Alternative Analysis Memorandum

PREPARED FOR: City of Boulder

COPY TO: Urban Drainage and Flood Control District

PREPARED BY: CH2M HILL

DATE: October 10, 2014

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**.

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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, 2010, and have been the basis for each subsequent study completed for the City of Boulder for Gregory Canyon Creek.

Summary of Peak Discharges

Hydrographs from the CUHP and HEC-1 analysis (Greenhorne & O'Mara, 1987) were extracted from output for use in the two – dimensional hydraulic analysis that was performed as part of this study. The FEMA effective flows identified in the 2010 Letter of Map Revision (LOMR) (Belt Collins West, 2010) were used for the one – dimensional Hydrologic Engineering Center River Analysis System (HEC-RAS) hydraulic modeling. A summary of the peak discharges and their approximate location are located in **Table 3**.

TABLE 3
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

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, 2010. The effective studies as well as the other studies performed along Gregory Canyon Creek are documented in **Table 4**.

TABLE 4
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

TABLE 4
Previous Studies

Document Type	Source	Description

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 5**. 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 6** 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 5
Existing Crossing Summary

Location	Percent Blockage	Belt Collins Geometry, 2010	Updated Geometry
Flagstaff Rd	50%	73.2	54
Private Drive at Old Baseline Road	100%	23	--
Pedestrian Bridge at Willowbrook Road Cul-de-sac	0%	Not Modeled	--
Private Drive at NW Corner of Willowbrook Road Cul-de-sac	50%	52.8	--
Private Drive at West Side of Willowbrook Road	50%	120 x 60	--
Willowbrook Road	50%	108 x 60	--
Pedestrian Bridge at Willowbrook Road	0%	Not Modeled	--
Private Drive 550 Aurora	0%	192 x 84	--
Aurora Crossing #1	0%	36	--
Aurora Crossing #2	0%	60 x 120	--
Euclid Avenue	100%	48	--
College Avenue	50%	62.4 x 72	72 x 78

TABLE 5
Existing Crossing Summary

Location	Percent Blockage	Belt Collins Geometry, 2010	Updated Geometry
Private Drive Wood Bridge DS of College Avenue	75%	Open Area = 77.4 sq. ft.	--
Pennsylvania Avenue	50%	56.4 x 36	--
7th Street	50%	48	--
Weir Split Flow Box DS of Anderson Ditch	0%	Not Modeled	--
704 Pleasant Street Patio	30%	66 x 34.8	--
Pleasant Street	20%	96 x 48	--
University Avenue	50%	72 x 60	--
8th street and Alley	50%	66 x 38.4	--
810 Marine Street	50%	48 x 36	75 x 54
Marine Street	50%	96 x 48	104 x 48
Alley Between Marine and Arapahoe	50%	62.4 x 42	--
Arapahoe Avenue	50%	120 x 36	108 x 36
Private Driveway To Old School	50%	42	48

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.

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

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 3**. 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 conducted a site walk on July 17, 2014. City staff was able to convey to CH2M HILL what was observed during the flood event of September 2013 and identify areas for improvements. Some of the residences that had been damaged by flood waters had already restored their property to pre-flood conditions or constructed improvements such as flood walls to help prevent future flooding. The objective during the site walk was to develop alternatives to help mitigate infrastructure flooding. These alternatives are discussed in detail in the subsequent sections. The preferred improvements as identified by the City of Boulder are located in **Table 8**.

TABLE 8
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

TABLE 8
Potential Improvement Summary

Location	Proposed Improvement	Number of Properties Impacted
7th Street at Arapahoe Avenue	Increase Roadway Conveyance	Varies - Residential Drives

In addition to the proposed improvements identified by the City, documented in **Table 8**, CH2M HILL noticed other deficiencies along Gregory Creek Canyon through detailed hydraulic modeling. The channel geometry between Euclid Avenue and College Avenue is the only existing section that is unable to convey the 10 – year storm event without causing infrastructure damage. 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 two 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 9**.

TABLE 9
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

Alternative Plans

The horizontal and vertical constraints along Gregory Canyon Creek limit the improvements that can be proposed without easements or impacts to adjacent property owners. The City of Boulder staff requested that CH2M HILL evaluate three different categories s: 1) Category One – Channel and Facility Maintenance; 2) Category Two – Channel Conveyance Improvements; and 3) Category Three – Flood Conveyance Improvements. The intent of the proposed categories is to mitigate flooding risk with Category One being confined predominately to the City ROW. The subsequent categories, Category Two and Category Three, will require work on private property but will help mitigate, but not eliminate impacts during larger storm events. For each category 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.

Category One – Channel and Facility Maintenance. This category was envisioned to provide recommendations for channel maintenance and brush and debris clearing. In addition, 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 without modifications to the channels. 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 culvert capacity is limited to the channel capacity immediately

upstream and downstream of the culvert. The intent of this category was to maximize the culvert size. Channel improvements in the immediate vicinity of the new culvert are needed to accommodate the larger culvert size. In addition, channel deficiencies were noted in areas with severely reduced capacity that did not meet the level of service experienced by the majority of the channel or the surrounding infrastructure. These areas are noted under Category One but will be further assessed in Category Two. For the majority of Gregory Canyon Creek, the existing channel can convey the 10 – year storm event. The 10-year storm became the level of service for Category One. However, if a larger culvert could be constructed based on visual horizontal and vertical constraints a larger culvert was proposed. These max culvert sizes and constraints are in **Table 3** in the technical appendix. Culvert improvements were recommended to pass the ten year flow. The improvements associated with Category One are located in **Figure 5** in the technical appendix.

Category Two – Channel Conveyance Improvements. The intent of Category Two is to improve on Category One by proposing additional channel improvements to improve the level of service to the ten year flow optimizing Gregory Canyon Creek without adversely impacting any structures. As mentioned in the proceeding sections, the Gregory Canyon Creek is located almost entirely within in private property. Any additional channel improvements needed to increase the capacity would require drainage easements from residents. In lieu of a drainage easement, a resident may work with the City to construct the improvements on their property per the master plan guidelines. The constraints for this category included the physical limitations of the channel. The goal was to achieve the 50 - year conveyance capacity in the channel but the maximum estimated width for Gregory Canyon Creek without impacts to structures is approximately 30 feet. However, due to horizontal constraints with existing infrastructure, a storm event beyond the 10 – year event cannot be conveyed without impacting existing residential structures. Channel improvements to accommodate the 10 - year event were identified with this category. The channel improvements associated with Category Two are located in **Figure 6** in the technical appendix.

Category Three – Flood Conveyance Improvements. For the purposes of this analysis, Category Three builds on the channel optimization of the Gregory Canyon Creek channel presented in Category two and seeks to maximize the flood conveyance of the major roadway overflow paths while adhering to the local criteria and constraints. Category Three consists of the culvert and channel improvements identified in Category Two with 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 170 cfs which is approximately 50% of the modeled 100 year flows in the street. This category, while not solving the 100-year flooding problem will go a long way to helping alleviate flood damage during more frequent storm providing benefits for the basin.

It is recommended that the City work with local emergency agencies to identify 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 Three are located in **Figure 7** in the technical appendix.

Technical Appendix

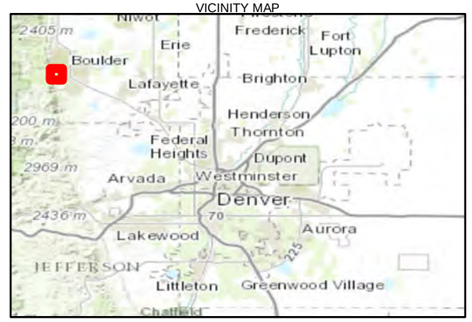
Figures

Tables

Technical Appendix

Figures

VICINITY MAP



LEGEND

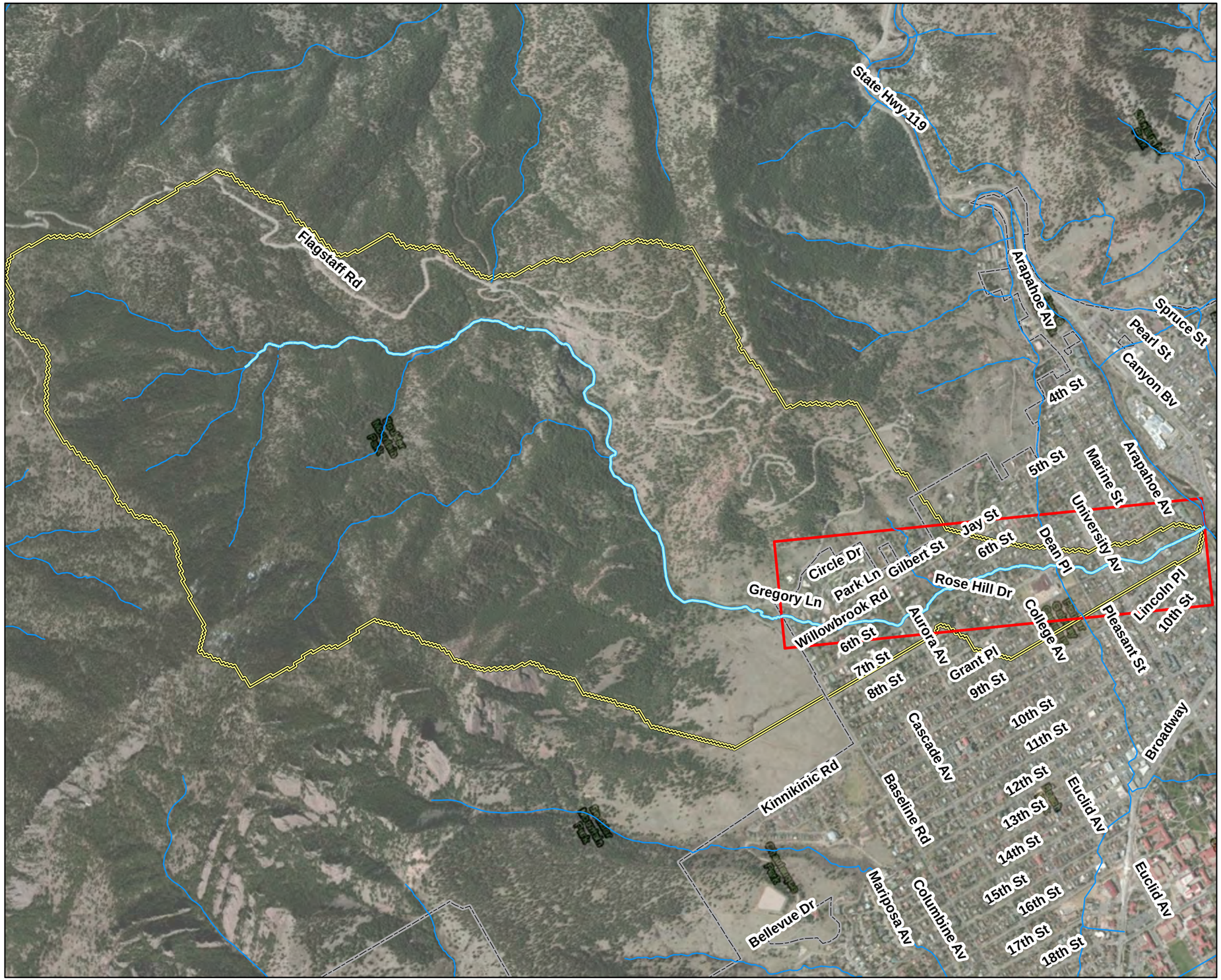
- Creeks and Streams
- Gregory Creek
- September 2013 Flood Extents
- City Limits

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



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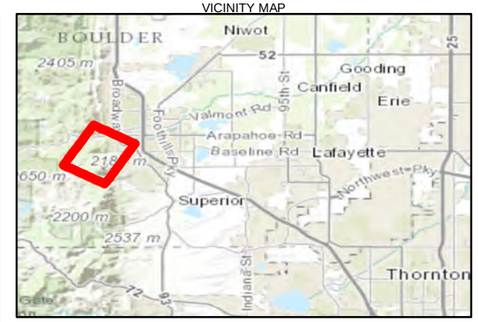


LEGEND

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

Notes:
1. Area of interest subject to change.

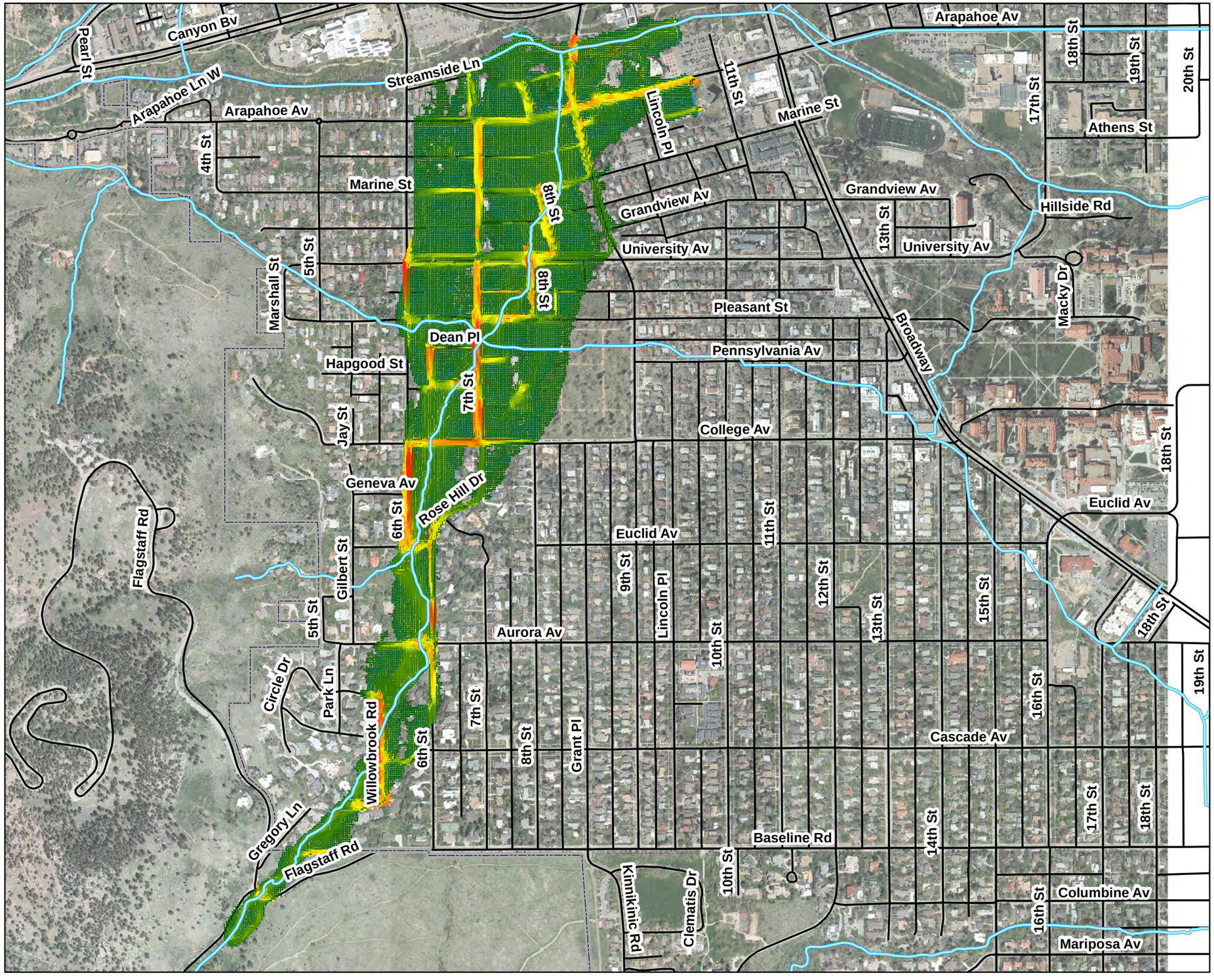
N

0.25 0.125 0 0.25

Miles

FIGURE 2
Area of Interest
Gregory Canyon Creek Flood Mitigation

CH2MHILL



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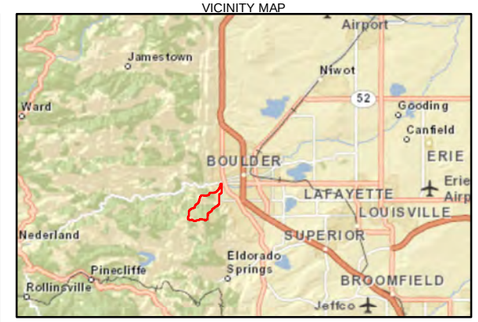


LEGEND

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

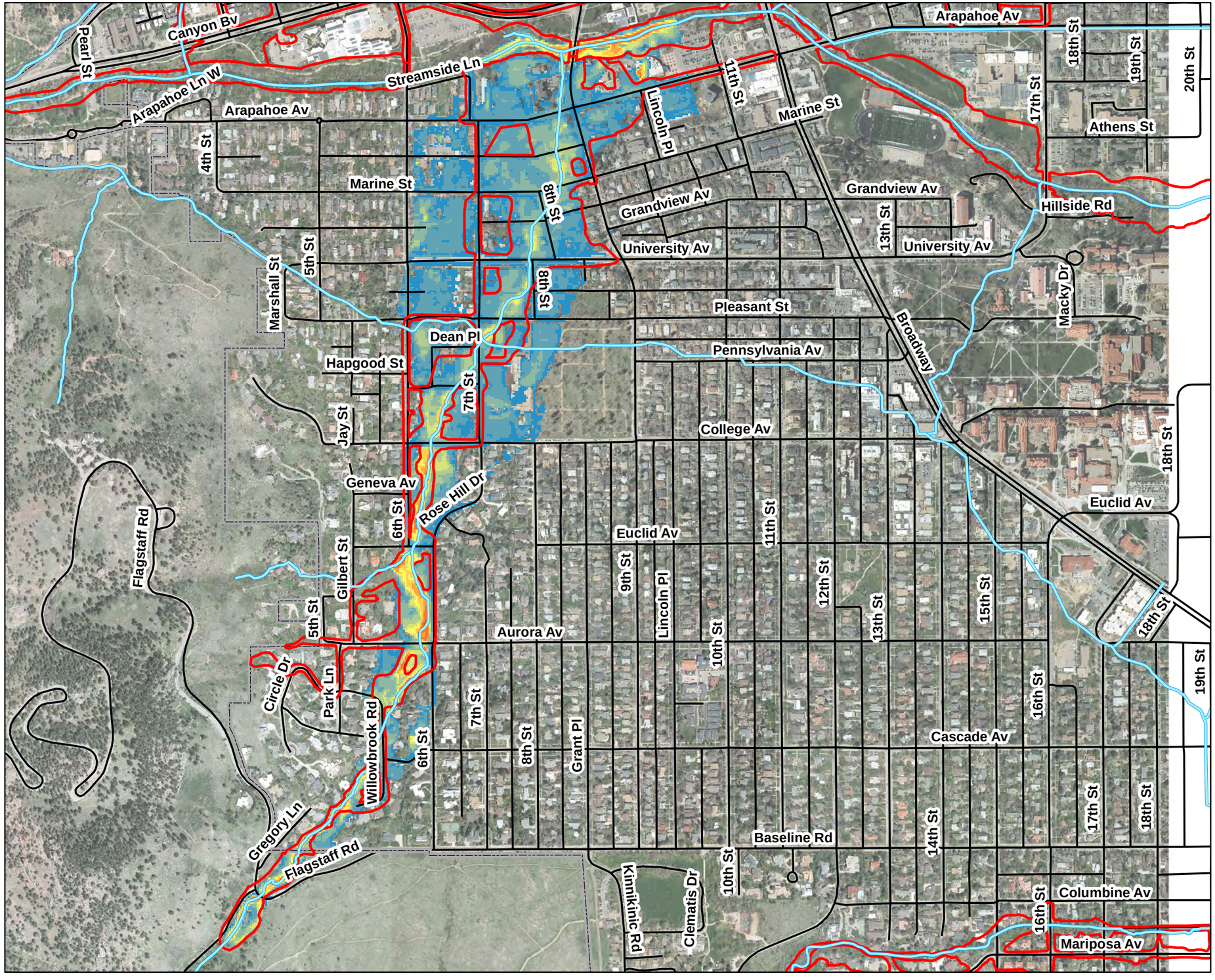
Notes:
1. Velocity in street is represented by velocity vectors.

N

0 25 50 100
Feet

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

CH2MHILL



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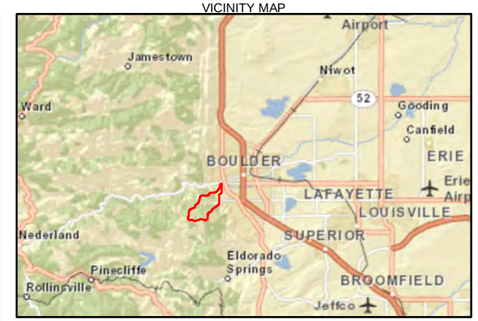


LEGEND

- 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

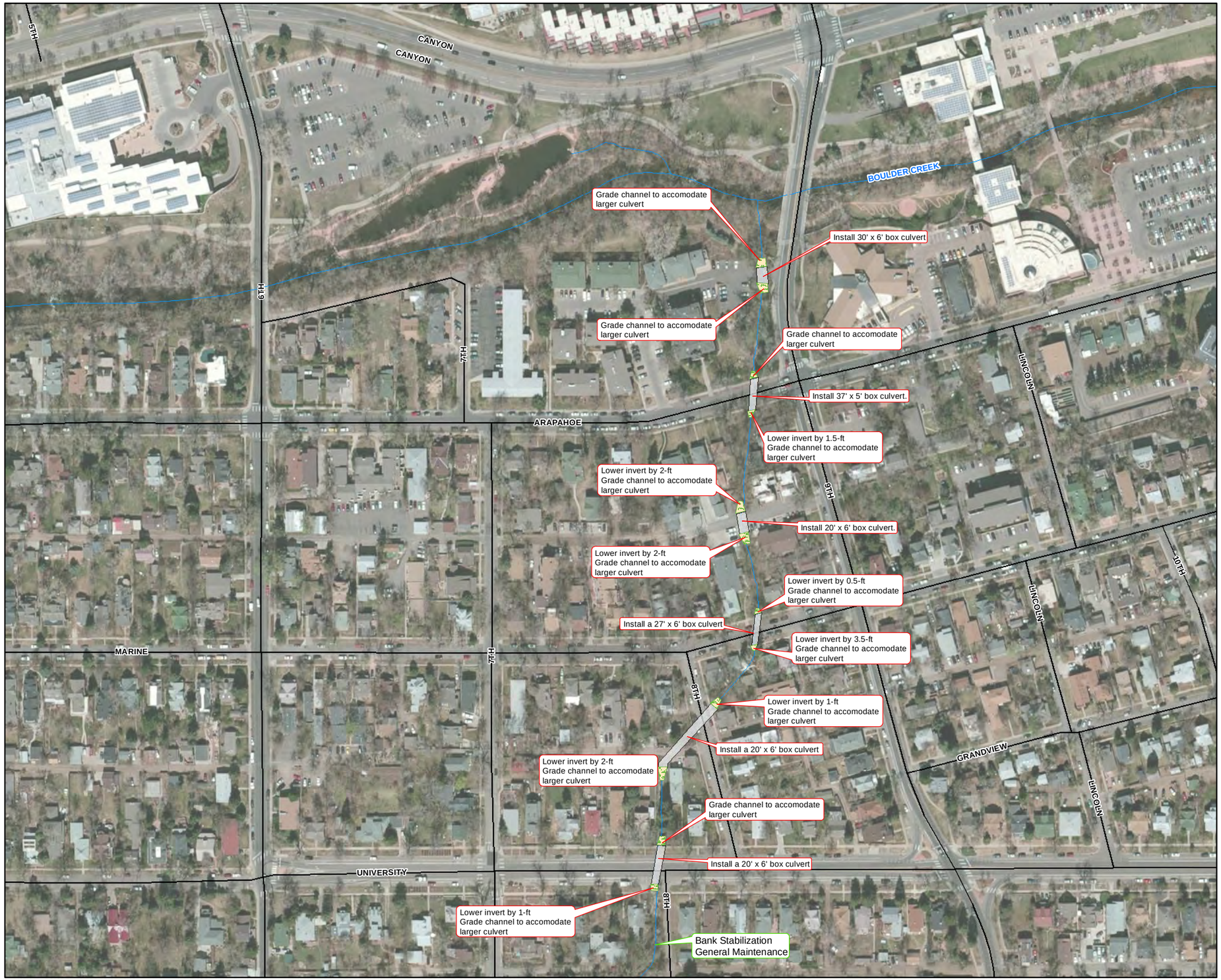
N

0 25 50 100

Feet

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

CH2MHILL



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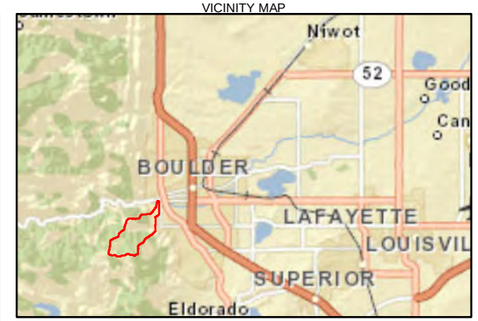


LEGEND

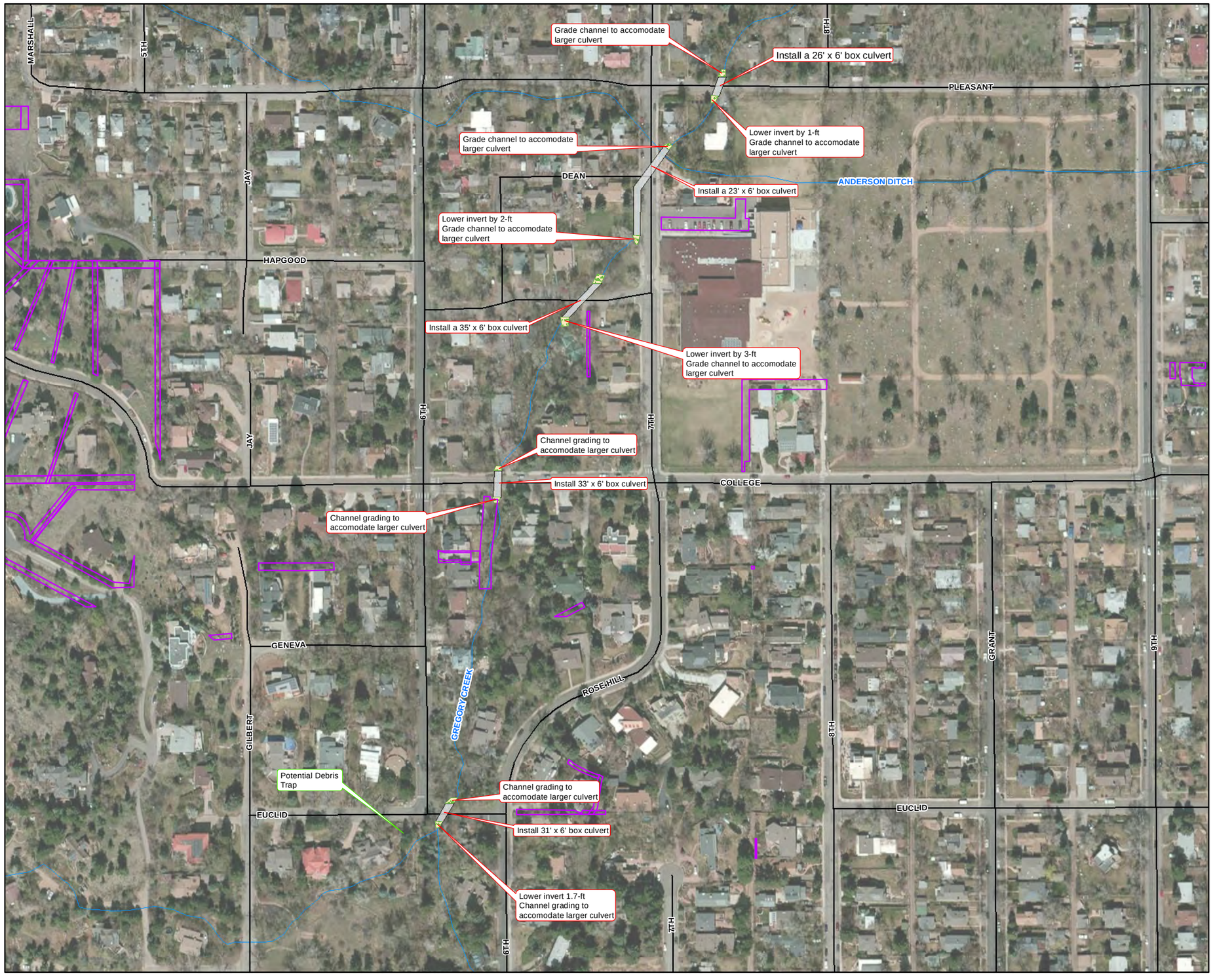
- Existing Easements
- Culvert Improvements
- Channel Grading

N

0 25 50 100 150
Feet

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

CH2MHILL



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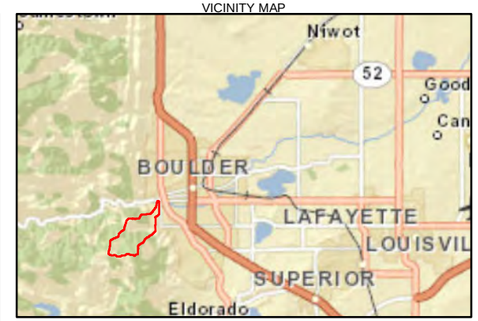


LEGEND

- Existing Easements
- Culvert Improvements
- Channel Grading

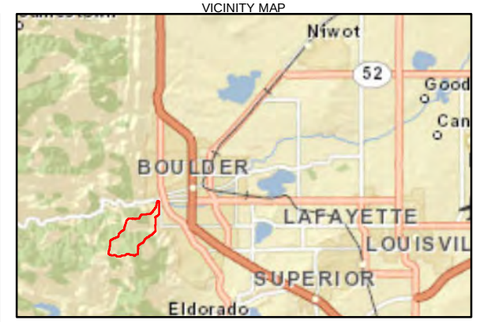
N

0 25 50 100 150
Feet

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

CH2MHILL

VICINITY MAP



LEGEND

- Existing Easements
- Culvert Improvements
- Channel Grading

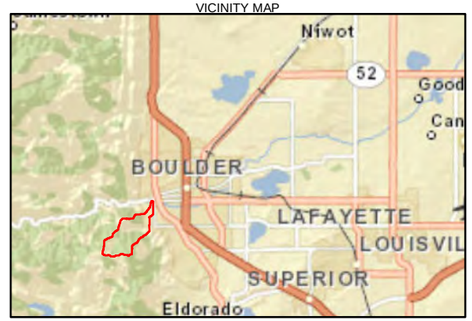
N

0 25 50 100 150
Feet

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

CH2MHILL

VICINITY MAP



LEGEND

Existing Easements

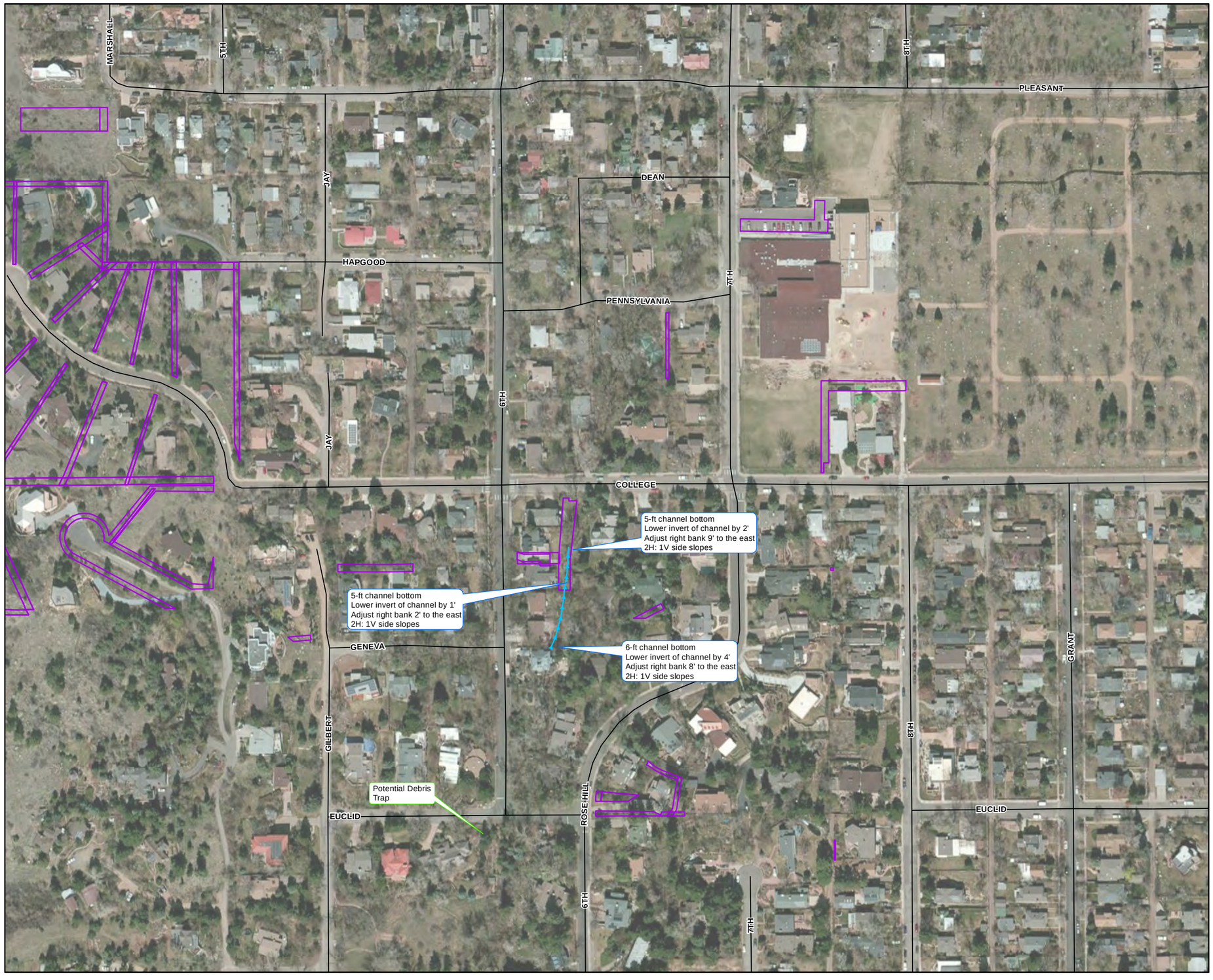
Channel Improvements

N

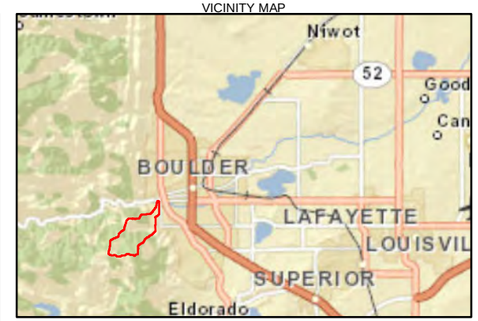
0 25 50 100 150

Feet

FIGURE 6 (1 of 3)
Category Two - Channel Conveyance Improvements
Gregory Canyon Creek Flood Mitigation



VICINITY MAP



LEGEND

Channel Improvements

Existing Easements

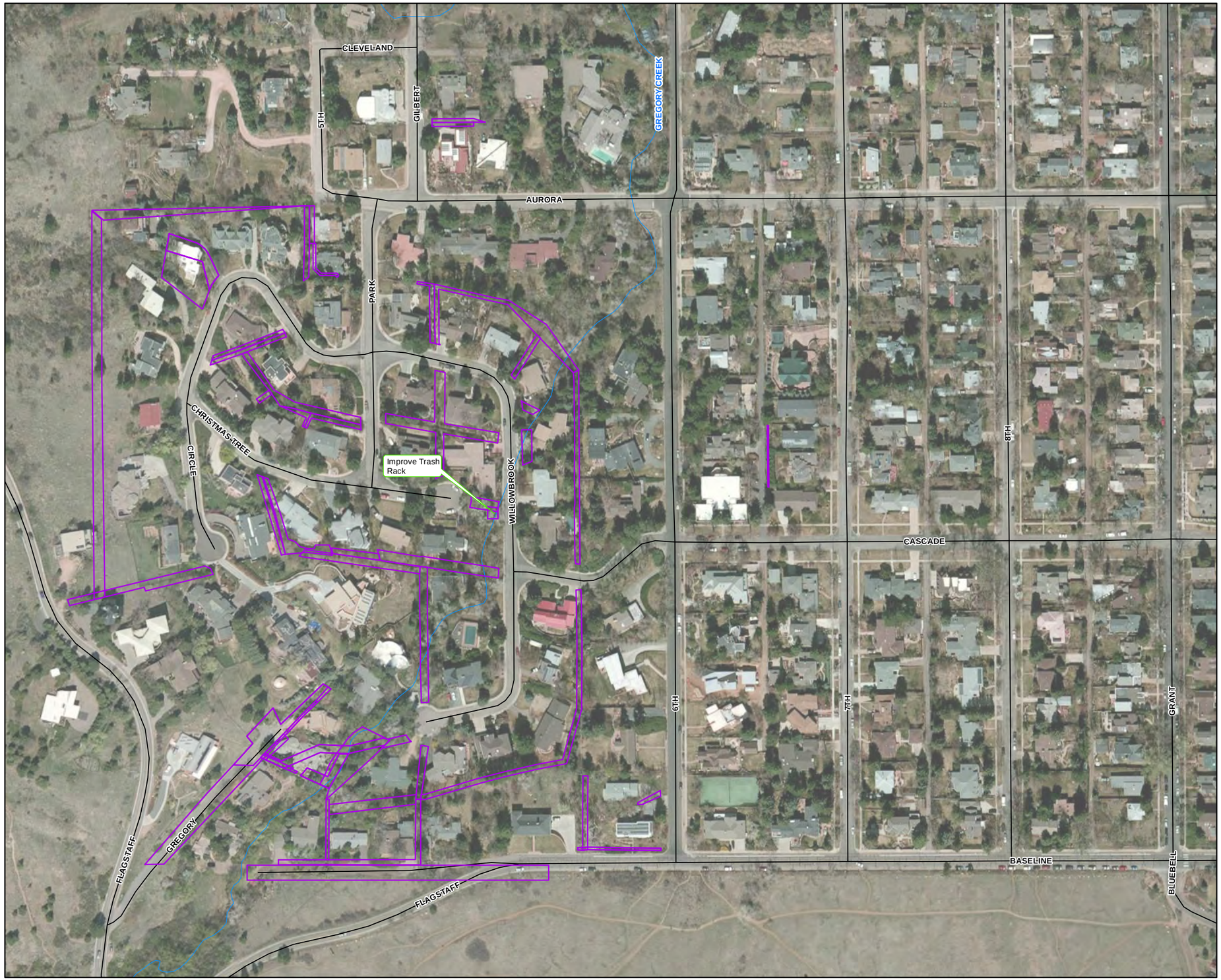
N

0 25 50 100 150

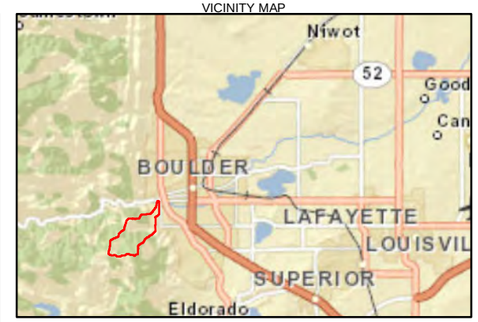
Feet

FIGURE 6 (2 of 3)
Category Two - Channel Conveyance Improvements
Gregory Canyon Creek Flood Mitigation

CH2MHILL



VICINITY MAP



LEGEND

Existing Easements

Channel Improvements

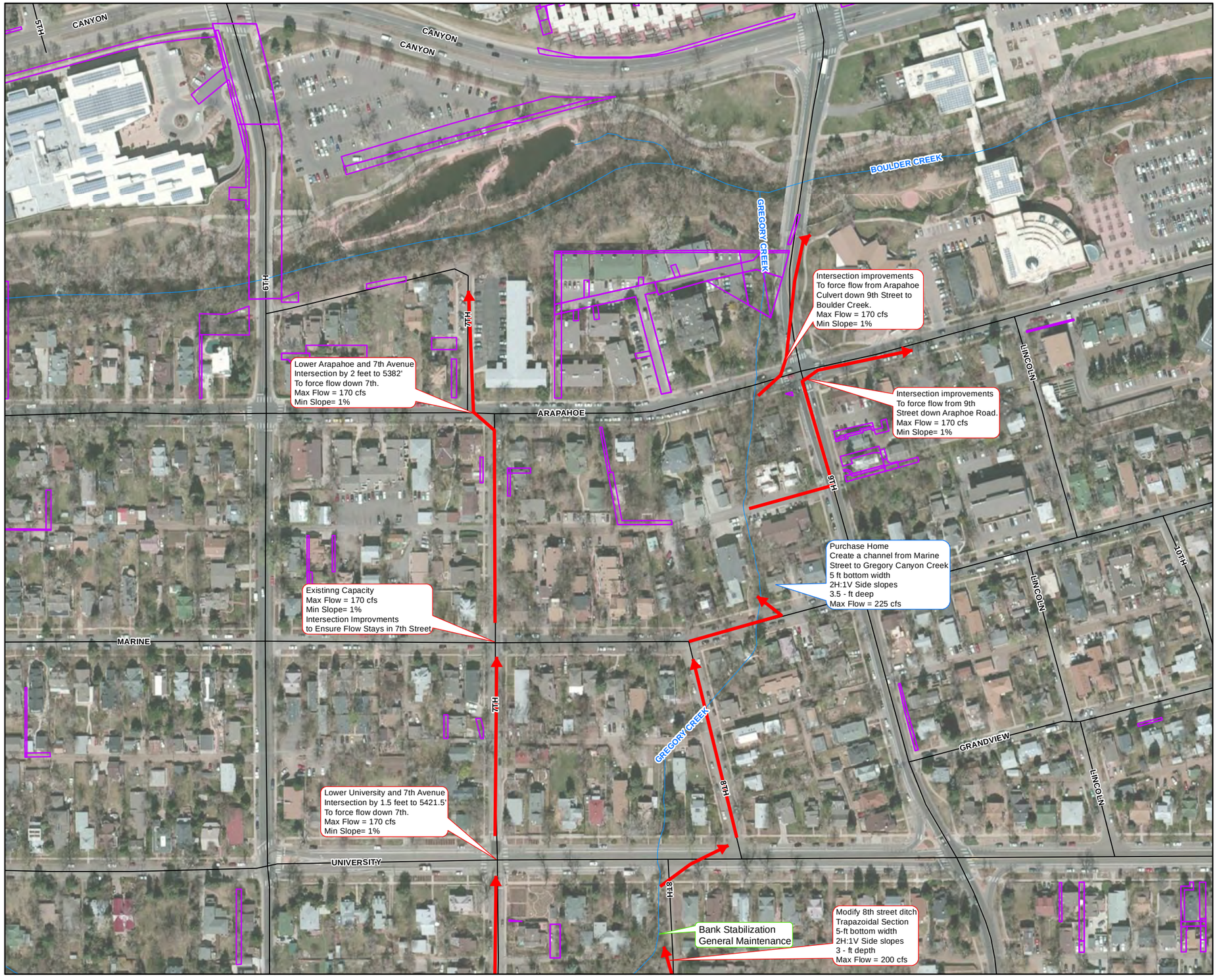
N

0 25 50 100 150

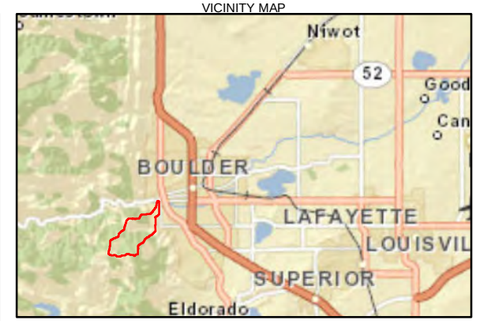
Feet

FIGURE 6 (3 of 3)
Category Two - Channel Conveyance Improvements
Gregory Canyon Creek Flood Mitigation

CH2MHILL



VICINITY MAP



LEGEND

Easements

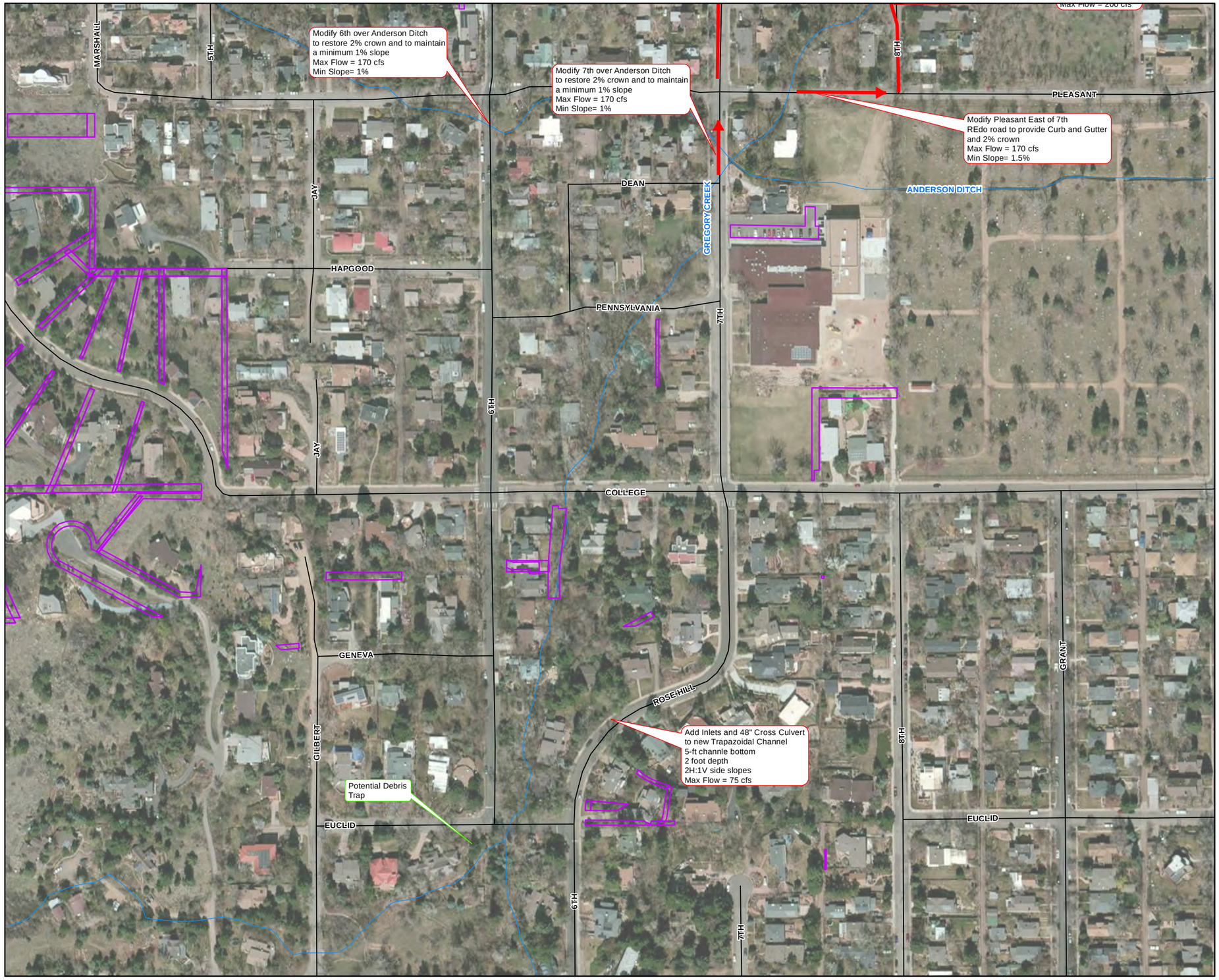
Street Overflows

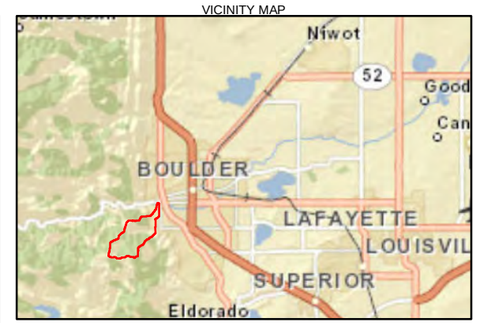
N

0 25 50 100 150
Feet

FIGURE 7 (1 of 3)
Category Three - Flood Conveyance Alternative
Gregory Canyon Creek Flood Mitigation

CH2MHILL





LEGEND

Easements

Street Overflows

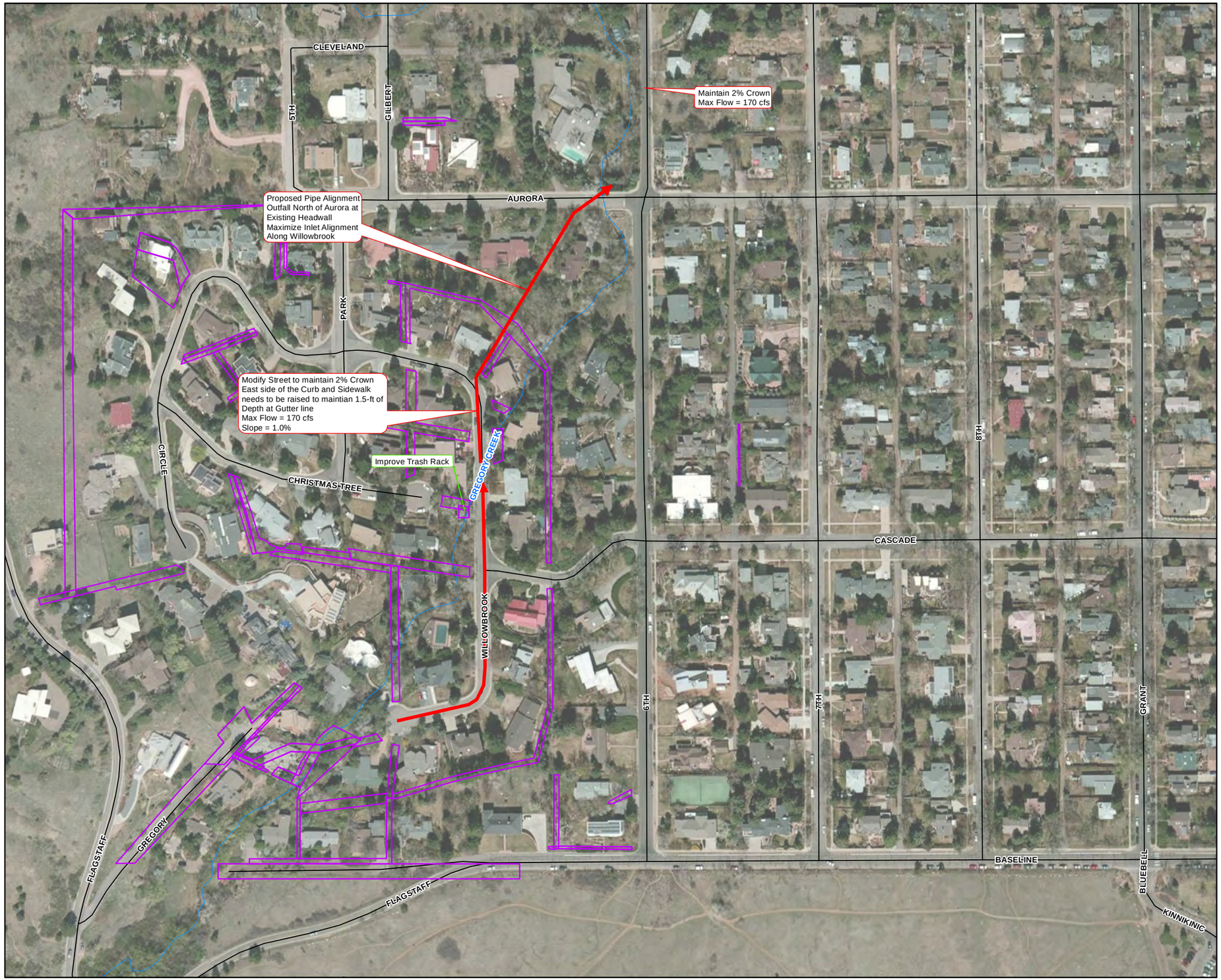
N

0 25 50 100 150

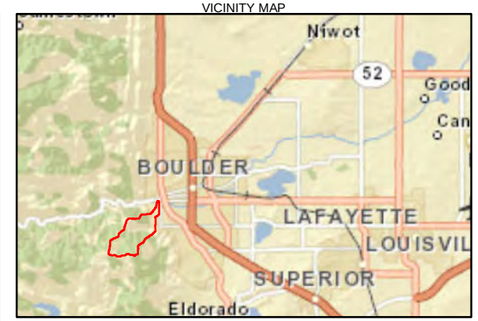
Feet

FIGURE 7 (2 of 3)
Category Three - Flood Conveyance Alternative
Gregory Canyon Creek Flood Mitigation

CH2MHILL



VICINITY MAP



LEGEND

Easements

Street Overflows

N

0 25 50 100 150
Feet

FIGURE 7 (3 of 3)
Category Three - Flood Conveyance Alternative
Gregory Canyon Creek Flood Mitigation

CH2MHILL

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

Improvements in Public Right of Way

Location	ID	Existing						10-yr Proposed								Max Proposed								Notes
		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)	
Drive to School (North of Arapahoe Avenue)	C13	4'	RCP	Circular	7.4	50%	< 10-yr	15' x 6'	25	1	RCBC	Box		20%	10-yr	$ 114,785.97	30' x 6'	25	1	RCBC	Box	1,166	20%	10-50yr	$ 208,580.40	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.
Arapahoe Avenue	C12	9' x 3'	RCBC	Box	141	50%	< 10-yr	20' x 5'	65	2	RCBC	Box		20%	10-yr	$ 215,669.35	37' x 5'	65	2	RCBC	Box	963	20%	10-50yr	$ 413,407.80	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	20' x 6'	45	3	RCBC	Box		20%	10-yr	$ 186,421.84	20' x 6'	45	3	RCBC	Box	840	20%	10-50yr	$ 222,352.20	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	18' x 6'	70	2	RCBC	Box		20%	10-yr	$ 241,988.79	27' x 6'	70	2	RCBC	Box	1,170	20%	10-50yr	$ 382,725.00	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	18' x 6'	170	5	RCBC	Box		20%	10-yr	$ 520,392.99	20' x 6'	170	5	RCBC	Box	732	20%	10-50yr	$ 740,919.60	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	18' x 6'	105	2	RCBC	Box		20%	10-yr	$ 339,429.99	20' x 6'	105	2	RCBC	Box	862	20%	10-50yr	$ 471,265.20	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	19' x 6'	50	2	RCBC	Box		20%	10-yr	$ 199,854.48	26' x 6'	50	2	RCBC	Box	982	20%	10-50yr	$ 164,327.40	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.
7th Street	C6	4.5'	RCP	Circular	11	50%	< 10-yr	20' x 6'	180	4	RCBC	Box		20%	10-yr	$ 578,890.24	23' x 6'	180	4	RCBC	Box	932	20%	< 10-yr	$ 673,491.60	Culvert is limited due to nearby infrastructure and homes. Channel capacity cannot convey all 1,165 cfs. Flooding may be experienced by nearby homes/properties. Utilities to be considered.
Pennsylvania Avenue	C5	4.75' x 3'	CMP	Arch	42	50%	< 10-yr	18' x 6'	45	3	RCBC	Box		20%	10-yr	$ 172,388.19	35' x 6'	45	3	RCBC	Box	1,203	20%	10-50yr	$ 307,854.00	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																								$ 95,000.00	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	14' x 6'	55	3	RCBC	Box		20%	10-yr	$ 175,073.20	33' x 6'	55	3	RCBC	Box	1,287	20%	50-yr	$ 340,457.40	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	15' x 6'	65	0	RCBC	Box		20%	10-yr	$ 200,687.96	31' x 6'	65	0	RCBC	Box	1,241	20%	50-yr	$ 413,407.80	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.
Aurora Avenue	C2	(2) 10' x 5'	RCBC	Box	495	0%	< 50-yr									$ -	40' x 6'	80	2	RCBC	Box	1,360	20%	50-100yr	$ 531,867.60	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	15' x 7'	140	3	RCBC	Box		20%	10-yr	$ 517,480.96	18' x 7'	140	3	RCBC	Box	1,160	20%	50-100yr	$ 499,510.80	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.
** - Capacity is potential capacity and may not experience stated capacity during a storm event								Total Improvement Costs for 10-yr Culverts:							$ 3,463,063.95	Total Improvement Costs for Max Culverts:								$ 5,465,166.80	

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

Location (Length)	Existing Channel Dimensions (Typ.) Width	Depth	lopes (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
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	$ 25,740.00	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	$ 11,374.00	Create open channel with 9' bottom width and 2H:1V side slopes.

Subtotal Channel Improvement Cost:		$ 37,114.00
Engineering	15%	$ 5,567.00
Legal/Administrative	5%	$ 1,856.00
Contract/Construction Management	10%	$ 3,711.00
Contingency	50%	$ 18,557.00
Total Improvement Costs:		$ 66,805.00

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.	1.25	80	$ 770.00	$ 61,600.00	15	460	$ 40.00	$ 18,400.00	2735	$ 63.65	$ 174,083.00	$ 254,083.00	To carry street flow from overtopping of private drive located in the cul-de-sac of Willowbrook Road.
7th Street Culvert	Boulder Creek	10-yr / 50-yr	1723	L.F.	1.25	160	$ 770.00	$ 122,844.00	15	960	$ 40.00	$ 38,400.00	5745	$ 63.65	$ 365,669.00	$ 526,913.00	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.	1.25	40	$ 770.00	$ 30,800.00	15	230	$ 40.00	$ 9,200.00	1360	$ 63.65	$ 86,564.00	$ 126,564.00	To carry street flow from overtopping of Pleasant Street culvert.
8th Street	Marine Street Culvert	50-yr	675	L.F.	1.25	65	$ 770.00	$ 50,050.00	15	375	$ 40.00	$ 15,000.00	2250	$ 63.65	$ 143,213.00	$ 208,263.00	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.	1.25	45	$ 770.00	$ 34,650.00	15	265	$ 40.00	$ 10,600.00	1570	$ 63.65	$ 99,931.00	$ 145,181.00	To carry street flow from overtopping of the culvert at the alley between Arapahoe and Marine.

Subtotal Street Conveyance Improvements Cost:		$ 1,261,004.00
Engineering:	15%	$ 189,151.00
Legal/Administrative:	5%	$ 63,050.00
Contract/Construction Management:	10%	$ 126,100.00
Contingency:	50%	$ 630,502.00
Total Improvement Costs:		$ 2,269,807.00

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