MEMORANDUM CH2MHILL®

Alternative Analysis Memorandum

PREPARED FOR: City of Boulder

COPY TO: Urban Drainage and Flood Control District

PREPARED BY: CH2M HILL

DATE: March 18, 2015

PROJECT NUMBER: 482330

In September 2013, the City of Boulder experienced an intense rainfall event between September 9 and September 18, approximately 10 days. This rainfall event generated flooding in and around the City of Boulder, including the area along and adjacent to Gregory Canyon Creek. Gregory Canyon Creek is a right bank tributary that enters Boulder Creek west of Broadway. During the storm event of 2013, many residents experienced damage to their property due to high flood waters as well as observed flooding in public roadways. The extents of the observed flooding is documented in **Figure 1.**

CH2M HILL was retained by the City of Boulder to evaluate potential alternatives to help alleviate flooding along Gregory Canyon Creek. The purpose of this Alternative Analysis Memorandum for the *Gregory Canyon Creek Major Drainageway Plan* (Study) is to present the findings of the hydraulic analysis, define problem areas, and develop preliminary categories to mitigate flood hazards within the basin.

Project Location

Gregory Canyon Creek watershed is located in the City of Boulder (City) and Boulder County. Gregory Canyon Creek originates in Boulder County Open Space in Boulder Mountain Park. As flow becomes more concentrated a well-defined channel is visible upstream of Flagstaff Road. At Flagstaff Road, Gregory Canyon Creek is conveyed into the City of Boulder via 60-inch RCP that is lined with a 54" PVC liner. From here, Gregory Canyon Creek is located entirely within the City of Boulder and is bounded by residential development until the confluence with Boulder Creek. The project watershed and study area are depicted in **Figure 2.**

Gregory Canyon Creek generally flows to the northeast direction through developed neighborhoods. The creek is conveyed through many crossings, both publically and privately constructed. Very few easements are dedicated to the City of Boulder throughout the channel corridor, with a number of crossings being owned and maintained by private property owners. In addition, as Gregory Canyon Creek exists on private property, homeowners are responsible for the channel maintenance. The lower portions of the channel are bounded by more dense residential housing, including multi-family development. Downstream of Arapahoe Road, the channel has recently been improved and appears to be stable prior to the confluence with Boulder Creek.

Description of Data Obtained

The City of Boulder provided CH2M HILL with current GIS data, topography information, reports, and as-built plans for Gregory Canyon Creek and surrounding areas. This information was used in the analysis presented in the memorandum. For a complete list of data provided please see **Table 1** in the attached technical appendix.

Acknowledgements

This memorandum was completed with the support and input from various individuals at the City of Boulder and Urban Drainage and Flood Control District (UDFCD). The key participants in the development of this memorandum are shown in **Table 2**.

TABLE 2
Project Contributors

Project Team Members	Affiliation	Role
Katie Knapp	City of Boulder	Project Manager
Annie Noble	City of Boulder	Stakeholder
Kristin Dean	City of Boulder	Stakeholder / Utilities Planner
Christin Shepard	City of Boulder	Stakeholder / GIS Analyst
Shea Thomas	UDFCD	Stakeholder
Alan Turner	CH2M HILL	Project Manager
Morgan Lynch	CH2M HILL	Project Engineer
Frans Lambrechtsen	CH2M HILL	Staff Engineer

Hydrology

A hydrologic analysis was not performed by CH2M HILL 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.

Hydraulics

For this memorandum, it was concluded that a detailed look at the hydraulic function of Gregory Canyon Creek was needed to better understand the natural flow paths. Through this understanding the City of Boulder formulates and CH2M HILL analyzed improvement elements into categories to decrease the flood risk to properties as part of the deliverable for the this analysis. These categories are described in detail in subsequent sections.

Previous Studies

In addition to the hydrologic analysis documented in the Major Drainageway Planning Study – *Boulder and Adjacent County Drainageways*, six other studies have been done along Gregory Canyon Creek. The most recent hydraulic analysis was completed by Belt Collins West (2007) to analyze the 100-year floodplain, the 0.5-ft rise floodway, and the high hazard zone for the City of Boulder. The study was based on the 1987 hydrology completed by Greenhorne & O'Mara as part of the Major Drainageway Planning Study – *Boulder and Adjacent County Drainageways*. The original hydraulic study was performed using HEC-2 but was never adopted by FEMA. Belt Collins West (2007) used HEC-RAS version 3.1.3 to update the floodplains along Gregory Canyon Creek. This analysis incorporated updated topography, dated 2007. Debris blockage at bridges and culverts were applied to the hydraulic analysis and a model for the split flow reach that was identified at Marine Street was developed to better define the floodplain in this area. This study was later updated in 2009 to define the structures in or adjacent to the high hazard zone with additional cross-sections and 1-ft ground survey. Alternatives to remove seven structures from the high hazard zone were documented in the 2009 report. The floodplain and floodway identified by Belt Collins *Gregory Canyon Creek LOMR Determination Data Reconciliation* in the 2010 analysis reflects the effective conditions published in the Boulder County FIS, dated December 18, 2012. The effective studies as well as the other studies performed along Gregory Canyon Creek are documented in **Table 3**.

TABLE 3
Previous Studies

Document Type	Source	Description
Major Drainageway Planning Study	Greenhorne and O'Mara, 1984	Boulder and Adjacent County Drainageways "Phase A"
Major Drainageway Planning Study	Greenhorne and O'Mara, 1987	Boulder and Adjacent County Drainageways "Phase B"
Flood Hazard Area Delineation	Greenhorne and O'Mara, 1987	Boulder and Adjacent County Drainageways
Hydraulic Mitigation Analysis	Belt Collins West, 2009	Gregory Canyon Creek High Hazard Zone Reanalysis – Mini - Master Plan
LOMR Determination	Belt Collins West, 2010	Gregory Canyon Creek LOMR Determination Data Reconciliation (Approved by FEMA, 2010)
Hydraulic Mitigation Analysis	WH Pacific, 2012	Gregory Canyon Creek Mitigation Analysis
Alternative Analysis	City of Boulder, 2014	Pennsylvania Avenue Flood Repair / Improvement Alternative 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. A summary of the existing crossings are located in **Table 4**. 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 and the updated Existing Conditions Models is located in **Table 5** in the technical appendix. No other

changes were made to the baseline model to create the existing conditions HEC-RAS model for the purpose of this analysis.

Table 4
Existing Crossing Summary

Location	Percent Blockage Assumption	Belt Collins Geometry, 2010	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

Detention Evaluation

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 Road;
- Smith Park;
- and Flatirons Elementary School.

Detention Upstream of Flagstaff Road

One foot contours from the 2013 LiDAR set were utilized to develop an Area-Storage relationship for this location. **Figure 7** in the technical appendix shows the Area-Storage curve. The proposed detention pond would hold 0.42 acre-feet. Using this curve and detention volume, a SWMM model was developed using the existing culvert as pipe conduit at the invert, and an overflow weir elevation that matched the road elevation. This minor attenuation in flows is the result of storage volume upstream of Flagstaff Road being filled on the rising limb of the hydrograph prior to the peak discharge arriving at Flagstaff Road, at which point the peak flows overtopped the road. To achieve additional attenuation, earth work would need to be completed including excavation upstream on Open Space and Mountain Parks property which is not desired.

Additional consideration for this site includes the requirement of a geotechnical analysis and potential reconstruction of Flagstaff Road to act as a dam. Flagstaff road is greater than 10 feet above Gregory Canyon Creek thalweg 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 through 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 down stream

Detention at Smith Park

The slope of Smith Park drops approximately 30 feet from Gilbert Street on the west to the Gregory Canyon Creek Channel. To accommodate an offline detention facility at Smith Park, a 10 foot excavation would be required to provide storage volume. This would extend to 18' deep on the west sides of the detention facility. This area would provide approximately 1.59 ac-ft. of storage and would fill during a 10 year storm in approximately 3 minutes providing very little attenuation to flow rates in the downstream direction. **Figure 8** in the technical appendix shows the Area-Storage curve. Due to the relative cost for construction and earthwork and the minimal benefits this facility would provide it was not moved forward for further consideration.

Detention at Flatirons Elementary School

The open fields on the south west corner of the school were suggested as a potential site for detention of flows from Gregory Canyon Creek. This site could potentially provide a maximum of 2.89 ac-ft of storage on the school open space at a depth of 6 feet deep. **Figure 9** in the technical appendix shows the Area-Storage curve. This pond would fill in approximately 6 minutes during a 10 year event and hold flows for up to 48 hours after an event. This would again provide very little attenuation of the peak flows down the mainstem of Gregory Canyon Creek as the pond would fill during the rising limb of the hydrograph. In addition, 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.

This site could continue to be used for a playground for the school but would fill and be full for up to 48 hours in a flooding situation and could pose a flash flood hazard to the school due to the proximity of the pond to

the school. Due to the potential safety issues, cost of excavation and piping and limited benefits from the pond, this pond alternative was not considered further.

Due to the relative expense and limited impacts of full detention on the peak flows along Gregory Canyon Creek, detention was determined to be an infeasible alternative for the basin. However, these sites and other small open areas can provide opportunities for sediment and debris traps which are discussed below.

Sediment Traps

One of the issues seen during the 2013 storm event was significant amounts of sediment and debris being transported by flood waters. The City requested that an analysis be performed to determine the feasibility of sediment traps being installed along the channel corridor. Potential locations for sediment traps include:

- Upstream of the Willowbrook Rd. culvert
- Upstream of Aurora Avenue culvert
- Between Pennsylvania Ave. and 7th St.

The open area at the corner of 7th Street and Pennsylvania Avenue was analyzed to determine the effectiveness of a sediment trap.

A sedimentation study prepared by Moser & Associates, in the nearby Fourmile Canyon, was conducted in 2008 for UDFCD title *Sediment Analysis Report – Four Mile Canyon Creek Downstream of 30th Street.* This report along with Muller's report *Evaluation of Fourmile Canyon Creek Sediment Basin Alternatives* completed in 2012 for the City of Boulder are the foundation for this analysis. According to these reports, sediment basins are useful for 2-year flows when sediment loads are the greatest. When considering a sediment basin, potential impacts to the floodplain should always be kept in mind so as to avoid increases in the regulatory floodplain.

Moser & Associates, in their 2008 report, stated that sediment loads for Fourmile Canyon were on the magnitude of 100 tons per square mile per year. While the study was developed for Fourmile Canyon Creek, Gregory Canyon Creek is located in a similar geographic region and may see similar loads. Under this assumption, 100 tons per square mile per year for Gregory Canyon Creek equaled a sediment load of 229 tons per year. This equates to 116 cubic yards.

With approximately 10,000 square feet available three sediment trap alternatives are proposed. One inline basin of 1,100 square feet, and two offline basins of 1,700 and 2,500 square feet. The efficiency of the basin is a function of the 2-year peak flow and the surface area of the basin; large flat basins are more efficient. The efficiencies, amount of sediment trapped, and estimated costs are shown for the 2-year peak flow of 161 cfs in **Table 6**. Cost assumptions came from Muller's report as an average cost per cubic yard of approximately $898.00 per cubic yard trapped. The Gregory Canyon Creek Master Plan contingency used for other costs developed in this study was applied and increased the cost per cubic yard to $1,616.00. Note that cost for sediment basins are a function of their overall efficiency. A consideration for impacts to property should also be considered. If space or easement acquisition is limited, an inline basin may be more effective. **Figure 10** in the technical appendix shows these proposed alternatives at this location.

TABLE 6
Sediment Trap Analysis

Alternate	7th St - Alt 1	7th St - Alt 2	7th St - Alt 3	Euclid Avenue	Willowbrook Road
Surface Area	2500	1100	1700	1700	1200
n (1 = inline, 2 = offline)	2	1	2	2	1
Vs (settlement velocity, fine sand)	0.059	0.059	0.059	0.059	0.059
R (efficiency)	0.53	0.29	0.42	0.42	0.31

TABLE 6
Sediment Trap Analysis

Alternate	7th St - Alt 1	7th St - Alt 2	7th St - Alt 3	Euclid Avenue	Willowbrook Road
Sediment Trapped (Ton)	121	66	96	96	70
Sediment Trapped (CY)	90	49	71	71	52
Estimated Cost ($)	$80,677.01	$43,762.94	$63,765.36	$63,765.36	$46,526.23

FLO-2D Evaluation

During the storm event that occurred in September 2013, 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, to better understand the flow paths of larger storm events. 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 **Table 7** for all Manning's N assumptions for the FLO-2D hydraulic model. A summary of the HEC- 1 peak discharges and their approximate location in the two – dimensional analysis are located in **Table 8**.

TABLE 7
Manning's N Documentation

Landuse 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

TABLE 8
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 **Table 8**. The results of the existing 100-year storm event are shown in **Figure 3** in the technical appendix. The results of the FLO-2D analysis confirmed what was observed by homeowners

during the September 2013 storm event. A comparison to the September 2013 event is also shown in **Figure 4**.

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. These alternatives are discussed in detail in the subsequent sections. The potential improvements identified during the site walk are located in **Table 9**.

TABLE 9
Potential Improvement Summary

Location	Proposed Improvement	Number of Properties Impacted
Upstream of Willowbrook Road Cul-de-Sac	Bank Stabilizations	3
Private Crossing on 711 Willowbrook Road	Culvert Improvements	2
Crossing at Willowbrook Road	Trash Rack / Culvert Entrance	0
Willowbrook Road at Gregory Gulch	Reconfigure Drainage Inlets	3
Crossing at Aurora Avenue	Culvert / Channel Improvements	3
Adjacent to 6th Street	Channel Improvements	1
6th Street North of Aurora Avenue	Increase Roadway Conveyance	Varies - Residential Drives
Euclid Avenue	Culvert Improvements	2
7th Street Past Rose Hill Drive	Increase Roadway Conveyance	Varies – Residential Drives
Crossing at College Avenue	Maximize Culvert Capacity / Alignment	4
1100 6th Street	Sidewalk Repair	1
Crossing at Pennsylvania Avenue	Culvert Repair / Removal	Varies – Potential Reroute of Traffic
7th Street at Anderson Ditch	Maximize Roadway Conveyance and Pipe Irrigation Ditch	Multiple with Street construction / Located adjacent to school
Between Pleasant Street and University Avenue	Bank Stabilization	2
University Avenue to Marine Street	Increase Culvert Capacity / Channel Improvements	Multiple
Alley Between Arapahoe Road and Marine Street	Increase Channel Capacity / Replace Aging Culvert	5
North of Arapahoe Road	Upsize Culvert / Construct Bridge	1
7th Street at Arapahoe Avenue	Increase Roadway Conveyance	Varies - Residential Drives

In addition to the proposed improvements identified during the site walk, documented in **Table 9**, CH2M HILL noticed other deficiencies along Gregory Creek Canyon through detailed hydraulic modeling. The channel geometry between Euclid Avenue and College Avenue is 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.

Alternative Analysis

Flood hazards within the Gregory Canyon Creek watershed are primarily due to undersized channel geometry and culvert crossings. The watershed is considered to be fully developed with the channel corridor located almost entirely on private property. The narrow channel corridor, lack of drainage easements, and narrow right-of-way, limits the flood control elements that can be proposed. Knowing these constraints, the City of Boulder directed CH2M HILL to look at categories of improvements that could mitigate flooding risks while working within the horizontal constraints of the existing channel. In addition to these constraints, criteria that were considered while developing the proposed alternatives are documented in **Table 10**.

TABLE 10
Design Criteria

Source	Document
City of Boulder	Design and Construction Standards – Storm Water Design, 2005
City of Boulder	Design and Construction Standards – Transportation Design, 2009
Urban Drainage and Flood Control District	Urban Storm Drainage Criteria Manual – Volume 2, 2008

Due to the horizontal and vertical constraints along Gregory Canyon Creek proposed improvements will likely require easements and impact adjacent property owners. The City of Boulder staff requested that CH2M HILL evaluate two different categories of elements

- Category One – Channel and Culvert Improvements;
- Category Two –Improvements Outside of the Channel.

The intent of the proposed categories is to mitigate flooding risk with Category One being confined along the main channel corridor and Category Two including improvements to accommodate spill flows that escape the channel. It is recommended that the City of Boulder work with the residents and property owners along Gregory Canyon Creek to clear channel brush and debris located in the floodway and stabilize channel banks. The following describes the categories of elements that were evaluated. Design Criteria and assumptions for the development and analysis of the alternatives and categories can be found in **TABLE 17** in the technical appendix.

Category One – Channel and Culvert Improvements. This category was envisioned to provide recommendations for improvements along the creek centerline along with brush and debris clearing. The existing culvert infrastructure was reviewed to recommend replacements and improvements to the aging infrastructure along Gregory Canyon Creek to ensure that the culvert crossings could pass flow contained within the Gregory Canyon Creek channel and identify required modifications to the channel. Due to the current condition of these culverts, it is assumed that culvert replacement along Gregory Canyon Creek may occur to replace any damaged or aging infrastructure. Hydraulically the channel capacity is limited to approximately the 10-year flow rate. Culverts were sized in this category to pass the ten year flow rate. Channel improvements in the immediate vicinity of new culverts would be needed to accommodate the larger culvert size, and are included in the project scope of each individual culvert. In addition, channel deficiencies were noted in areas with severely reduced capacity that did not meet the 10 year criteria by the majority of the channel or the surrounding infrastructure. In addition, if a larger culverts could be constructed based on

visual horizontal and vertical constraints these larger culvert sizes were analyzed. These maximum culvert sizes and constraints are in **Table 11** in the technical appendix. The improvements associated with Category One are illustrated in **Figure 5** in the technical appendix.

Category Two –Improvements Outside of the Channel. For the purposes of this analysis, Category Two builds on the channel optimization of the Gregory Canyon Creek channel presented in Category One and seeks to maximize the flood conveyance of the major overflow paths while adhering to the local criteria and constraints. Category Two includes proposed roadway sections to proactively convey floodwater that exceed the Gregory Canyon Creek channel in identified roadways. During the storm event in September 2013, floodwaters were observed in various roadways with primary conveyance paths being 6th Street, 7th Street and 8th Street. These flow paths were identified as potential options for conveying larger storm events in places where Gregory Creek is physically constrained by adjacent structures. A FLO-2D model was developed to understand how the streets conveyed flow during larger storm events. These flow paths are shown in **Figure 3**. Based on these models, 6th Street, 7th Street, 8th Street and Willowbrook were identified as major water courses and were then formalized and optimized as drainage routes. It became clear that the overflows from Gregory Canyon Creek into the road system during the 100-year event could exceed 350 cfs for the roads identified for conveyance. As 6th Street, 7th Street and 8th Street approach Boulder Creek, the grades of the roads flatten from almost 6% grade in the upper watershed to closer to 1% in the lower watershed. The flatter slope was used to understand the maximum flow that could be achieved in the street sections without exceeding the city's 12 – inches maximum flood criteria. Near Boulder Creek the maximum achievable flow is 193 cfs which is approximately 50% of the modeled 100 year flows in the street. This conveyance capacity is achieved by installing 30-foot wide roads, 6-inch curb and gutter, a four-foot sidewalk with an additional 6-inch curb on the back end. This category, while not solving the 100-year flooding problem could go a long way to help alleviate flood damage.

It is recommended that the City work with local emergency agencies to identify safety and access issues along these routes during flood events and to provide signage to indicate that the roads are designed as flood conveyance facilities. The roadway flood conveyance was assumed to have a typical gutter depth of 6-inches for each residential street. Flows were not allowed to exceed the City's 12-inch maximum requirement of depth of flow in the street. The improvements associated with Category Two are located in **Figure 6** in the technical appendix.

After the Public Open House and WRAB meeting on October 20, 2014 which provided public input on the categories, the city staff organized the elements into 15 alternatives. These alternatives are identified in **Table 12** below. The alternatives were used to develop benefit/cost relationships to help understand the most cost effective alternative in the basin to help improve public health and safety and minimize flood damages. Of the 15 alternatives the following alternatives were analyzed for the benefit cost analysis because they reflected the effects of all the infrastructure improvements on the Gregory Canyon Creek System.

- 10 Year Culvert and Channel Improvements.
  - Includes 10 Year culvert and channel improvements from Category 1
- Maximum Culvert Improvements with localized channel improvements.
- Includes maximum culverts and channel improvements from Category 1 10 Year Culvert and Channel Improvements with overflow path improvements
  - Includes 10-year culvert and channel improvements from Category 1, with roadway and overflow path improvements from category 2
- Maximum Culvert Improvements with localized channel improvements and roadway conveyance
  - Includes maximum culverts and localized channel improvements from Category 1, with roadway and overflow path improvements from category 2

The remainder of the alternatives identified by city staff are intended to reflect phasing of the alternatives to further analyze the system.

TABLE 12

Gregory Canyon Creek Alternatives

	Lower Reach			Middle Reach			Upper Reach		
	Culvert and Channel Improvements		Street Conv.	Culvert and Channel Improvements		Street Conv.	Culvert and Channel Improvements		Street Conv.
	10 yr	Max		10 yr	Max		10 yr	Max	
Alternative 1	x								
Alternative 2		x							
Alternative 3	x		x						
Alternative 4		x	x						
Alternative 5	x			x					
Alternative 6		x			x				
Alternative 7	x		x	x		x			
Alternative 8		x	x		x	x			
Alternative 9	x			x			x		
Alternative 10		x			x			x	
Alternative 11	x		x	x		x	x		x
Alternative 12		x	x		x	x		x	x
Alternative 13	Gregory Gulch Pipe								
Alternative 14	Piping Anderson Ditch								

All of the defined alternatives were built into the effective HEC-RAS models to determine the depth of flow throughout the system which was used to determine benefits. All figures and tables in the technical appendix have been updated to capture the revised alternatives. **Table 13** is a summary of the alternatives and their respective costs. Line items for Gregory Gulch Pipe at Willowbrook Road and the piping of Anderson Ditch are included separately.

TABLE 13

Summary of Alternative Costs

Alternative	Cost	Notes
10-year	$ 4,692,167.00	**Includes:** 10-year culvert improvements, adjacent channel improvements for culverts, and channel improvements in other areas to increase to 10-year capacity.
10-year With Overflow Conveyance	$ 8,505,643.00	**Includes:** 10-year culvert improvements, adjacent channel improvements for culverts, channel improvements in other areas to increase to 10-year capacity, and street conveyance in critical areas. Also includes the Gregory Gulch pipe.
Maximum	$ 7,876,974.00	**Includes:** Maximum culvert improvements, adjacent channel improvements for culverts, and channel improvements in other areas to increase to 10-year capacity.
Max With Overflow Conveyance	$ 11,690,450.00	**Includes:** Max culvert improvements, adjacent channel improvements for culverts, channel improvements in other areas to increase to 10-year capacity, and street conveyance in critical areas. Also includes the Gregory Gulch pipe.
Anderson Ditch Pipe	$ 23,450.00	**Includes:** Piping of Anderson Ditch.

Benefit Cost Analysis

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

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

Data Collection

The primary resource for allocating data to develop the benefit cost analysis was the Federal Emergency Management Agency (FEMA) HAZUS – MH computer program and the FEMA BCA tool. A HAZUS-MH database produced by FEMA that categorized the structures, foundation types, first floor elevation identification number, structure value and contents value created in response to the 2013 flood, provided the base information to determine benefits for each of the alternatives. This data included information on the first floor elevation value, foundation, type, structure type, and the number of stories. Additional data included assessor data from Boulder County which included a descriptor of the basement type to help identify how to modify the lowest adjacent grade to compute first floor elevation.

Methodology

In order to determine the benefit costs to the proposed alternatives, an analysis was performed using water surface elevations based on the HEC-RAS models developed for each alternative. Lowest adjacent grades for the homes were interpolated from a surface based on 1-ft contours using ArcGIS, and first floor elevations were assigned based on the county assessor information with specific attention given to basement type. The lowest adjacent grades were modified based on basement type using the values in Table 18 in the Appendix. If a basement type was "unfinished" then the structure was assumed to act as a slab on grade structure. This elevation was compared against the water surface elevations for the 10-, 50-, 100-, and 500-yr recurrence interval storms to develop the depth of flooding relative to the first floor elevation of all impacted structures. This analysis resulted in a list of structures within the floodplain for each storm event, and each alternative.

Depth-damage functions were pulled from the BCA Tool 5.1 program developed by FEMA. These functions provide a damage percentage of both the structure value and contents value of a structure based on the depth of flooding experienced at the structure. Both structure and contents values were included in the BCA analysis. The structure information acquired from FEMA included differing categories of structures. These included

- Structure type
  - Residential
  - Commercial
  - Industrial
  - Governmental
  - Education
- Number of stories
- Foundation Type
  - Basement
  - Crawl space
  - Slab on grade
- Basement Type
  - Walk-out (finished/unfinished)
  - Subterranean (finished/unfinished)
  - Garden (finished/unfinished)

These structure categories formed a unique identifier that corresponded to a specific depth – damage function from the BCA Tool model. A separate depth damage function was created separately for Garden and Subterranean basements to modify when damage began to occur. A lookup table was setup to match structure, with the assigned water depth, to determine the percentage of damage for each return period and alternative. Damages for each alternative were compared to existing conditions damages to determine the benefits of each alternative.

Average annual damages were determined for each alternative by multiplying the damages by the probability of recurrence. In addition, all costs for the alternatives were converted average annual costs. This was done by taking a 7% amortization rate and assuming a fifty year project lifespan per the guidance from the FEMA BCA guidance.

Table 14 presents a summary of the damages calculated for existing conditions and the alternatives. **Table 15** presents a summary of the benefit cost ratios. **Table 16**, in the technical appendix, provides a more detailed view of the damages per alternative.

ALTERNATIVE ANALYSIS MEMORANDUM

TABLE 14
Summary of Damages (Structure and Contents) for Existing Conditions and Alternatives

Probability	Storm Event	Damage from Storm Event				
		Existing	10-yr	10-yr w/ Street	Max	Max w/ Street
0.2	5-yr	$0.00	$0.00	$0.00	$0.00	$0.00
0.1	10-yr	$39,885,504	$28,624,736	$28,624,736	$26,807,549	$26,532,135
0.02	50-yr	$44,871,121	$36,296,256	$35,953,292	$35,388,630	$34,657,034
0.01	100-yr	$45,713,907	$37,709,166	$36,703,945	$36,511,272	$35,407,533
0.002	500-yr	$50,081,200	$41,610,872	$41,289,544	$41,132,626	$39,726,175

TABLE 15
Summary of Annualized Damage Costs, Benefits, Alternative Costs, and Benefit Cost Ratios

Conditions	Existing	10-yr	10-yr w/ Street	Max	Max w/ Street
Annualized damage	$4,430,766.00	$3,521,538.00	$3,492,949.00	$3,415,439.00	$3,345,260.00
Benefit	-	$909,228.00	$937,817.00	$1,015,327.00	$1,085,506.00
Annualized Alternative Cost (7% Amortization, 50-yr Life Span)	-	$339,994.00	$616,318.00	$570,764.00	$847,088.00
Benefit Cost Ratio	-	2.67	1.52	1.78	1.28

Engineers Recommended Plan

Introduction

The Engineer's Recommended Plan to minimize the identified flooding issues along Gregory Canyon Creek is the 10-year alternative (Recommended Plan). This Recommended Plan is offered for consideration based on feedback from public meetings, project stakeholders, staff input and preliminary discussions with WRAB.

The Engineer's Recommended Plan is only the first step in the adoption process. Several additional endorsement or approvals must be secured before any implementation is initiated. At each step, adjustments to the Recommended Plan may be identified that address specific concerns expressed by the reviewing entity or the Recommended Plan can be dismissed in favor of another alternative. At the end of the process, the city may choose to adopt a single plan that consolidates the refinements or selects an entirely different option, either studied as part of this Mitigation Planning Study or developed based on other criteria.

The Engineer's Recommended Plan has been presented to city staff. Comments by the group have been addressed and refinements incorporated into the Recommended Plan as necessary. The Recommended Plan, once reviewed and approved by city staff, is now ready to be presented to WRAB. It is also expected that a presentation will be made to the public and other stakeholders that describes the planning process and the elements of the Recommended Plan. In addition to these presentations, the team intends to present the Recommended Plan to City Council for formal consideration and adoption. Once the plan has been adopted, City Public Works Utilities staff will incorporate the recommendations into a long term Capital Improvements Program.

Plan Description

The Recommended Plan focuses on alleviating flooding along Gregory Canyon Creek, without affecting adjacent structures, minimizing Right – of – way takes while providing the greatest level of service throughout the corridor in the most cost effective way possible. This alternative focuses on making channel improvements to convey the 10-year storm event and replacing culverts along the channel to also convey the 10-year storm event. These improvements will provide additional protection from more frequent flooding events but will not eliminate the 100-year flood hazard. Additional options could be included at the City's discretion including sediment and debris traps, improvements to irrigation facilities or improvements to roads that could help contain and convey higher flow events along the roads within the basins.

Other Features of the Recommended Plan

The Recommended Plan also recognizes the City's considerable efforts to manage and control flood hazards. The City has an extensive body of floodplain and floodway protections built into the zoning, land use and development regulations. Physical infrastructure to warn citizens of an impending flood threat exists through sirens and other warning mechanisms and an impressive body of master planning exists for many of the city's drainageways.

In addition, the City also has regulations that are in place to protect the environmental values the community finds so valuable. Stormwater quality regulations have been adopted to assure that future construction activities do not create adverse environmental impacts. Existing stormwater discharge permits issued under the State's Stormwater NPDES program also include programs that promote public education and control other sources of pollution. These are intended to remain in place and are implicitly incorporated into the Recommended Plan.

Basis for Selection

The primary objective defined at the outset of the study was to reduce the flood impacts on properties along Gregory Canyon Creek with as little disturbance to private properties as possible. The Recommended Plan does reduce the flood hazard throughout the watershed for 40 structures for the 10-yr condition and 18 structures for the 100-yr condition. This reduced hazard provides much better access for emergency vehicles during flood events.

The Recommended Plan has the highest benefit-cost ratio among the plans evaluated. This means that the City's investment in infrastructure to address flooding generates a favorable return by reducing the average annual flood damages by a factor of 2.67 over the investment cost.

The Recommended Plan does create some unavoidable impacts to private properties. However, the elements of the Recommended Plan have been laid out to minimize these impacts.

List of Figure and Tables

Technical Appendix

Figures

LEGEND

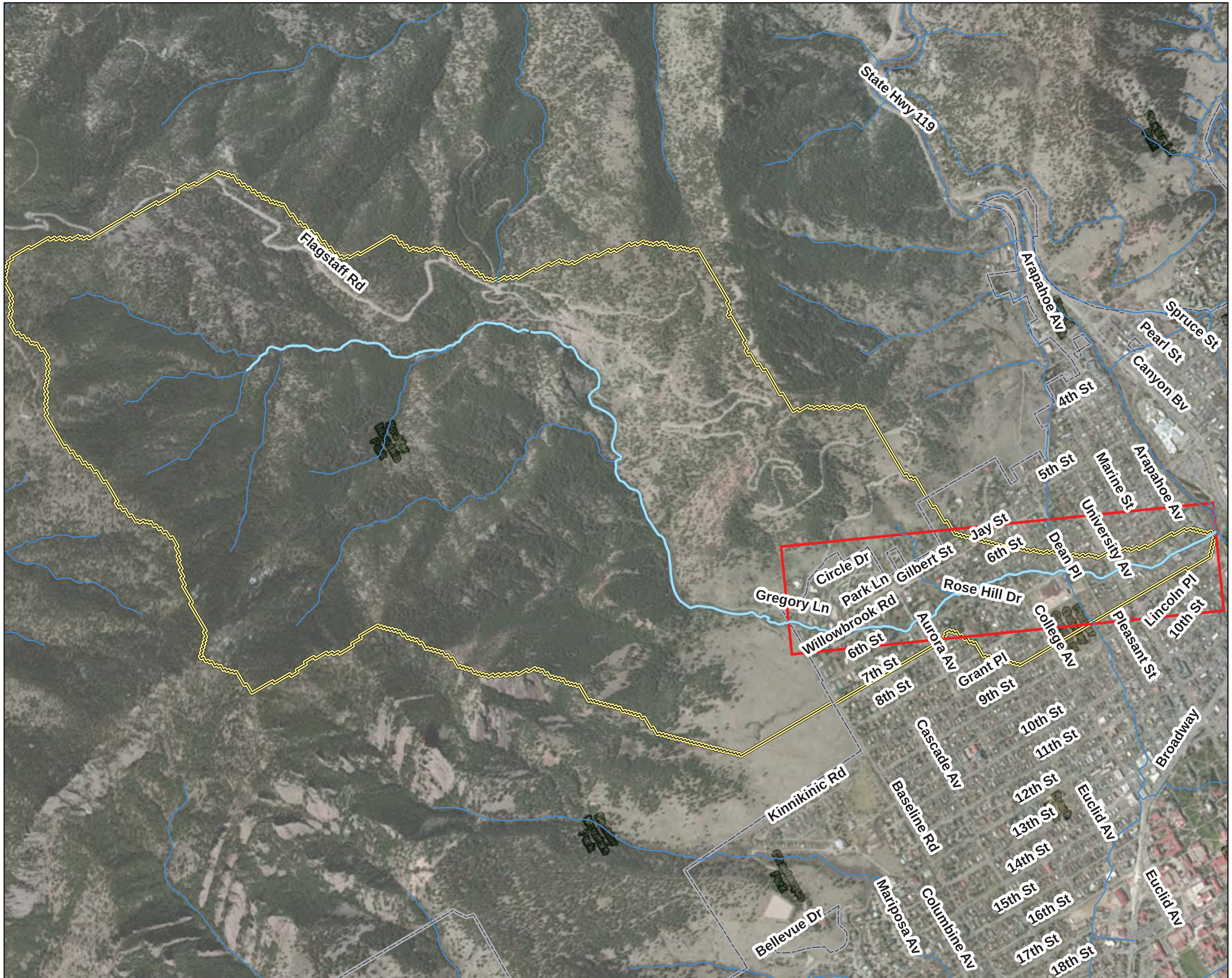
- Creeks and Streams
- Gregory Creek
- September 2013 Flood Extents
- City Limits

Notes:
1. Area of interest subject to change.

0.15 0.075 0 0.15 Miles

FIGURE 1
Spetember 2013 Flood Extents
Gregory Canyon Creek Flood Mitigation

CH2MHILL.



VICINITY MAP

LEGEND

- Creeks and Streams
- Gregory Creek
- Area of Interest
- City Limits
- Gregory Creek Watershed

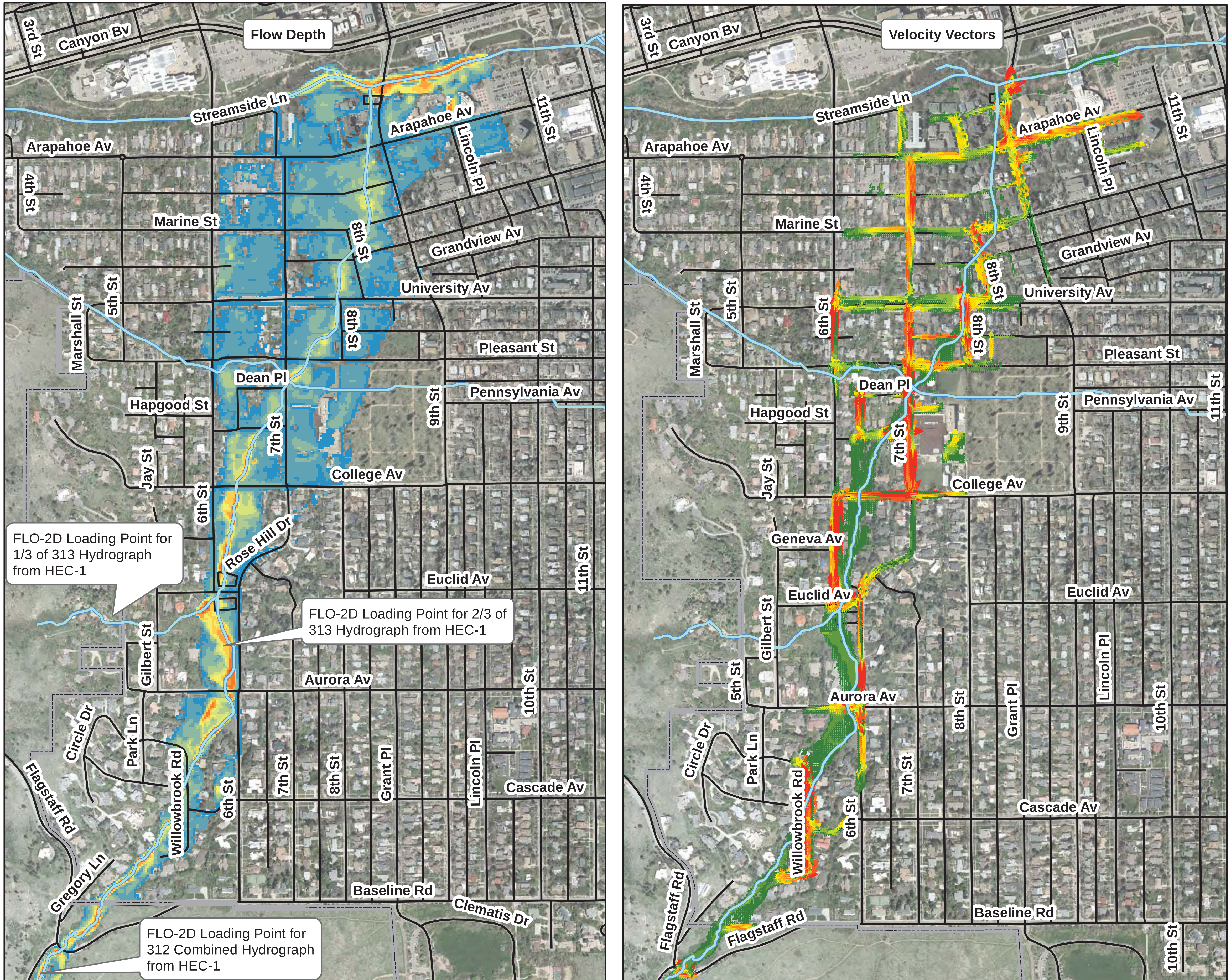
Notes:
1. Area of interest subject to change.

0.25 0.125 0 0.25
Miles

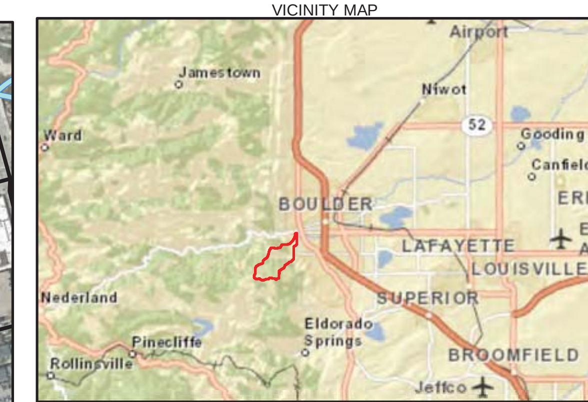
FIGURE 2
Area of Interest
Gregory Canyon Creek Flood Mitigation

UNK G:\498924_GREGORY_CREEK\03_GIS\MAPFILES\LOCATION FIGURE.MXD MLYNCH7 8/27/2014 3:22:21 PM

CH2MHILL.



VICINITY MAP



LEGEND

- Gregory Canyon Creek
- Streets

Flow Depth at Cell

Depth (ft)

- 0.5- 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- > 10

Velocity at Cell (Vectors)

Velocity Vectors (fps)

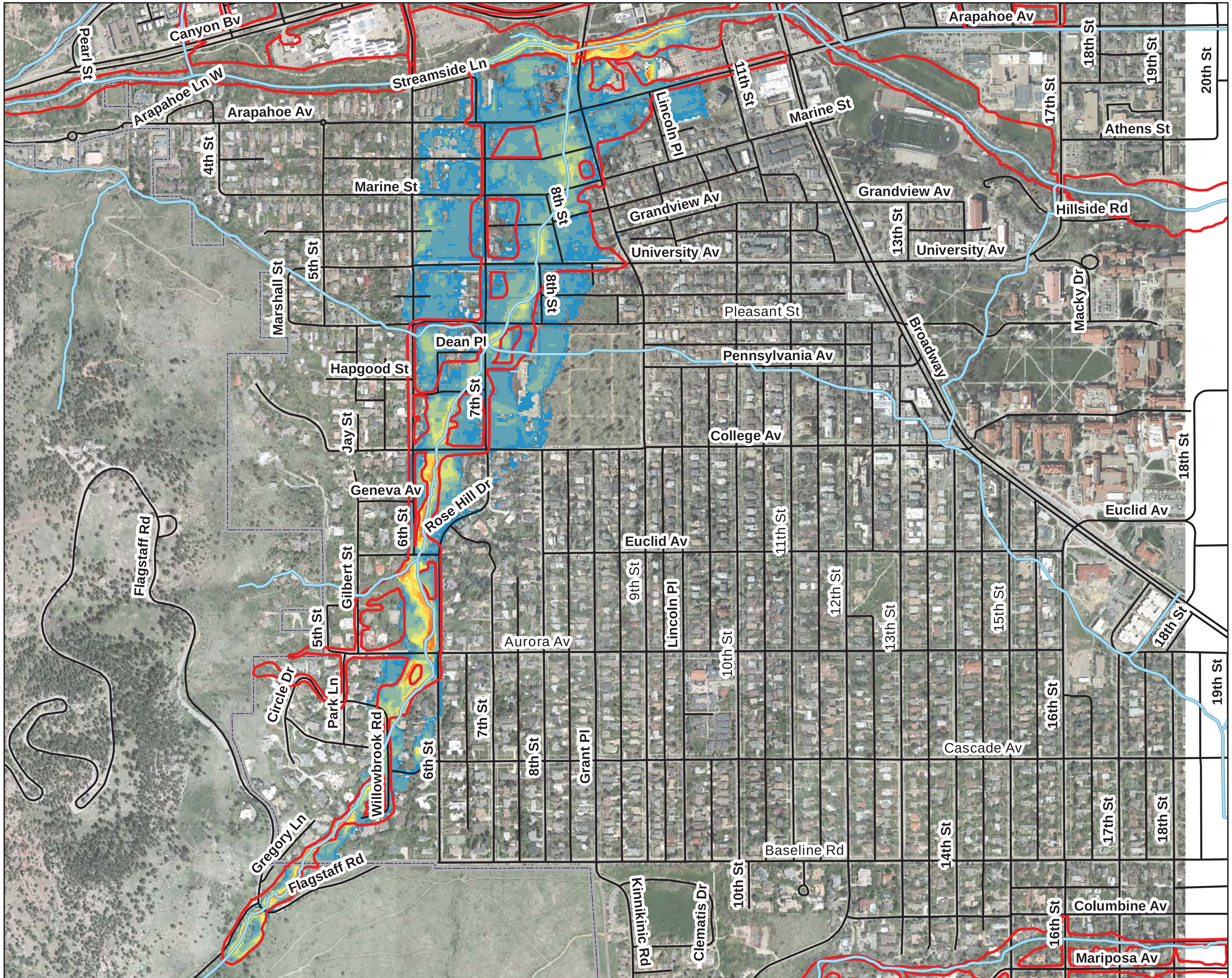
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 -8
- 8 - 9
- 9 - 10
- > 10

Notes:
1. Velocity in street is represented by velocity vectors.

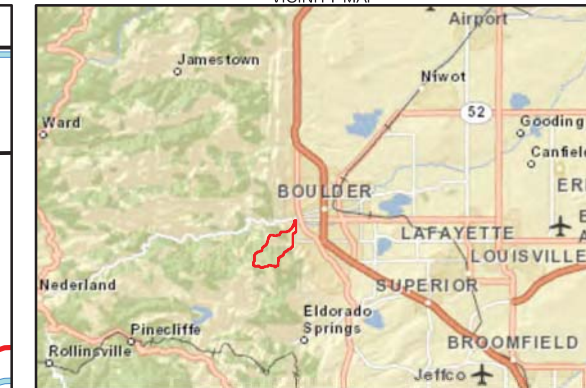
N

0 25 50 100
Feet

FIGURE 3
Existing 100-year 2-D Analysis Floodplain
Gregory Canyon Creek Flood Mitigation



VICINITY MAP



LEGEND

- Sept2013_UrbanFloodExtents
- Gregory Canyon Creek
- Streets

Flow Depth at Cell

Depth (ft)

- 0.5- 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- > 10

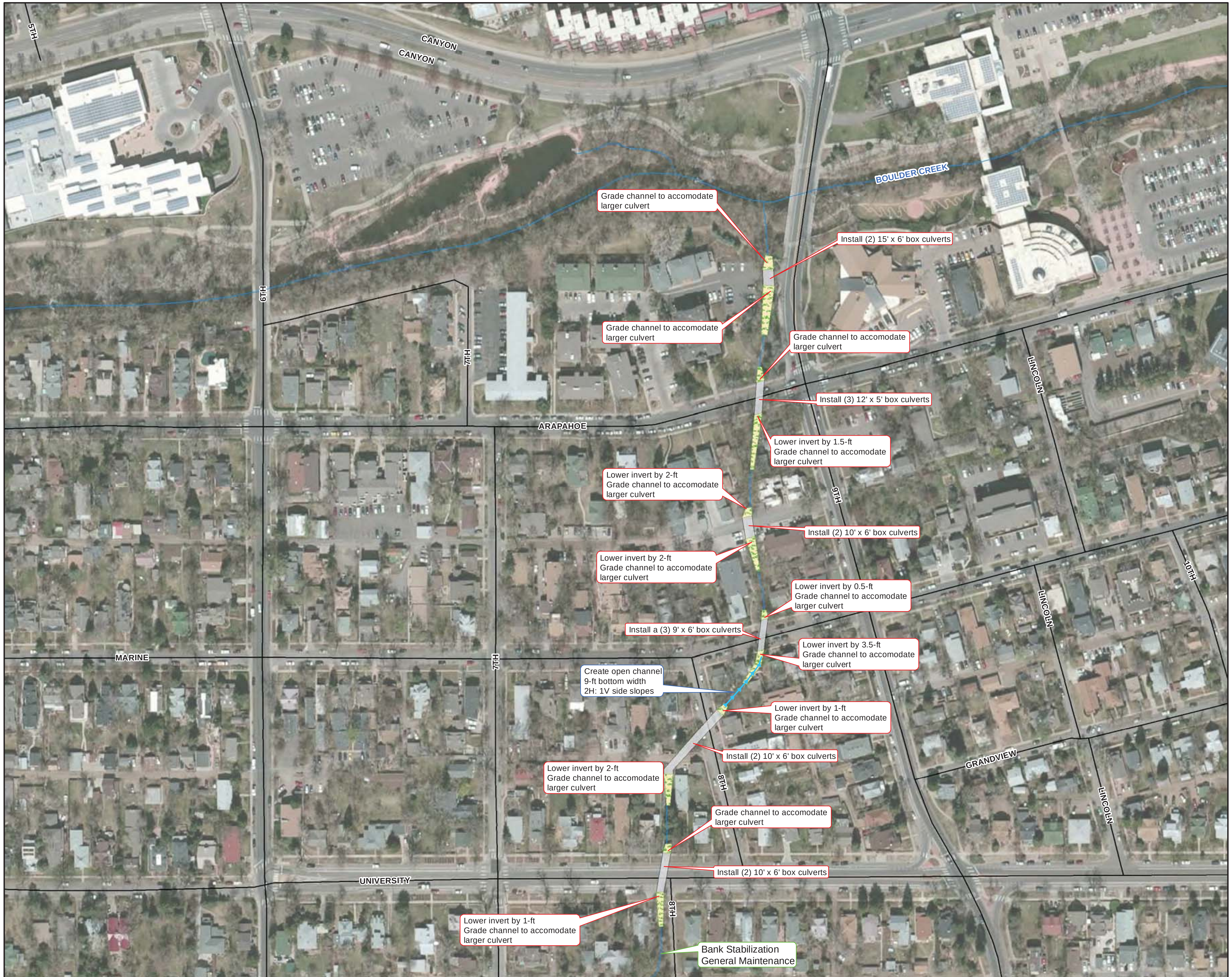
N

0 25 50 100
Feet

FIGURE 4
Comparison to September 2013 Event
Gregory Canyon Creek Flood Mitigation

UNK G:\498924_GREGORY_CREEK\03_GIS\MAPFILES\FIGURE4_COMPARISON.MXD MLYNCH7 8/28/2014 11:27:18 AM

CH2MHILL.



VICINITY MAP

LEGEND

- Existing Easements
- Culvert Improvements
- Channel Improvements
- Channel Grading

Notes:
1. Culvert dimensions are width x height (span x rise)

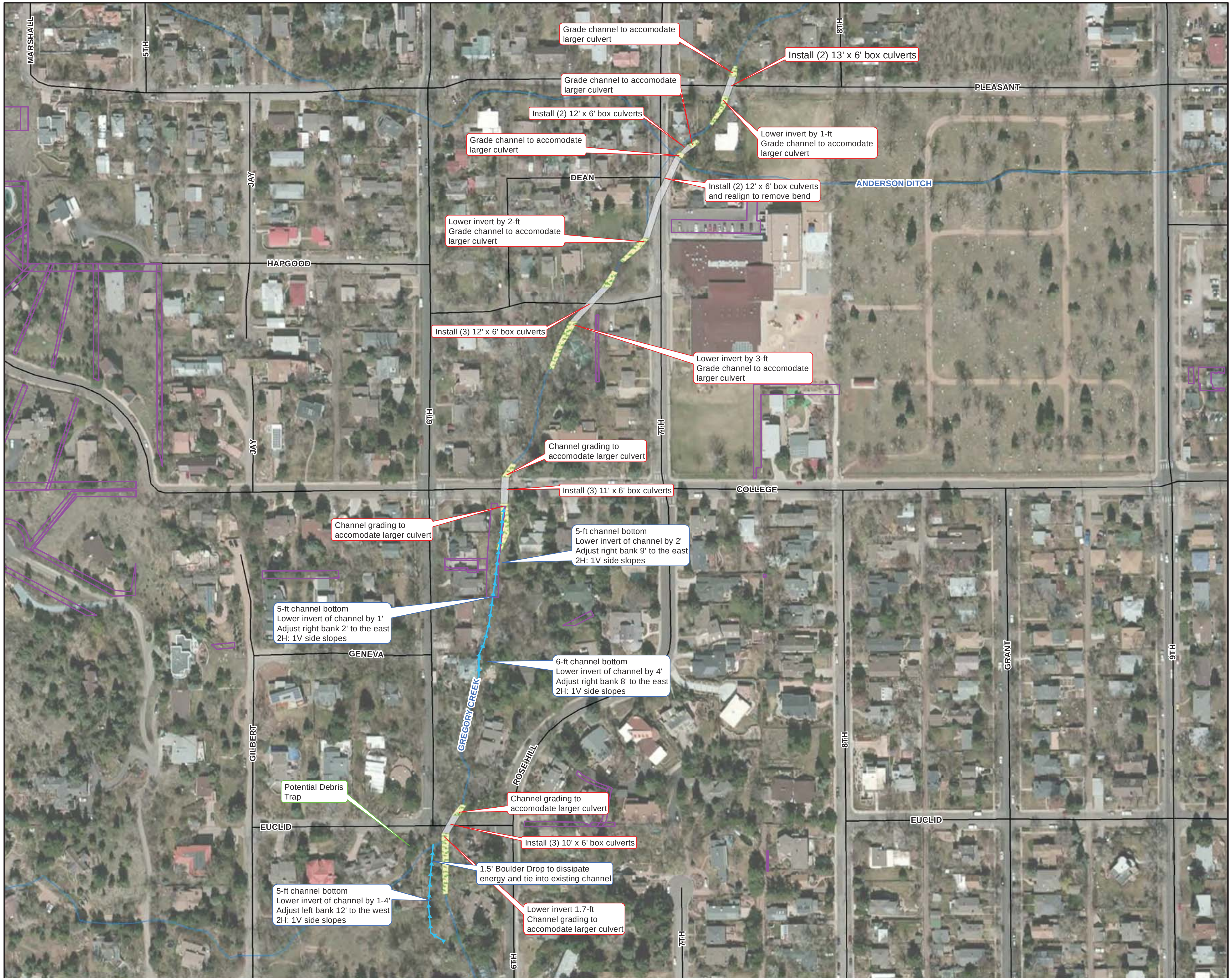
CALLOUT LEGEND

- Infrastructure
- Channel
- General Note

N

0 100 200 400
Feet

FIGURE 5 (1 of 3)
Category One - Culvert and Channel Improvements
Gregory Canyon Creek Flood Mitigation



VICINITY MAP

LEGEND

- Channel Improvements
- Existing Easements
- Culvert Improvements
- Channel Grading

Notes:
1. Culvert dimensions are width x height (span x rise)

CALLOUT LEGEND

- Infrastructure
- Channel
- General Note

N

0 100 200 400
Feet

FIGURE 5 (2 of 3)
Category One - Culvert and Channel Improvements
Gregory Canyon Creek Flood Mitigation

CH2MHILL.

VICINITY MAP

LEGEND

- Channel Improvements
- Existing Easements
- Culvert Improvements
- Channel Grading

Notes:
1. Culvert dimensions are width x height (span x rise)

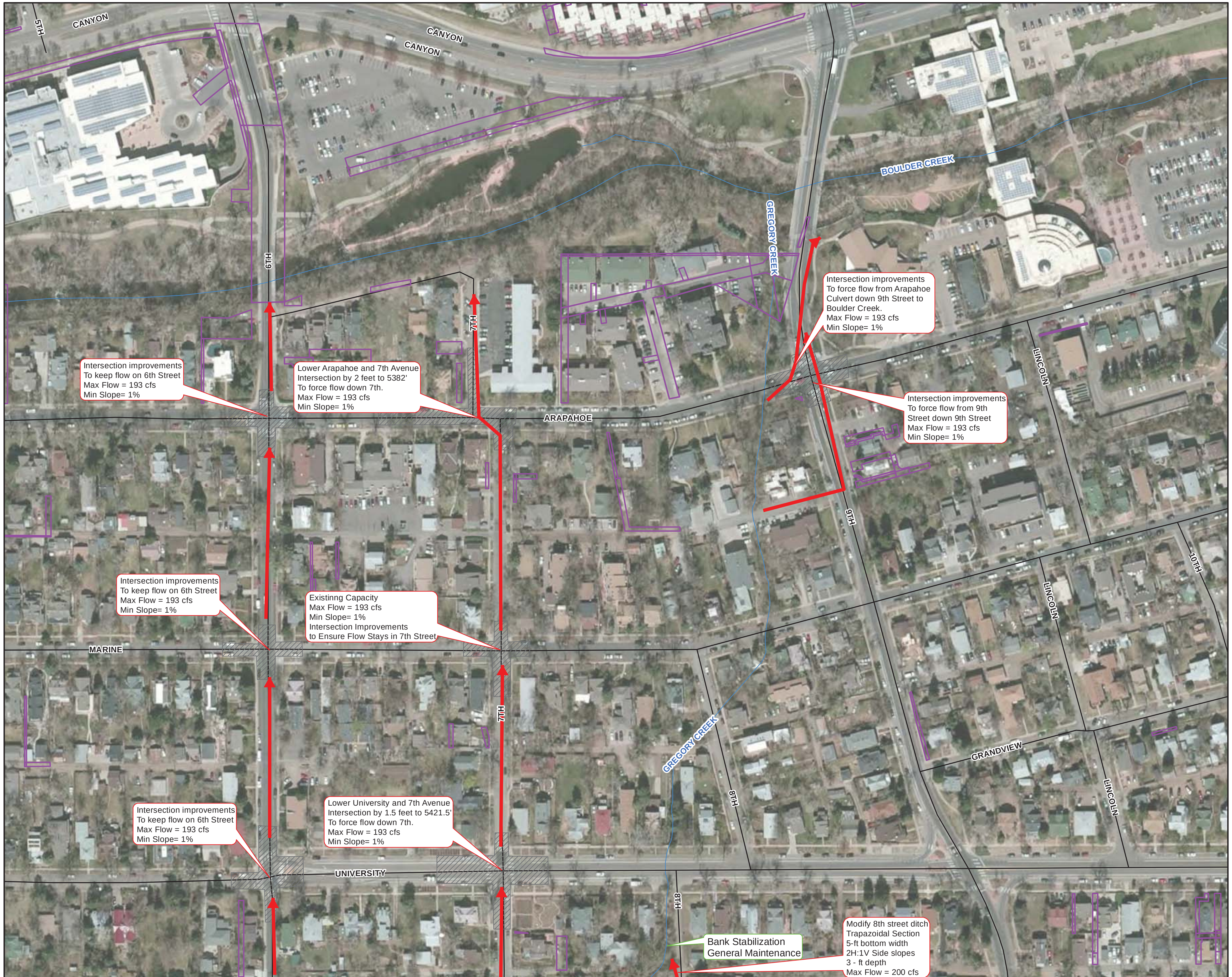
CALLOUT LEGEND

- Infrastructure
- Channel
- General Note

N

0 100 200 400
Feet

FIGURE 5 (3 of 3)
Category One - Culvert and Channel Improvements
Gregory Canyon Creek Flood Mitigation



VICINITY MAP

LEGEND

- Easements
- Street Improvements
- Street Overflows

CALLOUT LEGEND

- Infrastructure
- Channel
- General Note

N

0 100 200 400

Feet

FIGURE 6 (1 of 3)

Category Three - Improvements Outside of the Channel

Gregory Canyon Creek Flood Mitigation

VICINITY MAP

LEGEND

- Easements
- Street Overflows
- Storm_Inlets
- Street Improvements

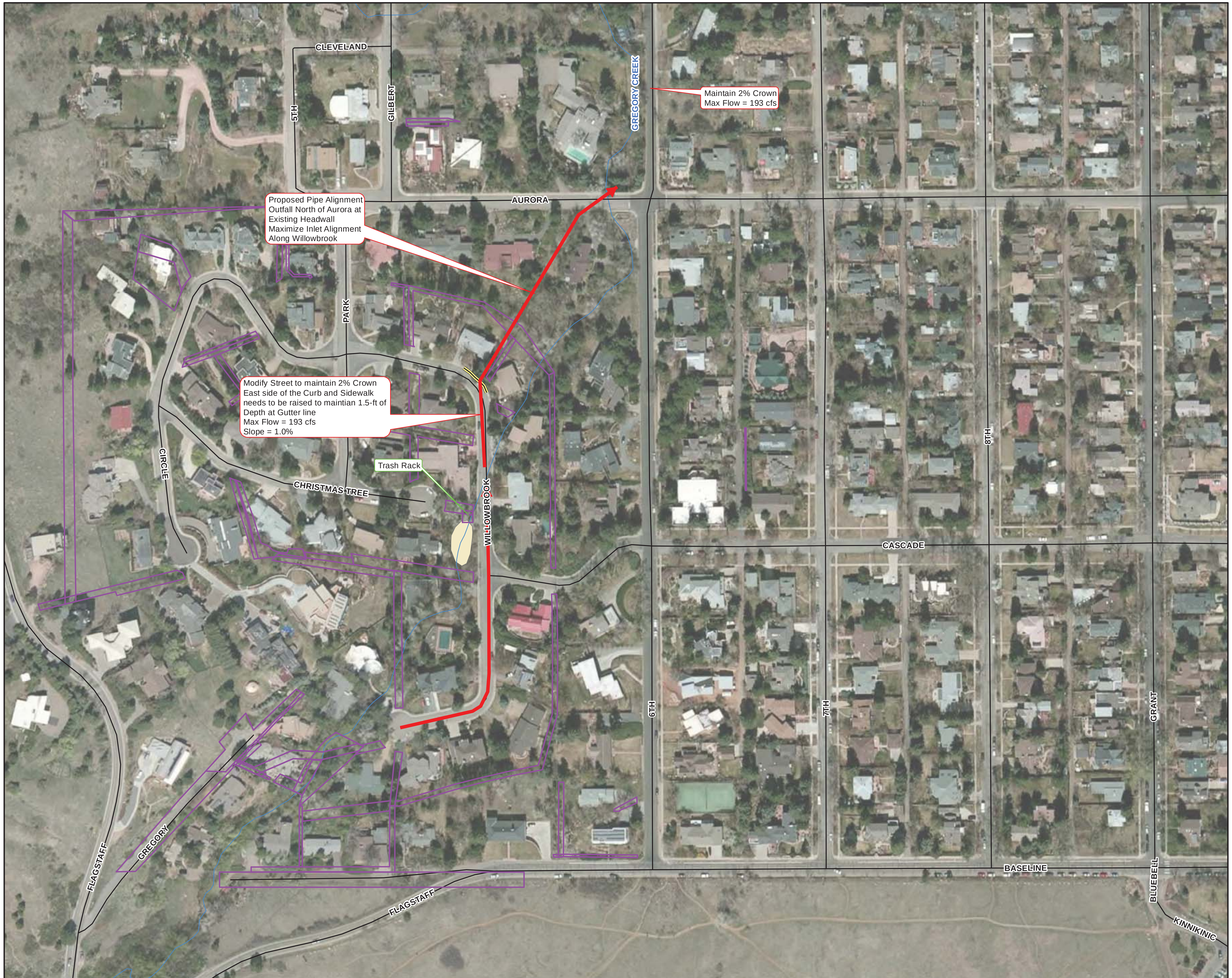
CALLOUT LEGEND

- Infrastructure
- Channel
- General Note

N

0 100 200 400
Feet

FIGURE 6 (2 of 3)
Category Three - Improvements Outside of the Channel
Gregory Canyon Creek Flood Mitigation



LEGEND

- Easements
- Street Overflows
- Storm_Inlets
- Sediment Trap Locations

CALLOUT LEGEND

- Infrastructure
- Channel
- General Note

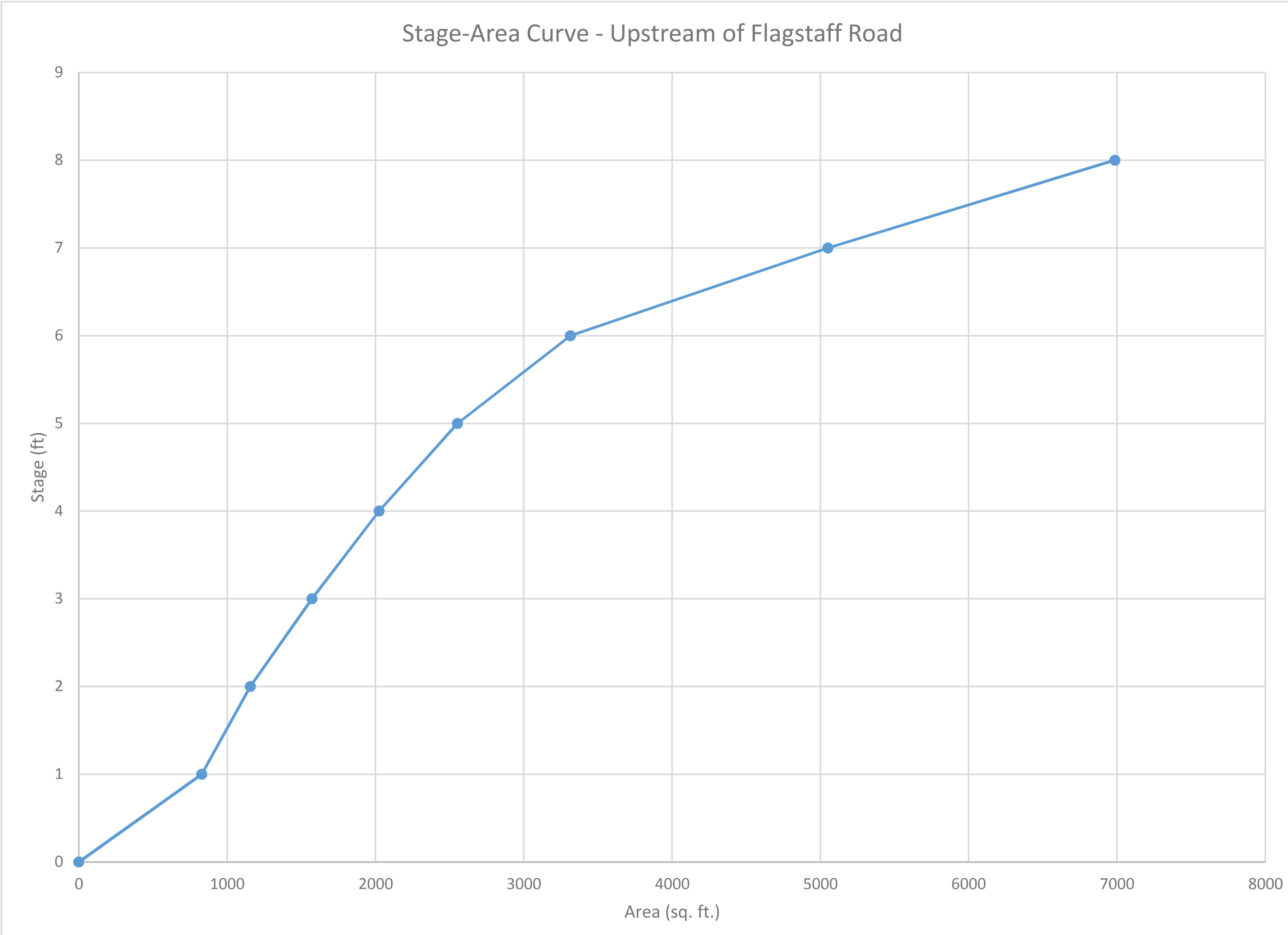
N

0 100 200 400
Feet

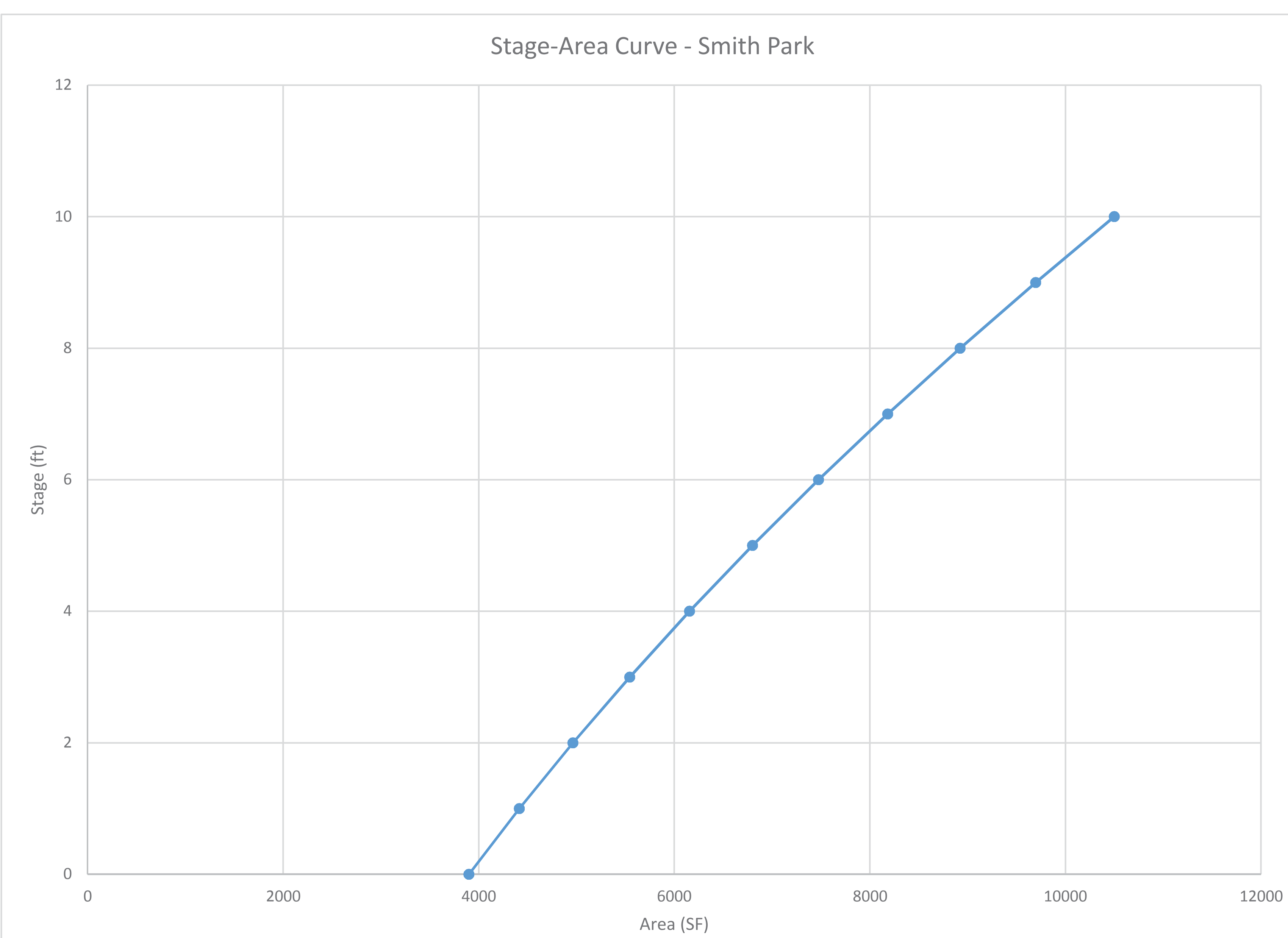
FIGURE 6 (3 of 3)
Category Three - Improvements Outside of the Channel
Gregory Canyon Creek Flood Mitigation

UNK W:\498924_GREGORY_CREEK\03_GIS\MAPFILES\2015.02.12 UPDATED FIGURES\FIG6_ALTERNATE3C(FIG7).MXD FLAMBREC 2/12/2015 6:46:25 PM

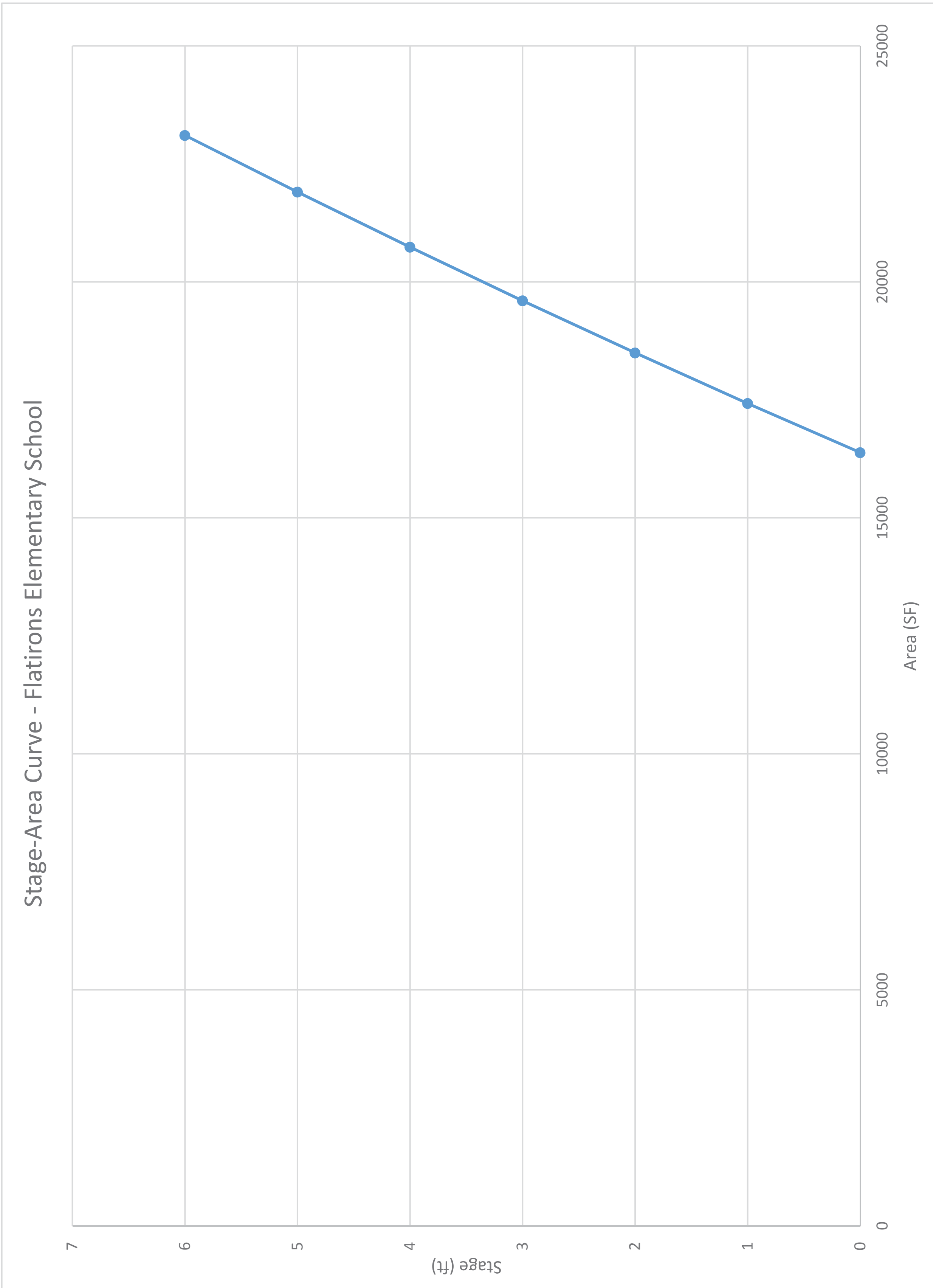
CH2MHILL.

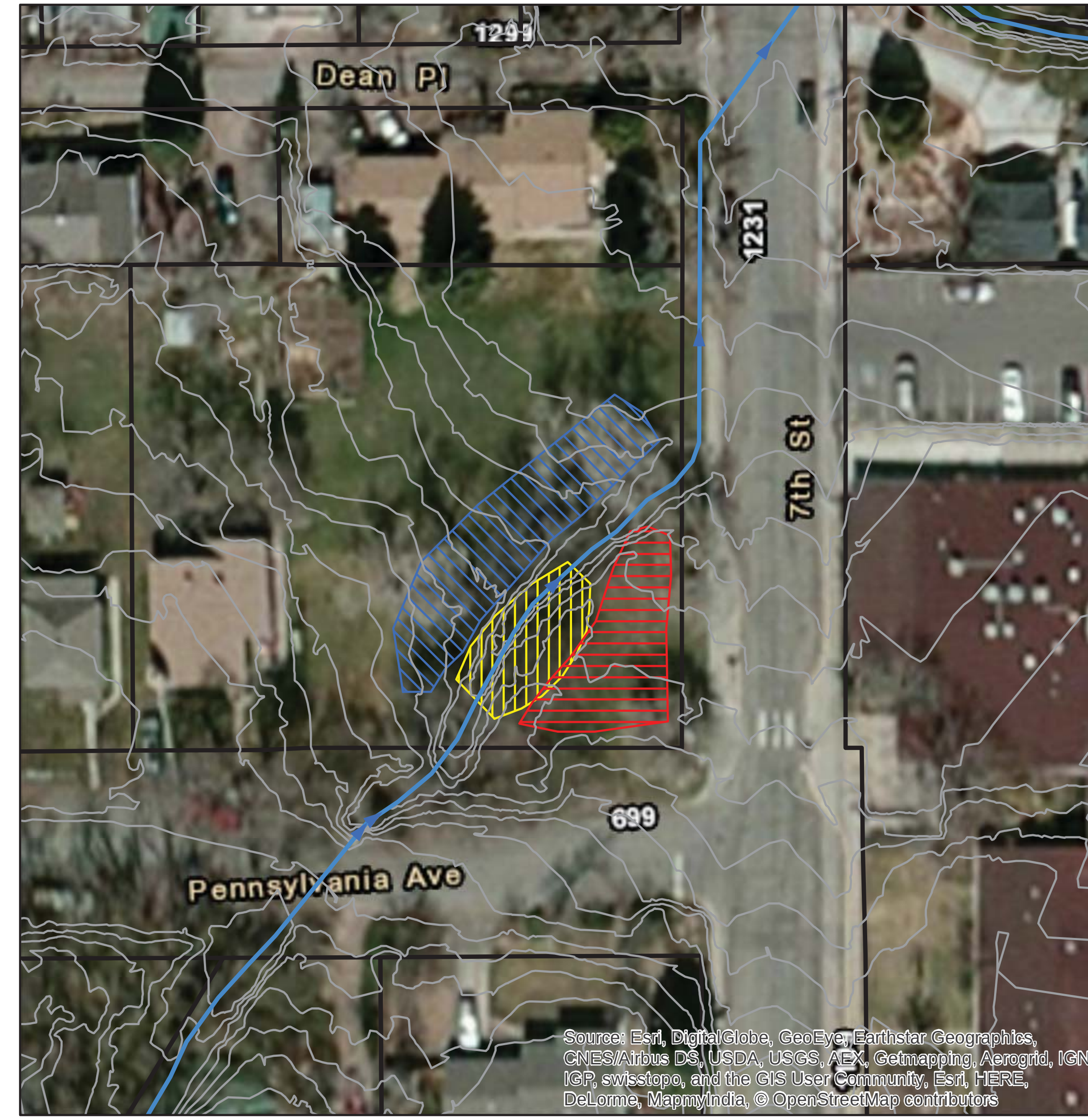


Stage-Area Curve - Upstream of Flagstaff Road
Stage (ft)
0
1
2
3
4
5
6
7
8
9
0
1000
2000
3000
4000
5000
6000
7000
8000
Area (sq. ft.)



Stage-Area Curve - Smith Park
Stage (ft)
0
2
4
6
8
10
12
0
2000
4000
6000
8000
10000
12000
Area (SF)





LEGEND

- Creek Centerline
- 1' Contours (2013)
- CountyParcels

Sediment Trap Alternatives

- Alt 1 - Offline
- Alt 2 - Inline
- Alt 3 - Offline

Gregory Canyon Creek Drainage Area = 2.29 sq. miles
2-year Q = 161 cfs
Sediment Load = 229 Tons (116 CY)

Alt 1 Area - 2500 sq. ft, 2' deep, 53% Efficiency (Fine Sand)
Alt 2 Area - 1150 sq. ft, 3' deep, 29% Efficiency (Fine Sand)
Alt 3 Area - 1700 sq. ft, 2' deep, 42% Efficiency (Fine Sand)

N

0 25 50 100
Feet

Sediment Trap Analysis (DRAFT)
Gregory Canyon Creek MDP

CH2MHILL.

UNK G:\498924_GREGORY_CREEK\03_GIS\MAPFILES\2015.02.12 UPDATED FIGURES\FIG10_ SEDIMENT TRAP ALTERNATIVES.MXD FLAMBREC 2/12/2015

Cross Section for Tiered Curb - Irregular Section - 1

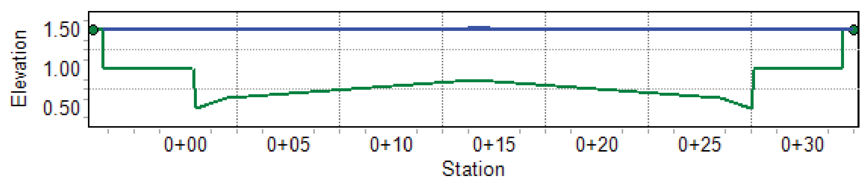
Project Description

Friction Method	Manning Formula
Solve For	Discharge

Input Data

Channel Slope	0.01000	ft/ft
Normal Depth	1.00	ft
Discharge	193.06	ft³/s

Cross Section Image



Technical Appendix

Tables

Table 1: Data Received From City of Boulder

Gregory Creek Master Plan
CH2M Hill
Location: W:\498924_Gregory_Creek\02_Recievables

Description	Filename	From	File Type	Location/Folder	No. of Files	Date Received
Master Plan Calendar	Master Plan Calendar	City of Boulder	PDF	2014.07.22_FromBoulder		7/22/2014
Instructions for Scanning Form	Instructions for Scanning Form	City of Boulder	PDF	Historic Documents		7/22/2014
Asbuilt of 7th street up to Pleasant St	7th_st	City of Boulder	TIFF	As-builts		7/22/2014
Asbuilt of trash rack replacement from 800 Block of Willobrook Rd to 16th St and Iris Ave	2014-04-08_COBTrashRacks_Stamped_Final Submittal	City of Boulder	PDF	As-builts		7/22/2014
Asbuilt of culvert and pipe work along Gregory Creek (1977)	09461	City of Boulder	PDF	As-builts		7/22/2014
Asbuilt of Willowbrook Rd culvert replacement and sewer replacement	22804_22811-GregoryCanyon-WillbrookRd	City of Boulder	PDF	As-builts		7/22/2014
Asbuilt of culvert installations for Aurora Ave, creek improvements along 8th street from university to pleasant	Gregory-Aurora to University	City of Boulder	PDF	As-builts		7/22/2014
Flood Hazard Area Delineation Report for Boulder Creek	Boulder Creek FHAD 1983	City of Boulder	PDF	Mapping		7/22/2014
Letter to Mayor of Boulder and Chair of Boulder County Board of Commissioners regarding LOMR	FEMA Approval Final	City of Boulder	PDF	GCC Final As Approved		7/22/2014
Letter to City of Boulder Utilities reconciling LOMR with LOD from FEMA -- Also the request for letter of map revision	Final LOMR Report Rectified to LOD	City of Boulder	PDF	GCC Final As Approved		7/22/2014
Topo survey from XXXX	ACAD-SURVEY	City of Boulder	AutoCAD DWG	CAD		7/22/2014
Topo survey from 2004	ACAD-SURVEY_2004	City of Boulder	AutoCAD DWG	CAD		7/22/2014
Floodway, 100yr, 500yr firm	ANNO-FIRM-REV-032210	City of Boulder	AutoCAD DWG	CAD		7/22/2014
Floodplain map with HHZ, Floodway, 100yr, 500yr layers	FLOODPLAIN-LAYERS-FINAL-091510	City of Boulder	AutoCAD DWG	CAD		7/22/2014
Floodplain map with HHZ, Floodway, 100yr, 500yr layers - contours are added along with Boulder Creek confluence and floodplain	LOMR-BASEMAP-FINAL-091510	City of Boulder	AutoCAD DWG	CAD		7/22/2014
Main reach profile with 10yr, 50yr, 100yr, 500yr profiles	MAIN-REACH-PROFILE	City of Boulder	AutoCAD DWG	CAD		7/22/2014
Spill reach profile with 10yr, 50yr, 100yr, 500yr profiles	SPILL-REACH-PROFILE	City of Boulder	AutoCAD DWG	CAD		7/22/2014
Boulder Creek Effective model	Bldr-Crk-Effective	City of Boulder	HEC-RAS	HEC-RAS\Bldr-Crk-Effective	2	7/22/2014
Flood Hazard Area Delineation model	FHAD-Model	City of Boulder	HEC-RAS	HEC-RAS\FHAD-Model	2	7/22/2014
Main channel post-project floodway analysis (including HEC-RAS files, text files, and microstation reference file)	MAIN-FW	City of Boulder	HEC-RAS	POST-PROJECT-MODELS\MAIN-FW	7	7/22/2014
Main channel post-project multi-profile analysis (including HEC-RAS files, text files, and microstation reference file)	MAIN-MP	City of Boulder	HEC-RAS	POST-PROJECT-MODELS\MAIN-MP	11	7/22/2014
Spill channel post-project floodway analysis (including HEC-RAS files, text files, and microstation reference file)	SPILL-FW	City of Boulder	HEC-RAS	POST-PROJECT-MODELS\SPILL-FW	12	7/22/2014
Spill channel post-project multi-profile analysis (including HEC-RAS files, text files, and microstation reference file)	SPILL-MP	City of Boulder	HEC-RAS	POST-PROJECT-MODELS\SPILL-MP	14	7/22/2014
FHAD versus Post Project cross sections and water surface elevations	FHAD-vs-Revised	City of Boulder	PDF	POST-PROJECT-MODELS\Supplemental-Models&Tables		7/22/2014
FlowMaster report of rectangular channels showing hydraulic information	FlowMaster-Report	City of Boulder	PDF	POST-PROJECT-MODELS\Supplemental-Models&Tables		7/22/2014
Flow path delineation for water that leaves the main the channel and flows through streets, etc.	Flow-Path Delineations	City of Boulder	PDF	POST-PROJECT-MODELS\Supplemental-Models&Tables		7/22/2014
Table of shallow flooding areas with cross section and location	Shallow-Flooding-Table	City of Boulder	PDF	POST-PROJECT-MODELS\Supplemental-Models&Tables		7/22/2014

Flowmaster shallow flooding sections file	SHALLOW-FLOOD-SECTIONS.FM2	City of Boulder	Flowmaster (.FM2)	POST-PROJECT-MODELS\Supplemental-Models&Tables		7/22/2014
High Hazard Zone ReAnalysis prepared by Belt Collins West in 2010	HHZ-Final as Approved	City of Boulder	PDF	HHZ		7/22/2014
Spreadsheet for older High Hazard Zone Analysis for downstream end performed by Love & Associates, Inc. (Belt Collins West)	HHZ Cross Section Output Gregory Main Channel DS Half 2-2-9	City of Boulder	Excel (XLSX)	HHZ\OLD HHZ 2-2-9		7/22/2014
Spreadsheet for older High Hazard Zone Analysis for upstream end performed by Love & Associates, Inc. (Belt Collins West)	HHZ Cross Section Output Gregory Main Channel US Half 2-2-9	City of Boulder	Excel (XLSX)	HHZ\OLD HHZ 2-2-9		7/22/2014
Spreadsheet for older High Hazard Zone Analysis for spill channel performed by Love & Associates, Inc. (Belt Collins West)	HHZ Cross Section Output Gregory Spill 2-2-9	City of Boulder	Excel (XLSX)	HHZ\OLD HHZ 2-2-9		7/22/2014
Major Drainageway Planning Phase A from July 1984 performed by Greenhorne & O'Mara, Inc.	Boulder Adj County MDP Ph A 1984	City of Boulder	PDF	Master planning documents		7/22/2014
Major Drainageway Planning Phase B from May 1987 performed by Greenhorne & O'Mara, Inc.	Boulder Adj County MDP Ph B 1987	City of Boulder	PDF	Master planning documents		7/22/2014
Flood Hazard Area Delineation for Boulder and Adjacent County Drainageways from May 1987 performed by Greehorne & O'Mara Inc.	Boulder and Adjacent County Drainageways FHAD 1987	City of Boulder	PDF	Master planning documents		7/22/2014
Creek Mitigation Analysis for Gregory Creek performed by WHPacific in July 2012	Gregory Canyon Creek Mitigation Analysis	City of Boulder	PDF	Master planning documents		7/22/2014
Mini Master Plan performed by Belt Collins West in March 2009	HHZ Mini Master Plan - Final as Approved	City of Boulder	PDF	Master planning documents		7/22/2014
Pennsylvania Avenue Flood Repair/Improvement Alternative Analysis performed by XXXXX in April 2014	Penn Ave Alt Analysis	City of Boulder	PDF	Master planning documents		7/22/2014
Field verification of culvert structures along Gregory Creek provided by City of Boulder	BoulderFieldChecks	City of Boulder	Shapefile (.shp)	Culvert Verification	8	8/4/2014
LiDar data in CAD format	328	City of Boulder	AutoCAD DWG	LiDAR		8/5/2014
LiDar data in CAD format	349	City of Boulder	AutoCAD DWG	LiDAR		8/5/2014
LiDar data in CAD format	350	City of Boulder	AutoCAD DWG	LiDAR		8/5/2014
LiDar data in CAD format	371	City of Boulder	AutoCAD DWG	LiDAR		8/5/2014
LiDar data in CAD format	372	City of Boulder	AutoCAD DWG	LiDAR		8/5/2014
Lidar data in GIS format	328	City of Boulder	Shapefile (.shp)	LiDAR	10	8/5/2014
Lidar data in GIS format	349	City of Boulder	Shapefile (.shp)	LiDAR	10	8/5/2014
Lidar data in GIS format	350	City of Boulder	Shapefile (.shp)	LiDAR	10	8/5/2014
Lidar data in GIS format	371	City of Boulder	Shapefile (.shp)	LiDAR	10	8/5/2014
Lidar data in GIS format	372	City of Boulder	Shapefile (.shp)	LiDAR	10	8/5/2014
LiDar data in Digital Elevation Model (DEM) format	328	City of Boulder	DEM	LiDAR	10	8/5/2014
LiDar data in Digital Elevation Model (DEM) format	349	City of Boulder	DEM	LiDAR	10	8/5/2014
LiDar data in Digital Elevation Model (DEM) format	350	City of Boulder	DEM	LiDAR	10	8/5/2014
LiDar data in Digital Elevation Model (DEM) format	371	City of Boulder	DEM	LiDAR	10	8/5/2014
LiDar data in Digital Elevation Model (DEM) format	372	City of Boulder	DEM	LiDAR	10	8/5/2014
Gregory Creek Colorado Urban Hydrograph Procedure (CUHP) developed in 1986	Gregory Creek CUHP 1986	UDFCD	PDF			8/6/2014
HEC1 input and output for the Gregory Creek CUHP model	Gregory Creek HEC1 1986	UDFCD	PDF			8/6/2014
Hydrographs pulled from HEC1 model used for Gregory Creek	HEC1 1986 Hydrographs	UDFCD	Excel (XLSX)			8/6/2014
Notes from the site walk with City of Boulder, UDFCD and CH2M HILL examining the structures and discussing potential solutions for alternatives	Site walk notes	City of Boulder	PDF			8/11/2014
September 2013 flood extents	Sept2013_UrbanFloodExtents	City of Boulder	Shapefile (.shp)		6	8/19/2014

Table 2a: Effective 100-year Hydraulic Output

HEC-RAS Plan: Multi-profil River: RIVER-1 Reach: Reach-1 Profile: 100-year

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach-1	600	100-year	1450.00	5750.20	5756.85	5756.85	5758.45	0.038880	10.98	175.50	60.17	0.82
Reach-1	590	100-year	1450.00	5718.23	5735.87	5730.31	5735.92	0.000876	2.53	973.97	161.14	0.11
Reach-1	585		Culvert									
Reach-1	580	100-year	1450.00	5717.80	5729.90	5729.90	5735.89	0.040251	19.64	73.82	88.34	1.00
Reach-1	560	100-year	1450.00	5684.47	5694.47	5693.18	5694.75	0.011242	5.70	419.85	133.66	0.36
Reach-1	555		Culvert									
Reach-1	550	100-year	1450.00	5683.10	5690.53	5690.53	5693.07	0.009648	14.73	168.71	48.50	1.02
Reach-1	540	100-year	1450.00	5660.98	5668.23	5668.23	5669.92	0.024603	11.70	156.41	46.95	1.04
Reach-1	530	100-year	1450.00	5652.10	5660.01	5660.01	5661.83	0.018625	10.93	141.55	46.24	0.94
Reach-1	520	100-year	1450.00	5645.52	5658.50	5657.66	5658.86	0.003028	6.00	528.70	144.84	0.31
Reach-1	515		Culvert									
Reach-1	510	100-year	1450.00	5643.57	5654.01	5654.01	5654.54	0.003467	6.31	339.68	80.77	0.36
Reach-1	508	100-year	1450.00	5640.03	5646.62	5646.62	5648.30	0.037649	10.49	146.30	49.62	0.98
Reach-1	507	100-year	1450.00	5639.21	5645.29	5645.29	5646.87	0.033230	10.35	158.98	54.52	0.95
Reach-1	505	100-year	1450.00	5638.27	5644.00	5644.00	5645.41	0.032480	10.18	185.63	75.13	0.94
Reach-1	500	100-year	1450.00	5625.60	5635.37	5634.97	5636.39	0.022416	9.78	276.81	125.14	0.55
Reach-1	495		Bridge									
Reach-1	490	100-year	1450.00	5624.40	5634.00	5634.00	5635.06	0.026436	9.96	264.01	125.71	0.57
Reach-1	470	100-year	1450.00	5607.68	5621.07	5614.06	5621.42	0.003823	5.22	439.53	128.91	0.26
Reach-1	465		Culvert									
Reach-1	460	100-year	1450.00	5603.33	5612.65	5612.65	5617.29	0.020842	17.28	83.92	96.84	1.00
Reach-1	455	100-year	1700.00	5596.39	5604.21	5604.21	5606.38	0.028299	11.84	148.33	39.92	0.98
Reach-1	450	100-year	1700.00	5590.81	5599.19	5599.19	5600.78	0.026792	10.27	182.25	106.22	0.93
Reach-1	440	100-year	1700.00	5587.69	5593.97	5593.97	5595.25	0.023836	9.76	254.43	136.04	0.89
Reach-1	436	100-year	1700.00	5578.63	5584.23	5584.23	5585.08	0.016562	9.62	410.40	224.64	0.78
Reach-1	431	100-year	1700.00	5571.70	5581.24	5578.80	5581.77	0.006021	6.76	494.40	217.07	0.40
Reach-1	425		Culvert									
Reach-1	420	100-year	1700.00	5571.10	5578.20	5578.20	5581.68	0.022498	14.97	113.58	124.36	0.99
Reach-1	410	100-year	1700.00	5565.61	5573.36	5570.92	5573.99	0.007520	6.39	266.98	59.28	0.50
Reach-1	405		Culvert									
Reach-1	400	100-year	1700.00	5563.35	5568.13	5566.97	5569.13	0.012078	8.04	211.36	59.64	0.67
Reach-1	398	100-year	1700.00	5563.39	5566.67	5566.67	5568.18	0.055920	12.44	216.26	89.81	1.33
Reach-1	395	100-year	1700.00	5555.00	5560.98	5560.98	5562.73	0.037266	10.61	161.08	48.30	1.01
Reach-1	390	100-year	1700.00	5551.40	5556.73	5556.73	5557.87	0.035820	10.19	257.62	108.50	0.98
Reach-1	389	100-year	1700.00	5550.00	5554.69	5554.69	5555.84	0.040472	10.35	249.04	105.65	1.04
Reach-1	385	100-year	1700.00	5537.75	5541.85	5541.85	5542.85	0.082417	11.83	240.83	115.58	1.35
Reach-1	380	100-year	1700.00	5529.50	5537.31	5536.86	5537.73	0.011916	6.26	389.63	203.44	0.56
Reach-1	375		Culvert									
Reach-1	370	100-year	1700.00	5527.68	5534.13	5534.13	5534.57	0.006855	5.88	465.53	213.82	0.46
Reach-1	360	100-year	1700.00	5511.80	5518.90	5518.90	5520.81	0.034722	11.20	162.13	49.18	0.95
Reach-1	352	100-year	1700.00	5507.30	5515.91	5514.42	5516.76	0.009700	8.62	308.02	138.43	0.56
Reach-1	351	100-year	1700.00	5506.80	5513.84	5513.84	5516.23	0.038249	12.41	140.01	63.47	0.97
Reach-1	350	100-year	1700.00	5503.40	5510.38	5510.38	5512.43	0.036908	11.49	147.99	36.51	1.01
Reach-1	342	100-year	1700.00	5494.95	5501.69	5501.69	5503.95	0.039860	13.71	182.40	53.93	1.08
Reach-1	340	100-year	1700.00	5493.14	5500.02	5500.02	5500.92	0.021112	8.73	341.61	219.50	0.75
Reach-1	334	100-year	1700.00	5488.11	5496.03		5497.34	0.017928	9.62	232.16	85.62	0.72
Reach-1	330	100-year	1700.00	5485.84	5495.23	5495.07	5496.17	0.018433	8.72	331.63	179.63	0.66
Reach-1	325		Culvert									
Reach-1	318	100-year	1900.00	5485.27	5493.73	5493.73	5494.51	0.024436	10.31	420.16	211.85	0.70
Reach-1	304	100-year	1900.00	5484.40	5491.10	5489.24	5491.69	0.007839	6.33	357.61	178.90	0.48
Reach-1	303		Bridge									
Reach-1	302	100-year	1900.00	5483.05	5487.95	5487.95	5489.29	0.032033	10.47	254.27	90.82	0.93
Reach-1	301	100-year	1900.00	5479.08	5484.81	5484.81	5486.17	0.022681	9.81	258.28	121.68	0.82
Reach-1	300	100-year	1900.00	5475.10	5479.93	5479.93	5480.86	0.031059	8.66	318.58	168.21	0.90
Reach-1	295	100-year	1900.00	5470.26	5474.88	5474.88	5475.76	0.039266	8.31	314.26	211.21	0.98
Reach-1	291	100-year	1900.00	5468.09	5472.49	5472.49	5473.34	0.026610	9.41	396.31	222.86	0.87
Reach-1	290	100-year	1900.00	5464.32	5470.48	5470.48	5471.36	0.018903	9.14	411.06	248.01	0.75
Reach-1	285		Culvert									
Reach-1	280	100-year	1900.00	5461.70	5467.89	5467.89	5468.21	0.009471	6.37	578.03	218.68	0.53
Reach-1	270	100-year	1900.00	5451.44	5458.04	5458.04	5459.11	0.012260	9.60	381.62	187.38	0.72
Reach-1	265		Culvert									
Reach-1	260	100-year	1900.00	5438.86	5447.50	5444.67	5448.11	0.004071	6.42	361.09	113.91	0.43
Reach-1	255		Culvert									
Reach-1	250	100-year	1900.00	5438.24	5446.48	5445.29	5447.11	0.006830	6.86	400.50	154.29	0.53
Reach-1	231	100-year	1900.00	5434.97	5444.40	5444.40	5445.82	0.032961	12.40	287.97	99.55	0.73
Reach-1	230	100-year	1900.00	5434.90	5443.56	5443.56	5444.92	0.026172	11.89	302.12	99.93	0.74
Reach-1	225		Culvert									
Reach-1	220	100-year	1900.00	5433.65	5440.67	5440.67	5441.57	0.029064	10.50	376.40	177.34	0.80
Reach-1	219	100-year	1900.00	5431.60	5437.71	5437.71	5438.59	0.041552	9.33	318.30	162.35	0.99
Reach-1	200	100-year	1900.00	5420.59	5427.24	5427.24	5428.76	0.039580	9.91	192.75	66.66	1.01
Reach-1	190	100-year	1900.00	5414.10	5423.33	5420.31	5423.54	0.004739	3.67	596.46	310.94	0.36
Reach-1	185		Culvert									
Reach-1	180	100-year	2092.00	5410.57	5420.01	5420.01	5420.11	0.003214	3.18	1217.59	674.14	0.30
Reach-1	175	100-year	2092.00	5408.70	5415.83	5415.83	5416.40	0.030651	7.26	483.53	374.88	0.85
Reach-1	170	100-year	2092.00	5404.97	5411.47	5409.06	5411.71	0.003619	4.38	828.55	481.65	0.34
Reach-1	165		Culvert									
Reach-1	160	100-year	2092.00	5398.60	5404.81		5405.04	0.003637	4.21	732.13	281.54	0.34
Reach-1	152	100-year	2092.00	5396.42	5403.72	5403.72	5404.48	0.027475	8.45	435.92	262.55	0.84
Reach-1	151		Culvert									

Table 2a: Effective 100 - year Hydraulic Output

HEC-RAS Plan: Multi-profil River: RIVER-1 Reach: Reach-1 Profile: 100-year (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach-1	150	100-year	2092.00	5393.63	5401.77	5401.77	5402.53	0.029509	10.54	468.31	242.77	0.67
Reach-1	130	100-year	2092.00	5393.48	5401.19	5401.19	5401.77	0.015732	8.97	667.32	476.01	0.60
Reach-1	125		Culvert									
Reach-1	120	100-year	2092.00	5389.00	5398.53	5398.53	5399.54	0.025696	8.70	358.11	229.03	0.80
Reach-1	119.9		Lat Struct									
Reach-1	110	100-year	2092.00	5387.39	5394.36	5394.36	5395.46	0.027042	10.34	365.31	167.32	0.88
Reach-1	100	100-year	2078.55	5383.00	5390.52	5390.52	5391.42	0.020586	10.43	454.21	234.73	0.73
Reach-1	95		Culvert									
Reach-1	90	100-year	2078.55	5383.14	5388.97	5388.97	5389.95	0.025933	10.61	392.68	183.54	0.86
Reach-1	89.9		Lat Struct									
Reach-1	60	100-year	1020.47	5374.50	5381.27	5379.67	5381.81	0.008189	6.30	241.21	135.42	0.48
Reach-1	55		Culvert									
Reach-1	50	100-year	1020.47	5372.70	5378.87	5378.87	5379.49	0.013344	7.46	235.74	97.87	0.56
Reach-1	49.9		Lat Struct									
Reach-1	45	100-year	883.31	5369.49	5375.46	5375.46	5376.58	0.025955	8.72	124.72	75.98	0.82
Reach-1	40	100-year	866.48	5363.57	5372.92	5370.77	5373.14	0.004936	4.09	303.93	153.24	0.36
Reach-1	35		Culvert									
Reach-1	30	100-year	866.48	5362.31	5370.77	5370.77	5370.93	0.002204	3.22	308.31	130.74	0.26
Reach-1	10	100-year	866.48	5356.30	5361.42	5360.20	5362.11	0.011073	6.77	141.35	44.00	0.58

Table 2b: Ch2M HILL Existing 100 - year Hydraulic Output

HEC-RAS Plan: MP Exist 072014 River: RIVER-1 Reach: Reach-1 Profile: 100-year

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach-1	600	100-year	1450.00	5750.20	5756.85	5756.85	5758.45	0.038880	10.98	175.50	60.17	0.82
Reach-1	590	100-year	1450.00	5718.23	5735.89	5730.31	5735.94	0.000868	2.52	977.51	161.26	0.11
Reach-1	585		Culvert									
Reach-1	580	100-year	1450.00	5717.80	5729.90	5729.90	5735.89	0.040251	19.64	73.82	88.34	1.00
Reach-1	560	100-year	1450.00	5684.47	5694.47	5693.18	5694.75	0.011242	5.70	419.85	133.66	0.36
Reach-1	555		Culvert									
Reach-1	550	100-year	1450.00	5683.10	5690.54	5690.54	5693.07	0.009615	14.71	169.00	48.60	1.01
Reach-1	540	100-year	1450.00	5660.98	5668.23	5668.23	5669.92	0.024603	11.70	156.41	46.95	1.04
Reach-1	530	100-year	1450.00	5652.10	5660.01	5660.01	5661.83	0.018610	10.92	141.60	46.25	0.94
Reach-1	520	100-year	1450.00	5645.52	5658.56	5657.67	5658.90	0.002927	5.91	537.13	145.29	0.31
Reach-1	515		Culvert									
Reach-1	510	100-year	1450.00	5643.57	5654.01	5654.01	5654.54	0.003470	6.31	339.48	80.69	0.36
Reach-1	508	100-year	1450.00	5640.03	5646.63	5646.63	5648.30	0.037525	10.48	146.46	49.64	0.98
Reach-1	507	100-year	1450.00	5639.21	5645.29	5645.29	5646.87	0.033293	10.36	158.87	54.52	0.95
Reach-1	505	100-year	1450.00	5638.27	5644.00	5644.00	5645.41	0.032480	10.18	185.63	75.13	0.94
Reach-1	500	100-year	1450.00	5625.60	5635.37	5634.97	5636.39	0.022426	9.78	276.75	125.14	0.55
Reach-1	495		Bridge									
Reach-1	490	100-year	1450.00	5624.40	5634.00	5634.00	5635.06	0.026436	9.96	264.01	125.71	0.57
Reach-1	470	100-year	1450.00	5607.68	5621.13	5614.06	5621.46	0.003719	5.16	446.33	129.14	0.25
Reach-1	465		Culvert									
Reach-1	460	100-year	1450.00	5603.33	5612.65	5612.65	5617.29	0.020842	17.28	83.92	96.84	1.00
Reach-1	455	100-year	1700.00	5596.39	5604.21	5604.21	5606.38	0.028330	11.85	148.27	39.91	0.98
Reach-1	450	100-year	1700.00	5590.81	5599.19	5599.19	5600.78	0.026792	10.27	182.25	106.22	0.93
Reach-1	440	100-year	1700.00	5587.69	5593.98	5593.98	5595.25	0.023797	9.75	254.63	136.18	0.89
Reach-1	436	100-year	1700.00	5578.63	5584.23	5584.23	5585.08	0.016562	9.62	410.40	224.64	0.78
Reach-1	431	100-year	1700.00	5571.70	5581.24	5578.80	5581.77	0.006021	6.76	494.40	217.07	0.40
Reach-1	425		Culvert									
Reach-1	420	100-year	1700.00	5571.10	5578.20	5578.20	5581.68	0.022498	14.97	113.58	124.36	0.99
Reach-1	410	100-year	1700.00	5565.61	5573.36	5570.92	5573.99	0.007520	6.39	266.98	59.29	0.50
Reach-1	405		Culvert									
Reach-1	400	100-year	1700.00	5563.35	5568.13	5566.97	5569.13	0.012078	8.04	211.36	59.64	0.67
Reach-1	398	100-year	1700.00	5563.39	5566.67	5566.67	5568.18	0.055920	12.44	216.26	89.81	1.33
Reach-1	395	100-year	1700.00	5555.00	5560.98	5560.98	5562.73	0.037266	10.61	161.08	48.30	1.01
Reach-1	390	100-year	1700.00	5551.40	5556.74	5556.74	5557.87	0.035761	10.19	257.78	108.53	0.98
Reach-1	389	100-year	1700.00	5550.00	5554.69	5554.69	5555.84	0.040472	10.35	249.04	105.65	1.04
Reach-1	385	100-year	1700.00	5537.75	5541.85	5541.85	5542.85	0.082357	11.82	240.89	115.59	1.34
Reach-1	380	100-year	1700.00	5529.50	5537.37	5536.86	5537.76	0.010956	6.07	401.46	203.84	0.54
Reach-1	375		Culvert									
Reach-1	370	100-year	1700.00	5527.68	5534.13	5534.13	5534.57	0.006872	5.88	465.00	213.79	0.46
Reach-1	360	100-year	1700.00	5511.80	5518.90	5518.90	5520.81	0.034734	11.20	162.11	49.18	0.95
Reach-1	352	100-year	1700.00	5507.30	5515.91	5514.42	5516.76	0.009700	8.62	308.02	138.43	0.56
Reach-1	351	100-year	1700.00	5506.80	5513.84	5513.84	5516.23	0.038249	12.41	140.01	63.47	0.97
Reach-1	350	100-year	1700.00	5503.40	5510.38	5510.38	5512.43	0.036908	11.49	147.99	36.51	1.01
Reach-1	342	100-year	1700.00	5494.95	5501.69	5501.69	5503.95	0.039860	13.71	182.40	53.93	1.08
Reach-1	340	100-year	1700.00	5493.14	5500.02	5500.02	5500.92	0.021216	8.74	340.76	219.42	0.75
Reach-1	334	100-year	1700.00	5488.11	5496.05	5495.56	5497.35	0.017688	9.58	233.71	86.02	0.72
Reach-1	330	100-year	1700.00	5485.84	5495.16	5495.07	5496.17	0.019843	8.97	319.14	178.29	0.68
Reach-1	325		Culvert									
Reach-1	318	100-year	1900.00	5485.27	5493.73	5493.73	5494.51	0.024523	10.32	419.54	211.79	0.70
Reach-1	304	100-year	1900.00	5484.40	5491.10	5489.24	5491.69	0.007839	6.33	357.61	178.90	0.48
Reach-1	303		Bridge									
Reach-1	302	100-year	1900.00	5483.05	5487.95	5487.95	5489.29	0.032033	10.47	254.27	90.82	0.93
Reach-1	301	100-year	1900.00	5479.08	5484.81	5484.81	5486.17	0.022681	9.81	258.28	121.68	0.82
Reach-1	300	100-year	1900.00	5475.10	5479.93	5479.93	5480.86	0.031059	8.66	318.58	168.21	0.90
Reach-1	295	100-year	1900.00	5470.26	5474.88	5474.88	5475.76	0.039266	8.31	314.26	211.21	0.98
Reach-1	291	100-year	1900.00	5468.09	5472.49	5472.49	5473.34	0.026536	9.40	396.74	222.91	0.87
Reach-1	290	100-year	1900.00	5464.32	5470.48	5470.48	5471.36	0.018903	9.14	411.06	248.01	0.75
Reach-1	285		Culvert									
Reach-1	280	100-year	1900.00	5461.70	5467.89	5467.89	5468.21	0.009494	6.37	577.50	218.60	0.53
Reach-1	270	100-year	1900.00	5451.44	5458.04	5458.04	5459.11	0.012260	9.60	381.62	187.38	0.72
Reach-1	265		Culvert									
Reach-1	260	100-year	1900.00	5438.86	5447.50	5444.67	5448.11	0.004070	6.42	361.15	113.91	0.43
Reach-1	255		Culvert									
Reach-1	250	100-year	1900.00	5438.24	5446.48	5445.29	5447.11	0.006830	6.86	400.50	154.29	0.53
Reach-1	231	100-year	1900.00	5434.97	5444.40	5444.40	5445.82	0.032961	12.40	287.97	99.55	0.73
Reach-1	230	100-year	1900.00	5434.90	5443.56	5443.56	5444.92	0.026172	11.89	302.12	99.93	0.74
Reach-1	225		Culvert									
Reach-1	220	100-year	1900.00	5433.65	5440.67	5440.67	5441.57	0.029030	10.49	376.58	177.36	0.80
Reach-1	219	100-year	1900.00	5431.60	5437.71	5437.71	5438.59	0.041552	9.33	318.30	162.35	0.99
Reach-1	200	100-year	1900.00	5420.59	5427.24	5427.24	5428.76	0.039499	9.90	192.91	66.70	1.01
Reach-1	190	100-year	1900.00	5414.10	5423.33	5420.31	5423.53	0.004766	3.67	594.82	307.97	0.36
Reach-1	185		Culvert									
Reach-1	180	100-year	2092.00	5410.57	5420.01	5420.01	5420.11	0.003225	3.19	1215.94	673.86	0.30
Reach-1	175	100-year	2092.00	5408.70	5415.83	5415.83	5416.40	0.030651	7.26	483.53	374.88	0.85
Reach-1	170	100-year	2092.00	5404.97	5411.47	5409.06	5411.71	0.003619	4.38	828.55	481.65	0.34
Reach-1	165		Culvert									
Reach-1	160	100-year	2092.00	5398.60	5404.81		5405.04	0.003637	4.21	732.13	281.54	0.34
Reach-1	152	100-year	2092.00	5396.42	5403.72	5403.72	5404.48	0.027475	8.45	435.92	262.55	0.84
Reach-1	151		Culvert									

Table 2b: Ch2M HILL Existing 100 - year Hydraulic Output

HEC-RAS Plan: MP Exist 072014 River: RIVER-1 Reach: Reach-1 Profile: 100-year (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach-1	150	100-year	2092.00	5393.63	5401.77	5401.77	5402.53	0.029509	10.54	468.31	242.77	0.67
Reach-1	130	100-year	2092.00	5393.48	5401.26	5401.26	5401.82	0.015066	8.84	701.86	486.33	0.59
Reach-1	125		Culvert									
Reach-1	120	100-year	2092.00	5389.00	5398.53	5398.53	5399.54	0.025696	8.70	358.11	229.03	0.80
Reach-1	119.9		Lat Struct									
Reach-1	110	100-year	2092.00	5387.39	5394.36	5394.36	5395.46	0.027028	10.34	365.40	167.33	0.88
Reach-1	100	100-year	2078.55	5383.00	5390.52	5390.52	5391.42	0.020586	10.43	454.21	234.73	0.73
Reach-1	95		Culvert									
Reach-1	90	100-year	2078.55	5383.14	5388.97	5388.97	5389.95	0.025933	10.61	392.68	183.54	0.86
Reach-1	89.9		Lat Struct									
Reach-1	60	100-year	1016.68	5374.50	5381.29	5379.62	5381.81	0.008006	6.24	243.47	136.79	0.48
Reach-1	55		Culvert									
Reach-1	50	100-year	1016.68	5372.70	5378.87	5378.87	5379.48	0.013277	7.44	235.50	97.86	0.56
Reach-1	49.9		Lat Struct									
Reach-1	45	100-year	878.35	5369.49	5375.45	5375.45	5376.57	0.026049	8.71	123.76	75.73	0.82
Reach-1	40	100-year	864.89	5363.57	5372.90	5370.77	5373.12	0.005008	4.11	301.39	152.95	0.36
Reach-1	35		Culvert									
Reach-1	30	100-year	864.89	5362.31	5370.77	5370.77	5370.92	0.002200	3.21	307.99	130.67	0.26
Reach-1	10	100-year	864.89	5356.30	5361.42	5360.20	5362.11	0.011033	6.76	141.35	44.00	0.58

Table 2c: Effective 100 - year Hydraulic Output at Lateral Weir

HEC-RAS Plan: Multi-profil River: RIVER-1 Reach: Reach-1 Profile: 100-year

Reach	River Sta	Profile	Q US	Q Leaving Total	Q DS	Q Weir	Q Gates	Wr Top Wdth	Weir Max Depth	Weir Avg Depth	Min El Weir Flow	E.G. US.	W.S. US.	E.G. DS	W.S. DS
			(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
Reach-1	119.9	100-year	2092.00	13.45	2078.55	13.45		18.51	0.94	0.47	5389.58	5399.54	5398.53	5391.42	5390.52
Reach-1	89.9	100-year	2078.55	1061.02	1020.47	1061.02		192.00	2.97	1.92	5380.40	5389.95	5388.97	5381.81	5381.27
Reach-1	49.9	100-year	1020.47	153.44	866.48	153.44		175.57	2.17	0.44	5372.50	5379.49	5378.87	5373.14	5372.92

Table 2d: CH2M HILL Existing 100 - year Hydraulic Output at Lateral Weir

HEC-RAS Plan: MP Exist 072014 River: RIVER-1 Reach: Reach-1 Profile: 100-year

Reach	River Sta	Profile	Q US	Q Leaving Total	Q DS	Q Weir	Q Gates	Wr Top Wdth	Weir Max Depth	Weir Avg Depth	Min El Weir Flow	E.G. US.	W.S. US.	E.G. DS	W.S. DS
			(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
Reach-1	119.9	100-year	2092.00	13.46	2078.55	13.46		18.52	0.94	0.47	5389.58	5399.54	5398.53	5391.42	5390.52
Reach-1	89.9	100-year	2078.55	1066.95	1016.68	1066.95		192.00	2.97	1.93	5380.40	5389.95	5388.97	5381.81	5381.29
Reach-1	49.9	100-year	1016.68	150.41	864.89	150.41		175.57	2.17	0.43	5372.50	5379.48	5378.87	5373.13	5372.90

Channel and Culvert Improvements

Location	ID	Existing						10-yr Proposed									Max Proposed									
		Size	Material	Shape	Capacity (cfs)	Blockage (%)	Storm Eq (Year)	Size	Length	Easements Needed per Culvert	Material	Shape	Capacity (cfs) **	Blockage (%)	Storm Eq (Year)	Total Cost (Engineering, Legal, Management, Contingency)	Size	Length	Easements Needed per Culvert	Material	Shape	Capacity (cfs) **	Blockage (%)	Storm Eq (Year)	Total Cost (Engineering, Legal, Management, Contingency)	Notes
Drive to School (North of Arapahoe Avenue)	C13	4'	RCP	Circular	7.4	50%	< 10-yr	15' x 6'	25	1	RCBC	Box	673	20%	10-yr	$ 161,657.82	(2) 15' x 6'	25	1	RCBC	Box	1,447	20%	10-50yr	$ 290,877.27	Culvert upstream has less capacity and may not convey all 1,400 cfs. Additionally, the channel upstream cannot convey all of the 1,400 cfs.
	Bridge															$ 108,675.00	30' bridge span / 26' deck width / 30" deck thickness		3	Steel	Bridge	830	0%	10-50yr	$ 108,675.00	Bridge to replace culvert crossing. Possibily converted to a covered bridge at expense of property owner.
Arapahoe Avenue	C12	9' x 3'	RCBC	Box	141	50%	< 10-yr	(2) 11' x 5'	65	2	RCBC	Box	673	20%	10-yr	$ 340,760.70	(3) 12' x 5'	65	2	RCBC	Box	1,350	20%	10-50yr	$ 543,291.99	Culvert upstream has less capacity and may not convey 1,200 cfs. The channel cannot convey1,200 cfs as well, which may cause flooding on nearby properties.
Alley between Marine Street and Arapahoe	C11	5' x 3.5'	CMP	Arch	45	50%	< 10-yr	(2) 10' x 6'	45	3	RCBC	Box	673	20%	10-yr	$ 278,519.58	(2) 10' x 6'	45	3	RCBC	Box	673	20%	10-yr	$ 280,871.26	Culvert is limited due to nearby homes. The channel may not be able to contain greater than a 10yr flow, and nearby homes may experience flooding.
Marine Street	C10	8.5' x 4'	RCBC	Box	155	50%	< 10-yr	(2) 9' x 6'	70	2	RCBC	Box	673	20%	10-yr	$ 342,101.19	(3) 9' x 6'	70	2	RCBC	Box	1,576	20%	10-50yr	$ 500,520.18	Culvert upstream cannot convey all 1,462 cfs and is limiting. Channel also cannot convey all 1,462 cfs to culvert. Nearby homes may experience flooding.
8th Street and Alley	C9	6' x 3.25'	CMP	Arch	64	50%	< 10-yr	(2) 9' x 6'	170	5	RCBC	Box	673	20%	10-yr	$ 717,874.74	(2) 10' x 6'	170	5	RCBC	Box	1,092	20%	10-50yr	$ 797,915.33	Culvert is limited due to nearby homes. Channel cannot convey all 915 cfs and nearby properties may experience flooding.
University Avenue	C8	6' x 5'	RCBC	Arch	104	50%	< 10-yr	(2) 9' x 6'	105	2	RCBC	Box	600	20%	10-yr	$ 475,753.14	(2) 10' x 6'	105	2	RCBC	Box	1,237	20%	10-50yr	$ 528,260.93	Culvert is limited due to location between structure and road. Channel may not be able to contain all 1,078 cfs; nearby homes may experience flooding.
Pleasant Street	C7	8' x 4.25'	RCBC	Arch	153	20%	< 10-yr	(2) 10' x 6'	50	2	RCBC	Box	600	20%	10-yr	$ 295,163.10	(2) 13' x 6'	50	2	RCBC	Box	1,339	20%	10-50yr	$ 374,740.00	Culvert upstream may not be able to convey all 1,227 cfs. Channel may also not be able to contain greater than a 10yr flow. Nearby properties may experience flooding.
704 Pleasant Street - Patio	C6-B	5.5' x 2.9'	CMP	Arch	65	30%	< 10-yr	(2) 8' x 6'	42	3	RCBC	Box	600	20%	10-yr	$ 260,061.51	(2) 12' x 6'	42	3	RCBC	Box	982	20%	10yr-50yr	$ 307,347.24	Culvert is located on private property and should be replaced to fully optimize the 7th Street culvert. Easements will need to be obtained by nearby property owners and the Anderson Ditch company.
7th Street	C6	4.5'	RCP	Circular	11	50%	< 10-yr	(2) 8' x 6'	180	4	RCBC	Box	600	20%	10-yr	$ 675,699.33	(2) 12' x 6'	180	4	RCBC	Box	1,310	20%	10yr-50yr	$ 973,871.58	Culvert is limited due to nearby infrastructure and homes. The broken style culvert is limiting the capacity, so to achieve full efficiency the culvert should be re-aligned. Channel capacity cannot convey all 1,165 cfs. Flooding may be experienced by nearby homes/properties. Utilities to be considered. Possible sediment basin upstream of culvert.
Pennsylvania Avenue	C5	4.75' x 3'	CMP	Arch	42	50%	< 10-yr	(2) 9' x 6'	45	3	RCBC	Box	600	20%	10-yr	$ 253,896.01	(3) 12' x 6'	45	3	RCBC	Box	1,469	20%	10-50yr	$ 464,894.90	Culvert downstream cannot convey same capacity of 1,203 cfs. Channel capacity is less than 1,203 cfs and nearby homes and properties may experience flooding.
	Pedestrian Bridge*	4.75' x 3'	CMP	Arch	42	50%	< 10-yr	30' bridge span / 6' deck width / 30" deck thickness / 4' handrails		3	Wood / Steel	Box / Arch	600	0%	10-yr	$ 90,000.00										Cost estimate from Pennsylvania Avenue Flood Repair/Improvement Alternative Analysis report (2014)
College Avenue	C4	6' x 6.5'	Brick	Arch	125	50%	< 10-yr	(2) 7' x 6'	55	3	RCBC	Box	495	20%	10-yr	$ 250,167.85	(3) 11' x 6'	55	3	RCBC	Box	1,286	20%	50-yr	$ 500,731.35	Channel upstream does not convey the 10yr flow but may flow within the overbanks. Homes/properties may experience flooding.
Euclid Avenue	C3	4'	RCP	Circular	0	100%	< 10-yr	(2) 8' x 6'	65	0	RCBC	Box	495	20%	10-yr	$ 291,125.52	(3) 10' x 6'	65	0	RCBC	Box	1,286	20%	50-yr	$ 529,777.95	Culvert size is limited due to nearby properties and homes. Channel capacity may not convey 1,286 cfs to culvert; nearby properties/homes may see flooding. Proposed channel improvements extend 250' upstream of the culvert to accommodate new flow. A 1.5' drop structure is proposed 20' upstream of the channel to dissipate energy.
Aurora Avenue	C2	(2) 10' x 5'	RCBC	Box	495	0%	< 50-yr									-	(4) 10' x 6'	80	2	RCBC	Box	1,696	20%	50-100yr	$ 794,609.26	Culvert upstream may not pass all 1,700 cfs. Additionally, channel capcity is limited and cannot convey 1,700 cfs.
Willowbrook Road	C1	9' x 5'	RCBC	Box	337	50%	< 10-yr	9' x 7'	140	3	RCBC	Box	400	20%	10-yr	$ 338,314.14	(2) 9' x 7'	140	3	RCBC	Box	1,187	20%	50-100yr	$ 642,814.91	Culvert is limited due to nearby properties. Channel upstream is limited in capacity and cannot convey 1,450 cfs. Nearby properties and homes may experience flooding. Utilities to be considered.
705 Willowbrook Court - Private	C1-A	4.4'	CMP	Circular	125	50%	< 10-yr	8' x 6'	34	1	RCBC	Box	400	30%	10-yr	$ 114,814.47	(2) 8' x 8'	34	1	RCBC	Box	1,060	20%	50-yr	$ 233,312.53	Culvert is limited due to nearby properties. Channel upstream is limited in capacity and cannot convey 1,450 cfs. Nearby properties and homes may experience flooding. Utilities to be considered.
															Total Improvement Costs for 10-yr Culverts:	$ 4,579,030.00								Total Improvement Costs for Max Culverts:	$ 7,763,837.00	

* - Cost estimate based on information from *Big R Bridge*
** - Capacity is potential capacity and may not experience stated capacity during a storm event

Notes:
- Culvert sizes will need to be confirmed during final design/construction
- Culvert sizes have been increased to their maximum limits without adversely affecting homes/properties
- Where culvert inverts have been lowered, utilities will need to be verified to identify possible relocation
- Channels adjacent to culverts will require alterations to transition to new culvert size

Improvements Outside of Public Right of Way

Channel Improvements Location (Length)	Existing Channel Dimensions (Typ.) Width	Depth	Slopes (L / R)	Capacity (cfs)	Storm Eq (Year)	Proposed Channel Dimensions Width	Depth	Slopes (L / R)	Capacity (cfs)	Storm Eq (Year)	Cost Quantity	Unit	Unit Cost	Cost	Notes
997 6th St & 580 Euclid Ave (200')	2	3	3 / 1.3		< 10-yr	5	5	2	495	10-yr	99000	L.F. / Q	$ 0.26	$ 46,332.00	Altering channel by creating 5-6' bottom width, lowering channel inverts by 1-4', pushing west bank further west by 12', with 2H:1V side slopes.
1010 N to 1030 N 6th Street (200')	3	4	4		< 10-yr	5	4.5	2	495	10-yr	99000	L.F. / Q	$ 0.26	$ 46,332.00	Altering channel by creating 5-6' bottom width, lowering channel inverts by 1-4', pushing east bank further east by 2-9', with 2H:1V side slopes.
810 Marine Street (65')	6	4	1.5		< 10-yr	9	4.5	2	673	10-yr	43745	L.F. / Q	$ 0.26	$ 20,473.00	Create open channel with 9' bottom width and 2H:1V side slopes.
														$ 113,137.00	

Other Improvements	Existing Size	Material	Type	Capacity (cfs)	Proposed Size	Material	Type	Capacity (cfs)	Reinforced Concrete Pipe Quantity	Unit	Unit Cost	Flared End Section Quantity	Unit	Unit Cost	Cost	
Anderson Ditch	6' x 2'	RCBC	Box	36	36-inch	RCP	Circular	25	64	L.F.	$ 139.00	2	EA	$ 2,066.00	$ 23,450.00	Piping Anderson Ditch alternative. Slope is 0.102%.
Gregory Gulch Pipe Alignment	-	-	-	-	48-inch	RCP	Circular	240	480	L.F.	$ 185.00	1	EA	$ 2,643.00	$ 164,597.00	Storm sewer pipe alignment. Slope is 7%.

	Size	Type	Capcity	Quantity	Size	Type	Capacity (cfs)	Quantity	Length	Unit	Unit Cost	Cost	Notes
Willowbrook Rd Storm Sewer Inlets	-	-	-	-	3' x 2'	Denver No. 13 Combination	240	20	60	L.F.	$ 1,475.50	$ 159,354.00	Inlets located at the North end of Willowbrook road.

Notes:
- Existing channel dimensions are represented as a trapezoidal channel for simplification
- Unit cost for channel improvements is based on a cost per linear foot, per design flow (Q)

Improvements to Street Conveyance

Location - From	To	Storm Eq (Year)	Quantity	Unit	Curb and Gutter Area (SF)	CY	Unit Cost	Cost	Excavation Area (SF)	CY	Unit Cost	Cost	Asphalt Area (SY)	Unit Cost	Cost	Cost Summary	Notes
Cul-de-sac Willowbrook Road	Gregory Gulch	10-yr / 50-yr	820	L.F.	2.81	171	$ 770.00	$ 131,425.00	15	460	$ 40.00	$ 18,400.00	2735	$ 63.65	$ 174,083.00	$ 323,908.00	To carry street flow from overtopping of private drive located in the cul-de-sac of Willowbrook Road.
Euclid Ave (6th Street)	Boulder Creek	10-yr / 50-yr	1351	L.F.	2.81	281	$ 770.00	$ 216,530.00	15	757	$ 40.00	$ 30,262.00	4503	$ 63.65	$ 286,637.00	$ 533,429.00	To carry street flow from overtopping of 6th Street culvert due to backwater occurring at Euclid Ave.
7th Street Culvert	Boulder Creek	10-yr / 50-yr	1521	L.F.	2.81	317	$ 770.00	$ 243,777.00	15	960	$ 40.00	$ 38,400.00	5745	$ 63.65	$ 365,669.00	$ 647,846.00	To carry street flow from overtopping of 7th Street culvert due to backwater effects occurring because of the private culvert on the property of 714 Pleasant Street.
Pleasant Street	8th Street	50-yr	408	L.F.	2.81	85	$ 770.00	$ 65,392.00	15	230	$ 40.00	$ 9,200.00	1360	$ 63.65	$ 86,564.00	$ 161,156.00	To carry street flow from overtopping of Pleasant Street culvert.
8th Street	Marine Street Culvert	50-yr	675	L.F.	2.81	141	$ 770.00	$ 108,185.00	15	375	$ 40.00	$ 15,000.00	2250	$ 63.65	$ 143,213.00	$ 266,398.00	To carry street flow from overtopping of Univeristy Avenue culvert.
9th Street at Alley b/w Arapahoe and Marine	Arapahoe Road	10-yr / 50-yr	470	L.F.	2.81	98	$ 770.00	$ 75,329.00	15	265	$ 40.00	$ 10,600.00	1570	$ 63.65	$ 99,931.00	$ 185,860.00	To carry street flow from overtopping of the culvert at the alley between Arapahoe and Marine.

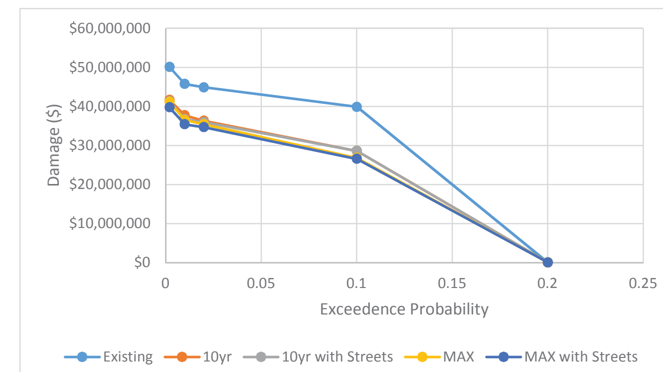
Subtotal Street Conveyance Improvements Cost:		$ 2,118,597.00
Engineering:	15%	$ 317,790.00
Legal/Administrative:	5%	$ 105,930.00
Contract/Construction Management:	10%	$ 211,860.00
Contingency:	50%	$ 1,059,299.00
Total Improvement Costs:		$ 3,813,476.00

Notes:
- Storm equivalent is based on when the designated street will likely see significant street conveyance
- Costs reflect street conveyance improvements of 12-inches of depth
- Street improvements include a 6" curb, 4' sidewalk, and 6" curb for a total of 12"

Cost Benefit Analysis
Gregory Canyon Creek Master Plan
March 13th, 2015

		Damage Costs Under Existing Conditions				Damage Costs Under Proposed Alternative			
Alternative	Cost	10yr	50yr	100yr	500yr	10yr	50yr	100yr	500yr
10yr	$4,692,167					$28,624,736	$36,296,256	$37,709,166	$41,610,872
10yr w/ Streets	$8,505,643	$39,885,504	$44,871,121	$45,713,907	$50,081,200	$28,624,736	$35,953,292	$36,703,945	$41,289,544
Max	$7,876,974					$26,807,549	$35,388,630	$36,511,272	$41,132,626
Max w/ Streets	$11,690,450					$26,532,135	$34,657,034	$35,407,533	$39,726,175
		0.1	0.02	0.01	0.002				

Probability	Storm Event	Damage from Storm Event				
		Existing	10yr	10yr w/ Street	MAX	MAX w/ Streets
0.2	5yr	0	0	0	0	0
0.1	10yr	$39,885,504	$28,624,736	$28,624,736	$26,807,549	$26,532,135
0.02	50yr	$44,871,121	$36,296,256	$35,953,292	$35,388,630	$34,657,034
0.01	100yr	$45,713,907	$37,709,166	$36,703,945	$36,511,272	$35,407,533
0.002	500yr	$50,081,200	$41,610,872	$41,289,544	$41,132,626	$39,726,175



	Existing	10yr	10yr w/ Street	MAX	MAX w/ Streets
Annualized damage	$4,430,765.96	$3,521,537.92	$3,492,949.38	$3,415,438.65	$3,345,259.57
Benefit		$909,228.04	$937,816.58	$1,015,327.31	$1,085,506.39
Annualized Alternative Cost (7% Amortization, 50-yr Life Span)		$339,993.71	$616,317.61	$570,764.35	$847,088.25
Benefit Cost Ratio		2.67	1.52	1.78	1.28

Rate 0.07

Gregory Canyon Creek Criteria and Assumptions

Gregory Canyon Creek

Table 17

Parameter		Criteria / Assumption
Street	Flow depth	Per the City's criteria, maximum allowable depth is 12" at the deepest point.
	Improvement Location	Street improvements, where proposed, were only deemed necessary at intersections where the slope was greater than 4%. Street improvements for the length of the street were proposed for slopes less than 4%.
	Slope	The most conservative slope of 1% found in the basin was used to determine the maximum safe street conveyance
Cost	Culverts	Costs for culvert and pipes were developed using the Urban Drainage Master plan cost estimation spreadsheet.
	Channel	A unit cost of $0.26 per length of channel per discharge was used for channel improvements.
	Streets	Cost for street improvements were developed using unit rates pulled from Urban Drainage's Bid Tabs.
Culvert	Blockage	Per the City's direction, a blockage assumption of 20% was used to model the culvert improvements.
FLO-2D	Flow rates	Flow rates for the FLO-2D model were pulled from the HEC-1 data provided for basins 212 and 213.
	Terrain	Terrain data used for the 2D modeling was developed from the 2013 LiDAR data provided by the City.
	Manning's n	Roughness values for the 2D modeling were developed using a combination of land use and street locations.
	Cost	The cost for the sediment traps is an average of the costs provided in Muller's Site Source report on Fourmile Canyon.
Sediment Trap	Modeling	The modeling of the detention upstream of Flagstaff Road used the blockage assumption for the Flagstaff culvert from the Effective FEMA model of 50%.
Detention	Widths	The width of channel grading improvements was assumed to be the width of proposed culverts. It is assumed that retaining wall/wingwalls would be used to limit the encroachment on adjacent properties.
Channel Grading	Expansion and Contraction	Channel improvement lengths were based on the following assumptions: 1. Upstream of Culvert barrels an expansion of 4:1 was used to transition from the existing channel to the 2. Downstream of the culverts a contradiction of 1:1 was used to move from the culvert barrels to the existing channel. These ratios were taking from HEC-RAS modeling guidance.

Acronyms and Abbreviations

BCA	Benefit Cost Analysis
cfs	cubic feet per second
CUHP	Colorado Urban Hydrograph Procedure
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
HAZUS-MH	Hazards United States *(FEMA)* Multi-Hazard
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Centers River Analysis System
LOMR	Letter of Map Revision
UDFCD	Urban Drainage and Flood Control District
USACE	U.S. Army Corps of Engineers
WRAB	Water Resources Advisory Board