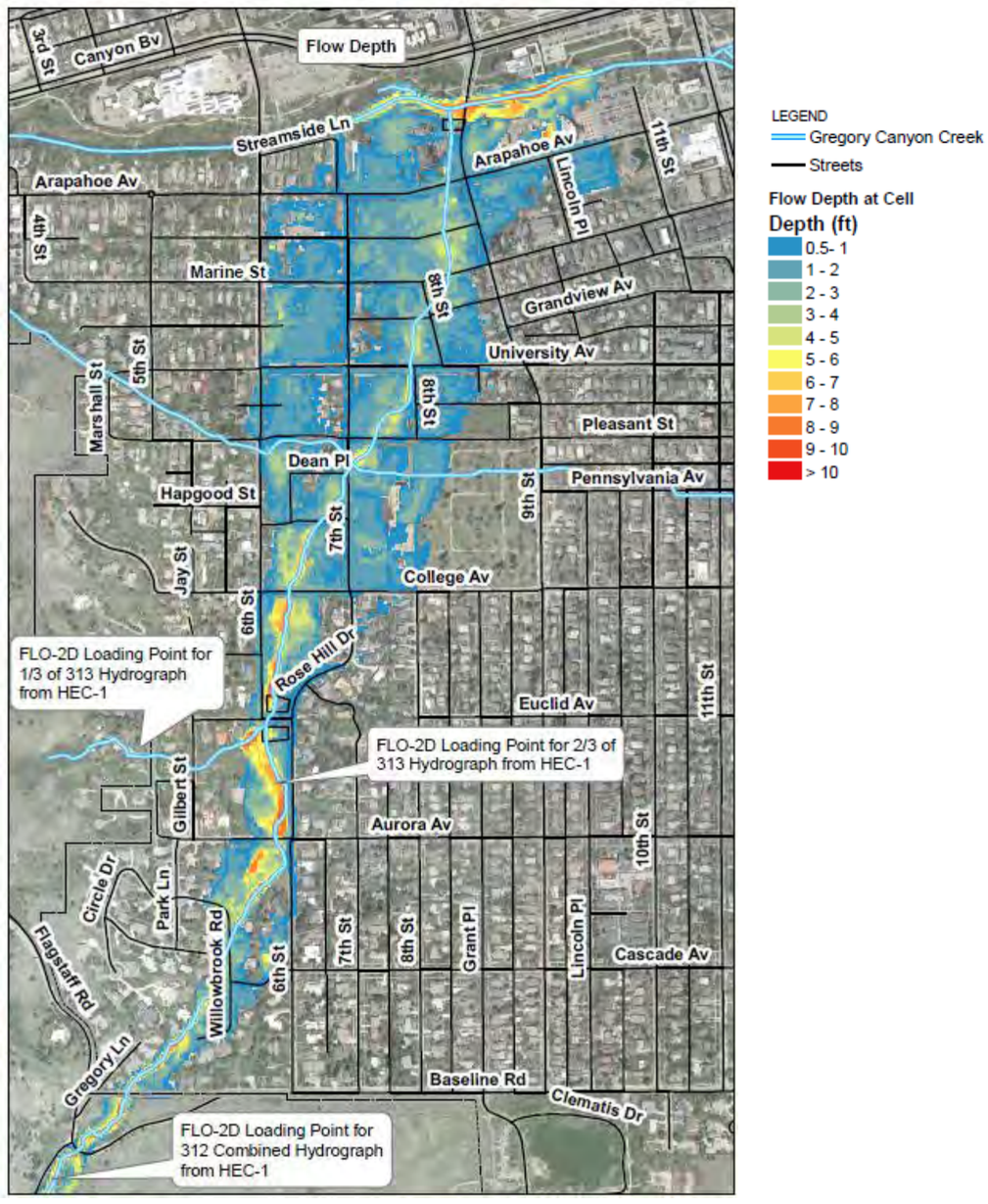
Peak Discharge Summary

Location	Return Interval (years), Peak Discharge (cfs)				
	2-yr	5-yr	10-yr	50-yr	100-yr
Approximately 150' upstream of Flagstaff Rd	32	168	328	937	1270
1/3 of discharge at Aurora Ave, with 2/3 placed on the local highpoint	168	269	485	959	1179

Once the FLO-2D geometry was created, the hydrographs from the HEC-1 Model (Greenhorne & O'Mara, 1987) were distributed at the appropriate flow change locations for the 2-, 5-, 10-, 50-, and 100-year storm events as documented in the figure to the right. The results of the existing 100-year storm event are shown in the figure to the right. The results of the FLO-2D analysis generally confirmed what was observed during the September 2013 storm event. Additional FLO-2D results including velocity vectors and a comparison to the September 2013 event is included in the Alternatives Analysis Memorandum **(Appendix A)**.

FLOOD HAZARDS

The City of Boulder and CH2M HILL staff conducted a site walk on July 17, 2014. City staff was able to convey to CH2M HILL observations during the flood event of September 2013 and identify potential areas for improvements. Some of the properties that had been damaged by flood waters had already been restored to pre-flood conditions or had improvements constructed such as flood walls to help prevent future flooding. The objective during the site walk was to identify alternatives to help mitigate flooding. In addition to the proposed improvements identified during the site walk, CH2M HILL noticed other deficiencies along Gregory Creek Canyon through detailed hydraulic modeling. The channel geometry between Euclid Avenue and College Avenue was identified as one of the existing sections that is unable to convey the 10–year storm event without causing infrastructure damage. Another section is the channel upstream of Euclid Avenue for approximately 200-feet. In addition, the crossing at Arapahoe Road is unable to convey the 10–year storm event that is being conveyed from the upstream channel section. These three areas were also considered for potential improvements during the alternative analysis. The alternatives are discussed in detail in the subsequent sections.



100-Year 2-D Analysis Flow Depths

SECTION 5-ALTERNATIVE ANALYSIS

ALTERNATIVE DEVELOPMENT PROCESS

Typically, flood mitigation plans are developed with the intent to adequately convey a 100-year storm event, consistent with the policies of the Boulder Valley Comprehensive Plan, the Comprehensive Flood and Stormwater Utility Master Plan and the UDFCD Drainage Criteria Manual.

Due to the existing residential development, channel mitigation to convey a 100–year event would not be feasible unless many of the existing homes along the creek corridor were removed. Currently, the Gregory Canyon Creek channel does not have adequate capacity to contain a 10-year event. During the development of the alternatives, it was determined that improvements along the creek could be constructed which would facilitate flows from a 10-year event. Each culvert was evaluated for existing conditions, the size required to convey a 10-year event, and the maximum size that could feasibly be constructed without impacting existing buildings.

Since the topographical and development constraints along Gregory Canyon Creek prevent modification which would convey flows that are greater than a 10-year event, it was recognized that the streets in the neighborhoods could be modified to better convey floodwaters in larger events.

During the September 2013 event, floodwaters were observed in various roadways, with primary conveyance paths being 6th Street, 7th Street and 8th Street. The flood did significant damage to these roads and left behind large amounts of debris. Thus, street improvements were considered which would direct and retain water within the streets, protecting private properties.

Sept. 2013 Flood Damage at 7th St. and Pleasant St.

Additionally, areas for sediment traps and habitat improvements were evaluated as well as opportunities to implement other improvements based on observations from the 2013 Flood, such as a sanitary sewer main relocation and additional drainage inlets.

ALTERNATIVE CATEGORIES

The alternatives analysis includes the following categories:

1. Channel and Culvert Improvements
2. Improvements Outside of the Channel
3. Property Acquisition
4. Detention
5. Other Improvements

CHANNEL AND CULVERT IMPROVEMENTS

The Gregory Canyon Creek channel was assessed between the Boulder city limits on the upstream end to the confluence with Boulder Creek. Opportunities for culvert and channel improvements were identified from the culvert on private property at 705 Willowbrook Rd. to the culvert under the private drive leading to the historic Highlands School just north of Arapahoe Ave. Each culvert was evaluated for existing conditions, the size required to convey a 10-year event, and the maximum size that could feasibly be constructed without impacting existing buildings. Most culvert replacements would necessitate work in the channel directly upstream and directly below stream and in most situations, easements would need to be acquired from the property owners. The tables below summarize the evaluation of each culvert including the channel work required. Following is a brief discussion about each culvert and the recommendations for replacement.

Culvert C1-A: Private Culvert at 705 Willowbrook Road

Improvement	Size	Total Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	4.4'	4.4	Circular	34			337	<10	
10-yr	8' x 6'	8	Box	34	14	4	400	10	$114,814
Max	(2) 8' x 8'	16	Box	34	42	11	1,060	50	$233,313

The existing culvert is one of the smallest along Gregory Canyon Creek. During the September 2013 flood, there was significant scour across the southern (upstream) side of the culvert, resulting in sediment and rocks being carried downstream. The limited capacity of the culvert also resulted in floodwaters spilling out of the creek channel, across Willowbrook Court and then back into the Gregory Canyon Creek channel.

Sept. 2013 Flood Damage

A reinforced concrete headwall was built at the upstream end of the culvert shortly after the flood. Although replacing the culvert with a larger culvert could increase the capacity, it was determined that this improvement would not provide significant benefit, since overtopping flood waters return to the creek channel. Due to the topography and other development surrounding this culvert, access for maintenance would be difficult. An easement would be required for any improvements since the culvert is located on private property.

Post-Flood Repair

Culvert C1: Willowbrook Rd.

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	9' x 5'	9	Box				337	<10	
10-yr	9' x 7'	9	Box	140	24	6	400	10	$338,314
Max	(2) 9' x 7'	18	Box	140	36	9	1,187	50-100	$642,815

The existing culvert conveys slightly less than a 10- year storm. The culvert is 140 feet in length and was constructed in 1997.

The trash rack at the upstream end of this culvert clogged with debris during the September 2013 event, and flood waters overtopped Willowbrook Rd., onto private property, and ultimately into the usually dry Gregory Gulch, located between 860 and 870 Willowbrook Rd. The flood waters caused damage to property and structures and scoured a significant amount of sediment and rocks.

Sept. 2013 Flood Damage

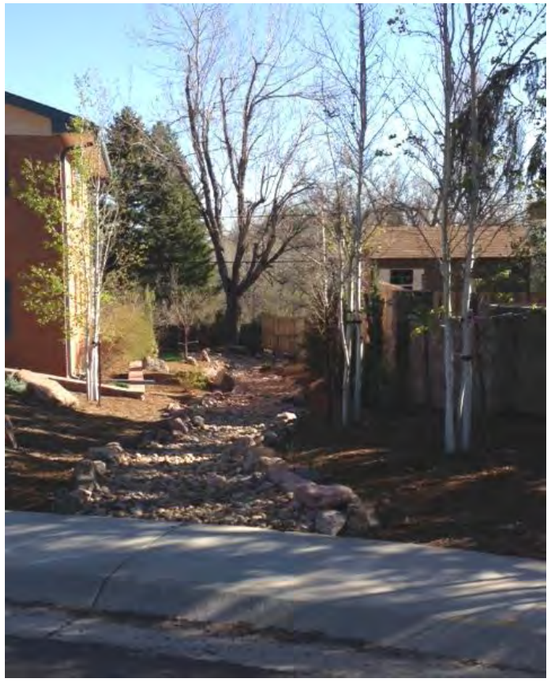
New Trash Rack

After the flood, the trash rack was redesigned and replaced with one that meets current design standards and could be better maintained during a flood.

Rather than replace this culvert with one only slightly larger, it is recommended that drainage inlets be installed to help control water in the event the culvert capacity is exceeded. Additionally, adding grates over the culvert could aid in directing flood waters directly into the culvert and should be further evaluated, although due to existing utilities in the roadway this may not be feasible.

In order to accommodate future flood waters along "Gregory Gulch", the property owners at 860 and 870 Willowbrook Rd. have made landscaping improvements incorporating flood walls and other measures that will help protect their properties from future flood damage.

Sept. 2013 Flood Damage



Post-Flood Repair (Upper Gregory Gulch)

The feasibility of installing a pipe along Gregory Gulch was also analyzed. The pipe could convey about 240 cfs and would cost approximately $165,000 to construct. Since both property owners have already made modifications to their properties to better direct the floodwaters away from their homes, the installation of this pipe is not recommended.

Culvert C2: 6th and Aurora

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	(2) 10' x 5'	20	box	80			495	10	
10-yr							495		
Max	(4) 10' x 6'	40	box	80	80	20	1,696	50-100	$ 764,142

The existing culvert in this location was constructed in 1995. It is designed to convey the 10-year event at 495 cfs.

During the 2013 flood, the east side of this culvert filled with debris. A chained-link fence/gate on the downstream side of the culvert failed to swing open and collected debris. The fence/gate has since been removed.

Sept. 2013 Flood Damage

Existing Culvert

Because this culvert is designed to pass the 10-year event, it is not recommended that it be replaced. In order to accommodate water that may come onto Aurora Ave. from Gregory Gulch, it is recommended that improvements to the road be constructed which would direct flows across the roadway into the creek channel.

Culvert C3: Euclid Ave. at 6th St.

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	4'	4	circular				-	<10	
10-yr	(2) 8' x 6'	16	box	65	44	11	495	10	$291,126
Max	(3) 10' x 6'	31	box	65	108	27	1,268	50	$529,778

There are actually two drainages at 6th and Euclid; the formal Gregory Canyon Creek drainage, and a tributary that flows off of Smith Park and through the property at 580 Euclid before it passes through a small culvert under Euclid into Gregory Canyon Creek. There was significant flooding in 2013 in this area, but much of it was reported to have come from the Smith Park area, and not from the main Gregory Canyon Creek channel.

Existing Culvert

It is recommended that the Gregory Canyon Creek culvert be replaced with two 8' x 6' box culverts in order to convey the 10-year storm. In order to preserve existing trees in the area, it is recommended that alternate culvert alignments be investigated. It is also recommended that an alternate alignment of the creek channel downstream of the culvert be considered in order to better protect the homes on the north side of Euclid.

Culvert C4: College Ave. and 6th St.

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	6' x 6.5'	6	arch				125	<10	
10-yr	(2) 7' x 6'	14	Box	55	32	8	495	10	$250,168
Max	(3) 11' x 6'	33	box	55	108	27	1,286	50	$500,731

This culvert was constructed in 1920 and, as designed, conveys 125 cfs. Where the culvert outlets to Gregory Canyon Creek, the creek makes a sharp turn to the east and then flows between two residential structures.

Existing Culvert

It is recommended that this culvert be replaced with two 7' x 6' box culverts and be re-aligned to where flows are directed further to the east and not directly toward the existing house. This would also result in a better alignment with the creek channel from that point north and eliminate a sharp turn in the channel alignment, which can cause scour and erosion.

The property where the culvert outlets is located within the High Hazard Zone and the September 2013 flood did impact this property. The bridge, which serves as the driveway and main access to the home, was damaged and is in need of repair.

Damaged Bridge

Culvert C5: Pennsylvania Ave.

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	4.75' x 3'	4.75	arch				42	<10	
10-yr	(2) 9' x 6'	18	box	45	53	13	600	10	$235,896
Max	(3) 12' x6'	36	box	45	121	30	1,469	10-50	$464,895
Pedestrian Bridge 30' bridge span / 10' deck width / 30" deck thickness / 4' handrails / 18' wide channel		18			53	13	600	10	$ 90,000

The road across Gregory Canyon Creek at Pennsylvania Ave. was completely washed out during the 2013 flood, exposing a culvert that that was severely damaged. The roadway was not immediately repaired because it looked like there was an opportunity to increase the flood conveyance capacity and improve the riparian habitat for what was initially considered to be a similar cost to replace the culvert pipe and repair the roadway. Therefore, prior to making repairs to the roadway, three different options were assessed:

Option 1: Replace the existing culvert and rebuild the roadway.

Option 2: Remove the culvert and damaged roadway above the creek, close the road to through traffic, and build a pedestrian bridge over the creek.

Option 3: Remove the culvert and construct a new roadway with a significantly larger culvert or a vehicular bridge over the creek.

An open house was held on Feb. 6, 2014 to obtain public input regarding these options. The public overwhelmingly supported Option 2; removing the culvert and building a pedestrian bridge over the creek. Closing the road to thru traffic on both sides of the bridge was also very much supported by the public. These options were then presented to the Greenways Advisory Committee (GAC). Due to the urgency of repairing the road in order to prevent more erosion and the accumulation of trash in the area, the GAC and utilities staff recommended that the culvert be replaced and the road repaired immediately and that Option 2 be further evaluated with the Gregory Canyon Creek Mitigation study.

Constructing a 30-foot long bridge across the creek, and maintaining an open channel under the bridge would convey 600 cfs, equivalent to conveying the 10-year event. Considering the public support of building the pedestrian bridge, and the fact that this is the least costly of the other alternatives, it is recommended that the bridge be considered the preferred alternative.

Sept. 2013 Flood Damage

Post Flood Repair

Culvert C6: 7th St. by Flatirons Elementary School

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	8' x 4.25'	8	circular				153	<10	
10-yr	(2) 10' x 6'	20	box	50	44	11	600	10	$278,764
Max	(2) 13' x 6'	26	box	50	72	18	1,339	10-50	$347,319

The trash rack at the upstream end of this culvert clogged with debris during the September 2013 event, and flood waters flowed south, down 7th St., damaging the roadway and properties in the area. During the flood, the trash rack was removed in order to help alleviate the flooding conditions, but the culvert filled with rocks and debris and flood waters continued to run down the street. Additionally, Anderson Ditch overtopped and filled with sediment.

Sept. 2013 Flood Damage

New Trash Rack

After the flood, the trash rack was redesigned and replaced with one that meets current design standards and could be better maintained during a flood.

The upstream end of this culvert is located on 637 Pennsylvania Ave. and the city holds a drainage easement on this property. Constructing a sediment trap upstream of this culvert has been identified as an additional alternative to help capture debris before it reaches the trash rack. The existing culvert only conveys 153 cfs. To convey the 10-year event (600 cfs) the culvert would need to be replaced with two 10' x 6' box culverts.

The downstream end of this culvert runs under the Anderson Ditch before it outlets at 704 Pleasant St. The creek then drains through a separate private culvert on this property before passing through an open channel until meeting Pleasant St.

Sept. 2013 Flood Damage (7th St. and Anderson Ditch)

The recommendation for this culvert is to replace it with the two 10' x '6 box culverts to convey the 10-year storm (600 cfs), but to also realign it more to the west before it outlets onto 704 Pleasant into an open channel, eliminating the need for the private culvert.

The feasibility of putting Anderson Ditch in a pipe from the point it currently daylights on the west side of 7th to the cemetery was also evaluated. The decreed and maintained water right flow for the ditch is 25 cfs. According to the city's stormwater agreement with the Anderson Ditch Company, the city has the right to use all of the excess capacity of the Anderson Ditch for the conveyance of storm water from lands within the corporate limits of the city. This agreement also states that the city has a right to make improvements to the Anderson Ditch, but that all such improvements must be constructed to convey a minimum of 25 cfs. A 36" RCP (Reinforced Concrete Pipe) is recommended and would cost approximately $43,400 to construct.

Culvert C6-B: Private Culvert on 704 Pleasant

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	5.5' x 2.9'	5.5	arch				11	<10	
10-yr	(2) 8' x 6'	16	box	180	62	16	600	10	$260,062
Max	(2) 12' x 6'	23	box	180	78	74	1,310	10-50	$307,347

As noted above, 704 Pleasant has a private culvert, along with the Anderson Ditch running along the southern edge of the property. This culvert only conveys 11 cfs. During the 2013 flood, this culvert filled with sediment. If this culvert were to be replaced instead of eliminated as recommended above, it could be replaced with two 8'x6' box culverts that would convey the 10-year storm (600 cfs).

2013 Flood Damage

Culvert C7: Pleasant St.

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	8' x 4.25'	8	arch				153	<10	
10-yr	(2) 10' x 6'	20	box	50	44	11	600	600	$295,163
Max	(2) 13' x 6'	26	box	50	72	18	1,339	10-50	$347,470

This culvert is located at Pleasant St., just east of 7th St. The properties just downstream of this culvert were impacted by flood waters in 2013. While this culvert was replaced in 1995, as designed, it has the capacity to only pass 153 cfs. It is recommended that this culvert be replaced with two 10' x 6' box culverts, totaling a width of 20 feet, to facilitate the passage of the 10-year storm (600 cfs).

Existing Culvert

Culvert C8: University Ave. at 8th St.

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	6' x 5'	6	arch				104	<10	
10-yr	(2) 9' x 6'	18	box	105	48	12	600	10	$475,753
Max	(2) 10' x 6'	20	box	105	56	14	1,237	10-50	$528,261

While flooding in 2013 was widespread throughout this drainage, the flooding extents became significantly more spread-out in this location and continued downstream, to the north until reaching Boulder Creek. In 2013 flooding spanned almost 950 feet down University (from 7th to 9th St.). This was also in large part due to the extreme crown on University that barred water from easily passing further north to Boulder Creek.

It was calculated that this culvert is only capable of conveying 104 cfs. It is recommended that this culvert be replaced with two 9'x 6' culverts with a combined width of 18-feet to facilitate the passage of the 10-year storm (600 cfs). Additionally, should any road improvements be considered for this section of University Ave., then it is recommended that improvements be made, such as removing the crown, to better facilitate drainage to the north, into Boulder Creek.

Existing Culvert

Culvert C9: 8th St. and the Alley

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	6' x 3.25'	6	arch				64	<10	
10-yr	(2) 9' x 6'	18	box	170	48	12	673	10	$278,520
Max	(2) 10' x 6'	20	box	170	56	14	1,092	10-50	$797,915

This culvert is located partially on private property between 745 University Ave. and 765 University Ave. The culvert was constructed in 1940 and can only convey 64 cfs. The culvert dog-legs across the alley, across 744 Marine, and then diagonally across 8th St. where it outlets onto 1544 8th St. Like much of the Gregory Canyon Creek corridor, the city does not currently hold any easements in this area.

During the 2013 flood event, flood waters were widely spread-out in this area and not contained within the main creek channel. Because of that, there were no specific issues with culvert blockage or overtopping. It is recommended that the culvert be replaced with two 9' x 6' culverts which will enable the passage of the 10-year storm (673 cfs). Replacing this culvert would require easements from all intervening property owners.

Existing Culvert

Culvert C10: Marine St. between 8th St. and 9th St.

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	8 x 5'4'	8.5	box				155	<10	
10-yr	(2) 9' x 6'	18	box	70	38	10	673	10	$342,101
Max	(3) 9' x 6'	27	box	70	74	19	1,576	10-50	$500,520

As with the majority of culverts along Gregory Canyon Creek, the existing culvert at Marine St. between 8th and 9th St. conveys far less than the 10-year event. In order to convey the 10-year storm (673 cfs), it is recommended that two 9'x 6' box culverts be constructed and higher capacity inlets be installed along the curbs over the new culvert.

Existing Culvert

Culvert C11: Alley between Marine and Arapahoe

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	5' x 3.5'	5	arch				45	<10	
10-yr	(2) 10' x 6'	20	box	45	60	15	673	10	$278,520
Max	(2) 10' x 6'	20	box	45	60	15	673	10	$280,871

This alley provides vehicular access to several multi-family units. During the 2013 flood, a portion of the road at the downstream (north) side the culvert was washed out. This culvert was constructed in 1940 and was not replaced after the flood, although it was noted to be in very poor condition. It is recommended that the culvert be replaced with two 10' x 6' culverts which would convey the 10-year storm (673 cfs).

Existing Culvert

Culvert C12: Arapahoe Ave. just west of 9th St.

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	9' x 3'	9	box				141	<10	
10-yr	(2) 11' x 5'	21	box	65	48	12	673	10	$340,761
Max	(3) 12' x 5'	37	box	65	112	28	1,350		$543,292

Arapahoe Ave. also has a high crown, but not to the extent as University Ave. The culvert under Arapahoe was built in 1930 and is far too undersized for the attenuation that occurs during even a 10-year event at this point along Gregory Creek. It is recommended that this culvert be replaced with two 11' x 5' culverts in order to convey the 10-year storm (673 cfs).

Existing Culvert

Culvert C13: Drive to the Highlands School

Improvement	Size	Width	Shape	Length of culvert (ft)	Upstream Grading (ft)	Downstream Grading (ft)	CFS	Storm Eq.	Cost
Existing	4'	4	circular				7	<10	
10-yr	15' x 6'	15	box	25	44	11	673	10	$146,625
Max	(2) 15' x 6'	30	box	25	104	26	1,447	10-50	$290,877
Bridge: 30' Bridge span/ 26'deck width/30" deck thickness							830	10-50	$108,675

This culvert was constructed in 1970, and only conveys 7 cfs. Considering that this is the last culvert before Gregory Canyon Creek's confluence with Boulder Creek, and thus attenuation will be at its highest at this location, increasing the capacity at this location should be a priority. Installing a 15' x 6' culvert would convey the 10-year storm (673 cfs). However, constructing a bridge at this location was determined to be a more cost effective solution and could present opportunities to create an entrance that reflects the history and character of Boulder as well as offering opportunities to work in partnership with the owner of this historic property. Doing so would allow the creek to pass through in an open channel rather than a culvert and thus 830 cfs could then be conveyed.

Existing Culvert

CHANNEL MODIFICATIONS

In order to achieve better capacity along the creek, channel modifications were considered. Improvements to achieve a 100-year design capacity were determined to be infeasible due to the existing development along the creek corridor, but improvements could be constructed to achieve a 10-year design capacity. Culvert replacements would also require a certain amount of channel improvements both on the upstream end and the downstream end, as noted in the tables associated with each culvert.

Through the engineering evaluation, the following areas were identified as requiring channel improvements in order to achieve 10-year design capacity:

- Upstream of Euclid (200-foot reach)
- Between Euclid and College (200-foot reach)
- Between Marine and 8th St. (65-foot reach)

Based on qualitative field observations of the existing conditions, the following additional areas were identified for potential channel improvements:

- Downstream of Euclid (100-foot reach)
- Unnamed tributary across Smith Park to Euclid (450-foot reach)
- Between Pennsylvania Ave. and 7th St. (200-foot reach)
- Four creek sections between University Ave. and Arapahoe Ave. (four different 200-foot reaches)

In most of these locations, easements would be needed to construct and maintain the improvements.

IMPROVEMENTS OUTSIDE OF THE CHANNEL

Since the topographical and development constraints along Gregory Canyon Creek prevent modifications to the channel which would convey flows that are greater than a 10-year storm, it was recognized that the streets in the neighborhoods could potentially be modified to convey floodwaters for larger storm events. During the September 2013 event, floodwaters were observed in various roadways, with primary conveyance paths being 6th Street, 7th Street and 8th Street.

In some locations, such as along University Ave., crossing roadways acted as barriers to flood flows due to the high crown of the street. Therefore, potential street improvements were considered to help direct and retain water within the streets.

Existing Roadway Crown of University Ave. at 7th St.

The flow modeling used to formulate the mitigation measures showed that overflows from Gregory Canyon Creek onto the road system during a 100-year event could exceed 350 cfs for the roads identified for conveyance. Near Boulder Creek, the maximum achievable flow is 193 cfs which is approximately 50% of the modeled 100-year flows in the street. Street improvements would help to lessen flood damage during more frequent storm events.

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.

The property at 810 Marine St., which is located along Gregory Canyon Creek, was purchased by the city and the structure was removed in 2012 (see photographs next page). Along this creek, there are 32 structures located in the high hazard zone. Purchasing certain properties in the high hazard zone would not only remove the life-safety risk, but would also open up additional opportunities to improve flood conveyance in these areas.

810 Marine Before Acquisition

810 Marine After Deconstruction

810 Marine Before Acquisition

810 Marine After Deconstruction

Through this flood mitigation planning effort, the city has identified several properties in the high hazard zone along Gregory Canyon Creek which should be prioritized for purchase. There properties are along the downstream section of Gregory Canyon Creek, in close proximity to each other and to the recently purchased 810 Marine St. property, and therefore could facilitate a more consolidated and comprehensive flood mitigation planning effort. The properties identified for prioritization are listed in the table below:

Property Acquisition Priority Properties

Address	Assessed Value
704 Pleasant St.	$676,000
755 Pleasant St.	$863,000
744 University	$520,000
765 University	$585,900
1544 8th	$398,600
802 Marine St.	$429,400
818 Marine St.	$450,000
833 Marine St.	$570,600
1655 9th St.	$1,400,000
1639 9th St. #1	$289,600
1641 9th St. #2	$289,600
1643 9th St. #3	$289,600
1645 9th St. #4	$289,600
1647 9th St. #5	$289,600
1649 9th St. #6	$289,600
Total	$7,631,100

Note: 755 Pleasant St. includes two properties under the same ownership. One property has a residential structure and the other is vacant.

These properties were prioritized due to the following factors:

- Amount of the structure located within the high hazard zone
- Proximity to the creek channel/opportunities for additional flood mitigation measures
- Age and condition of the structure

In addition to removing the life safety risks associated with properties in the high hazard zone, purchasing these properties and removing or relocating the structures could open up opportunities for better channel maintenance, additional flood mitigation measures and the potential of neighborhood pocket parks.

Considering the complexities involved in purchasing a multi-unit/multiple owner condominium building (Units #1-6 at 1647 9th St.), if these units were not included as a priority, the remaining value of the prioritized properties is $5,729,500.

Since the high hazard acquisition program purchases properties that are on the market, the ability to purchase these properties is limited. Thus, the ability to plan a comprehensive mitigation plan that incorporates property acquisition is not currently feasible. It is acknowledged, though, that should one or more of these properties become available and there is a willing seller to the city, then mitigation planning should commence.

DETENTION

An evaluation of detention along Gregory Canyon Creek was performed to identify possible areas where detention facilities could help improve flows by attenuation or other means. The following areas were reviewed for potential detention:

- Immediately upstream of Flagstaff Rd.
- Smith Park
- Flatirons Elementary School

Detention upstream of Flagstaff Rd. would hold .42 acre-feet. Significant impacts associated with detention in this location could include excavation on Open Space and Mountain Park's property, potential reconstruction of Flagstaff Rd. to act as a dam. Flagstaff Rd. is greater than 10 feet above Gregory Canyon Creek which would cause the detention facility to be classified a jurisdictional dam and subject to the regulation of the Colorado State Engineers Office (SEO). This would require the completion of a hazard Classification Report to classify the hazard of the structure and increased regulatory approval and oversight though all phases of the dam design, construction and operation which would significantly increase the cost of the design, construction and ongoing operations and maintenance for a facility that would provide limited benefit to reducing peak flows downstream. Due to these consideration, detention upstream of Flagstaff Rd. is not recommended.

Detention at Smith Park could provide approximately 1.59 acre feet of storage, but this would fill in approximately three minutes in a ten year storm. The detention would necessitate excavation at depths ranging from 10-feet to 18-feet. Due to the relative cost for construction and earthwork and the minimal benefits this facility would provide, detention at Smith Park is not recommended.

The open fields on the south west corner of the Flatirons Elementary School were suggested for detention. This site could potentially provide 2.89 acre-feet of storage at a depth of 6-feet. During a 10-year storm, this pond would fill in approximately six minutes and hold flows for up to 48 hours after an event. This site would require approximately 400 feet of RCP pipes to deliver flow from Gregory Canyon Creek to the pond and up to 450 feet of pipe to return the flow to Gregory Canyon Creek.

The site could be continued to be used for the school playground, but as noted, once the pond fills, it would be full for up to 48 hours in a flooding situation and could pose a flash flood hazard to the school. Considering the safety issues, costs of excavation and piping and the limited benefits that this pond would provide, this site is not recommended for detention.

In summary, options for detention along Gregory Canyon Creek did not appear viable and therefore were not carried forward as feasible alternatives.

OTHER IMPROVEMENTS

Additionally, areas for sediment traps and habitat improvements were evaluated as well as opportunities to implement other improvements based on public input and observations from the 2013 Flood, such as a sanitary sewer main relocation and additional drainage inlets and possible grates.

Sewer Manhole Damage - Sept. 2013

Sediment Traps

The watershed contains natural areas with highly erodible soils. The 2013 flood resulted in unstable areas with loose rocks and debris. In order to better manage sediment, rocks and debris, sediment traps were considered. Areas initially identified for potential sediment traps included:

- Upstream of Culvert C1 (Willowbrook Rd.)
- Upstream of Culvert C2 (Aurora Ave.)
- Upstream of Culvert C6 (7th St. across from Flatirons School)
- Smith Park

These sites were selected because they were observed to have significant debris during the Sept. 2013 flood and are adjacent to existing streets or public land, providing adequate maintenance access. During the conceptual design the sediment traps at Aurora Ave. and Smith Park were eliminated from the recommended plan because existing site conditions made them infeasible or difficult to maintain. At the request of City Council, the sediment trap upstream of Culvert C6 was eliminated. No sediment trap should be installed on private property without property owner consent. Additional locations for sediments traps should be investigated, especially on properties owned by the City of Boulder.

Habitat Improvements

Protecting streams and enhancing wildlife habitat are important values of the community. Therefore, habitat improvements should be considered in addition to flood mitigation measures. Within the city limits, the majority of the Gregory Canyon Creek channel is 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

Storm Drain and Sanitary Sewer Improvements

Although this is a major drainageway mitigation plan and is not focused on storm drainage system improvements or the sanitary sewer system, a few areas were highlighted where improvements could be beneficial during a major storm event:

- Additional storm drainage inlets on Willowbrook Dr. to help capture overtopping floodwaters
- Relocation of the sanitary sewer manhole and pipes currently located within the "Gregory Gulch", which washed-out during the Sept. 2013 flood.
- Installation of grates above culverts

Civic Area Redevelopment

Flood hazards are a significant issue in the current planning efforts for the Civic Area, which includes portions of the Gregory Canyon Creek floodplain. The existing West Senior Center sustained damages from Gregory Canyon Creek during the September 2013 flood event. The Civic Area planning efforts have committed to being proactive about planning for and educating about floods that support sustainable and resilient development. As the Civic Area plan is developed, further evaluation of potential flood mitigation work is being undertaken.

ALTERNATIVE COSTS

Five alternatives were examined during the development of this mitigation plan, with four being developed by the consultant and one by the City. The first alternative included an upgrade of infrastructure for the 10-year storm event, which included adjacent channel grading to allow for proper expansion and contraction around the culvert; additionally, channel improvements through the corridor were included in this alternative. The second alternative examined what was termed as the maximum upgrade to infrastructure which included culvert sizes capable of handling flow between a 10-year and 50-year storm event, with similar channel grading for expansion and contraction; similarly, channel improvements through the reach were included as well. The third and fourth alternatives added additional improvements to the first and second alternatives by considering street conveyance enhancements throughout the corridor. The first alternative of 10-year infrastructure improvements was recommended by the consultant and City staff built upon this recommendation to develop their own recommended plan, or fifth alternative. This alternative includes select street conveyance improvements examined in the third and fourth alternatives, with additional work including sediment traps, habitat improvement, piping of Anderson ditch, and others. Cost estimates for the proposed alternatives are included in **Appendix A**.

ALTERNATIVE PLANS

The following figures graphically represent the alternatives considered in the analysis. The complete Alternative Analysis Memorandum with the Engineer's Recommended Plan is included in **Appendix A**.

LEGEND

- City Limits
- Creek
- Existing Sanitary Sewer
- Channel Improvements
- Existing Culverts
- Culvert Improvement
- Overflow Path
- Street Improvements
- 10Yr Channel Grading
- Max Channel Grading
- Potential Storm Inlet
- Potential Sediment Trap
- Proposed Detention Pond

Infrastructure Improvement
Dimensions are width x height
Recommended Plan in Bold

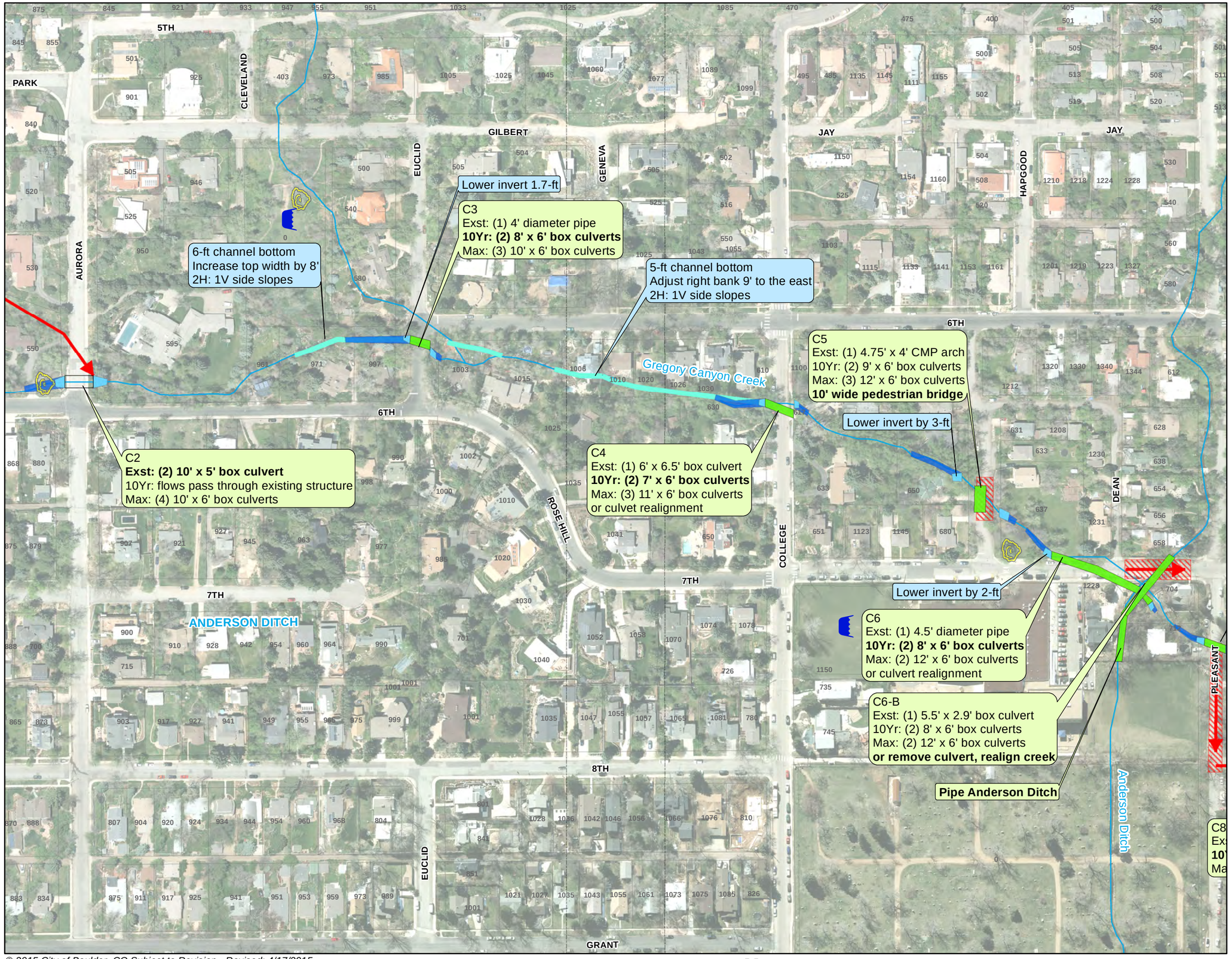
Channel Improvement

Gregory Canyon Creek Alternative Analysis Plan

Map 1 of 3

N

0 50 100 200 Feet



LEGEND

- City Limits
- Creek
- Existing Sanitary Sewer
- Channel Improvements
- Existing Culverts
- Culvert Improvement
- Overflow Path
- Street Improvements
- 10Yr Channel Grading
- Max Channel Grading
- Potential Storm Inlet
- Potential Sediment Trap
- Proposed Detention Pond

Infrastructure Improvement
Dimensions are width x height
Recommended Plan in Bold

Channel Improvement

Gregory Canyon Creek Alternative Analysis Plan

Map 2 of 3

N

0 50 100 200 Feet

C7
Exst: (1) 8' x 4.25' box culvert
10Yr: (2) 10' x 6' box culverts
Max: (2) 13' x 6' box culverts

Bank Stabilization
General Maintenance

Lower invert by 2-ft

C9
Exst: (1) 6' x 3.25' box culvert
10Yr: (2) 9' x 6' box culverts
Max: (2) 10' x 6' box culverts

Lower invert by 1-ft

Create open channel
9-ft bottom width
2H: 1V side slopes

Lower invert by 1-ft

C8
Exst: (1) 6' x 5' box culvert
10Yr: (2) 9' x 6' box culverts
Max: (2) 10' x 6' box culverts

Lower invert by 1-ft

Lower invert by 3.5-ft

C10
Exst: (1) 8' x 5' box culvert
10Yr: (2) 9' x 6' box culverts
Max: (3) 9' x 6' box culverts

Lower invert by 0.5-ft

Lower invert by 2-ft

C11
Exst: (1) 5' x 3.5' box culvert
10Yr: (2) 10' x 6' box culverts
Max: (2) 10' x 6' box culverts

Lower invert by 2-ft

Lower invert by 1.5-ft

C12
Exst: (1) 9' x 3' box culvert
10Yr: (2) 11' x 5' box culverts
Max: (3) 12' x 5' box culverts

C13
Exst: (1) 4' diameter pipe
10yr: (1) 15' x 6' box culverts
Max: (2) 15' x 6' box culverts
26' wide driveway bridge

Gregory Canyon Creek
Boulder Creek
UNIVERSITY
MARINE
ARAPAHOE
CANYON
PLEASANT
GRANDVIEW
6TH
7TH
8TH
9TH

LEGEND

- City Limits
- Creek
- Existing Sanitary Sewer
- Channel Improvements
- Existing Culverts
- Culvert Improvement
- Overflow Path
- Street Improvements
- 10Yr Channel Grading
- Max Channel Grading
- Potential Storm Inlet
- Potential Sediment Trap
- Proposed Detention Pond

Infrastructure Improvement
Dimensions are width x height
Recommended Plan in Bold

Channel Improvement

Gregory Canyon Creek Alternative Analysis Plan

Map 3 of 3

N

0 50 100 200 Feet

QUALITATIVE EVALUATION PROCEDURE

Typically, flood mitigation plans for the City of Boulder are developed with the intent to adequately convey a 100-year storm event. Due to the existing residential development along Gregory Canyon Creek, channel mitigation to convey a 100–year event would not be feasible unless many of the existing homes along the creek corridor were removed. Therefore, the following alternatives were assessed:

DO NOTHING

This alternate maintains the existing floodplains and channel configurations. Debris cleanup and routine maintenance in the floodplain would be required at regular intervals and following flood events. Maintaining the existing floodplain is the alternative that is used for comparison against all other alternatives.

10-YEAR IMPROVEMENTS

Currently, the Gregory Canyon Creek channel does not have adequate capacity to contain a 10-year storm event. While assessing mitigation alternatives, it was determined that improvements along the creek could be constructed which would facilitate flows from a 10-year event.

GREATER THAN 10-YEAR IMPROVEMENTS

This alternate includes improvements to culverts that could convey greater than the 10-year storm, the majority of which could convey 50- to 100-year storm events. While sections of the creek channel cannot be improved to convey an event greater than 10 years without the removal of existing houses, there are locations where culverts could be improved to convey 50- to 100-year events.

IMPROVEMENTS OUTSIDE OF THE CHANNEL

Since the topographical and development constraints along Gregory Canyon Creek prevent modification which would convey flows that are greater than a 10-year event, it was recognized that the streets in the neighborhoods could be modified to better convey floodwaters in larger events. Therefore, the alternatives analysis also includes street improvements to direct and retain flood waters within the streets in order to protect private properties.

PROPERTY ACQUISITION

This alternate identifies structures located in hazardous areas with high flood damage potential. The city's current property acquisition program, in conjunction with flood mitigation improvements has been very successful over the years and has resulted in a significant decrease in the number of structures within the High Hazard Zone. Removing structures in the high hazard zone also allows for additional channel improvements in selected areas. Acquisition of all flood prone properties was rejected because of the high costs. The plan does identify priority properties for acquisition.

DETENTION

This alternate would provide flood storage to reduce the peak discharge of floodwaters and related flood damages downstream of the facility. A flood storage facility can also be designed to be multi-purpose with park lands, open space, and playing fields located within it.

The alternatives analysis investigated the following locations for detention facilities:

- Immediately upstream of Flagstaff Rd.
- Smith Park
- Flatirons Elementary School

It was determined that detention facilities along Gregory Canyon Creek would provide little benefit in attenuating peak flows, and would result in increased safety risks and/or significant environmental impacts. Therefore detention was determined to be an infeasible alternative for the basin and was not further evaluated.

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 as a sub-alternate of every other alternate, not a "stand alone" alternate.

Evaluation

The alternatives were evaluated based on the cost of improvements, hydraulic calculations and benefits provided. They were also evaluated on qualitative aspects, including constructability, existing land use constraints, habitat impacts, public safety, public acceptance, and maintenance considerations. The feasibility of each alternative was also evaluated. The recommended alternative provides the highest benefit when considering quantitative and qualitative aspects of the project.

The first screening process of alternatives was the constructability, feasibility and overall benefit. If the improvements could not be feasibly constructed or would not result in any significant benefit, then there was no need for further investigation. Upon completion of the initial hydraulic analysis, the alternatives were evaluated based on how the costs compared to the benefits, and how well they could be implemented into the existing conditions. The remaining qualitative aspects were evaluated to develop the recommended plan. Each alternative and the corresponding advantages and disadvantages are included in the table below:

Comparison of Alternatives

Description	Advantages	Disadvantages
Do Nothing	- No construction impacts to wetlands and wildlife habitat - No land acquisition required - No construction costs	- No flood mitigation benefit - Aging infrastructure not replaced prior to failure
10-Year Improvements	- Increased drainage capacity - Greatest benefit/cost ratio - Minimal impacts to private property	- Requires work on private property - Requires easement acquisition - Wetland and wildlife habitat impacts - Does not provide 100-year flood protection
Greater than 10-Year Improvements	- Maximizes drainage capacity - Positive benefit/cost ratio	- Requires significant work on private property - Requires easement acquisition - Wetland and wildlife habitat impacts - Does not provide 100-year flood protection
Improvements Outside Of Channel	- Provides additional flood protection to private properties - Does not require work on private property - No construction impacts to wetlands and wildlife habitat - No land acquisition required*	- Low benefit cost ratio - Increased flood risk along streets - Does not provide 100-year flood protection
Property Acquisition	- Removes structures with highest flood risk - Provides opportunities for additional mitigation measures - Provides open space - Provides opportunities to enhance wetlands and wildlife habitat	- Low benefit cost ratio - Does not provide flood mitigation benefits to other properties - Requires private property acquisition

*Some land or easement acquisition could be beneficial in select locations.

SECTION 6-RECOMMENDED PLAN

PLAN DESCRIPTION

The Recommended Plan includes the following elements:

10-YEAR IMPROVEMENTS

The following channel and culvert/bridge improvements would facilitate flows from a 10-year design storm. These channel and culvert improvements are considered to be interrelated and necessary for the cohesive conveyance of Gregory Canyon Creek. To facilitate the phasing of future construction, the culvert and channel improvements have been divided into reaches that should be constructed from downstream to upstream in order to minimize adverse impacts to downstream property owners. The different reaches are illustrated on both the Recommended Plan and the conceptual design drawings (**Appendix E**).

Reach:	Cost
R1 – Private Drive to Highland School property	$248,900
R2 – Arapahoe Ave.	$471,200
R3 – Alley between Arapahoe Ave. and Marine St.	$1,725,300
R4 – Marine St.	$1,065,500
R5 – 8th Street	$1,513,600
R6 – University Ave.	$1,149,000
R7 – Pleasant St.	$487,900
R8 – 7th St.	$1,686,500
R9 – Pennsylvania Ave.	$452,000
R10 – College Ave.	$505,500
R11 – Euclid Ave.	$619,000
Total:	$9,924,400

STREET CONVEYANCE

It is recommended that flood mitigation street improvements be constructed in concert with other street construction projects. The street improvements proposed for 7th St. and Pleasant Ave. should be constructed that the time that the culverts in this area are replaced. The following street conveyance improvements are included in the Recommended Plan:

Street Conveyance	Cost
1. Lowering the intersection of University Ave. and 7th St. by 1.5 feet	$343,700
2. Lowering the intersection of Arapahoe Ave. and 7th St. by 2 feet	$343,700
3. Lowering the intersection of University and 6th St. by 1.5 feet	$330,500
4. Lower the intersection of Arapahoe Ave. and 6th St by 2 feet	$310,600

5. Increase the crown to 2% in the following locations:
   a. 6th and Anderson Ditch $62,100
   b. 7th and Anderson Ditch $101,800
   c. 6th, between Geneva and Euclid $217,300
   d. 6th , between Euclid and Aurora $372,500
6. Install a concrete gutter pan on the west side of the culvert at 6th and Aurora (C2) to better convey any street flows back into Gregory Canyon Creek $20,000

Total: $2,102,200

PROPERTY ACQUISITION

Continue acquiring high hazard zone properties, focusing on the properties identified as priority structures:

Property Acquisition Priority Properties

Address	Assessed Value
704 Pleasant St.	$676,000
755 Pleasant St.	$863,000
744 University	$520,000
765 University	$585,900
1544 8th	$398,600
802 Marine St.	$429,400
818 Marine St.	$450,000
833 Marine St.	$570,600
1655 9th St.	$1,400,000
1639 9th St. #1	$289,600
1641 9th St. #2	$289,600
1643 9th St. #3	$289,600
1645 9th St. #4	$289,600
1647 9th St. #5	$289,600
1649 9th St. #6	$289,600
Total	$7,631,100

CIVIC AREA PLAN RECOMMENDATIONS

Flood hazards are a significant issue in the current planning efforts for the civic area, which includes portions of the Gregory Canyon Creek floodplain. The civic area planning efforts have committed to being proactive about planning for and educating about floods that support sustainable and resilient development. The existing West Senior Center sustained damages from Gregory Canyon Creek during the September 2013 flood event and options for the redevelopment of this site are under evaluation. As the Civic Area plan is further developed, potential flood mitigation options will be further evaluated. This planning effort is shown on the recommended plan.

OTHER IMPROVEMENTS

Additional improvements included in the recommended plan are listed below.

Other Improvements	Cost
1. Pipe the Anderson Ditch to the east of 7th St.	$43,400
2. Assess stream and riparian areas and identify habitat improvements	TBD
3. Provide a sediment trap upstream of Culvert C1 (Willowbrook Rd.)	$86,100
4. Add new storm drainage inlets on Willowbrook Rd. to help capture floodwaters that overtop the culvert	$147,600
5. Relocate the sanitary sewer manhole and pipes currently located within the "Gregory Gulch".	$164,600
6. Investigate installing grates above culverts	TBD
Total:	$441,700

IMPLEMENT NON-STRUCTURAL METHODS

Continue to implement non-structural measures and encourage property owners to prepare for floods and protect their properties and themselves.

The recommended plan is graphically depicted on the following pages:

LEGEND

- City Limits
- Creek
- Ditch
- Existing Sanitary Sewer
- Priority HHZ Property Aquisition
- Channel Improvements
- Existing Culverts
- Culvert/Bridge Improvement
- Street Improvements
- Flood Mitigation Opportunity
- Habitat Improvements
- Proposed Storm Inlet
- Potential Sediment Trap

Culvert/Bridge Improvement
Dimensions are width x height

Other Improvement

Gregory Canyon Creek Recommended Plan

Map 1 of 3

N

0 50 100 200 Feet

Weed management
Channel improvements
Path overflow

C3
10Yr: (2) 8' x 6' box culverts

Install new concrete gutter pan

C2
Exst: (2) 10' x 5' box culvert

C4
10Yr: (2) 7' x 6' box culverts

C5
10' wide pedestrian bridge

C6
10Yr: (2) 8' x 6' box culverts

C6-B
Remove culvert, realign creek and pipe Anderson Ditch

5th St
Park Ln
Cleveland Pl
Gilbert St
Aurora Av
Euclid Av
Geneva Av
Jay St
Happood St
6th St
Pennsylvania Av
Gulch
Gregory Canyon Creek
Dean Pl
7th St
Rose Hill Dr
College Av
8th St
Anderson Ditch
Grant Pl

LEGEND

- City Limits
- Creek
- Ditch
- Existing Sanitary Sewer
- Priority HHZ Property Aquisition
- Channel Improvements
- Existing Culverts
- Culvert/Bridge Improvement
- Street Improvements
- Flood Mitigation Opportunity
- Habitat Improvements
- Proposed Storm Inlet
- Potential Sediment Trap

Culvert/Bridge Improvement
Dimensions are width x height

Other Improvement

Gregory Canyon Creek Recommended Plan

Map 2 of 3

N

0 50 100 200 Feet

LEGEND

- City Limits
- Creek
- Ditch
- Existing Sanitary Sewer
- Priority HHZ Property Aquisition
- Channel Improvements
- Existing Culverts
- Culvert/Bridge Improvement
- Street Improvements
- Flood Mitigation Opportunity
- Habitat Improvements
- Proposed Storm Inlet
- Potential Sediment Trap

Culvert/Bridge Improvement
Dimensions are width x height

Other Improvement

Gregory Canyon Creek Recommended Plan

Map 3 of 3

N

0 50 100 200 Feet

SECTION 7-CONCEPTUAL DESIGN

OVERVIEW

Conceptual design drawings were developed based on the Recommended Plan and are included as **Appendix E.** These drawings are intended to depict a long-range plan for future flood mitigation projects and show the general extents and nature of the proposed improvements. The conceptual design drawings are not intended for construction use. Prior to the construction of any improvements, a complete design will be required and construction documents developed. In addition to the conceptual design drawings, CH2M completed a Conceptual Design Memorandum to document design criteria and the results of the hydraulic analysis. The Conceptual Design Memorandum is included as **Appendix B**.

During the development of the conceptual design drawings, city staff met with individuals and small groups of property owners directly impacted by the proposed improvements to discuss the proposed plans and receive feedback on the conceptual design drawings. The conceptual design drawings were revised to incorporate the comments and concerns received from property owners, to the greatest extent possible.

Input from property owners and City Council, and the engineering analysis conducted during the development of the conceptual design drawings resulted in additional refinements to the Recommended Plan, including:

- A proposed sediment trap at Smith Park was eliminated because existing site grades are too steep to make it feasible.
- A proposed sediment trap upstream of Aurora Ave. was eliminated because the existing channel is much lower than the existing street elevation, so maintenance of the sediment trap would be difficult.
- A proposed sediment trap upstream of 7th St. was eliminated due to property owner concerns.
- The replacement of the private culvert at 705 Willowbrook was removed from the recommended plan because private property improvements were being implemented in this area to reduce flood risks and therefore the replacement would provide little benefit.

PRIORITIZATION AND PHASING

The proposed improvements have been divided into reaches, as depicted on the Recommended Plan and the conceptual design drawings. The channel and culvert/bridge improvements required to convey the 10-year design storm were assigned a high priority while inlet and sediment trap construction was regarded as low priority. To minimize adverse impacts to downstream property owners, the improvements should be constructed from downstream, R-1, to upstream, R-11. The proposed piping of the Anderson Ditch should occur with the construction of the culvert C6 at 7th Street (R-8). The following table summarizes the prioritization and phasing the different improvements:

Prioritization and Phasing

Construction Phasing		High Priority		Low Priority	
		Culvert / Bridge Improvements	**Channel Improvements**	**Sediment Trap**	**Inlet Improvements**
Downstream		**R-1 – Private Drive**			
		R-2– Arapahoe Avenue	x		
		R-3 – Alley Way	x		
		R-4 – Marine Street	x		
		R-5 – 8th Street	x		
		R-6 – University Avenue	x		
		R-7 – Pleasant Street			
		R-8 – Anderson Ditch	(Construct with 7th St. Improvements)		
		R-8 – 7th Street	x	x	
		R-9 – Pennsylvania Avenue	x		
		R-10 – College Avenue	x		
Upstream		**R-11 – Euclid Avenue**	x		
		Willowbrook Road		x	x

BENEFIT COST ANALYSIS

The benefit cost analysis conducted during the alternative analysis was updated for the conceptual design. The conceptual design included additional channel improvements, with a more structurally constructed channel and several drop structures to achieve a stable slope. Although this resulted in increased costs, the calculated benefits also increased. The resulting BCR of the proposed improvements is 2.82. Detailed benefit cost analysis information is included in **Appendix B**.

SECTION 8-REFERENCES

A September to Remember; Urban Drainage and Flood Control District, 2014.

Alternative Analysis - Pennsylvania Avenue Flood Repair / Improvement Alternative Analysis; City of Boulder, 2014.

The Anderson Ditch: http://bcn.boulder.co.us/basin/ditchproject/?Our_Ditches:Anderson_Ditch

Boulder Valley Comprehensive Plan; 2010; https://www-static.bouldercolorado.gov/docs/boulder-valley-comprehensive-plan-2010-1-201410091122.pdf

City of Boulder-Comprehensive Flood and Stormwater Utility Master Plan; 2004; https://bouldercolorado.gov/flood/comprehensive-flood-and-stormwater-master-plan

City of Boulder-Greenways Master Plan; 2010; https://www-static.bouldercolorado.gov/docs/2011-greenways-master-plan-update-1-201304221316.pdf

The Columbia Cemetery: https://bouldercolorado.gov/parks-rec/columbia-cemetery

Floods in Boulder County, Colorado, A Historical Investigation; Sherry D. Oaks; 1982.

Flood Hazard Area Delineation- Boulder and Adjacent County Drainageways; Greenhorne and O'Mara, 1987.

Hannah Barker House: http://www.historicboulder.org/the_hannah_barker_house.html

Highlands School: http://historichighland.com/building-grounds/history/

Hydraulic Mitigation Analysis - Gregory Canyon Creek High Hazard Zone Reanalysis – Mini - Master Plan; Belt Collins West, 2009.

Hydraulic Mitigation Analysis - Gregory Canyon Creek Mitigation Analysis; WH Pacific, 2012.

LOMR Determination - Gregory Canyon Creek LOMR Determination Data Reconciliation; Belt Collins West, 2010 (Approved by FEMA, 2010).

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.

Rainfall-Runoff Analysis for the September 2013 Flood in the City of Boulder, Colorado; Prepared by Wright Water Engineers for the City of Boulder and released in Sept. of 2014.

Soil Survey of Boulder County Area, Colorado, United States Department of Agriculture Soil Conservation Service in cooperation with Colorado Agriculture Experiment Station, 1975

Summary Report of Private Property and Resident Flood Impact Survey and Analysis, September 2013 Flood Disaster prepared by the City of Boulder-Utilities Division; Dec. 3, 2014: https://www-static.bouldercolorado.gov/docs/summary-report-private-property-resident-september-2013-flood-impact-survey-analysis-1-201412031729.pdf

APPENDICES

APPENDIX A-ALTERNATIVE ANALYSIS MEMORANDUM

APPENDIX B-CONCEPTUAL DESIGN MEMORANDUM

APPENDIX C-PUBLIC COMMENTS

APPENDIX D-WETLAND AND HABITAT EVALUATIONS

APPENDIX E-CONCEPTUAL DESIGN DRAWINGS