C I T Y OF B O U L D E R
WATER RESOURCES ADVISORY BOARD
AGENDA ITEM

MEETING DATE: OCTOBER 20, 2014

AGENDA TITLE: Information Item – Gregory Canyon Creek Flood Mitigation Study

PRESENTER/S:
Jeff Arthur, Director of Public Works for Utilities
Robert Harberg, Principal Engineer for Utilities
Annie Noble, Flood and Greenways Engineering Coordinator
Katie Knapp, Engineering Project Manager
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EXECUTIVE SUMMARY

The purpose of this memorandum is to provide a general summary of the preliminary proposal for flood mitigation measures to facilitate improved flood conveyance along Gregory Canyon Creek as it traverses the City of Boulder from Flagstaff Rd. to its confluence with Boulder Creek.

The city has retained CH2MHill to evaluate potential alternatives to help alleviate future flooding along Gregory Canyon Creek. CH2MHill has conducted a study of the creek corridor and developed three sets of categorical options which would improve flood conveyance. These categories include:

1. Improvements in Public Right-of-Way and Easements;
2. Improvements outside Public Right-of-Way and Easements; and,
3. Improvements for street conveyance.

CH2MHill's Alternative Analysis Memorandum ("Analysis") is included as **Attachment A**. This analysis contains a detailed description of the data and models used to determine the improvements which would help flood conveyance along Gregory Canyon Creek. The intent of the draft mitigation plan is to identify various types of improvements which could be constructed along the creek corridor in order to discern the costs and benefits associated with each improvement, or group of improvements, and to prioritize these improvements.

BOARD AND COMMISSION FEEDBACK

The Gregory Canyon Creek flood mitigation study has not been brought to any Boards or Commissions prior to WRAB. The October WRAB meeting is intended to be an opportunity for WRAB and the public to weigh in on the preliminary concepts being analyzed. This feedback will enable staff and CH2MHill to further refine the

improvements and to prepare a draft Mitigation Plan for review at the December WRAB meeting.

PUBLIC FEEDBACK

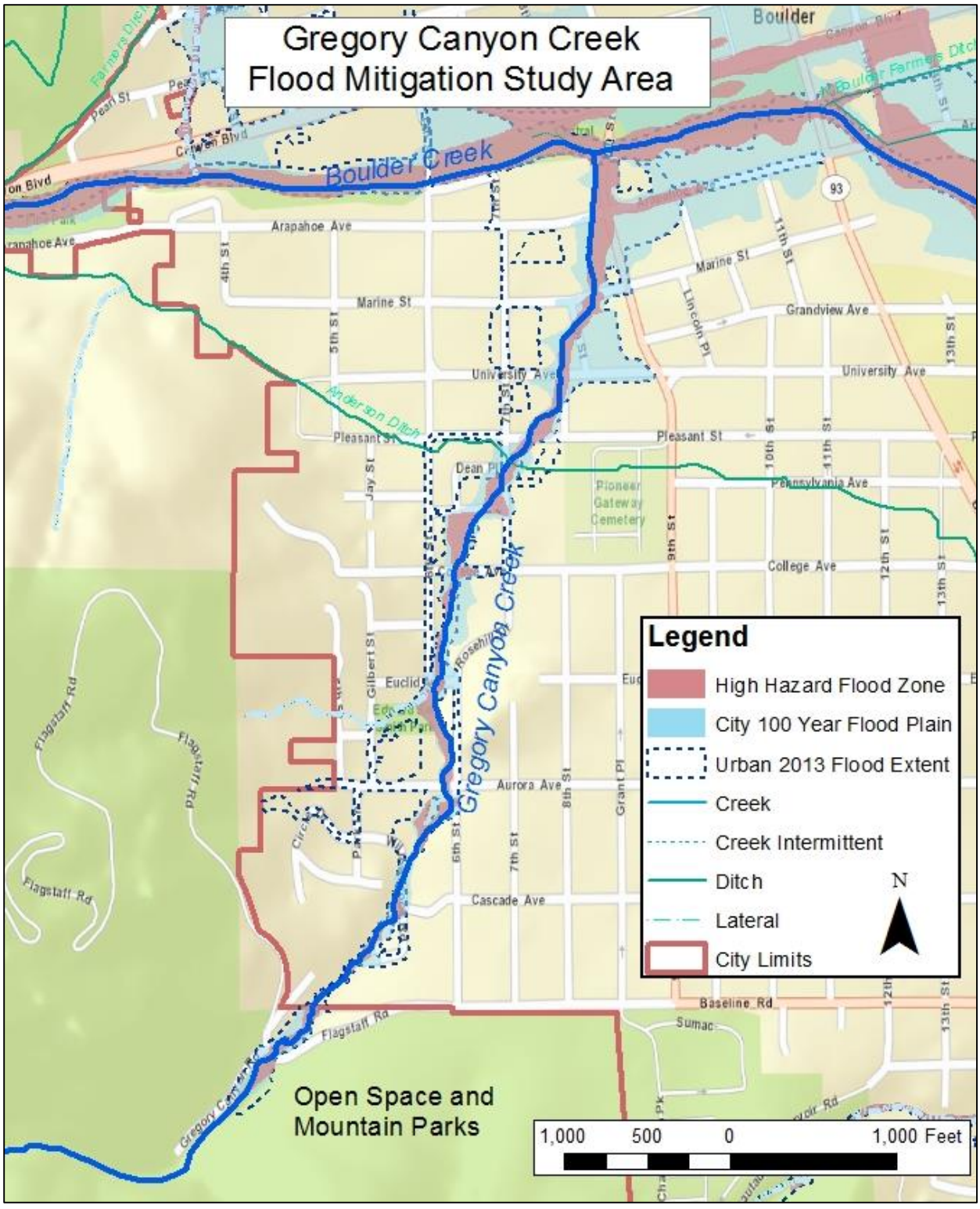
Public notification post cards about this WRAB meeting and the preceding Open House were sent to all property owners in the study area and a project web site has been developed to provide information (https://bouldercolorado.gov/flood/gregory-canyon-creek-flood-mitigation-study). Additionally, posters notifying the neighborhood of the meeting and open house were posted at various visible locations along the creek. Emails have been sent to all interested parties whom have signed up for email notifications and to all parents of children attending Flatirons Elementary School.

An Open House was held on October 13, 2013 (post September 2013 flood) to provide flood recovery information to impacted residents and gather input about the flood event. Approximately 67 people attended this meeting. Additionally, another open house was held on June 2014 to hear suggestions for future projects along Gregory Canyon Creek; approximately 17 people attended this open house.

An open house meeting is being held immediately prior to this WRAB meeting to inform the public about the preliminary alternatives analysis and obtain their feedback. A summary of public input gathered at the open house will be provided at a future WRAB meeting.

BACKGROUND

Gregory Canyon Creek originates in City of Boulder Open Space and has a drainage area of 2.29 square miles. A well-defined channel is visible upstream of Flagstaff Road. The creek then generally flows to the northeast through developed neighborhoods, crossing both public and private land. The creek is mostly confined in narrow channels, due to fairly dense residential development, and conveyed under streets through culverts. Residential development along Gregory Canyon Creek began as early as 1890 in areas closer to the center of the city and peaked between the 1950's and 1960's as development moved closer to Baseline Rd. Most of the development within the Gregory Canyon Creek floodplain occurred prior to the city's adoption of floodplain regulations and drainage system requirements, and therefore does not conform to current development standards. There are currently only a few drainage and flood control easements across the private properties.



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

- Culvert replacement at Willowbrook Rd. (1996)

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

The floodplain maps for Gregory Canyon Creek were last updated in 2010. Table 1, below, shows the number of structures located in each floodplain zone.

Table 1

Flood Zone:	Number of Structures
100-year Floodplain	approx. 95-98
Conveyance Zone	63
High Hazard Zone	32

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

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

In September of 2013, Gregory Canyon Creek experienced significant flooding, resulting in property damage within and outside of the mapped 100-year floodplain. Post flood damage assessments and discussions with property owners in the Gregory Canyon Creek area highlighted the need to re-evaluate flood mitigation options for smaller and more frequent storm events along Gregory Canyon Creek.

Master Plan Guidance and Policies

The Boulder Valley Comprehensive Plan (BVCP), the Comprehensive Flood and Stormwater Utility Master Plan ("CFS"), the Greenways Master Plan and the Urban Drainage and Flood Control District (UDFCD) Drainage Criteria Manual all contain

policies related to floodplain preservation, development, and mitigation. These documents guide the flood mitigation master planning.

The following applicable policies are included in the BVCP:

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

3.20 Flood Management
The city and county will protect the public and property from the impacts of flooding in a timely and cost-effective manner while balancing community interests with public safety needs. The city and county will manage the potential for floods by implementing the following guiding principles: a) Preserve floodplains b) Be prepared for floods c) Help people protect themselves from flood hazards d) Prevent unwise uses and adverse impacts in the floodplain e) Seek to accommodate floods, not control them. The city seeks to manage flood recovery by protecting critical facilities in the 500-year floodplain and implementing multi hazard mitigation and flood response and recovery plans.

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

3.22 Protection of High Hazard Areas
The city will prevent redevelopment of significantly flood-damaged properties in high hazard areas. The city will prepare a plan for property acquisition and other forms of mitigation for flood-damaged and undeveloped land in high hazard flood areas. Undeveloped high hazard flood areas will be retained in their natural state whenever possible. Compatible uses of riparian corridors, such as natural ecosystems, wildlife habitat and wetlands will be encouraged wherever appropriate. Trails or other open recreational facilities may be feasible in certain areas.

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

The CFS contains the following guiding principles for flood management:

1. Preserve Floodplains (Preservation);
2. Be Prepared for Floods (Preparedness);

3. Help People Protect Themselves from Flood Hazards (Education);
4. Prevent Adverse Impacts and Unwise Uses in the Floodplain (Regulation);
5. Seek to Accommodate Floods, Not Control Them (Mitigation).

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

- Seek to accommodate floods, not control them through planned and monitored system maintenance, nonstructural flood proofing, opening non-containment corridors, overbank land shaping to train flood waters, and limited structural measures at constrained locations. Possible tools for implementation include:
    - Update mitigation master plans to emphasize nonstructural measures.
    - Re-evaluate mitigation priorities to eliminate bottlenecks, acquire land to avoid channel improvements, provide non-structural overbank grading, target limited flood protection improvements for high hazards, and research alternative mitigation approaches.
    - Assess any need for structural improvements with evaluation of multiple alternatives.
    - Focus on mitigating high hazard locations citywide and give priority to areas of the greatest risk.

The UDFCD Drainage Criteria Manual contains the following basic policies:

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

The purpose of the Greenways Program is to extend the stewardship of the city to important riparian areas along the tributaries of Boulder Creek. The Greenways Master Plan includes the following objectives:

- To protect and restore riparian, floodplain, and wetland habitat;
- To enhance water quality;
- To facilitate storm drainage and mitigate floods;
- To provide alternative transportation routes or trails for pedestrians and bicyclists;
- To provide recreation alternatives;
- To protect cultural resources.

Due to this historical development patterns along Gregory Canyon Creek, the opportunities to provide alternative transportation routes, trails, or recreational options are limited. However, the intent of the flood mitigation plan is to mitigate floods and facilitate storm drainage. Improvements along this creek corridor could also include enhancements to water quality and riparian areas.

These various master plan guiding principles and policies, specifically those related to mitigation, have provided the foundation for developing the Gregory Canyon Creek Mitigation Plan. The initial alternatives under consideration include only structural improvements necessary to better convey flood waters along this drainageway and specifically include upgrades to the majority of the culverts. Improvements are also proposed within the streets in order to utilize them for conveyance. Open channel enhancements are proposed in various locations, with most being located on private property. The goal of this mitigation plan is to identify various options for culvert and street improvements in the right-of-way, along with channel improvements on private property in order to convey a 10-year event, at minimum, but convey larger events where feasible. Additionally, acquisition of property in the high hazard zone is also being evaluated as a part of this plan.

ANALYSIS

Typically, flood mitigation plans are developed with the intent to adequately convey a 100-year storm event. Designing major drainageways systems to transport the 100-year event is a policy standard included the Boulder Valley Comprehensive Plan, the Comprehensive Flood and Stormwater Utility Master Plan and the UDFCD Drainage Criteria Manual and is applicable to new development in the city.

Due to the existing residential development, channel mitigation to convey a 100–year event would not be feasible unless many of the existing homes along the creek corridor were removed. It is estimated that approximately 58 existing residential structures (with a total estimated property value of more than $55 million) would need to be acquired in order to accommodate a 100-year channel.

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

The alternatives analysis includes improvements to culverts that could convey events greater than 10 years, the majority of which could convey 50- to 100-year events. Thus, while sections of the creek channel cannot be improved to convey an event greater than 10 years without the removal of existing houses, there are locations where the city could invest in culverts to convey 50- to 100-year events, with minimal additional cost. This would allow future improvements to the channel for a larger storm event. In terms of street conveyance, several roads already adequately convey 50-year flows. The street improvements shown are necessary to complete the system.

The alternatives have been broken out into three categories:

1. Category 1: Improvements in Public Right-of-Way;
2. Category 2: Improvements outside Public Right-of-Way; and,
3. Category 3: Improvements for street conveyance.

The final master mitigation plan will include priorities for each of these categories, note the upstream or downstream improvements which would be necessitated from installation of certain improvements, and group recommended improvements according to geographic location.

Category 1- Improvements in Public Right-of-Way

The improvements included in Category 1 include channel maintenance, brush and debris clearing, and replacements and improvements to aging infrastructure to ensure that the culvert crossings could pass flow contained within the creek channel without major modifications to the channel. The improvements proposed are predominantly within city ROW. Hydraulically, the culvert capacity is limited to the channel capacity immediately upstream and downstream of the culvert. In maximizing culvert sizes, channel improvements in the immediate vicinity of the new culvert will be needed to accommodate the larger culvert size. Proposed maximum culvert sizes could convey between a 50 and 500-year storm, depending on location, but the channel can likely only be improved to convey a 10-year storm. Improvements to achieve a 10-year storm capacity would require the acquisition of easements and improvements on private property, discussed under Category 2. Thus, a consideration for culvert replacement centers upon the ability to replace aging culverts with only those that could convey a 10-year storm, or to replace them with larger culverts, the majority of which could convey 50 to 100-year events.

Category 2- Channel Conveyance Improvements:

The improvements suggested in Category 2 involve channel modifications on private property. The channel improvements suggested would couple well with the culvert improvements proposed under Category 1 and would serve to better facilitate the conveyance of a 10-year event. Property owners could have the option of granting drainage easements and thus allowing for the city to construct and maintain the channel modifications. If residents were unwilling to grant easements and would prefer to construct the improvements on their own, then the Mitigation Master Plan could serve as the guide for modifications. This approach might present some difficulties, because without continuous easements, the city could have problems maintaining the channel where easements were granted. The improvements proposed under Alternative 2 would accommodate a 10-year event.

Category 3-Street Conveyance:

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

and 8th Street. Thus, street improvements have been proposed which would direct and retain water within the streets. All street conveyance improvements proposed are shown on Figure 7. 6th Street, 7th Street and 8th Street are shown as being the primary streets for conveyance along with Willowbrook at the more southerly area of the stream reach (i.e. in close proximity to Flagstaff Road). Segments of these streets already convey 50-year flows. Thus, the improvements proposed are to segments which do not adequately convey a 50-year flow under current conditions.

The flow modeling used to formulate the mitigation measures showed that overflows from Gregory Canyon Creek onto the road system during a 100-year event could exceed 300 cfs for the roads identified for conveyance. Near Boulder Creek, the maximum achievable flow is 170 cfs which is approximately 50% of the modeled 100-year flows in the street. Improvements along 7th Street and 8th Street. would help to lessen flood damage during more frequent storm events. Examples of street improvements proposed near Boulder Creek, which would facilitate the conveyance of 170 cfs., include, but are not limited to, the following:

1. Lowering the intersection of University Ave. and 7th St. by 1.5 feet;
2. Lowering the intersection of Arapahoe Ave. and 7th St. by 2 feet;
3. Lowering the intersection of University of 7th St. by 1.5 feet;
4. Lower the intersection of Arapahoe Ave. and 6th St by 2 ft.

Additional street improvements proposed include:

1. Increase the crown to 2% in the following locations:
    a. 6th and Anderson Ditch;
    b. 7th and Anderson Ditch;
    c. Pleasant Ave. between 7th and 8th;
    d. 6th, between Geneva and Euclid;
    e. 6th , between Euclid and Aurora;
    f. Willowbrook Rd.
2. Adding or modifying curb and gutter in the following locations:
    a. Pleasant Ave. between 7th and 8th - add curb and gutter;
    b. 6th , between Geneva and Euclid – raise existing curb to maintain 12-inches of depth at gutter line;
    c. Willowbrook - raise existing curb to maintain 12-inches of depth at gutter line

Should street conveyance be found to be an acceptable method of mitigation, then it is recommended that appropriate signage be added to indicate that the roads are used for flood conveyance. Further analysis of the life safety issues concerning street conveyance will need to be more closely evaluated as the study is developed.

Acquisition of High Hazard Properties

Additionally, the city could consider purchasing certain properties in the high hazard zone. Removing structures in the high hazard zone could allow for additional channel improvements in selected areas. Opportunity-based property acquisition is a key element of the floodplain management program given the city's interest in working with a willing seller. The property acquisition program, in conjunction with flood mitigation

improvements has been very successful over the years and has resulted in 134 of 279 identified high hazard structures being removed from the high hazard floodplain.

More recently, 810 Marine St., which is located along Gregory Canyon Creek, was purchased by the city and the structure was removed in 2012. Along this creek, there are 32 structures located in the high hazard zone. In 2010, the city conducted an analysis to prioritize the structures in the high hazard zone along Gregory Canyon Creek which should be considered for acquisition. The prioritization centered on the life-safety risk from flooding and the value of the structure. The current total assessed value of these priority properties is $4,710,500. Purchasing certain properties in the high hazard zone would not only remove the life-safety risk, but would also open up additional opportunities to improve flood conveyance in these areas.

COST BENEFIT ANALYSIS

A preliminary cost estimate for proposed improvements is included in the Analysis (**Attachment A)**. A cost benefit analysis will be conducted after a full list of alternatives is developed. This cost benefit analysis will be completed using the FEMA HAZUS process and will be presented to WRAB at the next meeting for this project.

NEXT STEPS:

Following input from the October Open House and WRAB meeting, Staff and the consultants with continue to assess the alternatives and prepare a draft mitigation plan. This mitigation plan is scheduled to be presented to WRAB at the December 2014 meeting. The mitigation plan may need to be reviewed by WRAB again sometime in the 1st Quarter 2015. Once WRAB has made a recommendation to approve the mitigation plan, then the plan will be presented to City Council for consideration.

ATTACHMENTS

Attachment A: Alternative Analysis Memorandum
Attachment B: 2010 Mini-Master Plan
Attachment C: 2012 Mitigation Analysis

MEMORANDUM CH2MHILL®

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**.

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

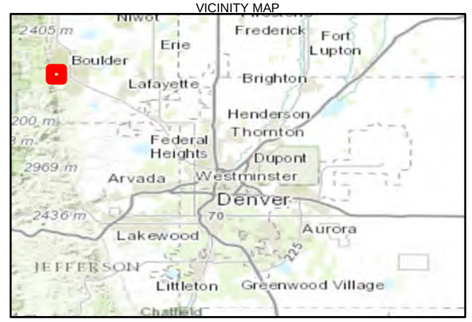
Figures

Tables

Technical Appendix

Figures

VICINITY MAP



LEGEND

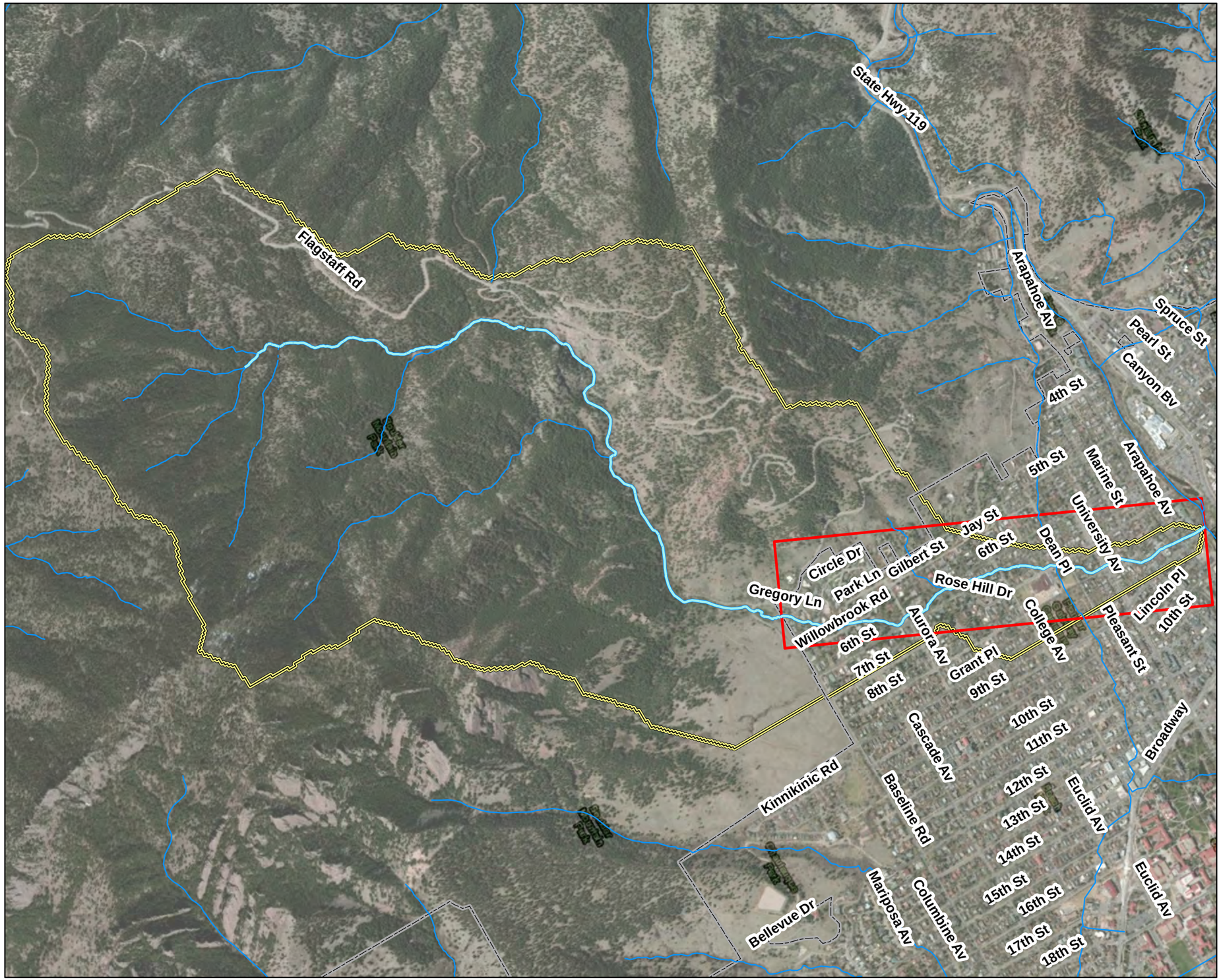
- Creeks and Streams
- Gregory Creek
- September 2013 Flood Extents
- City Limits

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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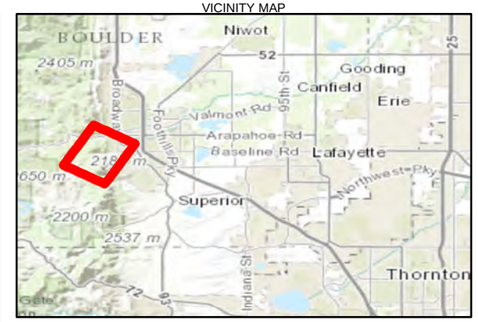


LEGEND

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

Notes:
1. Area of interest subject to change.

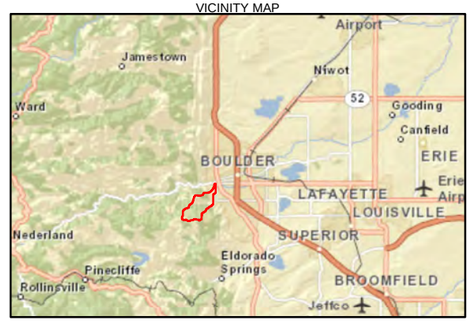
N

0.25 0.125 0 0.25

Miles

FIGURE 2
Area of Interest
Gregory Canyon Creek Flood Mitigation

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

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

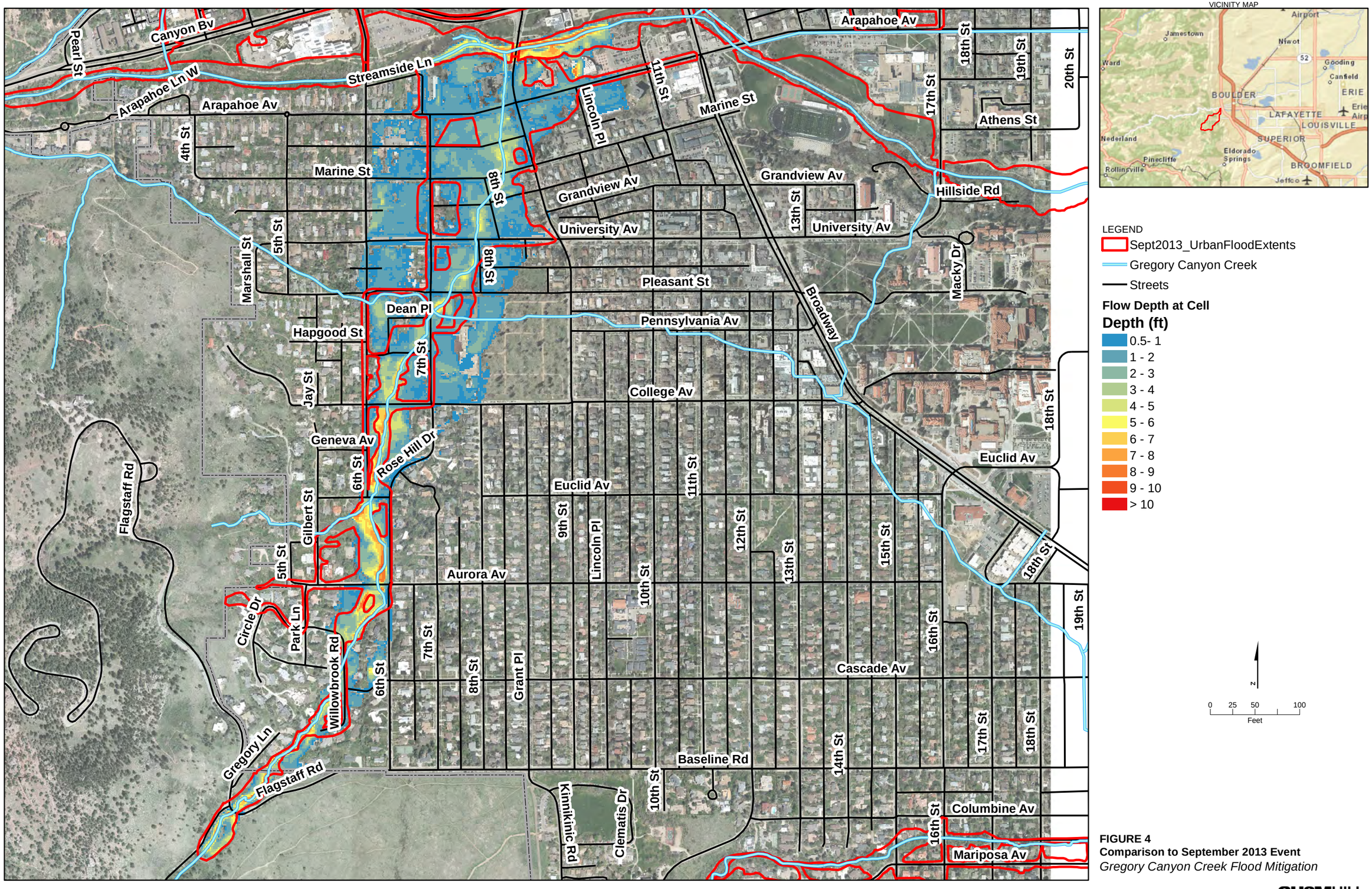
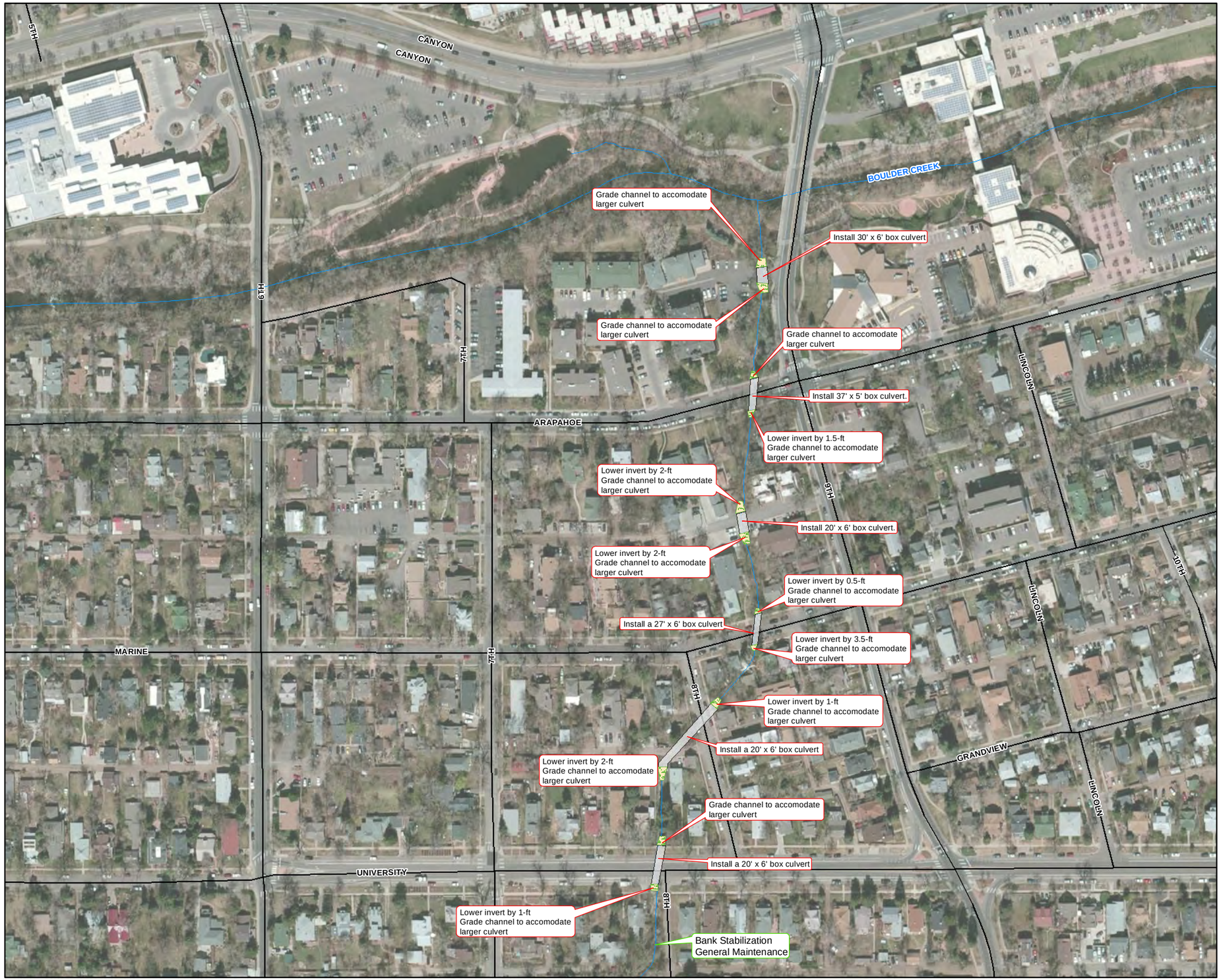


FIGURE 4
Comparison to September 2013 Event
Gregory Canyon Creek Flood Mitigation



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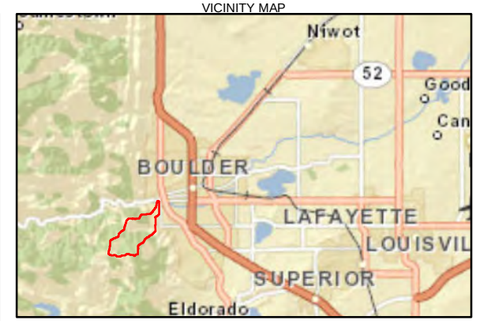


LEGEND

- 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

Grade channel to accomodate larger culvert

Install a 26' x 6' box culvert

Lower invert by 1-ft
Grade channel to accomodate larger culvert

Grade channel to accomodate larger culvert

Install a 23' x 6' box culvert

Lower invert by 2-ft
Grade channel to accomodate larger culvert

Install a 35' x 6' box culvert

Lower invert by 3-ft
Grade channel to accomodate larger culvert

Channel grading to accomodate larger culvert

Install 33' x 6' box culvert

Channel grading to accomodate larger culvert

Channel grading to accomodate larger culvert

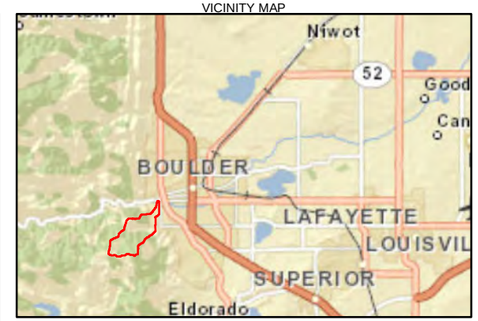
Potential Debris Trap

Install 31' x 6' box culvert

Lower invert 1.7-ft
Channel grading to accomodate larger culvert

MARSHALL
5TH
JAY
HAPGOOD
DEAN
8TH
PLEASANT
ANDERSON DITCH
6TH
7TH
COLLEGE
GENEVA
GILBERT
GREGORY CREEK
ROSE HILL
GRANT
9TH
EUCLID

VICINITY MAP



LEGEND

- Existing Easements
- Culvert Improvements
- Channel Grading

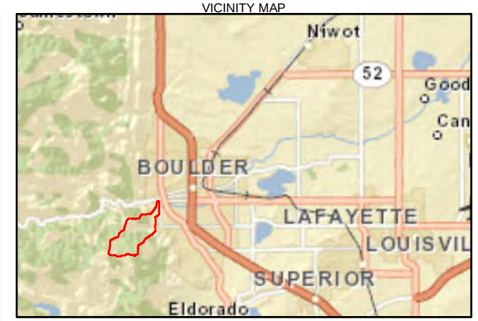
N

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

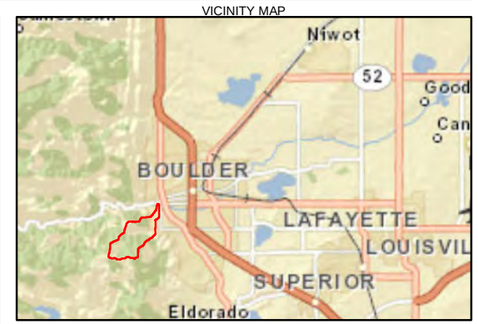
- Existing Easements
- Culvert Improvements
- Channel Grading

N

0 25 50 100 150
Feet

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

CH2MHILL



LEGEND

Existing Easements

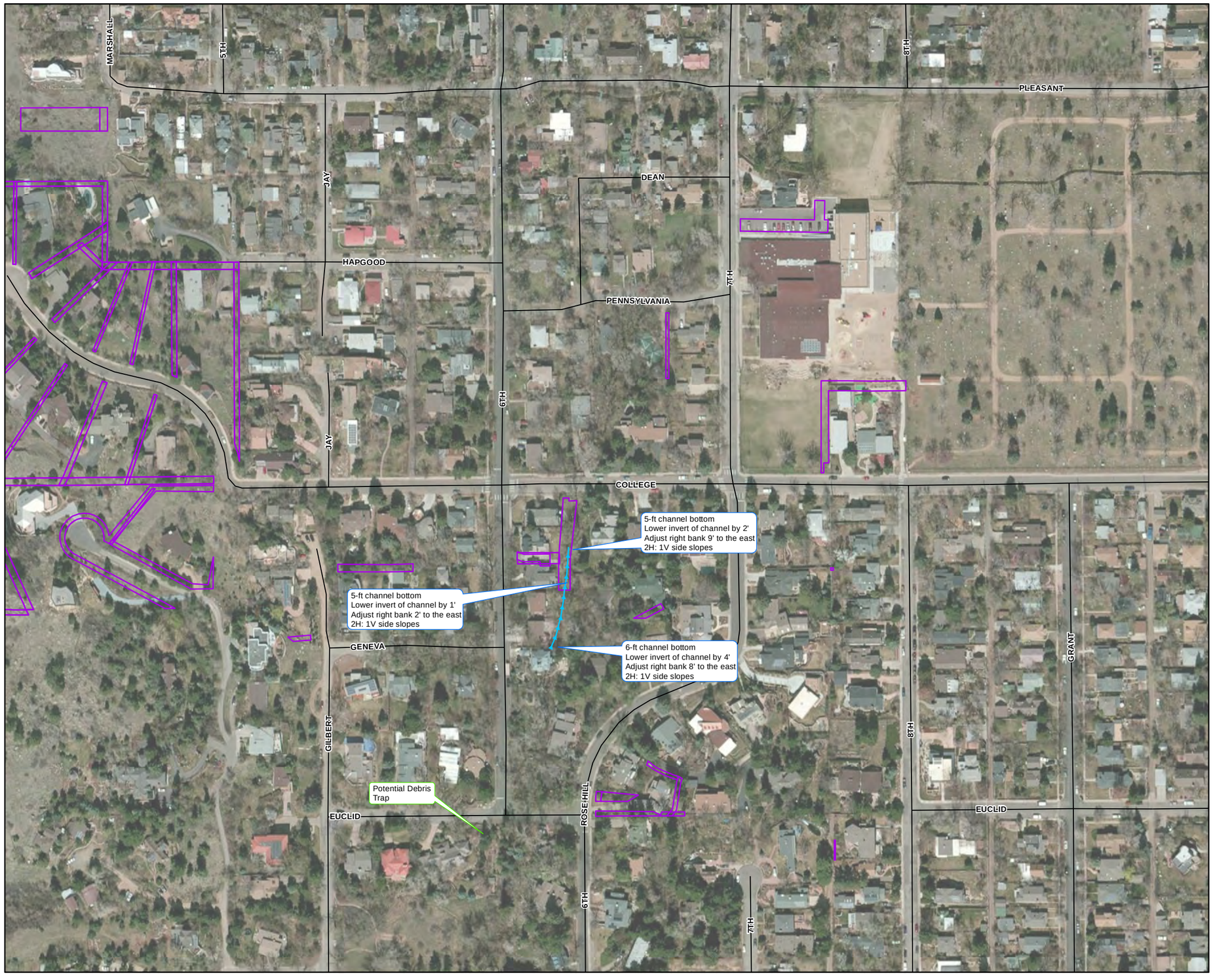
Channel Improvements

N

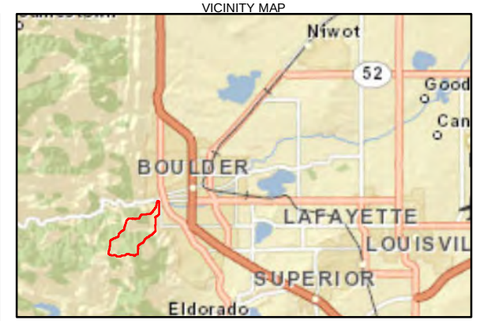
0 25 50 100 150

Feet

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



VICINITY MAP



LEGEND

Channel Improvements

Existing Easements

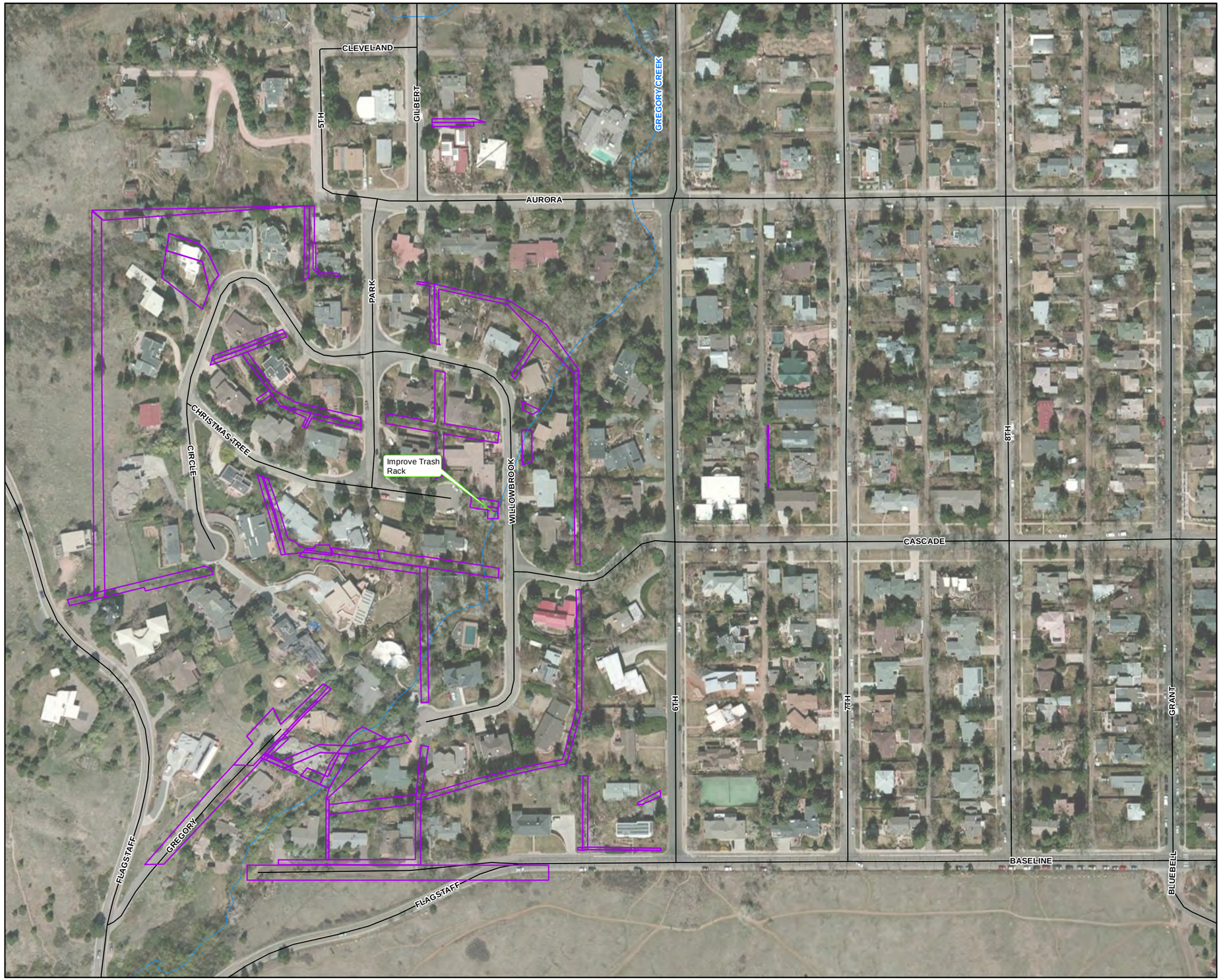
N

0 25 50 100 150

Feet

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

CH2MHILL



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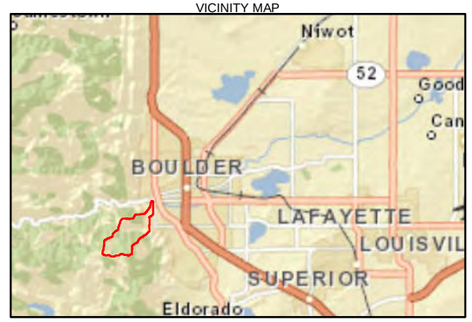


LEGEND

Existing Easements

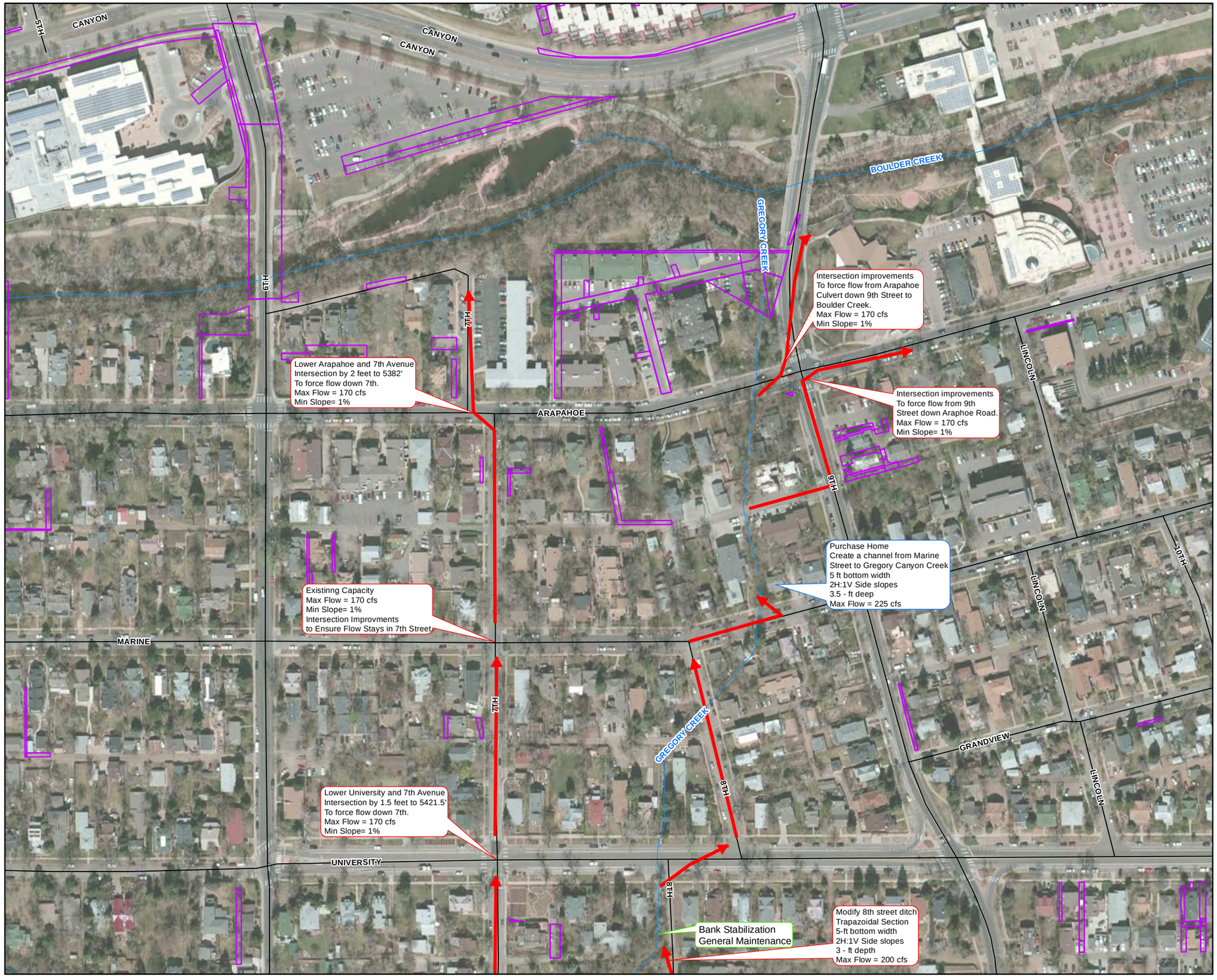
Channel Improvements

N

0 25 50 100 150

Feet

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



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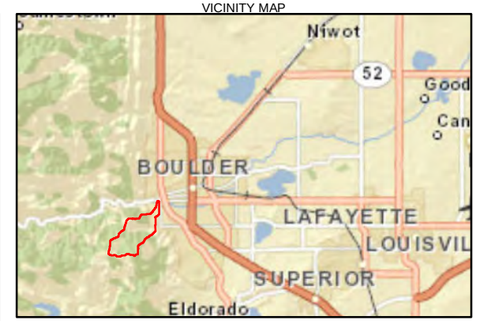


LEGEND

Easements

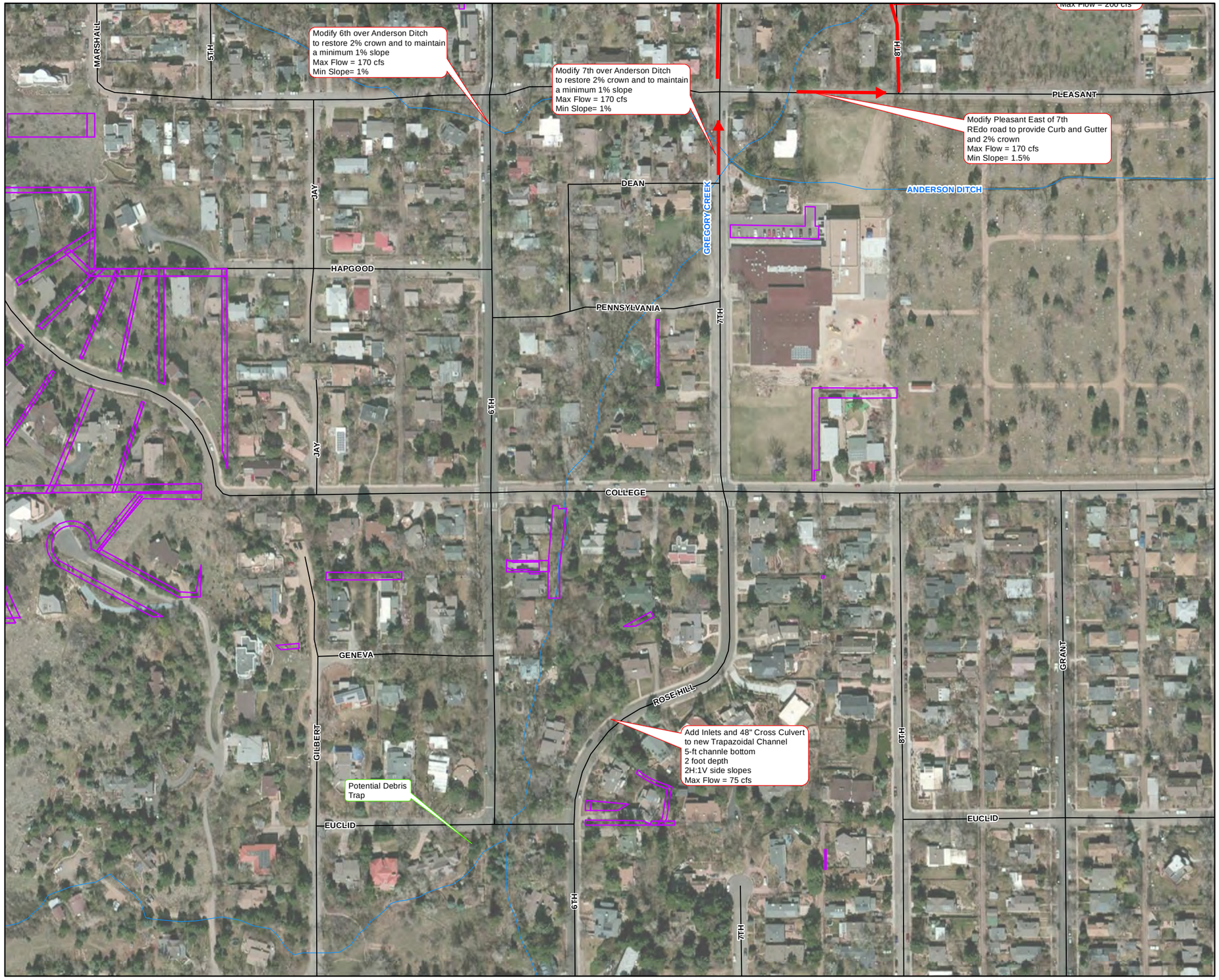
Street Overflows

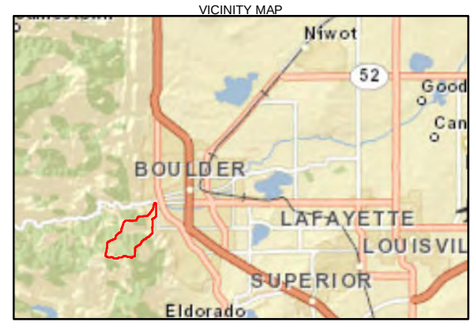
N

0 25 50 100 150
Feet

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

CH2MHILL





LEGEND

Easements

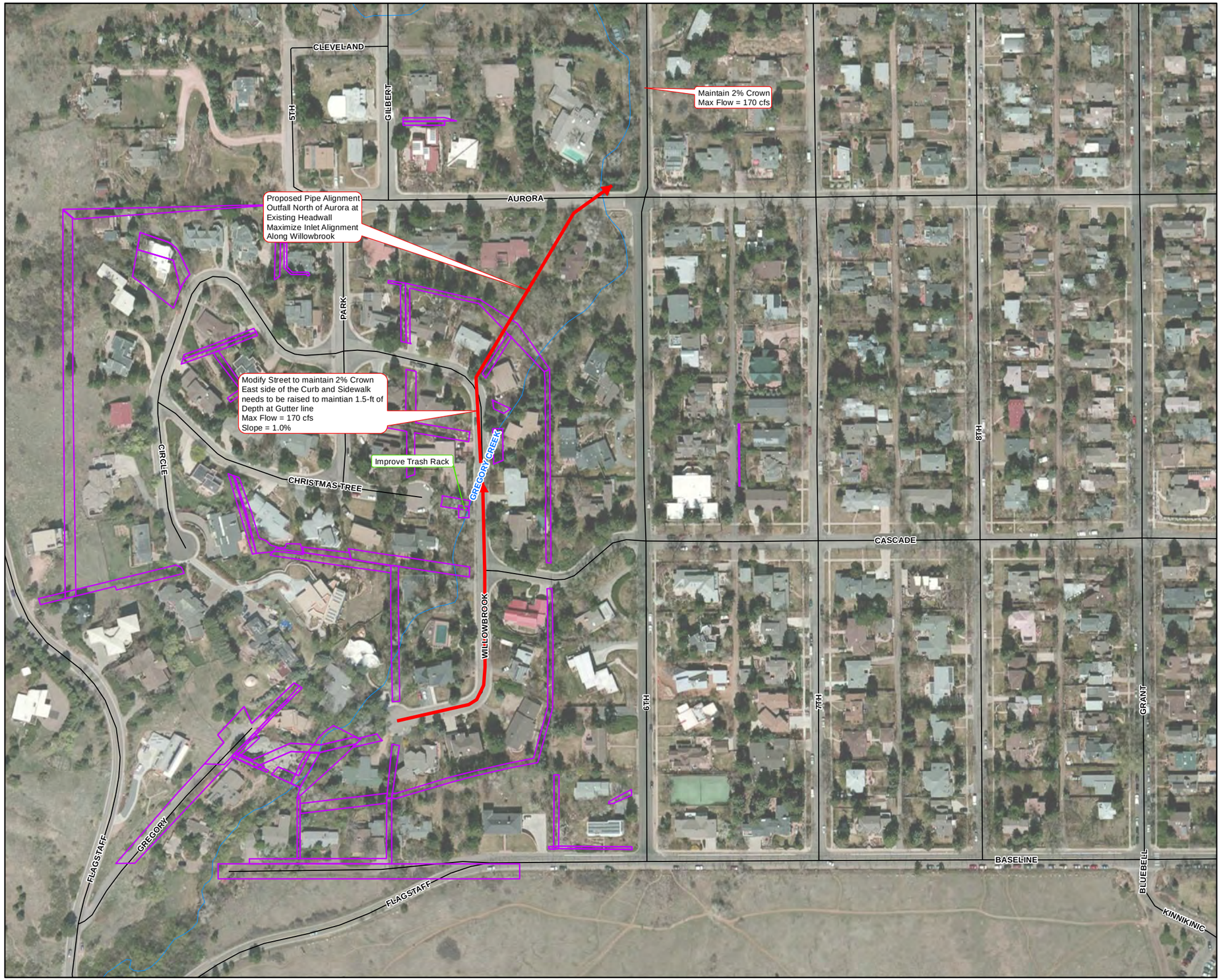
Street Overflows

N

0 25 50 100 150

Feet

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



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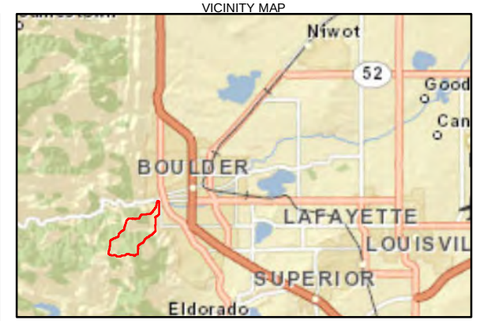


LEGEND

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)	Curb and Gutter Quantity	Unit	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

March 24, 2009

Ms. Christie Coleman, P.E.
Project Manager
Utilities Division
City of Boulder
P.O. Box 791
Boulder, CO 80306

REF: 0328C – GREGORY CANYON CREEK HIGH HAZARD ZONE REANALYSIS - MINI-MASTER PLAN

Dear Christie:

Love & Associates, Inc. dba BELT COLLINS WEST (BCW) has recently completed a reanalysis of the high hazard zone (HHZ), 100-year floodplain, and 0.5-ft rise floodway along Gregory Canyon Creek through the City of Boulder which incorporates new field survey information. The floodplain restudy was undertaken to address the potential for changes within the Gregory Canyon Creek floodplain due to updated 1-foot contour mapping and modifications to road crossings and channel sections. The restudy found several additional properties which should be located within the City's HHZ. This Mini-Master Plan was undertaken to specifically address those homes which were not previously within the City of Boulder's (City) HHZ, but were added to the HHZ as a result of the floodplain reanalysis BCW performed on Gregory Canyon Creek in 2007. Please refer to the 2007 floodplain reanalysis map in Appendix A. The addresses of all properties newly added to the Gregory Canyon Creek HHZ as defined by the 2007 study include:

- 951 Arapahoe Avenue
- 952 Arapahoe Avenue
- 953 Arapahoe Avenue
- 818 Marine Street
- 828 Marine Street
- 728 and 740 University Avenue (a single duplex structure)

- 712 Pleasant Street
- 620, 621, and 622 Pennsylvania Avenue (is a single triplex structure)
- 610 College Street
- 1026 6th Street
- 1170 6th Street (apartment only added by latest field survey data)
- 1116 6th Street

The new field survey data in the vicinity of these structures provided more accurate ground surface elevations than shown by the LIDAR and 1-foot contour topography utilized in the original re-analysis of the Gregory Canyon Creek floodplain in some areas. Incorporation of the new field survey data into the hydraulic model of Gregory Canyon Creek resulted in the removal of five of the above identified structures from the HHZ. These structures are:

- 951 Arapahoe Avenue
- 952 Arapahoe Avenue
- 828 Marine Street
- 728 and 740 University Avenue (a single duplex structure)
- 610 College Street

In addition to revising the HHZ, 100-year floodplain, and floodway, BCW investigated options for removing the remaining homes at 953 Arapahoe Avenue, 818 Marine Street, 712 Pleasant, 620-622 Pennsylvania, 1026 6th Street, 1170 6th Street, and 1116 6th Street from the HHZ. Modifications were investigated to potentially remove the remaining structures from the HHZ and include roadway and/or culvert improvements and channel modifications. A Mini-Master Plan has been developed for Gregory Canyon Creek and is composed of those alternates which, if implemented, could remove these structures from the HHZ. This Mini-Master Plan addresses only those properties identified as within the City's HHZ by the 2007 floodplain restudy of Gregory Canyon Creek and by the latest field survey data (1170 6th Street). Costs for each of the five alternates addressed herein are included in Appendix B.

I. SUMMARY OF HYDRAULIC ANALYSES

The updated hydraulic analysis for Gregory Canyon Creek will be submitted to the Federal Emergency Management Agency (FEMA) as a Letter of Map Revision (LOMR) in order to adopt the revised base flood elevations and floodplain and floodway delineations. A summary of the hydraulic studies for Gregory Canyon Creek is included below. A complete description of the updated hydraulic analysis can be found in the LOMR document (separate document).

Regulatory Floodplain and FHAD Study

The regulatory FEMA floodplain for Gregory Canyon Creek is an approximate floodplain with no base flood elevations or floodway defined. A detailed study was

completed in HEC-2 in 1987 by Greenhorne & Omara, Inc. (*Flood Hazard Area Delineation (FHAD), Boulder and Adjacent County Drainageways*) but base flood elevations from this study were not adopted by FEMA. The FHAD established hydrology for the 10-, 50-, and 100-year flood events. The FHAD HEC-2 file name is GREG.dat.

2007 Study

BCW completed several updated hydraulic models of Gregory Canyon Creek, the latest of which is dated October 29th, 2007. This model was completed in HEC-RAS version 3.1.3 and the file name is greg05.prj. The hydrology from the FHAD for the 10-, 50-, and 100-year events was used for the 2007 study. The 500-year flow rate was determined through extrapolation. The extrapolation procedure is described in a memo by Love & Associates titled "Gregory Canyon Creek 500-year Hydrology" and dated September 12, 2005.

The 2007 hydraulic analysis includes improvements at several crossings as well as more accurate LIDAR 1-ft contour topographic mapping and detailed field survey for structures and select cross sections performed by Robert Sayre, PLS. The hydraulic analysis includes both a multi-profile and a 0.5-ft floodway model.

The Manning's 'n' roughness coefficients are generally consistent with those used in the FHAD model for much of the reach. Roughness coefficients were updated in some areas to more accurately represent current channel and overbank conditions. Manning's 'n' ranges from 0.03 to 0.11 for the study reach.

The upstream limit of the study is at cross section 600, approximately 300-ft upstream of Flagstaff Road. Data for cross section 600 was taken directly from the FHAD model and converted from the NGVD 29 vertical datum to NAVD 88 (NGVD 29 + 3.2-ft = NAVD 88).

The downstream limit of the study is at cross section 10 at the confluence with Boulder Creek just upstream of 9th Street. The 100-year starting water surface elevation for Gregory Canyon Creek was determined using the regulatory 100-year water surface of 5361.42 (NAVD 88 vertical datum) in Boulder Creek near cross section 60 just upstream of the 9th Street Bridge.

Debris blockage at bridges and culverts was determined in consultation with City representatives. Low flow culverts were assumed to have 100% blockage. Bridges replaced with 100-year structures since the FHAD are assumed to have 0% blockage. Intermediate blockage was assumed based on culvert conditions and historical information.

A split flow occurs along the right bank of the main channel from Marine Street to the confluence with Boulder Creek, a stream distance of approximately 0.2-mi. The spill flows along 9th Street and Arapahoe Avenue before rejoining the Boulder Creek

floodplain near 11th Street.

A peer review of the 2007 study was performed by Doug Laiho, P.E. and all issues found in this peer review were addressed to the satisfaction of Alan Taylor, P.E. of the City of Boulder and Doug Laiho.

2009 Restudy

As stated previously, the 2007 hydraulic analysis added several residences to the HHZ which were not located within the City's existing regulatory HHZ. The 2009 restudy was initiated to obtain more accurate topographic information (the LIDAR 1-ft contour topography was obscured in some areas by dense vegetation) to assess whether the structures added to the HHZ in 2007 could be removed from the HHZ with more accurate survey data.

Several cross sections were updated with new topography for the reanalysis and cross sections 291, 334, and 342 were added to the model. The HEC-RAS model was rerun in HEC-RAS version 4.0.0 which was released in March 2008. Because the topography was updated, cross sections were added, and the latest version of HEC-RAS was being used, the split flow optimization was rerun for the 100-yr event to balance the split flow along Arapahoe Avenue with the new data incorporated into the hydraulic model. Rerunning the split flow optimization increased the 100-yr spill flow to Arapahoe Avenue by 5.6%. The updated spill flows were inserted into the spill reach model. During the 100-year flood, flows of approximately 1,185 cfs spill over the east bank of the main channel toward Arapahoe Avenue. The reanalysis main channel model is named GREGMAIN.prj and the spill reach hydraulic model is named GREGSP.prj.

The delineation of the 100-year and 500-year floodplains was updated at locations where the water surface elevation or lateral extents of the floodplain changed as a result of this analysis for both the main channel and the spill reach. Additionally, the 0.5-ft floodway was rerun and the encroachment stations were revised where necessary to eliminate negative surcharges and maintain the 0.5-ft rise limit. The updated 100-yr floodplain and floodway are shown in Figures 1-3.

The HHZ was rerun for the entire stream. The delineation was revised and is shown in Figures 1-3. The revised analysis removed five structures from the HHZ. The structures removed from the HHZ are located at:

- 610 College Street
- 728 and 740 University Avenue (a single duplex structure)
- 828 Marine Street
- 951 Arapahoe Avenue
- 952 Arapahoe Avenue

II. ALTERNATE EVALUATION

Alternates were evaluated to determine what, if anything, could be done to remove the structures located at 953 Arapahoe Avenue, 818 Marine Street, 712 Pleasant Street, 620 – 622 Pennsylvania, 1026 6th Street, 1170 6th Street, and 1116 6th Street from the updated HHZ. It is assumed the City will not be responsible for implementing the improvements identified in this Mini-Master Plan. The individual property owner's may elect to implement an alternate if they desire to remove their property from the HHZ. Cost estimates have been prepared for each alternate and are broken down by cost per street address. It is assumed only the homeowner's whose properties are removed from the HHZ by an alternate would share in the cost of implementing the alternate.

Detailed preliminary cost estimates are included in Appendix B of this document. A 35% contingency was added to the construction cost estimates and includes the costs of engineering, temporary facilities, construction services, right-of-way and floodplain development permits, and water control. The costs included herein do **NOT** include the costs of temporary construction easements or permanent drainage easements on private property which may be extensive. Many of the properties where construction must occur to remove adjacent properties from the HHZ will remain within the HHZ following implementation of the project. The necessary easements may not be obtainable without significant additional costs. To implement Alternates 2-5, the City may have to purchase the properties that will not benefit from the improvements but on which construction must occur.

1. Lower Arapahoe Avenue Roadway – Removes 953 Arapahoe

Along Arapahoe Avenue, the building owned by the City of Boulder Housing Authority at 953 Arapahoe Avenue was added to the HHZ by the 2007 restudy. Alternates for removing this structure from the HHZ were evaluated. 953 Arapahoe can be removed from the HHZ by lowering the roadway elevation of Arapahoe Avenue in the vicinity of the building. This alternate is described in detail below.

- Lower the roadway by approximately 1.5-ft for a length of 180-ft beginning on the west near cross section 910. Tie back into existing grades with a slope of 5.5% on the west end of the transition and 0.5% on the east end of the transition. The existing steep cross slope will be reduced to approximately 2%.
- Storm sewer pipe and manholes will have to be replaced.
- Improvements will be contained to the street right-of-way and will not be located on private property.
- **Cost = $460,687** (100% of cost incurred by City of Boulder – owner of 953 Arapahoe)

The alternate analysis for removing 953 Arapahoe Avenue from the HHZ also considered constructing a wall between Arapahoe Avenue and the City buildings at 951 and 953 Arapahoe. The wall would create an ineffective flow area on the north side of the wall and additional conveyance would have to be provided by lowering the sidewalks and

roadway. Because this alternate would not eliminate the requirement to lower the roadway, it was not considered further.

2. Marine Street Culvert Replacement and Channel Improvements - Removes 818 Marine

The residence located at 818 Marine Street was added to the HHZ by the 2007 reanalysis. Alternates were considered for removing this home from the HHZ. 818 Marine Street can be removed from the HHZ by replacing the Marine Street culvert and the private driveway culvert at 810 Marine Street, widening the channel, and lowering the channel invert elevation. The modifications which must be performed to remove 818 Marine Street from the HHZ are described below.

- Lower the channel invert at cross sections 152, 150, and 130 which are located upstream of the driveway culvert at 810 Marine Street, downstream of the driveway culvert at 810 Marine Street, and upstream of the culvert at Marine Street, respectively.
  - Invert of XS 152 dropped from 5396.42 to 5395.5
  - Invert of XS 150 dropped from 5393.63 to 5392.5
  - Invert of XS 130 dropped from 5393.48 to 5392.00
- Lower the upstream and downstream inverts of the driveway box culvert at 810 Marine Street from 5396.4 to 5395.5 on the upstream side and from 5394.4 to 5392.6 on the downstream side (will require culvert replacement).
- Lower the roadway of the driveway culvert at 810 Marine Street from 5399.9 to 5399.0 on the upstream side and from 5399.0 to 5397.4 on the downstream side (will require driveway demolition and reconstruction).
- Widen the channel from cross section 152 to 130 by up to 8-ft on the west bank and up to 14-ft on the east bank adjacent to the residence at 818 Marine Street.
- Enlarge the Marine Street concrete box culvert from an 8-ft x 4-ft box (with 50% blockage assumed) to a 16-ft x 4-ft concrete box (with 0% blockage assumed). Widen the cross section downstream of the Marine Street culvert to 16-ft to accommodate the enlarged culvert and tie into existing grades approximately 30-ft downstream from culvert outlet.
- Remove the fence spanning the downstream chord of the driveway culvert at 810 Marine Street. This fence is obstructing the floodway and would cause downstream blockage if it broke away during a flood event.
- **Cost = $336,267** (100% of cost incurred by 818 Marine Street). The bulk of construction would occur on the private property at 810 Marine Street which will not be removed from the HHZ. Construction will also occur on the private properties at 802 Marine, 828 Marine, and 1544 8th Street which will not be removed from the HHZ.

The alternate analysis for removing 818 Marine Street from the HHZ also considered lowering the roadway of Marine Street in front of the residence at 818 Marine in order to limit reconstruction to the public right-of-way. Lowering Marine Street would not remove the residence at 818 Marine Street due to the backwater effects created by the

driveway culvert at 810 Marine Street.

3. Pleasant Street Culvert Replacement and Channel Improvements - Removes 712 Pleasant

The home at 712 Pleasant Street was added to the HHZ by the 2007 reanalysis. Alternates were considered which would remove 712 Pleasant Street from the HHZ. The alternate analysis shows 712 Pleasant Street could be removed from the HHZ by enlarging the box culvert under Pleasant Street and widening the channel upstream of the culvert. The details of this alternate are described below.

- Enlarge box culvert from the existing 8-ft X 4-ft box (with 20% blockage assumed) to a 16-ft x 4-ft box with (0% blockage assumed).
- Widen the channel to a width of 16-ft and use vertical rock walls to increase channel conveyance capacity. The widened reach will extend from the box culvert to approximately 70-ft upstream of the box culvert. The existing vertical wall on the east bank can remain in-place. The west side of the channel will be extended to accommodate the increased width and the boulder wall must be rebuilt on this side of the stream.
- **Cost = $207,179** (100% of cost incurred by 712 Pleasant Street). The majority of the channel work would occur on the parcel containing the residence at 712 Pleasant Street. A portion of the channel improvements would extend onto the properties at 704 and 755 Pleasant Street which will not be removed from the HHZ.

4. Channel Modifications South of Pennsylvania – Removes 620-622 Pennsylvania, 1170 6th Street (apartment), and 1116 6th Street

There is an existing low area west of the main channel from south of 617 College (due south of 620-622 Pennsylvania Avenue) to north of 620-622 Pennsylvania. Flood waters overtop the wooden driveway bridge at 617 College and inundate this low ground. Flooding within this "secondary channel" puts 620-622 Pennsylvania, the apartment at 1170 6th, and 1116 6th within the HHZ.

To remove 620-622 Pennsylvania, 1170 6th, and 1116 6th from the HHZ, BCW first considered enlarging the culvert beneath Pennsylvania. This did not reduce flood elevations within the low ground area west of the main channel significantly enough to remove the property from the HHZ.

Channel modifications including widening the channel for a length of approximately 165-ft from approximately 125-ft downstream of the wooden driveway bridge at 617 College to 50-ft upstream of Pennsylvania and lowering the channel invert through this stream segment were then analyzed. Channel modifications would contain the majority of flow within the main channel, thus limiting the portion of flow entering the low ground to the west. 620-622 Pennsylvania, the apartment at 1170 6th Street, and 1116 6th can be removed from the HHZ by implementing this alternate. The details of this alternate are

described below.

- Widen the channel progressively to 12-ft at cross section 300 to 19-ft at cross section 295. Taper back into the existing channel width just upstream of cross section 291.
- Lower channel invert up to 3.26-ft (at cross section 295). The stream invert would be lowered by 1.5-ft at cross section 300 and 1.34-ft at cross section 291.
- The channel centerline will be slightly realigned to accommodate the widened channel between the residences at 630 and 650 Pennsylvania.
- 2:1 boulder or riprap-lined side slopes may be used on the west side of the widened stream channel. 2:1 boulder or riprap-lined side slopes may be used for a portion of the east side of the widened channel. A near vertical boulder wall approximately 70-ft in length will be required for a portion of the east bank (wall would be located from approximately 35-ft of south of cross section 295 to 35-ft north of cross section 295).
- **Cost = $134,819** (33% of cost incurred by 620-622 Pennsylvania, 33% of cost incurred by 1170 6th Street, and 33% of cost incurred by 1116 6th Street). Improvements would occur on the properties at 617 and 633 College (already outside of HHZ) and 630 and 650 Pennsylvania which will not be removed from the HHZ. The improvements would not be located on the properties at 620-622 Pennsylvania or 1170 6th Street which are removed from the HHZ due to the improvements.

5. Channel Modifications South of College Street – Removes 1026 6th

The residence at 1026 6th Street is located west of Gregory Canyon Creek and is bound by College Street on the north and Euclid Avenue on the south. The existing conditions HHZ bows west into the structure at 1026 6th Street. The property slopes downward toward the stream and the home is located in a low area, causing the HHZ to extend westward and into the structure.

In order to remove 1026 6th Street from the HHZ, channel modifications are required. The required channel modifications must occur not only on the property at 1026 6th Street, but also on the properties at 1025 Rose Hill Drive, 1020 6th Street, 1030 6th Street, and 630 College Avenue.
The required improvements are described below and include:

- Widen channel by constructing boulder rock wall on both the left and right banks. The widened reach will be approximately 140-ft long and 26-ft wide (at the widest point adjacent to the residence at 1026 6t[h]).
- The channel transition will begin on property at 1020 6th Street, proceed through the properties at 1026 6th Street and 1025 Rose Hill Drive, and transition back to the existing channel on the properties at 1030 6th Street and 630 College Avenue.
- There is an existing hill or high point on the east side of the stream through the widened reach (on the properties at 1025 Rose Hill Drive and 630 College Avenue). Much of the hill must be excavated and the boulder rock wall will be

constructed in tiers up to 4-ft tall for safety.

- The channel invert will be lowered through the widened reach by up to 1.15-ft.
- **Cost = $214,622** (100% of cost incurred by 1026 6th Street). Construction will occur on the properties at 1026 6th Street (removed from the HHZ) and the properties at 1025 Rose Hill Drive, 1020 6th Street, 1030 6th Street, and 630 College Avenue which are already outside of the HHZ.

III. CONCLUSION

This Mini-Master Plan describes the hydraulic reanalysis of Gregory Canyon Creek and the development and evaluation of floodplain alternatives necessary to remove select properties from the HHZ. The estimated costs for the five alternates which were developed range from $135,000 for Alternate 4 to $461,000 for Alternate 1. The cost estimates for each alternate do **NOT** include the costs of temporary construction easements or permanent drainage easements on private property which may be extensive. The Mini-Master Plan will assist the City and individual property owners as they consider the costs and benefits of the alternates discussed herein.

Please contact us with any questions you may have or to discuss this report in further detail.

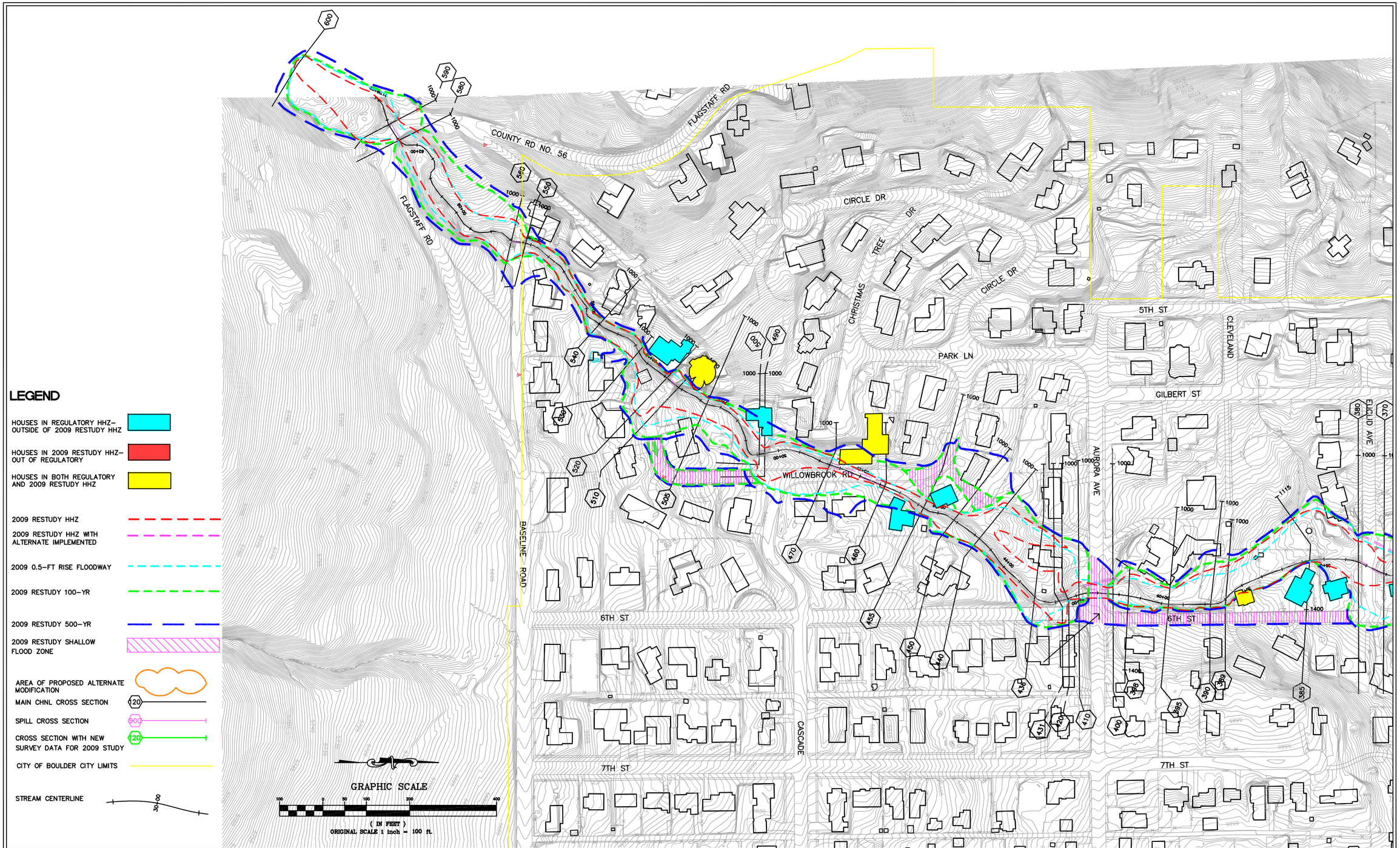
Sincerely,

BELT COLLINS WEST
(formerly Love & Associates, Inc.)

By Brianna L. Wallace
Brianna L. Wallace, E.I.

Reviewed By David J Love
David J. Love, P.E.
Principal

Enclosures: Appendix A
Appendix B



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CITY OF BOULDER, COLORADO

DESIGNED: BLW
DRAWN: PEM
CHECKED: DJL
DATE: FEB 2009

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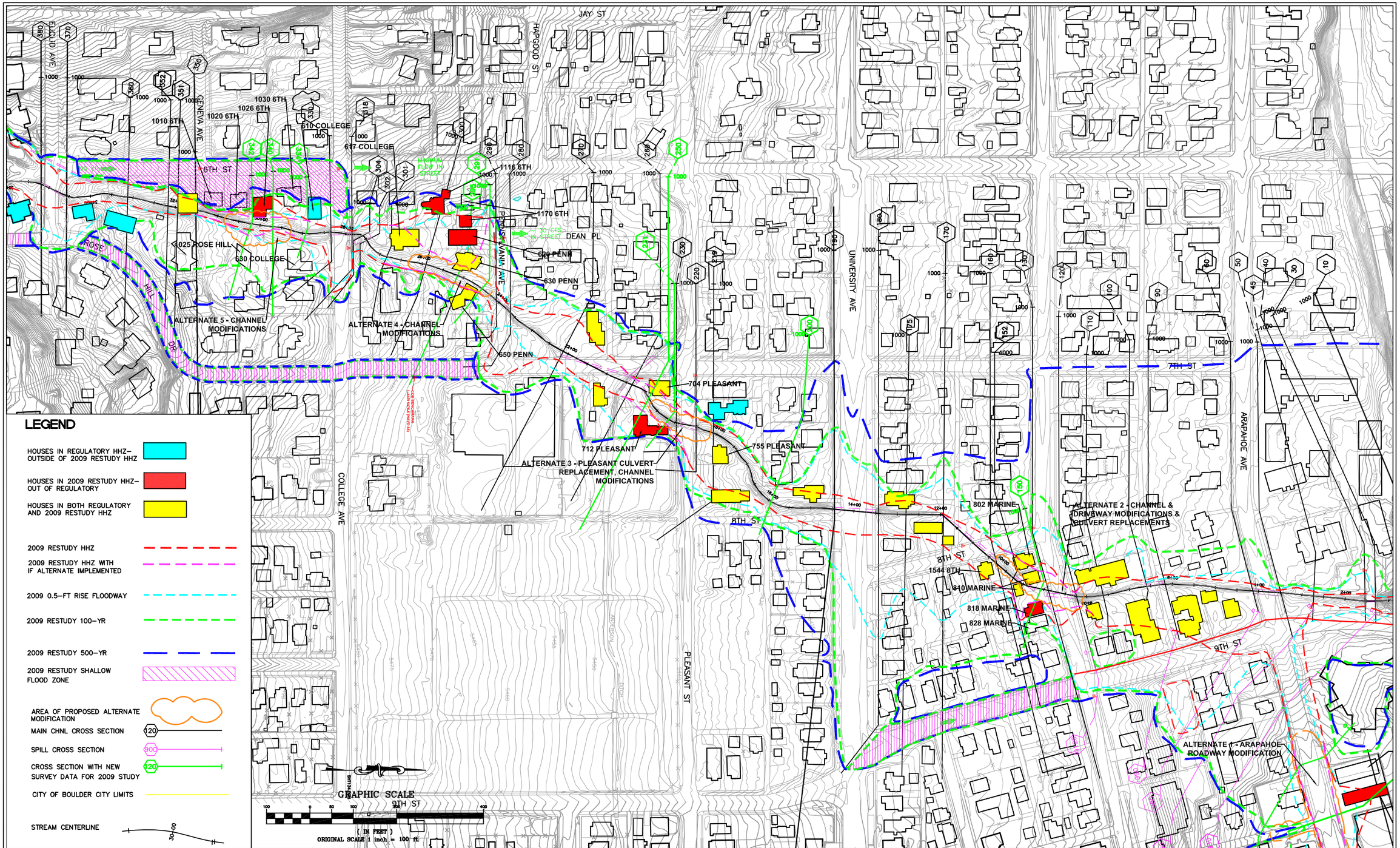
DATE	REVISIONS	BY

GREGORY CANYON CREEK MINI-MASTER PLAN STA. 63+60 TO STA. 34+00

SHEET 1 / 3



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DATE	REVISIONS	BY

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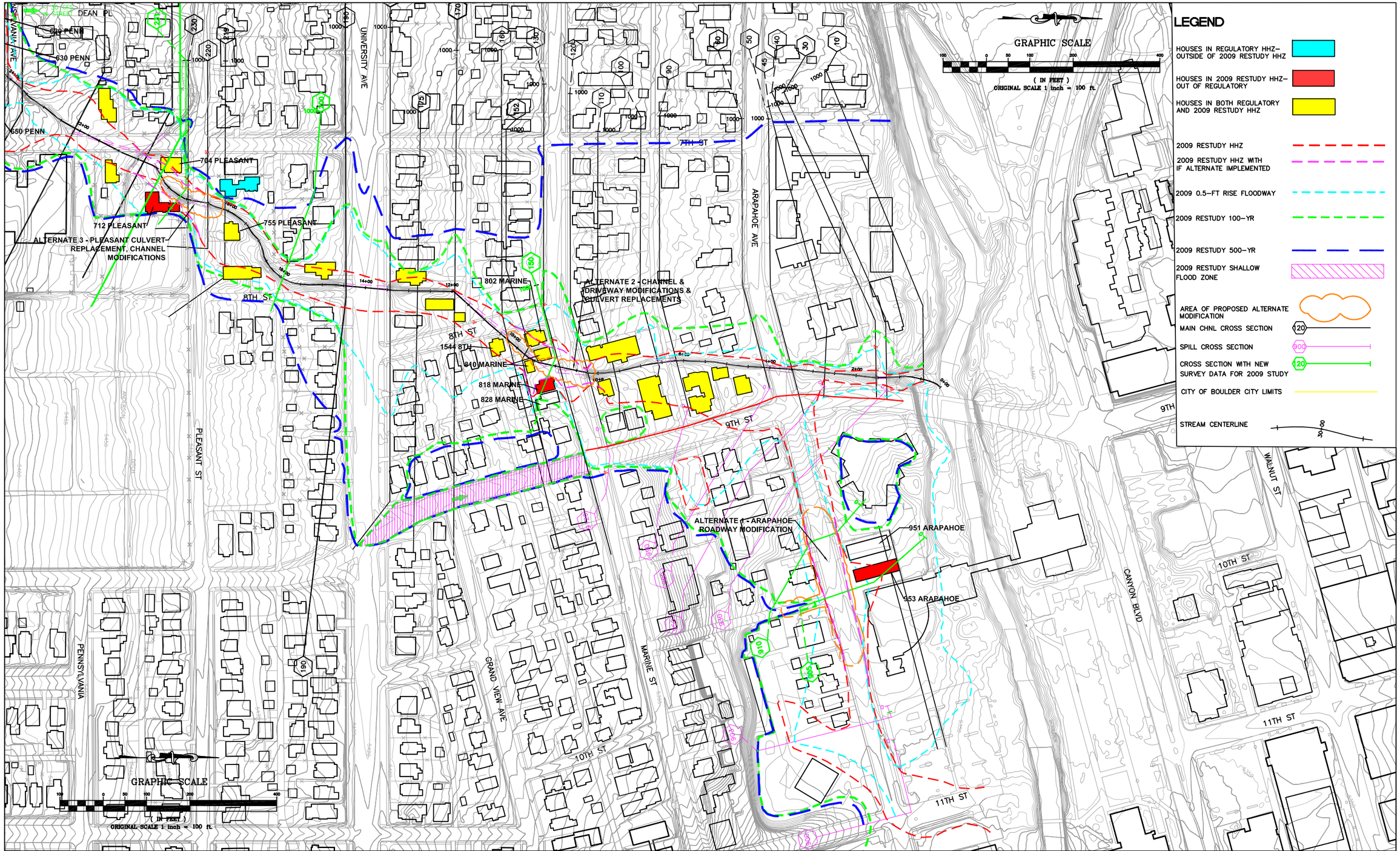
SHEET 2 / 3



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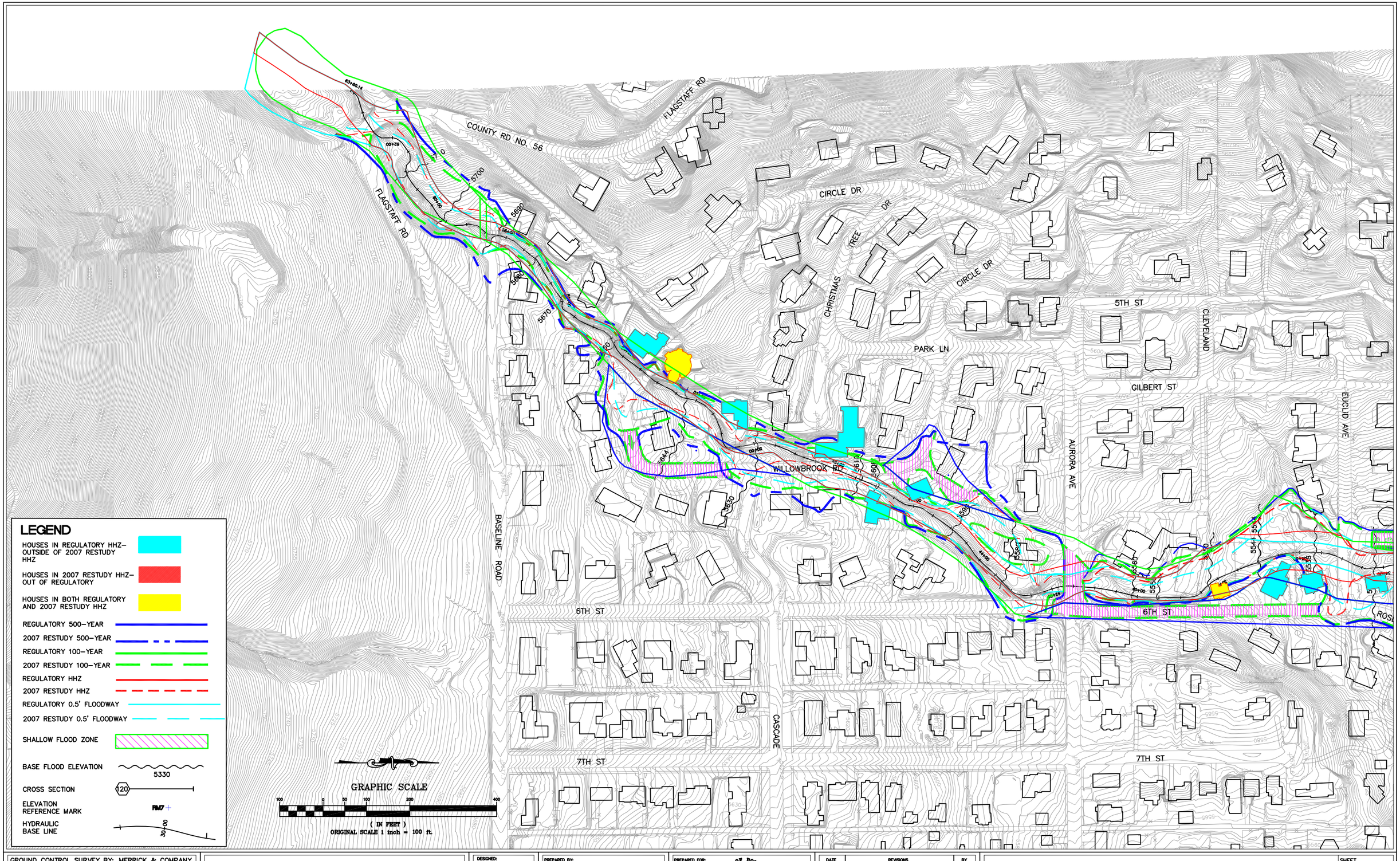
SHEET 3 / 3

APPENDIX A

FLOODPLAIN WORK MAPS FOR GREGORY CANYON CREEK 2007 RESTUDY



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GREGORY CANYON CREEK 2007 RESTUDY STA. 63+60 TO STA. 34+00

SHEET 1 / 3

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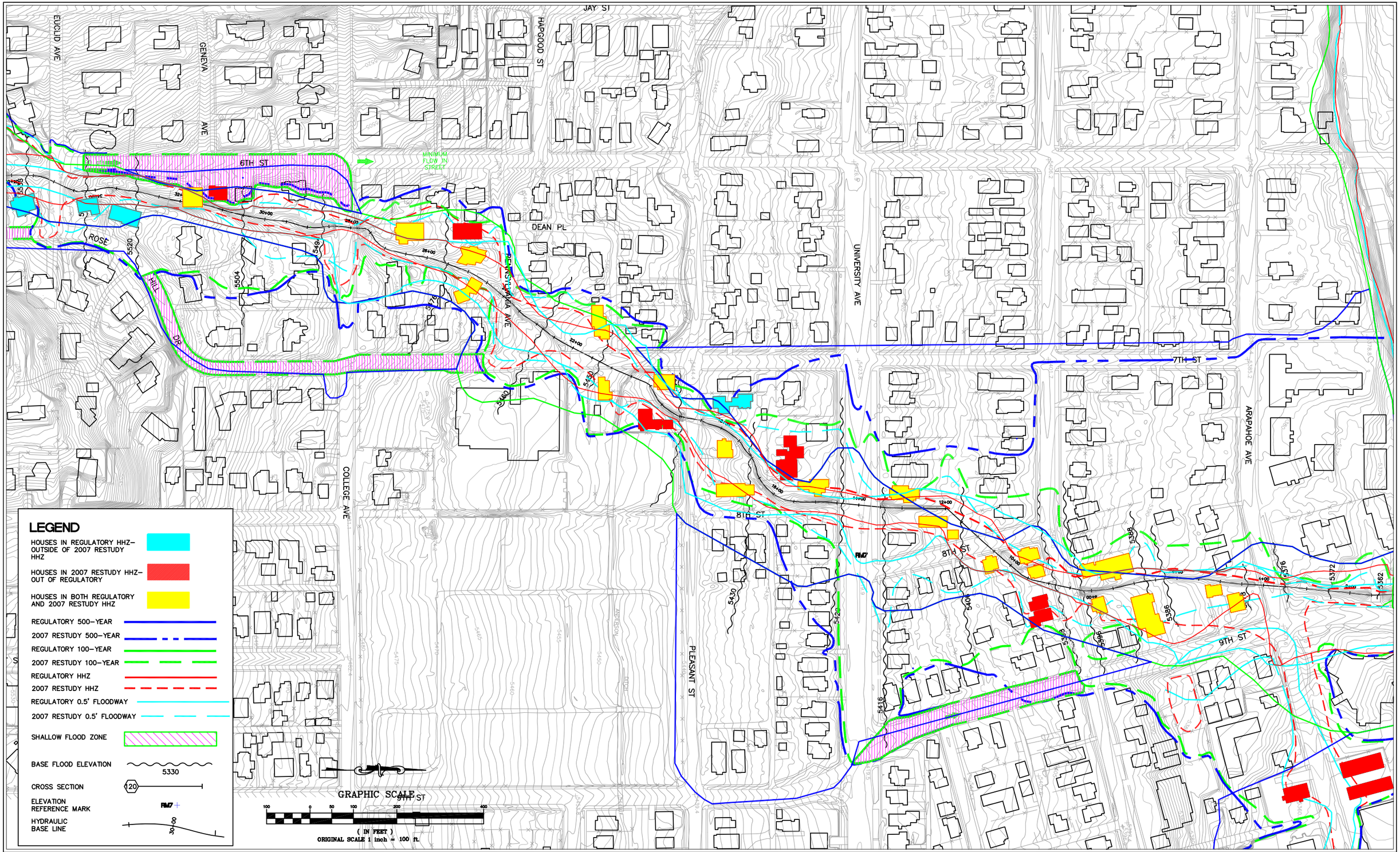

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CITY OF BOULDER, COLORADO

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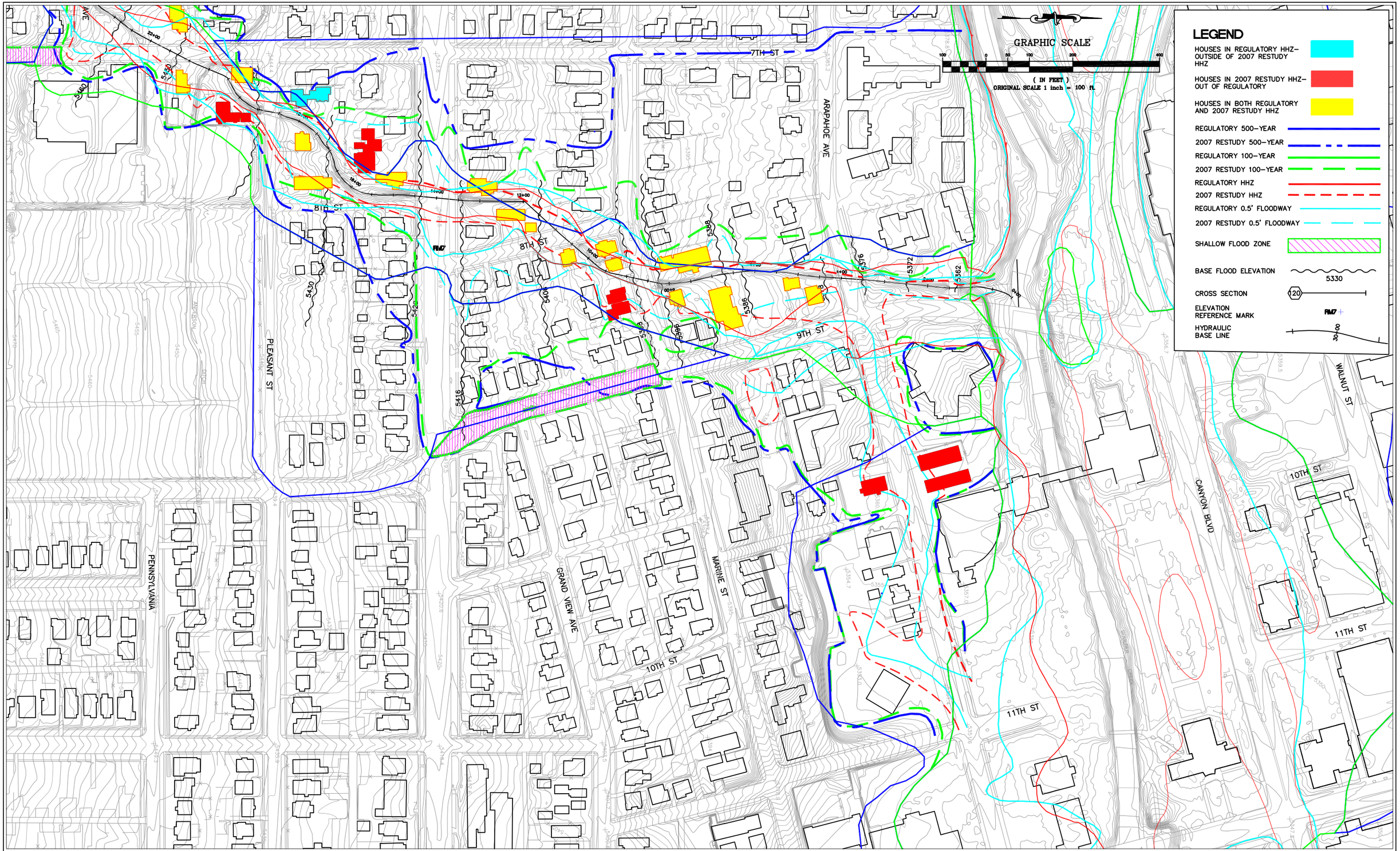
GREGORY CANYON CREEK 2007 RESTUDY STA. 34+00 TO STA. 02+00

SHEET 2 / 3



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DATE	REVISIONS	BY

GREGORY CANYON CREEK 2007 RESTUDY STA. 22+00 TO STA. 0+00

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APPENDIX B

COST ESTIMATE FOR ALTERNATES

ITEM NO	ITEM DESCRIPTION	QUANTITIY	PAY UNIT	UNIT COST	TOTAL COST OF ITEM
Alternate 1 - Lower Arapahoe Avenue Roadway					
1.1	Mobilization/Demobilization (5%)	1	EA	$14,130	$14,130
1.2	Demolish, remove pavement and curb	1,600	SY	$8	$12,800
1.3	Demo existing concrete sidewalk	175	SY	15	$2,625
1.4	Excavate in roadway	645	CY	$15	$9,675
1.5	Asphalt paving	1,590	SY	$70	$111,300
1.6	6-in curb and gutter	880	LF	$25	$22,000
1.7	Lower sanitary manholes	3	EA	$600	$1,800
1.8	Demo existing 12-in VC sanitary sewer	387	LF	$20	$7,740
1.9	Sanitary sewer pumping - 12-in replacement	3	EA	$5,000	$15,000
1.10	12-in VC sanitary sewer	387	LF	$120	$46,440
1.11	Demo existing 8-in PVC sanitary sewer	195	LF	$20	$3,900
1.12	Sanitary sewer pumping - 8-in replacement	1	EA	$5,000	$5,000
1.13	8-in PVC sanitary sewer	195	LF	$19	$3,705
1.14	Additional sanitary manhole on Lincoln Ave	1	EA	$2,500	$2,500
1.15	Lower storm manhole	2	EA	$600	$1,200
1.16	Demo existing 12-in storm sewer	216	LF	$20	$4,320
1.17	12-in storm sewer	216	LF	$30	$6,480
1.18	Replace 5-ft wide concrete sidewalk	175	SY	$32	$5,600
1.19	Regrade shoulder	348	SY	1	$348
1.20	Fine grading	348	SY	$2	$696
1.21	Topsoil	348	SY	$5	$1,740
1.22	Sod	3,131	SF	$0.875	$2,740
1.23	Erosion Control	1	EA	$15,000	$15,000
1.24	Traffic Control and Detours (15% of construction costs)	1	EA	$44,511	$44,511
	SUBTOTAL				**$341,250**
	Contingencies (35%: includes engineering, temp. facilities, construction services, water control, & permits)				$119,437
	TOTAL				**$460,687**

ITEM NO	ITEM DESCRIPTION	QUANTITIY	PAY UNIT	UNIT COST	TOTAL COST OF ITEM
Alternate 2 - Marine Street Culvert Replacement and Channel Improvements					
2.1	Mobilization/Demobilization (5%)	1	EA	$10,314	$10,314
2.2	Demo existing 8-ft x 4-ft RCB	65	LF	$50	$3,250
2.3	16-ft x 4-ft RCB (L = 65-ft)	121	CY	$750	$90,750
2.4	Demolish, remove pavement and curb	125	SY	$8	$1,000
2.5	Asphalt paving	125	SY	$70	$8,750
2.6	6-in curb and gutter	60	LF	$25	$1,500
2.7	Demo existing sidewalk	30	SY	$15	$450
2.8	Replace 5-ft wide concrete sidewalk	30	SY	$32	$960
2.9	Demo existing 8-in VC sanitary sewer	70	LF	$20	$1,400
2.10	Sanitary sewer pumping - 12-in replacement	1	EA	$5,000	$5,000
2.11	8-in VC sanitary sewer	70	LF	$67	$4,690
2.12	Remove and replace grated manholes above culvert	2	EA	$600	$1,200
2.13	Regrade shoulder	145	SY	$1	$145
2.14	Fine grading	123	SY	$2	$246
2.15	Topsoil	62	SY	$5	$310
2.16	Demo existing 4-ft x 3-ft driveway RCB	55	LF	$50	$2,750
2.17	4-ft x 3-ft RCB (L= 55-ft)	41	CY	$750	$30,750
2.18	Demolish, remove bituminous driveway	127	SY	$6	$762
2.19	Excavation in driveway	47	CY	$15	$705
2.20	Replace driveway paving	1150	SF	$2	$2,300
2.21	Remove existing rock wall (avg height ~ 4.95-ft)	450	CF	$5	$2,250
2.22	Remove rock in channel	45	SY	$65	$2,925
2.23	Channel excavation	155	CY	$15	$2,325
2.24	Type M Riprap minium 18-in thickness	65	SY	$93	$6,045
2.25	Boulder wall (average height ~ 6.25-ft)	225	FSF	$72	$16,200
2.26	Remove segment of fence	20	LF	$5	$100
2.27	Replace fence posts	2	EA	$35	$70
2.28	Remove trees	4	EA	$1,200	$4,800
2.29	Replace trees elsewhere on site	4	EA	$500	$2,000
2.30	Revegetate channel & disturbed area	0.05	AC	$3,000	$150
2.31	Erosion Control	1	EA	$12,500	$12,500
2.32	Traffic Control and Detours (15% of construction costs)	1	EA	$32,490	$32,490
	SUBTOTAL				**$249,087**
	Contingencies (35%: includes engineering, temp. facilities, construction services, water control, & permits)				$87,180
	TOTAL				**$336,267**

ITEM NO	ITEM DESCRIPTION	QUANTITIY	PAY UNIT	UNIT COST	TOTAL COST OF ITEM
Alternate 3 - Pleasant Street Culvert Replacement and Channel Improvements					
3.1	Mobilization/Demobilization (5%)	1	EA	$6,355	$6,355
3.2	Demo existing 8-ft x 4-ft RCB	45	LF	$50	$2,250
3.3	16-ft x 4-ft RCB (L = 45-ft)	84	CY	$750	$63,000
3.4	Demolish, remove pavement	100	SY	$8	$800
3.5	Asphalt paving	100	SY	$70	$7,000
3.6	Remove existing rock wall (avg height ~ 3.85-ft)	780	CF	$10	$7,800
3.7	Channel excavation	200	CY	$15	$3,000
3.8	Type M Riprap minium 18-in thickness	68	SY	93	$6,324
3.9	Boulder wall (average height ~ 3.85-ft)	310	FSF	$72	$22,320
3.10	Remove trees	4	EA	$1,200	$4,800
3.11	Replace trees elsewhere on site	4	EA	$500	$2,000
3.12	Revegetate channel and disturbed area	0.1	AC	$3,000	$300
3.13	Erosion Control	1	EA	$7,500	$7,500
3.14	Traffic Control and Detours (15% of construction costs)	1	EA	$20,017	$20,017
	SUBTOTAL				**$153,466**
	Contingencies (35%: includes engineering, temp. facilities, construction services, water control, & permits)				$53,713
	TOTAL				**$207,179**

ITEM NO	ITEM DESCRIPTION	QUANTITIY	PAY UNIT	UNIT COST	TOTAL COST OF ITEM
Alternate 4 - Channel Modifications South of Pennsylvania					
4.1	Mobilization/Demobilization (5%)	1	EA	$4,135	$4,135
4.2	Remove existing boulders in channel	75	SY	$65	$4,875
4.3	Channel excavation	400	CY	$15	$6,000
4.4	Boulder wall (average height ~ 7-ft)	490	FSF	$72	$35,280
4.5	Type M Riprap minium 18-in thickness	150	SY	$93	$13,950
4.6	Remove trees	10	EA	$1,200	$12,000
4.7	Replace trees elsewhere on site	10	EA	$500	$5,000
4.8	Revegetate channel and disturbed area	0.2	AC	$3,000	$600
4.9	Erosion Control	1	EA	$5,000	$5,000
4.10	Traffic Control and Detours (15% of construction costs)	1	EA	$13,026	$13,026
	SUBTOTAL				**$99,866**
	Contingencies (35%: includes engineering, temp. facilities, construction services, water control, & permits)				$34,953
	TOTAL				**$134,819**

ITEM NO	ITEM DESCRIPTION	QUANTITIY	PAY UNIT	UNIT COST	TOTAL COST OF ITEM
Alternate 5 - Channel Modifications South of College Street					
5.1	Mobilization/Demobilization (5%)	1	EA	$6,583	$6,583
5.2	Remove existing boulders in channel	40	SY	$65	$2,600
5.3	Channel excavation	320	CY	$15	$4,800
5.4	Boulder wall (average height ~ 5.45-ft)	1360	FSF	$72	$97,920
5.5	Type M Riprap minium 18-in thickness	80	SY	$93	$7,440
5.6	Remove trees	8	EA	$1,200	$9,600
5.7	Replace trees elsewhere on site	8	EA	$500	$4,000
5.8	Revegetate channel and disturbed area	0.1	AC	$3,000	$300
5.9	Erosion Control	1	EA	$5,000	$5,000
5.10	Traffic Control and Detours (15% of construction costs)	1	EA	$20,736	$20,736
	SUBTOTAL				**$158,979**
	Contingencies (35%: includes engineering, temp. facilities, construction services, water control, & permits)				$55,643
	TOTAL				**$214,622**

GREGORY CANYON CREEK MITIGATION ANALYSIS

FOR:

CITY OF BOULDER

BY:

1536 Cole Boulevard, Suite 150, Lakewood Colorado 80401

July 10, 2012

July 10, 2012

Ms. Christie Coleman, PE
City of Boulder, Utilities Division
P.O. Box 791 Boulder, Colorado 80306

RE: Gregory Canyon Creek Mitigation Analysis

Dear Ms. Coleman:

Gregory Canyon Creek is 2.29 sq. mile drainageway which is approximately 70% undeveloped open space and mostly residential development for the remainder of the watershed. Most of the creek from the confluence at Boulder Creek to the project study limits lies within privately owned property, and development has dramatically encroached within the 100-year floodplain. A High Hazard Zone mini-masterplan (Belt Collins, 2009) identified 32 structures in the High Hazard Zone (HHZ). The mini-masterplan removed 10 structures that were shown in previous studies, but also added 7 properties that were not in the HHZ in previous studies. The mini-masterplan identified proposed improvements that could remove these additional seven structures from the HHZ.

The City of Boulder asked WHPacific to further investigate improvement options to remove more structures from the HHZ in addition to those identified in the mini-masterplan. Specifically, WHPacific has reviewed the following possible alternatives:

- A high flow diversion conduit between University Avenue and Arapahoe Avenue
- A high flow diversion conduit between Euclid Avenue and Pennsylvania Avenue
- Channel improvements between Arapahoe Avenue and Marine Street
- Channel improvement and possible HHZ property acquisition upstream of Pennsylvania Avenue

During the course of the analysis the property at 810 Marine Street, currently in the HHZ, came up for sale and the City was interested in the property if it could be used to reduce the HHZ for other properties.

The analysis for the above possible alternatives and the property at 810 Marine Street are found in this report.

STUDY AREA

Figure 1 shows the study area. The project is generally located west of 10th Street, and bounded by Boulder Creek on the north and approximately Euclid Avenue on the south. Additional detail regarding the project street names, delineation of the 100-year floodplain and the HHZ, and properties in the HHZ is found on Sheets 1 through 3 in Appendix A. These sheets are copied from the mini-masterplan with permission from the City for the convenience of this report. The sheets show more detail than the location map and should be referred to for specific structure addresses.

Figure 1: Project Location

HYDROLOGY

No new hydrology was completed for this study. For convenience, the following table summarizes design event flows for major storm return periods for Gregory Canyon Creek. The table is prepared from steady flow data found in the regulated floodplain HECRAS file.

Table 1

		Flow (cfs)			
Creek Station	Location	10-year	50-year	100-year	500-year
180	University Avenue to Boulder Creek	673	1672	2092	3700
318	College Avenue to University Avenue	600	1504	1900	3300
455	Willowbrook Road to College Avenue	495	1286	1700	3000
600	Upstream Study Limits to Willowbrook Road	400	1060	1450	2600

HYDRAULIC ANALYSES

University Avenue Conduit Diversion

The concept for the University Avenue and Arapahoe Avenue Conduit Diversion is to intercept excessive flood flows during extreme events at University Avenue, then divert the flow from the Gregory Canyon Creek main channel so that currently affected structures are removed from the HHZ. About 14 structures are currently in the HHZ between University Avenue and Arapahoe Avenue as shown on Sheet 2 in Appendix A. For this analysis the intent was to remove all properties from the HHZ. A HECRAS model of the creek was set up using increasing flow profiles.
HHZ values were calculated at critical structures for each flow value. Left or right overbank velocities were used in the calculations as well as depths at select cross section stations to approximate the HHZ value.

HECRAS cross sections from the mini-masterplan were examined in the reach. It was determined that the most restrictive location was at Section 150, and a maximum flow of 550 cfs could be conveyed at that location before the HHZ affected structures. At the other sections slightly higher flows could be allowed before structures are within the HHZ. This location is at address 810 Marine Street, which is discussed in another section to follow.

Figure 2. Looking Downstream from Arapahoe Avenue.

From flow values given in the hydrology section, the target flow in the proposed diversion pipe would be

about 1,542 cfs, which is found by subtracting the the maximum allowed flow in the creek (550 cfs) from the 100-year event peak (2,092 cfs). A special structure would be required at University Avenue to allow base flows and minor event flows to continue in Gregory Canyon Creek until a peak flow of about 550 cfs is reached. All flow in excess of 500 cfs would be diverted to the new pipe.

Due to challenging site conditions, base criteria were established for the new pipe:

- Maximum flow velocity in the pipe for the 100-year event was set at 20 ft/sec.
- Maximum cut to the pipe invert set at 20 feet.
- Concrete pipe or box structures were selected for durability and depth of bury concerns.

The proposed pipe would be installed in University Avenue, which is relative flat at about 0.5 % slope, and 9th Street, which is steeper with slopes near 4.4%. The pipeline would daylight at Boulder Creek at the 9th Street crossing. A range of conveyance sections was examined by using normal depth calculations, and a 10'w x 8'h RCB section at 1.0% was selected to determine rough cost estimates of a diversion conduit. Trial sections using slopes steeper than 1.0% exceeded the velocity criterion.

Alternative Cost

A profile of the proposed route was prepared, and a rough layout of the new conduit was plotted on the profile. On 9th Street a stair-stepped layout of the conduit resulted from maintaining the depth of bury and conduit slope requirements. The profile showed that approximately nine special drop structures and custom manholes would be required for vertical grade breaks and direction changes along the route. The costs for potential utility relocations for water and sanitary main lines and services were estimated. Water line relocation would probably be required for crossings at 8th Street and 9th Street as well as new service lines along the proposed route. From Marine Street to Arapahoe Avenue, relocation of a sanitary sewer is likely and those costs were estimated.

A cost estimate for the alternative is shown in the table below. A contingency of 20% was used to cover adjustments to quantities, unit costs, and engineering fees. As can be seen in the table, the total estimated fee for the conduit installation is about $3,548,000. It does not appear likely that this option would be selected by the City to remove 14 structures from the HHZ.

Table 2. Cost Estimate for University to Arapahoe Reach

NO.	ITEM	QUANTITY	UNIT	UNIT PRICE	TOTAL COST
1	Mobilization	1	LUMP SUM	$147,800.00	$147,800
2	10 X 8 RCB	2,000	LF	$1,200.00	$2,400,000
3	Special Junctions	9	EACH	$10,000.00	$90,000

NO.	ITEM	QUANTITY	UNIT	UNIT PRICE	TOTAL COST
4	Entrance Box at University	1	LUMP SUM	$10,000.00	$10,000
5	Outlet Box at Creek, Wingwalls, Headwalls	1	LUMP SUM	$28,000.00	$28,000
6	Relocate Water Line - 8th Street	90	LF	$100.00	$9,000
7	New Water Service Lines	14	EACH	$500.00	$7,000
8	Water Main Crossing	4	EACH	$10,000.00	$40,000
9	Replace Sanitary Sewer at Crossings	60	LF	$75.00	$4,500
10	New Sanitary Manholes	3	EACH	$4,000.00	$12,000
11	Relocate 8" Sanitary Sewer	480	LF	$75.00	$36,000
12	Extend Sanitary Service Lines, Adjust Exist.	1	LUMP SUM	$6,400.00	$6,400
13	Asphalt	2,209	TONS	$75.00	$165,701
	TOTAL				**$2,956,401**
	Contingency (20%)				$591,280
	TOTAL ESTIMATE				**$3,547,681**

As noted above, this alternative is an all or nothing approach, meaning that all affected structures in the HHZ would be removed from the HHZ. Other options and pipe sizes could be examined that would convey less flow in the pipe, and therefore remove a smaller number of structures from the HHZ. These potential options were not examined in this study.

Euclid Avenue and Pennsylvania Avenue Conduit Diversion

In this reach, 11 structures are in the currently regulated HHZ. However, some structures have encroached so significantly into the HHZ conveyance zone that a diversion pipeline would have to carry nearly all of the 100-year event in order to remove all structures from the HHZ. The following table shows a decision matrix of allowable creek flow and affected properties. Based on the table, a practical

Figure 3. Property near the Extension of Geneva Avenue

diversion pipeline that conveyed 1250 cfs was established as a starting point for the analysis. Four properties would still be in the HHZ as shown in the table.

Table 3. Decision Matrix for Upper Gregory Creek

Maximum Allowable Creek Flow (cfs)	Diverted Flow (cfs)	Properties in HHZ	Description
100	1800	1006 - 6TH Street 650 Penn	1006 6th Street will always be in the HHZ - no practical way of removing it from HHZ. 650 Penn is also adjacent to creek, no practical way of removing it from the HHZ.
250	1650	1006 - 6TH Street 650 Penn 630 Penn	Property at 630 Penn (west side of creek) is in HHZ at flow of 250 cfs.
650	1250	1006 - 6TH Street 650 Penn 630 Penn 1026 6th	650 cfs affects house at 1026 6th
1450	450	1006 - 6TH Street 650 Penn 630 Penn 1026 6th 617 College	1450 cfs affects house at 617 College

The peak flow in the proposed conduit diversion is slightly less than the flow in the University and Arapahoe reach, however, normal depth calculations determined that the same box size at a 1.0% slope could convey the 100-year event. The conduit would have slightly more reserve capacity than the University and Arapahoe conduit, but the next smaller size was undersized. The proposed conduit would require a modified entrance at Euclid Avenue. The conduit route would be in Euclid Avenue, and then turn down Rose Hill Road to the intersection of Rose Hill and the Kennedy Ditch. A new modified outfall would be required at the ditch and Gregory Canyon Creek crossing. Proposed improvement costs are shown in the table below.

Figure 4. Structure at Kennedy Ditch/Gregory Canyon Creek Crossing

A contingency of 20% was used to cover adjustments to quantities, unit costs, and engineering fees. As can be seen in the table the total estimated fee for the pipeline installation is about $2,930,000. These costs appear excessive compared to the benefits of the alternative.

Table 4. Cost Estimate for Euclid to Pennsylvania Reach

NO.	ITEM	QUANTITY	UNIT	UNIT PRICE	TOTAL COST
1	Mobilization	1	LUMP SUM	$122,100.00	$122,100
2	10 X 8 RCB	1,640	LF	$1,200.00	$1,968,000
3	Special Structures	9	EACH	$10,000.00	$90,000
4	Entrance Box at Euclid	1	LUMP SUM	$10,000.00	$10,000
5	Outlet Box at Jefferson Ditch, Wingwalls, Headwalls	1	LUMP SUM	$30,000.00	$30,000
6	Relocate Water Line - Euclid (18" Steel)	1	LUMP SUM	$20,000.00	$20,000
7	Relocate Water Line - 7th	580	LF	$90.00	$52,200
8	New Water Service Lines	14	EACH	$500.00	$7,000
9	Replace Sanitary Sewer at Crossings	60	LF	$75.00	$4,500
10	New Sanitary Manholes	2	EACH	$4,000.00	$8,000
11	Relocate 8" Sanitary Sewer	350	LF	$75.00	$26,250
12	Extend Sanitary Service Lines, Adjust Exist.	1	LUMP SUM	$6,000.00	$6,000
13	Asphalt	1,299	TONS	$75.00	$97,403
	TOTAL				**$2,441,453**
	Contingency (20%)				$488,290
	TOTAL ESTIMATE				**$2,929,743**

Channel Improvements between Arapahoe Avenue and Marine Street

The concept for this alternative is to install a new open channel that could convey the HHZ, yet allow overbank flow to adjacent properties during the 100-year event. A difficulty in this reach is the close encroachment of private structures relative to the existing creek. As shown on the figures in Appendix A, in some cases the structures are located directly across the creek from each other, so available space to construct a new channel is limited.

Between Arapahoe Avenue and Marine Street the average slope between street crossings is about 4.3%. An open channel at this slope would most likely have to be lined with riprap or grouted rock to resist erosion. A flatter slope would be preferred, and grade transitions to the existing culvert at Marine Street would require drop structures.

The reach is very restrictive, and the narrowest section is located at about 1683 9th Street (address is

approximate). A section was best fit between two structures at this location. The section had a base width of 12 feet and was tied to existing grades adjacent to structures on the east and west of the channel. The section invert was set using the Arapahoe culvert invert and a proposed channel slope of 0.5%. Normal depth calculations were used to approximate the hydraulic conditions at this location, and a maximum flow of about 800 cfs could be conveyed here before the adjacent structures are affected by the HHZ. An open channel option does not appear feasible at this location.

Upon further examination, the existing HHZ width at Marine Street is about 100 feet, the width at Arapahoe Avenue is about 120 feet, and the width at the alley between these crossings is about 110 feet. In order to effectively remove all structures from the HHZ, culvert replacement would be required at all of these crossing locations.

It should be noted that a concrete lined channel with vertical banks could fit within the reach. Since a channel of that shape and size would probably not be preferred by residents or the City, cost estimates for this option were not pursued. It is possible that property acquisition could free up more land for a feasible option channel, but this option was not explored.

Channel Improvement and HHZ Property Acquisition Upstream of Pennsylvania Avenue

In the reach between Pennsylvania Avenue and Euclid Street, eight structures are in the regulated HHZ. Two structures, one at 1006 6th Street and the other at 650 Pennsylvania, are over the top of or adjacent to the creek centerline, and no creek adjustments are possible that would remove these structures from the HHZ.

After discussion with City staff, it was concluded that further effort in this reach would probably not result in a cost effective option. Property acquisition options for these properties remain open.

Analysis at 810 Marine Street

During the course of this study, the property at 810 Marine Street came up for sale. The City wanted to determine if purchasing the property and removing the two structures at 810 Marine Street could have a positive effect on other adjacent structures.

Removing the two structures at 810 Marine would open up more available land for an open channel. A new open channel option was therefore considered for the reach from Marine Street to 8th Street. As discussed in previous sections, it is assumed that a steep, concrete lined channel would not be desired. A proposed channel slope of 0.5% was set for the reach between Marine Street and 8th Street, which will require a 7.0 foot drop structure at Marine Street or at another location between the two crossings.

As shown in the drawings in Appendix A, another site constraint is found between the properties at 1544 8th Street and 802 Marine Street, which are separated by about 55 feet. The existing HECRAS model was modified to include a new open channel section in this reach. The new channel section width was set at 12 feet and 3 to 1 sideslopes were used to tie into existing grades. An existing small culvert crossing in the reach was removed for the analysis.

The HECRAS results show that the HHZ is approximately 50 feet wide near 802 Marine Street, and about 99 feet wide just upstream of Marine Street. At 8th Street, the reduced HHZ topwidth is helpful, but it appears that the 8th Street HHZ width of about 120 feet would still affect the property at 802 Marine Street. Therefore culvert replacement is also needed at 8th Street in order for channel improvements to be effective.

Figure 5. Structures at 810 Marine Street include the primary residence (right), and a separate garage (center).

At Marine Street, the 99 foot wide topwidth would still affect the property at 818 Marine Street. Culvert replacement at Marine Street may influence the HHZ calculation just upstream.

It appears that channel widening alone in this reach would not be completely effective in removing adjacent structures from the HHZ. Culvert replacement at 8th Street and Marine Street is necessary for effective reduction of the HHZ in this reach

CONCLUSIONS

Gregory Canyon Creek has experienced encroachment into the 100-year floodplain and HHZ. Such encroachments would not be allowed using current City criteria. Mitigation efforts for the alternatives described herein do not appear financial feasible compared to the benefits of the proposed work. Sub-alternatives are possible that would use smaller diversion pipes yet remove fewer structures from the HHZ. These sub-alternatives were beyond the scope of this study, however they would probably not yield favorable results.

The City has identified two properties at 1006 6th Street and 650 Pennsylvania Avenue in the upper part of Gregory Creek as properties that could be purchased and converted to floodplain open space. As this point, conversion of property to open space appears to be the best policy to enact in along Gregory Creek.

Sincerely,
WHPacific, Inc.

Brian E. Chevalier, P.E.
Senior Engineer

REFERENCES

1. Belt Collins West, 2009. 0328C – Gregory Canyon Creek High Hazard Zone Reanalysis – Mini-Master Plan.

2. Belt Collins West, 2010. Gregory Canyon Creek LOMR, High Hazard Zone Reanalysis

3. Greenhorne and O'Mara, Inc., 1983. City of Boulder and Adjacent Boulder County Drainageway Planning, Bluebell, Gregory, King's Gulch, and Sunshine Canyon Creeks Hydrology Report.

4. Urban Drainage and Flood Control District. Urban Storm Drainage Criteria Manual, Volumes I, II, and III (current versions).

APPENDIX A

DRAWINGS

The following drawings are copies from the Gregory Canyon Creek Mini-Master Plan (Belt Collins, 2009), reproduced here for convenience.