INFORMATION PACKET
MEMORANDUM

To: Water Resources Advisory Board

From: Jeff Arthur, Director of Public Works for Utilities
Annie Noble, Acting Principal for Flood and Greenways
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Date: April 27, 2015

Subject: Information Item: Bear Canyon Creek Flood Mitigation Plan

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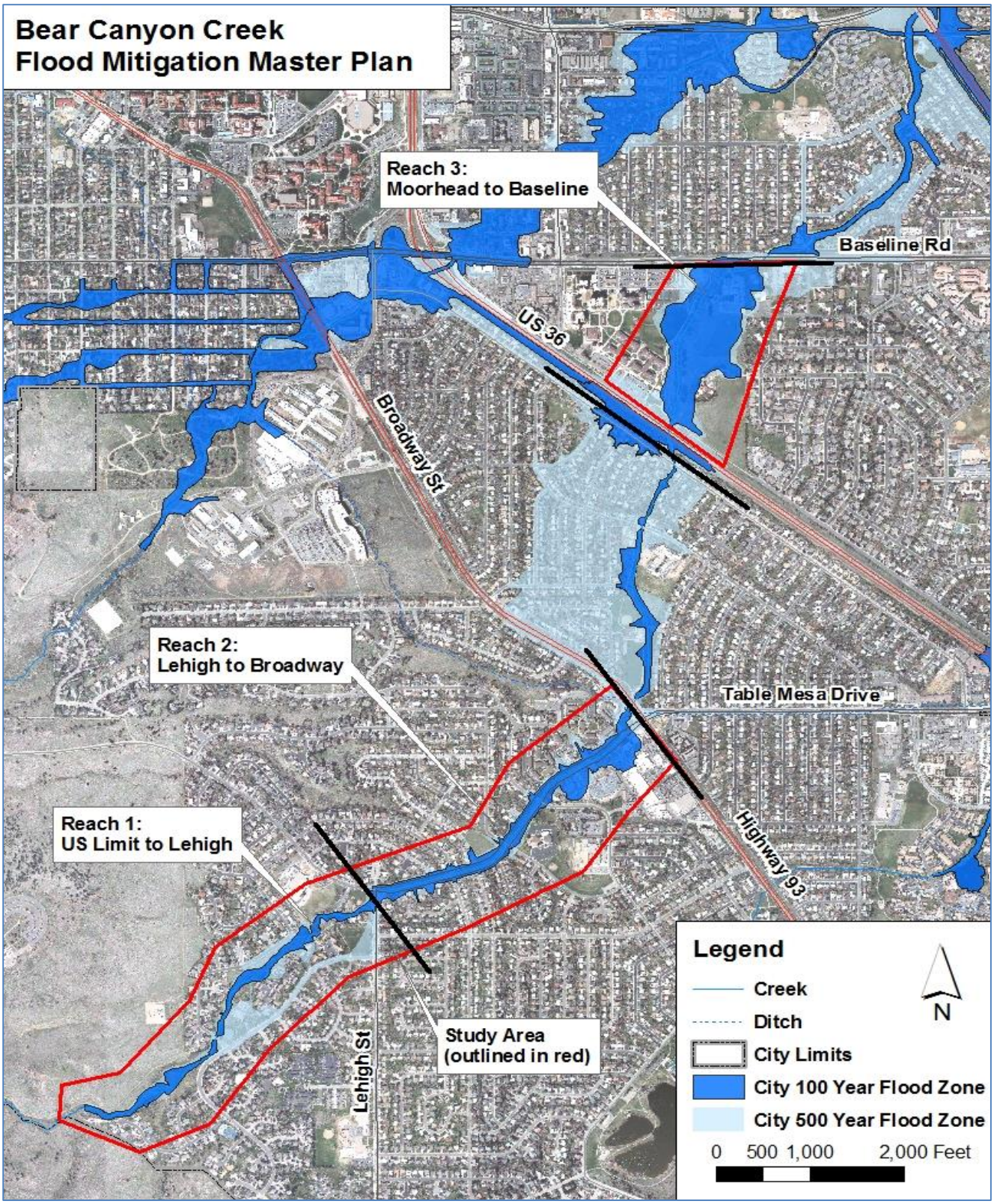
EXECUTIVE SUMMARY:

Bear Canyon Creek currently has no adopted master flood mitigation plan. Although much of the drainage has been significantly improved to convey 100-year flood flows, the 2013 flood event raised performance concerns about areas in the drainage way. The Flood Management and Greenways group, as part of a comprehensive mitigation study, initiated the Bear Canyon Creek Mitigation Plan in 2014. The purpose of this memorandum is to update WRAB on the mitigation plan progress and describe the overall study approach. This study focuses on three distinct areas based on performance concerns during the 2013 flooding event:

- Reach 1: City Limits to Lehigh Street
- Reach 2: Lehigh Street to Broadway
- Reach 3: Moorhead Avenue to Baseline Road



The city retained AMEC Foster Wheeler (AMEC) in December 2014 to help identify mitigation needs and evaluate potential alternatives to alleviate future flooding along Bear Canyon Creek in the selected stream reaches.

The study will be comprised of 3 phases with distinct goals.

- **Phase 1**: consists of creating baseline hydraulic and loss models to help identify problem areas and inform mitigation alternative choices for consideration. Mitigation alternatives will be broadly identified. Phase 1 summary memos from the consultant are attached and summarized within.

- **Phase 2**: utilizes the baseline models created in Phase1. Alternatives will be analyzed and incorporated into the models to determine their benefit. A Cost-Benefit analysis will be performed to help rank the feasibility of alternatives. (Information item and presentation to WRAB scheduled for August 2015)

- **Phase 3**: refines the alternative measures. The recommended alternatives will be compiled as a recommended Flood Mitigation Plan. This plan will be presented to WRAB with a request for a recommendation to City Council. (Action item November 2015)

The Phase 1 (Draft) Flood Mitigation Master Plan for Bear Canyon Creek Conceptual Alternative Development memo ("Analysis") is included as **Attachment A**. This is AMEC's analysis describing existing conditions and considerations for the preliminary alternative recommendations. Additionally, AMEC has provided a memo describing their baseline model for the study area. This memo entitled Phase 1: Flood Loss Estimation Technical Memorandum is attached as **Attachment B**.

BOARD AND COMMISSION FEEDBACK

The Bear Canyon Creek Mitigation Plan is in the preliminary phase and has had no board or commission feedback.

PUBLIC FEEDBACK

An Open House was held on July 1, 2014 to introduce this mitigation plan. Approximately 45 people attended this meeting, where the initial study parameters and extents were discussed. Additionally, another open house is scheduled for April 27th, 2015 directly prior to the WRAB meeting. Poster boards will be presented for discussion, outlining the study reaches and potential mitigation options.

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 and receive comments, with 24 comments received via the website comment tool to date (https://bouldercolorado.gov/flood/bear-canyon-creek-flood-mitigation-project). 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 who have signed up for email notifications and to all parents of children attending Bear Creek Elementary School.

BACKGROUND

Bear Canyon Creek originates in City of Boulder Open Space and has a drainage area of 5.3 square miles. The creek is 6.3 miles long. Much of the Bear Canyon Creek basin within the Boulder City limits was developed for residential use during the late 1950's and early 1960s. Channel infrastructure along Bear Canyon Creek has been overwhelmed during flood events on May 7th 1969, May 1995, August 15th 2007 and September 2013, among others.

Since the initial development, this major drainage way has undergone numerous improvements and benefits from a formal maintenance plan, however the flooding of September 2013 brought to light some key issues which contributed to property damage and safety concerns. In general, problems stemmed from poor conveyance capabilities, debris blockage at major crossings and lack of effective flow return zones.

Much of the Bear Canyon Creek ecosystem consists of non-native species that do not do well during extreme flood events in the foothills. These species create large amounts of debris as compared to more native species and this debris can be transported downstream creating blockages to flow.

Although the channel is relatively stable during normal flows, unstable channel conditions contribute to the generation and transport of sediment during extreme events. In the upper reaches of Bear Canyon Creek, a steeper channel gradient encourages sediment transport. The sediment typically deposits at culverts or shallower sections, reducing their capacity. During the 2013 flood, sediment deposition blocked many of the culverts completely and caused flows through surrounding neighborhoods and streets.

This study focuses on 3 distinct areas better described below.

Reach 1

The reach is defined from the City Limits to Lehigh Street and consists of City Open Space, medium density suburban, and high density townhome use. Major constrictions occur at Wildwood Road, a pedestrian bridge connecting Bear Creek Elementary school to Bear Mountain Drive, and an old boiler tank (as a culvert) crossing the stream at Wildwood and Ithaca. Although the regulatory floodplain is narrow in this area, Reach 1 had significant flooding and property damage during the September 2013 flood. Much of the damage was caused by flows created as the channel dammed with debris. Locations with potential for debris mitigation, floodplain storage and stream stabilization requirements will be identified.

Reach 2

Reach 2 is divided into two sections, Reach 2A and Reach 2B. Reach 2A extends from the crossing at Lehigh to the crossing at Broadway, while reach 2B extends from Broadway to Moorhead Avenue. Although the mitigation study will only examine alternatives in Reach 2A, Reach 2B is included because it will benefit from the upstream mitigation measures and should be included in the benefit cost analysis.

Reach 2A is an urban transportation zone, with the floodplain mainly confined to Table Mesa Drive and the creek situated within the parkway. The stream channel is designed to

contain the 25-year event with drop structures and crossings sized for stability and conveyance, while the Parkway itself forms the floodplain. Residential structures would be minimally impacted by flooding, however, commercial properties at the downstream limits of the reach are susceptible to damage in larger events. The Harvard lane culvert in particular has insufficient capacity to pass flood flows, especially with debris blockage, which causes spill flows downstream in Reach 2B, where substantial damage results.

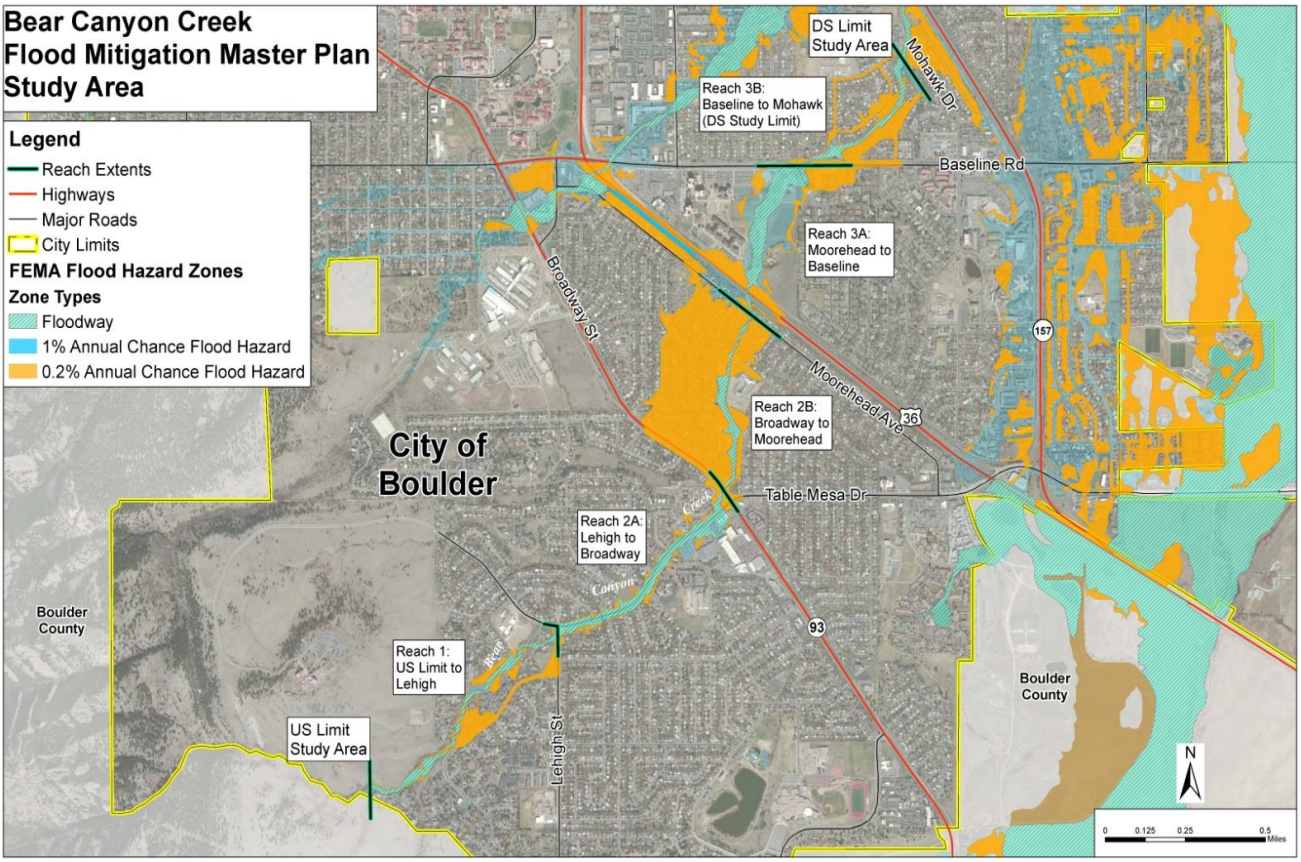
Reach 2B passes through Martin Park and a small residential area until it reaches Moorhead. This area has 100-year flood mitigation improvements that were constructed in the 1980s and 1990s, but saw damages during the 2013 flood event from spill flows at the Harvard Lane culvert. It became clear that this area (Martin Acres), which was previously excluded from the scope, needed to be included as improvements in reach 2A could benefit this area.

Reach 3

Reach 3 is also separated into a study reach, Reach 3A and an impacted reach, Reach 3B. Reach 3B sees diverted flows originating from Reach 3A. Reach 3A begins at US Highway 36 and extends through the University of Colorado Williams Village Campus to Baseline Road. This reach is currently undeveloped except for the lower limits, and consists of disturbed land and low flow crossings. The channel has insufficient capacity for any flows above the 2 year event, and is overgrown with invasive species. Poor outlet conditions at the US Highway 36 culvert exacerbate flooding upstream and create a spill situation across highway 36 in extreme events. The private drive of St. Andrews Presbyterian Church at the downstream limits of the reach just upstream of Baseline Rd., contributes to spills across Baseline Rd, severely limiting the effectiveness of the Bear Canyon Creek culvert under Baseline Rd. This church location demarks the northern end of the study area for this mitigation plan.

Reach 3B begins at Baseline Road and continues to Mohawk Drive. It was included for cost benefit analysis only.

The remainder of the drainage has had significant improvements up to the confluence of Bear Canyon Creek and Boulder Creek which occurs just to the north of Arapahoe Rd. and east of Foothills Parkway.



ANALYSIS

Typically, flood mitigation plans are developed with the intent to adequately convey a 100-year storm event. Designing major drainage way systems to transport the 100-year event is a policy standard included in 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 and previous channel mitigation in several reaches of the creek, this mitigation planning effort covers only 3 specific sections of the drainage, Reaches 1, 2, and 3 which were described in detail in the Background section of this memo. To understand the full implications of mitigation alternatives, three steps were taken to provide the analysis for Bear Canyon Creek Mitigation Plan - Phase 1:

1. A baseline conditions model was created,
2. The potential property damage during a 100-year storm event in the baseline conditions model were analyzed, and
3. Mitigation improvements were identified based on this baseline model and observations from the 2013 flood event. These mitigation alternatives will be modeled and analyzed in Phase 2 of the study.

Development of the Baseline Conditions Model – Best Available Information Model

In order to accurately analyze flows and potential improvements in the area of Bear Canyon Creek, a complete hydraulic model needed to be created. In April of 1985, a Flood Insurance Study (FIS) was conducted that produced detailed hydrologic and hydraulic information for the City of Boulder and its vicinity. In May of 1987, Greenhorne & O'Mara, Inc developed a final Hydrologic Analysis Report that developed and delineated flood hazard areas for Bear Canyon Creek. These reports did not result in a complete hydraulic model for the entire stretch of Bear Creek (from City Limits to its confluence with Boulder Creek).

Segments of Bear Canyon Creek had been analyzed and smaller hydraulic models developed for each area but they did not seamlessly connect as one cohesive model. In order to fully analyze the potential mitigation efforts along this major drainage way, a complete HEC-RAS model of the entire stream was needed. The City and the Urban Drainage and Flood Control District (UDFCD) transferred all available modeling data to AMEC who developed a Best Available Information model to produce the 10-year flood (10% annual chance), 50-year flood (2% annual chance), 100-year flood (1% annual chance), and 500-year flood (0.2% annual chance) events under existing conditions as a baseline model. UDFCD has informed the city that, when no complete model exists, a Best Available Information model is acceptable to use for planning and mitigation purposes.

Potential Damages Incurred During 100-year Flood Event in Baseline Model

Hazus-MH, FEMA's GIS-based natural hazard property damage estimation tool, was initially used to perform a flood loss estimation within the three study reaches. Site-specific building information for each of the study areas was provided by the FEMA Region VIII via the City. This data required some coordination to accurately represent on the ground scenarios. The second input into the model was a depth grid, which is a grid-based GIS file that indicates the depth of flooding at a particular grid cell. Flood depth grid data provided by FEMA was limited to the effective 100 year (1% annual chance) return period. The building data was formatted and imported into the Hazus regions for loss analysis using the 100-year FEMA depth grid.

The building point layer was overlaid onto each depth grid in GIS and a spatial join was performed to determine the depth of flooding at each structure for each return period. The tabular database was incorporated into the modified Benefit Cost Analysis (BCA) spreadsheet to perform the property damage loss calculations. Per FEMA guidance, loss curves from the Army Corps of Engineers were used during this analysis.

Each reach has been modeled for the 2-, 10-, 50-, 100- and 500-year event. Reaches 2 and 3 have risk to losses during the 100 and all reaches have losses during a 500-year event but only reach 3 has risk during the 50 year event.

Reach 1 has the lowest risk to flooding of the 3 reaches and does not result in flood loss from the 100-year event. The 500-year event affects 35 residential structures, with a total damage of $1.1M. While there is no modeled risk during the more frequent interval

floods, it should be noted that debris and culvert blockage during the 2013 flood (estimated to be a 25 year event) caused flooding in the 500-year floodplain in this reach.

Reaches 2A and 2B have the most buildings of the three reaches, including the most commercial structures. The commercial structures are associated with the Table Mesa Shopping Center at the intersection of Table Mesa and Broadway. Reaches 2A and 2B have the greatest risk from the 100 and 500-year floods. The majority of this damage is associated with reach 2B east of Broadway. The 100-year flood analysis results in less than $400k in damages between Lehigh and Broadway in reach 2A, and $1.1M associated with the 500 year event. When losses in the 2B reach are included, estimated losses are closer to $5.5M and $8.5M for the 100 and 500-year events respectively.

Reaches 3A and 3B have 213 residential structures, and several religious institutions at risk to flooding. This reach is the only reach to have some risk to the more frequent 50-year flood event (8 structures total). Reach 3A has substantial risk to the 500-year flood event.

Total estimated damages across all study reaches for the theoretical 50 year flood event is estimated at $335,000; the 100- year and 500-year total estimated damages are $6.9M and $18.7M respectively.

Proposed Improvements and Their Affect on Potential Losses

The purpose of this analysis was to explore mitigation strategies aimed at reducing damage from flood events and to create a 'planning level' benefit cost analysis to assist with mitigation alternatives analysis in Phase 2 of the study

These alternatives fall into three categories: non-structural measures, structural improvements, and debris management.

- Non-structural alternatives: These will target vegetation management and maintenance. The riparian zone will be evaluated for vegetative debris production, transport and control.

- Structural alternatives: These will consist of stream restoration strategies, floodplain creation or modification and capacity improvements to stream crossings. The feasibility of debris control structure solutions will be evaluated as well as improvements to pedestrian crossings.

- Debris management: Sediment and debris catchment areas will be evaluated for storage potential, location relative to downstream crossings and maintenance access.

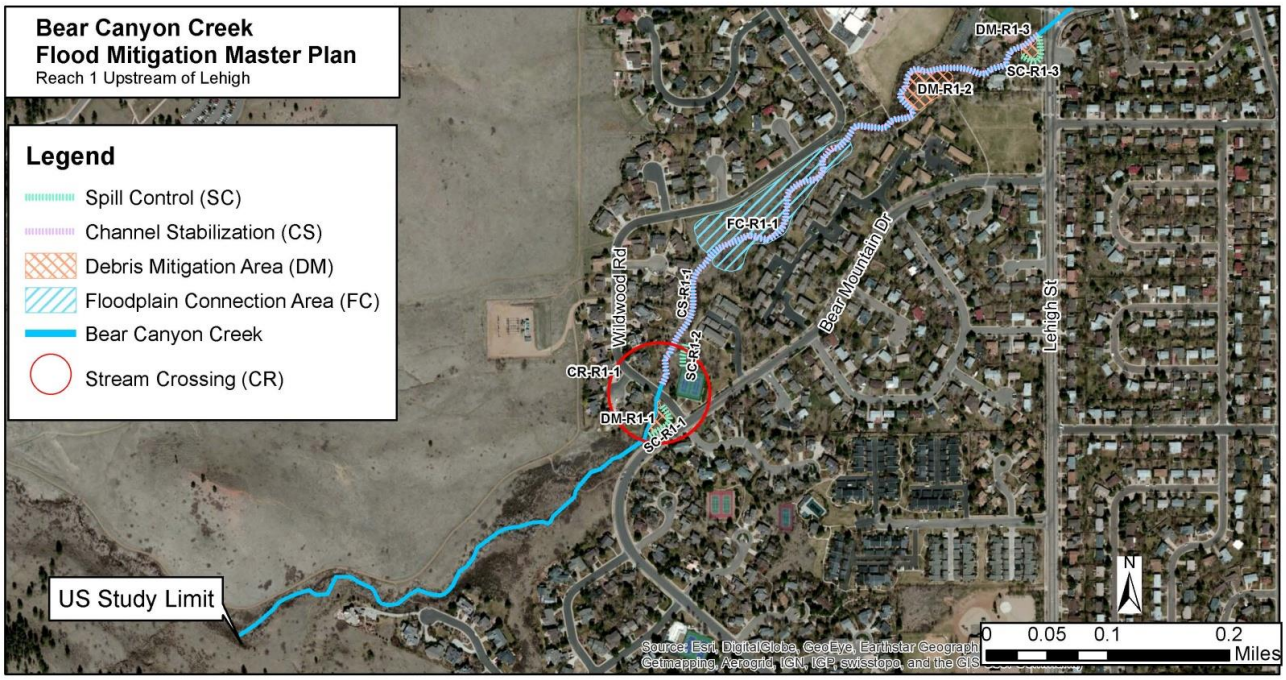
Reach 1

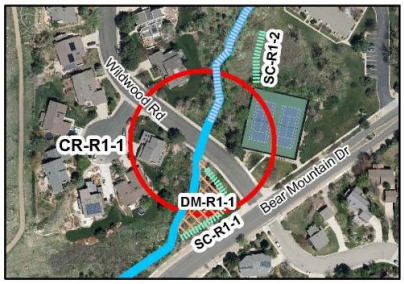
Vegetation management and debris control are crucial to improving the capacity of the channel. Invasive species should be controlled and the channel stabilized to reduce channel degradation. Several opportunities exist for debris mitigation, including areas immediately upstream of Wildwood and Lehigh. Another opportunity exists for a larger area immediately adjacent to the Bear Creek Elementary School within the Bear Creek

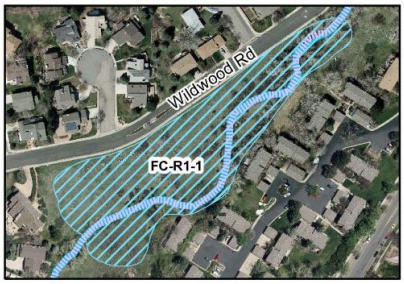
Park. These areas could be graded to receive debris deflected into them with strategically placed rock structures in the stream, and maintenance access provided to remove the accumulated debris periodically.

The area immediately adjacent to Wildwood above Ithaca is currently degraded and full of invasive species, both willow and elm trees. This area could be re-graded to connect the floodplain and be stabilized with non-structural treatments such as root wads and faschines (bundles of straw staked with native willow and seeded with a riparian seed mix). The area could then be replanted and managed as a riparian corridor per the Greenways Master Plan.

The Wildwood culvert should be assessed for improvements to hydraulics and debris control. These improvements may consist of maintenance near the up and downstream face of the structure for sediment and vegetation, modifications to the structure including beveling of the top section, placing fins or a debris deflector in front of the entrance or increasing the cell size or number. The pedestrian bridge (shown in the attached map as CR-R1-2) was replaced after the 2013 flood, however, the channel approaches up and downstream are severely incised and should be stabilized. The old boiler section culvert will be recommended for removal, and the sharp bend below assessed for stability. A map outlining planning level potential mitigation alternatives is included below.



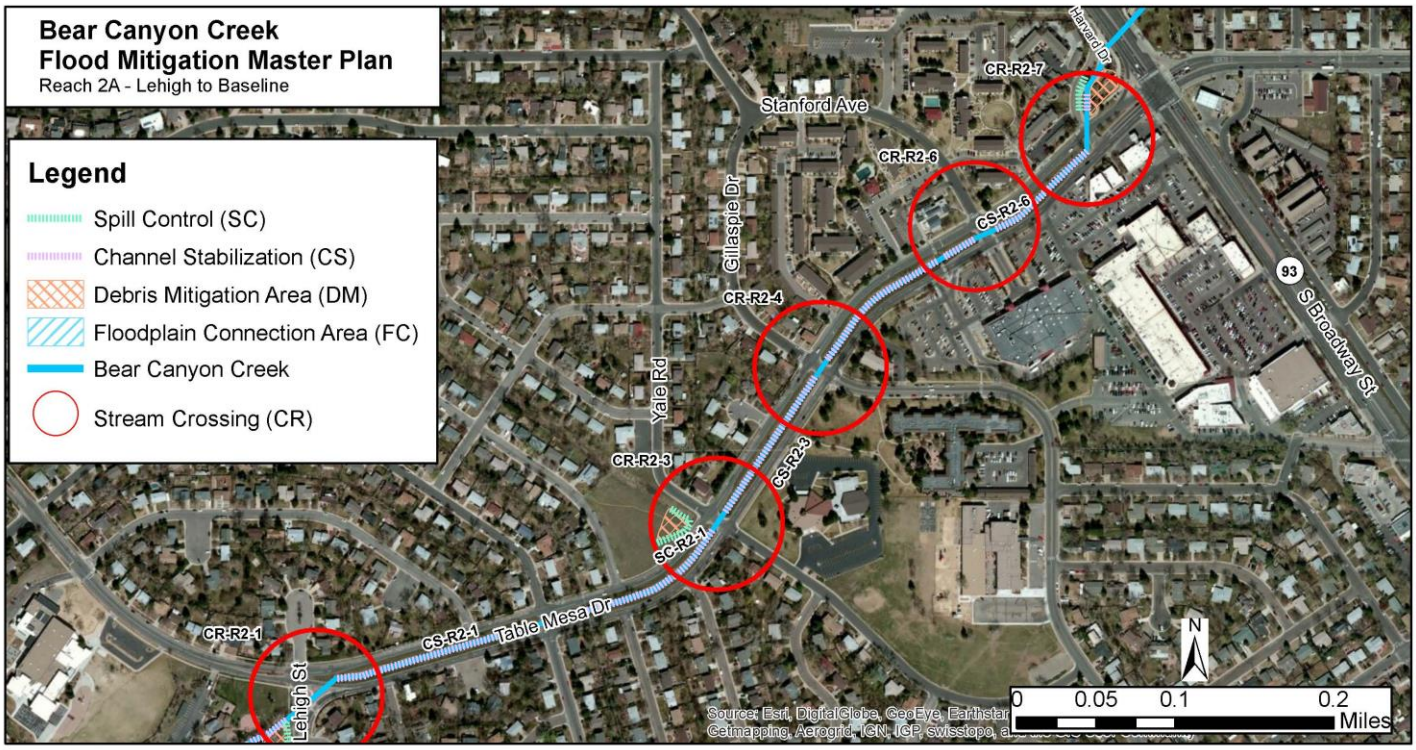


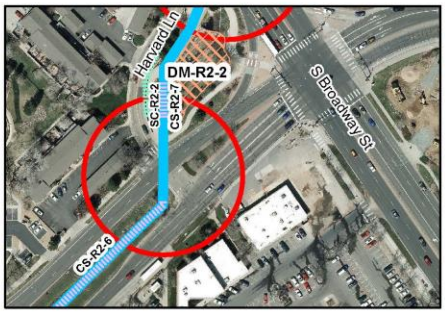


Reach 2

While much of this channel functioned well during the 2013 flood event, there are mitigation alternatives that could improve key functions of the reach. Minimizing street flooding in this reach could benefit the access and egress in the nearby neighborhoods. An alternative exploring an enlarged channel capable of conveying up to the 100-year event without impacting the travel lanes of Table Mesa Drive could be beneficial. This enlarged channel section could include a multi-use path within the channel. Culverts downstream of Broadway have already been improved in this manner, and the crossing at Lehigh would benefit greatly from enlarging the structure to accommodate both foot traffic and flood flows. As part of a federal grant application for the Transportation Improvement Program (TIP), a preliminary feasibility analysis and conceptual level design for an underpass across Table Mesa at the Harvard Lane intersection was explored.

Reach 2B extends from Broadway to Moorhead Avenue. This reach performed well during the 2013 flood, with the exception of damage caused by spill flows from upstream.





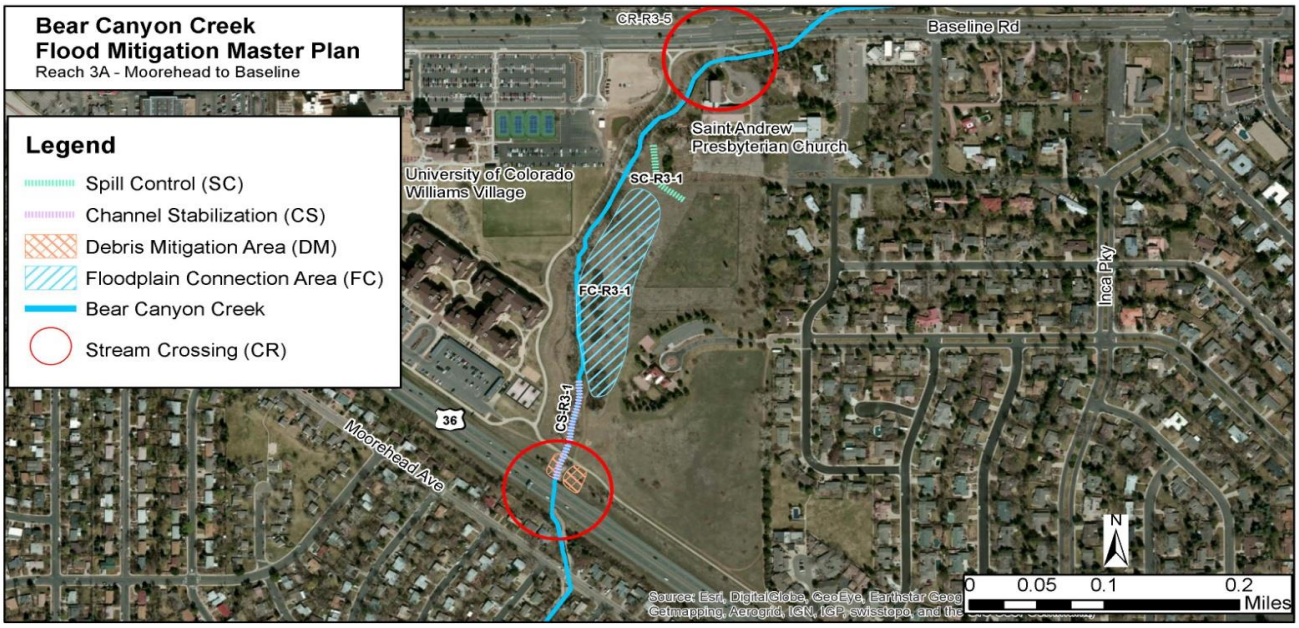
Reach 3

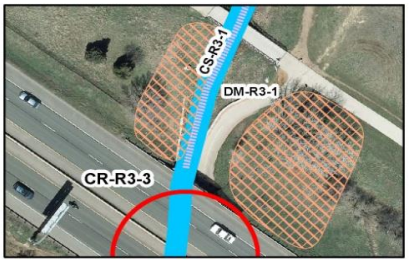
Since reach 2B is included for property loss purposes only, a small section has been included in the mitigation study for Reach 3A. The area immediately downstream of Moorhead Avenue is inundated by flows during a 100-year storm, some contributed by Skunk Creek from the north upstream of US Highway 36, as well as the culvert from the highway itself. Much of the storm water accumulation in this area may be solved by altering the outlet conditions for the Highway 36 culvert. This culvert could be improved by re-grading the area immediately downstream and reconfiguring the pedestrian path as it connects to the pedestrian bridge to the north of Highway 36. Currently, the separation wall for the path effectively limits flows in the culvert to only one of the two cells. It may also be necessary to install a third cell at this crossing to insure passage of higher flows given debris blockage and pedestrian path considerations.

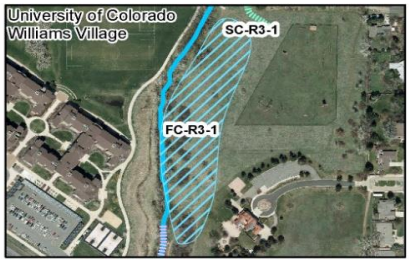
Downstream of the pedestrian bridge, the floodplain opens up to the Williams Village Campus of the University of Colorado (CU). CU has a master plan for this area that includes residential/institutional use (family student housing) and incorporates a stream crossing for access. Vegetation management and grading to create floodplains are two possible strategies that could be beneficial in this reach.

Finally, the private drive for the church located immediately upstream of Baseline Road severely limits the capacity of the Baseline culvert. This undersized culvert at the church diverts flows on to Baseline Road instead of allowing them to flow through the Baseline culvert. During the 2013 event, this split flow caused damage at and around the church as well as into reach 3B.

Reach 3B begins at Baseline and extends downstream to Mohawk Drive. The channel in Reach 3B functions relatively well with some exceptions. Damages in this area are mainly influenced by spills upstream of the reach, and thus no mitigation measures are planned for this reach as a part of this study.







COST BENEFIT ANALYSIS

During Phase 2 of the study, a cost benefit analysis will be conducted after a full list of alternatives is developed.

NEXT STEPS:

Following public input from the April Open House and WRAB meeting, staff and the consultants will continue to prepare a draft Mitigation Plan. Phase 2 of the plan will consist of a feasibility analysis of mitigation alternatives. AMEC and city personnel will develop these alternatives into a complete plan for comparison and public comment. Potential environmental impacts, as well as legal and Right of Way issues will be identified for further analysis by city staff. Phase 2 of the mitigation study is scheduled to be presented to WRAB at the August 2015 meeting. Phase 3 of the study will include a set of alternatives which will be presented to WRAB in November 2015 with a request for a recommendation to approve the mitigation plan. If approved, the plan will be presented to City Council for consideration.

ATTACHMENTS

Attachment A: Conceptual Alternative Development memo
Attachment B: Phase 1: Flood Loss Estimation Technical Memorandum
Attachment C: Open House Figures (5)
Attachment D: Master Plan Guidance and Policies

Phase 1: Flood Mitigation Master Plan for Bear Canyon Creek
Conceptual Alternative Development

Background

The current conditions along Bear Canyon Creek do not represent a natural ecosystem. Currently, many non-native species are present that negatively contribute to the functioning of the system. Species diversity is low, consisting of primarily non-native crack willow (Salix fragilis), Russian olive (Elaeagnus angustifolia), and Siberian elm (Ulmus pumila). Crack willow specifically is highly susceptible to breaking branches during extreme weather events, and likely contributed to the clogging of culverts and subsequent overland flooding. In urbanized neighborhoods, constrained channels undermine the root systems of species such as Siberian Elm, resulting in large woody debris transported downstream during an extreme event.

In addition, unstable channel conditions contribute to the generation and transport of sediment. In the upper reaches of Bear Canyon Creek, channel slope in excess of 5 to 7 percent create excessive potential energy which results in high velocities and channel shear stress. The stream transitions from its headwaters as a cascading gully in the sandstone of the Fountain Formation which make up the Flatirons to an alluvial floodplain across the Pierre shale to the east, passing through the uplifted sandstone layers of the Dakota sandstone making up the first hogback west of boulder. The changes in gradient result in an imbalance of energy which seeks equilibrium through picking up and transporting sediment. This high energy gradient passes through the softer alluvium formed by natural erosive forces forming meanders until the stream meets a constriction, either from the hard underlying sandstone or by an anthropomorphic feature such as a bridge or culvert. As flows pass through a constriction, the head loss is translated upstream as a slowing in velocity and the sediment load is deposited, while the cleaner water then accelerates through the constriction.

In an extreme event, such as the 2013 flood, deposition at these constrictions actually block the channel and flows overtop whatever feature has formed the constraint. In the case of a culvert or bridge, these overtopping flows then find their way back to the natural stream valley via roadways and neighborhoods, picking up more debris from damaged structures and creating more deposition zones where smaller constrictions develop. Typically, the culverts and bridges are designed for a 10-25 year event considering debris blockage. In the 2013 event, characterized as a 25-50 year peak flow over the Bear Canyon Creek watershed, the actual precipitation distribution was on the order of a *one thousand year event*. This resulted in saturated soils and friable (easily transported) debris in the floodplain which created a slurry flow as the peak runoff occurred. Culverts and bridges were completely blocked by debris, and the resultant overtopping condition resembled a 100 year flooding event. This resemblance however, is only in the pathways seen by the floodwaters. An actual 100 year event would produce greater depth along these pathways, creating far more damage to structures and utilities.

The purpose of this study is to explore mitigation strategies aimed at reducing damage from flood events. The creek in general has been described as being relatively stable during baseflow conditions and smaller events, requiring only routine maintenance. Conceptual level alternatives have been developed here which address the problems associated with larger events, but must also take into account the underlying morphology and ecology of the stream. These alternatives fall into three categories: non-structural measures, structural improvements, and debris management. Non-structural alternatives will target vegetation management and maintenance. The riparian zone will be evaluated for vegetative debris production, transport and control, while the maintenance program will be assessed and suggestions made for improvements. Structural alternatives consist of stream restoration, floodplain connection and capacity improvements to stream crossings. The feasibility of debris control structure solutions will be evaluated as well as improvements to pedestrian crossings. Finally, debris catchment areas will be evaluated for storage potential, location relative to downstream crossings and maintenance access. They will also be evaluated as either public or ecosystem amenities depending on ownership and designated use.

Reach 1

Reach 1 extends from the upstream limit of the study area at the corporate limits to just upstream of Lehigh Street. The reach consists of City open space, medium density suburban, and high density townhome use. Major constrictions occur at Wildwood Road, a pedestrian bridge connecting Bear Creek Elementary school to Bear Mountain Drive, and an old boiler tank crossing the stream at Wildwood and Ithaca. The stream itself transitions from a high gradient,cascading gully section upstream of Wildwood to a V-shape section below Wildwood which becomes deeply incised downstream of Ithaca.

Vegetation management and debris control are crucial to improving the capacity of the channel. Invasive species should be controlled and the channel stabilized to reduce channel degradation. Several opportunities exist for debris mitigation, including areas immediately upstream of Wildwood and Lehigh. Another opportunity exists for a larger area immediately adjacent to the Bear Creek Elementary school within the Bear Creek park. These areas could be graded to receive debris deflected into them with strategically placed rock structures in the stream, and maintenance access provided to remove the accumulated debris periodically.

The area immediately adjacent to Wildwood above Ithaca is currently degraded and full of invasive species, both willow and elm trees. This area could be regraded to connect the floodplain and stabilized with non-structural treatments such as root wads and faschines (bundles of straw staked with native willow and seeded with a riparian see mix). The area could then be replanted and managed as a riparian corridor per the greenways master plan.

The Wildwood culvert should be assessed for improvements to hydraulics and debris control. These improvements may consist of maintenance near the up and downstream face of the structure for sediment and vegetation, modifications to the structure including beveling of the top section, placing fins or a debris deflector in front of the entrance or increasing the cell size or number. The pedestrian bridge (CR-R1-2) was replaced after the 2013 flood, however the channel approaches up and downstream are severely incised and should be stabilized. The old boiler section will probably need to be removed, and the sharp bend below assessed for stability.

Reach 2

Reach 2 is divided into two sections. Reach 2A extends from the crossing at Lehigh to Broadway, while reach 2B extends from Broadway to Moorhead. The upstream limits of these reaches are technically at the upstream face of these crossings so that the downstream mitigation impacts can be assessed.

Reach 2A is an urban transportation zone, with the floodplain mainly confined to Table Mesa Drive and the creek situated within the parkway. The stream channel is designed to contain the 25 year event with drop structures and crossings sized for stability and conveyance, while the Parkway itself forms the floodplain. Residential structures are minimally impacted by the flooding source, however commercial properties at the downstream limits of the reach are susceptible to damage in larger events. The Harvard lane culvert in particular has insufficient capacity to pass flood flows, especially with debris blockage, and overland flows are translated to Reach 2B, where substantial damage results.

Debris management is limited in this area to the catchment immediately upstream of Lehigh described earlier, and a small catchment upstream of Yale Road. The catchment at Yale receives flows from a significant tributary area, and could be important in mitigating debris downstream.

A great opportunity exists to combine an enlarged channel through this reach capable of conveying up to the 100 year event with a pedestrian path system. Culverts downstream of this area have already been improved to this degree, and the crossing at Lehigh would benefit greatly from enlarging the structure to accommodate both foot traffic and flood flows. This could be combined with a structural channel section downstream to Harvard with at grade crossings in between to minimize cost. The crossing at Harvard Lane and Broadway has already undergone a preliminary feasibility analysis and conceptual level design, but must include a more comprehensive consideration of the hydraulics involved.

Reach 2B extends from Broadway to Moorhead Street. This reach performed well during the 2013 flood, with the exception of damage caused by spill flows from upstream. The area immediately downstream of Moorhead is inundated by flows contributed by Skunk Creek from the north upstream of US Highway 36, as well as the culvert from the highway itself. For this reason, the areas of flooding immediately upstream and extending downstream are included in Reach 3. No opportunities for flood mitigation as part of this plan are identified in Reach 3B.

Reach 3

Reach 3 is also divided into two sections for the same reasons identified in Reach 2. Reach 3A begins at US Highway 36 and extends through the University of Colorado South Campus to Baseline Road. This reach is currently undeveloped except for the lower limits, and consists of disturbed land and low flow crossings. The channel has insufficient capacity for any flows above the 2 year event, and is overgrown with invasive species. Poor outlet conditions at the US Highway 36 culvert exacerbate flooding upstream and create a spill situation across highway 36 in extreme events. A private drive at the downstream limits of the reach just upstream of Baseline contribute to spills across Baseline, severely limiting the effectiveness of the Bear Canyon Creek culvert under Baseline Road.

The outlet conditions for the Highway 36 culvert could be greatly enhanced by regarding the area immediately downstream and reworking the pedestrian path. Currently, the separation wall for the path effectively limits flows in the culvert to only one of the two cells. By extending the path approach farther to the east, perhaps incorporating this into improvements with the

pedestrian bridge immediately downstream, the hydraulic efficiency of the Highway 36 crossing may be enough to pass extreme events. It may also be necessary to install a third cell at this crossing to insure passage of higher flows given debris blockage and pedestrian path considerations.

Downstream of the pedestrian bridge, the floodplain opens up to the South Boulder Campus of the University of Colorado. A master plan has been developed for this area that includes residential/institutional use (student housing) and incorporates a stream crossing for access. Vegetation management could enhance the conveyance capabilities in this area and reduce floodplain width. It is anticipated however, that this measure will not provide sufficient gains to eliminate flooding which impacts downstream areas adjacent to Baseline Road. A strategy which incorporates a complete restructuring of the riparian corridor through this reach including grading to reconnect the floodplain (FC-R3-1), stabilization of the stream, and a careful design of any crossings could provide benefits to both the property owner (CU) and residential and commercial interests downstream.

Finally, the private drive located immediately upstream of Baseline Road severely limits the capacity of the Baseline culvert. This drive consists of two 36” squashed culverts which barely have sufficient capacity to convey the channel discharges during spring runoff events. This drive may benefit from a much larger culvert, a combination culvert low water crossing, or by abandoning the crossing altogether. This crossing would require investigation in conjunction with both improvements upstream aimed at confining the floodplain, and consideration of containing resultant flows to downstream reaches.

Reach 3B begins at Baseline and extends downstream to Mohawk Drive. This area is greatly influenced by the dynamics of flooding upstream. Spills which occur above baseline are transmitted overland through residential neighborhoods to the confluence area immediately upstream of Foothills Highway. This is a complicated confluence zone influenced by both South Boulder Creek to the south and east, and Skunk Creek to the west. The channel itself in Reach 3B functions relatively well except for a sharp bend to the right immediately upstream of Mohawk. Damages in this area are mainly influenced by spills upstream of the reach, and thus no mitigation measures are planned for this reach as a part of this study. The capacity and stability of the channel will, however be assessed as part of containing flows from upstream.

Memo

March 30, 2015

To: Ward Bauscher, Engineering Project Manager, City of Boulder Public Works - Utilities

From: Jeff Brislawn, Hazard Mitigation Lead/Associate

CC: Joel McGuire, Project Manager

Ref: Flood Mitigation Master Plan Bear Canyon Creek

Re: Phase 1: Flood Loss Estimation Technical Memorandum

This report summarizes a study that estimated the building damage impacts from flooding on existing development in three stream reaches along Bear Creek in the City of Boulder, Colorado. The results and additional details on the methods follow in this technical memorandum.

Modeled Flood Losses

Background

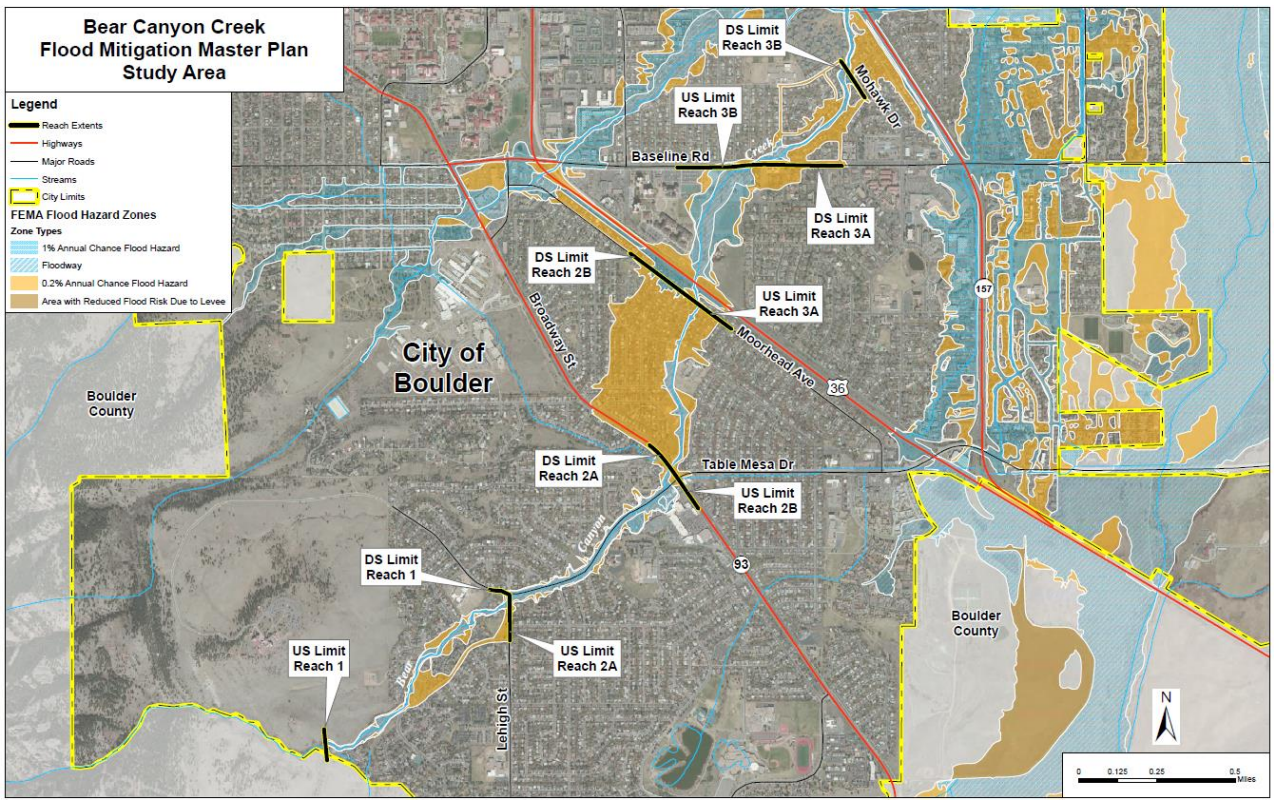
Hazus-MH, FEMA's GIS-based natural hazard loss estimation tool, was initially used to perform a flood loss estimation within the reaches. Site-specific building information for each of the study areas was provided by the FEMA Region VIII via the City. Inspection of the databased revealed that the building dataset was missing point locations for several buildings within the 100 or 500 year floodplain. At least 452 points were missing, including one of the Bear Canyon townhomes that was flooded in 2013. Amec Foster Wheeler staff identified the missing parcels and City staff was able to assist with developing point data for these parcels and populate 8 columns of attributes to match up to the FEMA point data. We also developed additional points so that individual condos/townhomes and business were represented in the model. Many of these were represented by one point for large commercial parcels such as the Table Mesa Shopping Center. Additionally, the provided attribute data needed additional processing steps to prepare it for import into Hazus, including adding content value, estimated first floor height based on building type, and latitude longitude.

The second input into the model was a depth grid, which is a grid-based GIS file that indicates the depth of flooding at a particular grid cell. Flood depth grid data provided by FEMA was limited to the effective 100 year (1% annual chance) return period. The building data was formatted and imported into the Hazus regions for loss analysis using the 100 year FEMA depth grid. Default reports to display Hazus results do not work well with user-defined data, so the loss data needed to be aggregated outside of Hazus in a spreadsheet. QC of the results revealed that the depth damage curves were not being applied appropriately by Hazus and thus the loss estimation was underestimated. This is a known bug in Hazus. In order to fix this we had to use a spreadsheet developed for a previous project as a work around to ensure that the appropriate depth damage curve was being applied.

On February 25 the City provided an email that suggested the FEMA Benefit Cost Analysis (BCA) methodology should be used instead of Hazus for a more comprehensive and accurate loss analysis. The BCA module also uses Army Corp of Engineers (Corp) - developed depth damage curves as opposed to the National Flood Insurance Program – Flood Insurance Administration curves in Hazus. The Corp curves are considered more appropriate and are also used by UDFCD in master planning studies. Subsequent conversations with the City suggested we should use the Corp curves and consider doing a 'planning level' benefit cost analysis to assist with alternative selection.

Further analysis of the 2013 flood event damage data and flood extent (including GIS and YouTube video information) revealed that losses outside of the 100 year flood plain occurred in the Martin Acres reach between Broadway and US 36. These losses were due to split flows near the Table Mesa – Broadway intersection that diverted flows down streets and into the neighborhood and flooded homes in the 500 year floodplain. From this analysis it became clear that the area between Broadway and US 36 (Martin Acres) that was previously excluded from the scope needed to be included, as improvements in reach 2 could benefit this area. A similar conclusion was reached for the area downstream of reach 3 north of Baseline Rd. Additional building data was collected in these areas for analysis.

The following figure displays the study area and the limits of the 3 reaches and sub-reaches analyzed.



Loss Estimation Methodology

The methodology utilized shifted from Hazus-based to an initial planning-level BC analysis. A spreadsheet provided by FEMA was used to aggregate building loss information. This was developed by FEMA for input of detailed structure information into the FEMA BCA tool for drainage projects. Amec

Foster Wheeler used this spreadsheet tool moving forward. The spreadsheet was modified to include depth damage curves for commercial properties as these properties are present in the study area.

This method utilizes estimated first floor heights based on the following building relationships from the Hazus technical manual.

Table 3.11 Default Floor Heights Above Grade to Top of Finished Floor (Riverine)

ID	Foundation Type	Pre-FIRM	Post-FIRM
1	Pile	7 ft	8 ft
2	Pier (or post and beam)	5 ft	6 ft
3	Solid Wall	7 ft	8 ft
4	Basement (or Garden Level)	4ft	4 ft[1]
5	Crawlspace	3 ft	4 ft
6	Fill	2 ft	2 ft
7	Slab	1 ft	1 ft[1]

Source Data: Expert Opinion

Notes:

1 Typically not allowed, but may exist

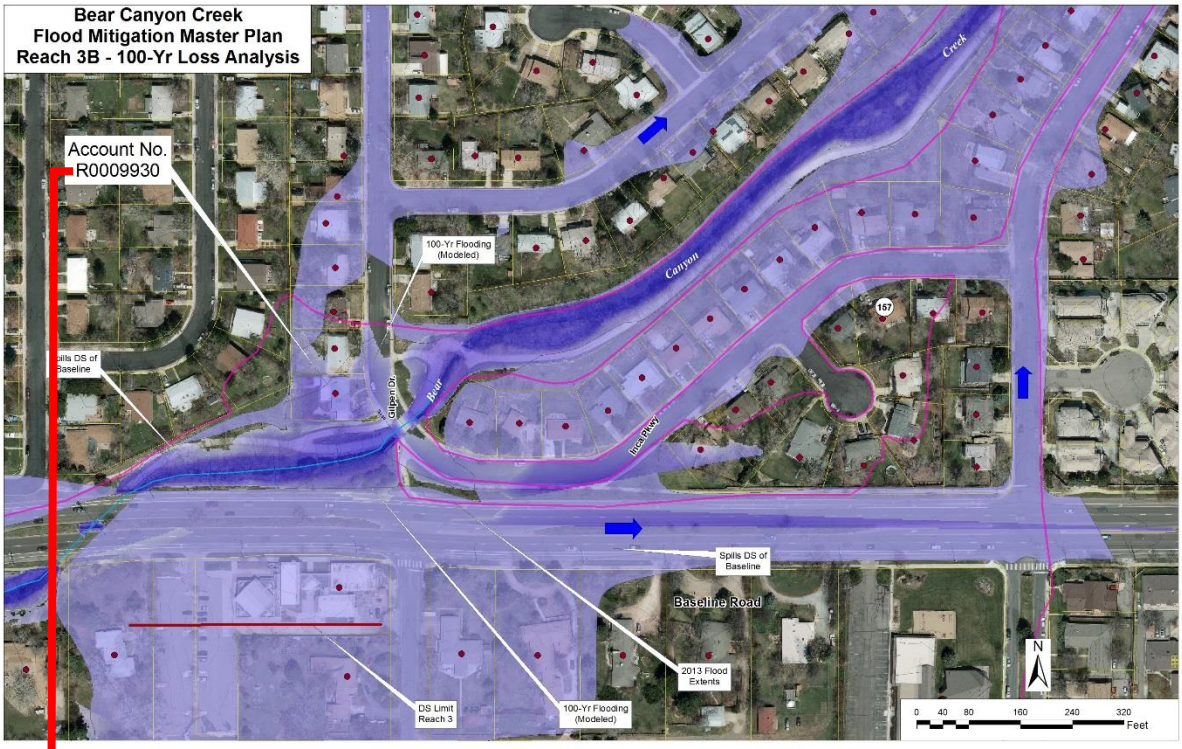
Source: Hazus Riverine Flood Technical Manual

The majority of the structures in the watershed are Pre-FIRM (constructed prior to the adoption of the first Flood Insurance Rate Map on July 17, 1978) residential structures with a mix of slab and basements. A grant-level BC analysis would require additional analysis, possibly including surveyed first floor elevations or analysis of LiDAR data to refine the estimate of these. A grant-level BCA may also require gathering additional benefit information to produce a benefit cost ratio of 1 or greater.

A best available information model was developed to produce the 10-year flood (10% annual chance), 50-year flood (2% annual chance), 100-year flood (1% annual chance), and 500-year flood (0.2% annual chance) events. Due to the complex nature of the flooding source, certain assumptions had to be made in the modeling process. Overtopping occurs at several major crossings, most notably Broadway Street and Baseline Road. Spills from these areas become hydraulically disconnected from the main channel, flow overland through streets and neighborhoods and then rejoin the floodplain downstream. Boundaries for these flows were manually delineated in the original FHAD study, and digitized as part of the current DFIRM. For the purposes of this analysis, areas outside of the main AE zone, yet within the 500-year floodplain were assumed to have a flooding depth of 2 feet for the 500-Yr analysis, 1 foot for the 100-Yr analysis, and zero for the 50-Yr analysis. These areas were joined to the calculated depth grid for areas within the main AE Zone for each corresponding recurrence interval.

The building point layer was overlaid onto each depth grid in GIS and a spatial join was performed to determine the depth of flooding at each structure for each return period. The tabular database was incorporated into the modified BCA spreadsheet to perform the loss calculations. Depth damage functions in the BCA spreadsheet were applied to create a detailed loss estimate for buildings in the reaches for the various flood events. The following figure is a snapshot from reach 3B that illustrates

the depth grid and flooded structures and how depth values were used in the spreadsheet to calculate building damage, based on depth-damage curves within the spreadsheet tabs.



2	DB Key	Structure Data						Valuation				Flood Risk				100 year Return Interval					
3																Total 100 yr Damages $					6,885,564.44
4	Structure ID	Occupancy	Building Type	Foundation	Stories	Year Built	Flood Class	Total Square Footage	Building Value	Content Value	Total BRV	Ground Elevation (NAVD88)	First Floor Height	Flood Zone	Reach	Bldg DDF Damage	Content DDF Damage	Displacement DDF (Days)	Bldg Damages	Content Damages	Damages
504	R0009781	RE	1 STORY - RA	CONCRETE	1	1965	B1SNB	2854	$ 147,100.00	$ 73,550.00	$ 220,650	5284.09	1 ft	50 YEAR FLO	3B	2.5%	2.4%	0 DAYS	$ 3,677.50	$ 1,765.20	$ 5,443
505	R0009808	RE	BI-LEVEL	CONCRETE	2	1965	B2SYB	0	$ 165,200.00	$ 82,600.00	$ 247,800	5298.78	4 ft	0	3B	0.0%	0.0%	0 DAYS	$ -	$ -	$ -
506	R0009818	RE	1 STORY - RA	CONCRETE	1	1966	B1SNB	0	$ 141,900.00	$ 70,950.00	$ 212,850	5287.22	1 ft	0	3B	0.0%	0.0%	0 DAYS	$ -	$ -	$ -
507	R0009827	RE	BI-LEVEL	CONCRETE	2	1966	B2SYB	0	$ 166,400.00	$ 83,200.00	$ 249,600	5294.29	4 ft	0	3B	0.0%	0.0%	0 DAYS	$ -	$ -	$ -
508	R0009895	RE	BI-LEVEL	CONCRETE	2	1966	B2SYB	0	$ 214,000.00	$ 107,000.00	$ 321,000	5295.43	4 ft	0	3B	0.0%	0.0%	0 DAYS	$ -	$ -	$ -
509	R0009919	RE	BI-LEVEL	CONCRETE	1	1966	B1SYB	0	$ 173,300.00	$ 86,650.00	$ 259,950	5291.46	4 ft	0.2 PCT ANN	3B	0.0%	0.0%	0 DAYS	$ -	$ -	$ -
510	R0009923	RE	BI-LEVEL	CONCRETE	2	1966	B2SYB	0	$ 172,100.00	$ 86,050.00	$ 258,150	5291.71	4 ft	0.2 PCT ANN	3B	0.0%	0.0%	0 DAYS	$ -	$ -	$ -
511	R0009930	RES1	SPLIT LEVEL	CONCRETE	1	1964	B1SYB	3206	$ 198,900.00	$ 99,450.00	$ 298,350	5305.74	4 ft	50 YEAR FLO	3B	13.8%	10.5%	0 DAYS	$ 27,448.20	$ 10,442.25	$ 37,890
512	R0009956	RES1	1 STORY - RA	CONCRETE	1	1965	B1SYB	3368	$ 181,400.00	$ 90,700.00	$ 272,100	5300.18	4 ft	0	3B	0.0%	0.0%	0 DAYS	$ -	$ -	$ -
513	R0009982	RES1	SPLIT LEVEL	CONCRETE	1	1966	B1SYB	2325	$ 168,600.00	$ 84,300.00	$ 252,900	5292.00	4 ft	0	3B	0.0%	0.0%	0 DAYS	$ -	$ -	$ -
514	R0010068	RES1	SPLIT LEVEL	CONCRETE	1	1966	B1SYB	2597	$ 164,400.00	$ 82,200.00	$ 246,600	5298.30	4 ft	0	3B	0.0%	0.0%	0 DAYS	$ -	$ -	$ -
515	R0010106	RES1	BI-LEVEL	CONCRETE	1	1966	B1SYB	0	$ 174,100.00	$ 87,050.00	$ 261,150	5290.15	4 ft	0	3B	0.0%	0.0%	0 DAYS	$ -	$ -	$ -

Results

Results of the analyses are presented in the following table, which is followed by a discussion of the results by reach.

Table 1 Estimated Flood Loss by Stream Reach

Return Period	Structures Damaged	Building Damage	Contents Damage	Total Damages	Displacement Days
Reach 1; US Study Limit to Lehigh					
500-year Flood	35	$ 816,208	$ 330,054	$ 1,146,262	0 Days
100-Year Flood		$ -	$ -	$ -	0 Days
50-Year Flood		$ -	$ -	$ -	0 Days
Reach 2A; Lehigh to Broadway					
500-year Flood	20	$ 722,622	$ 386,778	$ 1,109,400	315 Days
100-Year Flood	11	$ 252,533	$ 67,119	$ 319,652	0 Days
50-Year Flood		$ -	$ -	$ -	0 Days
Reach 2B; Broadway to Moorhead					
500-year Flood	143	$ 5,738,407	$ 1,717,123	$ 7,455,529	7560 Days
100-Year Flood	117	$ 4,006,369	$ 1,139,296	$ 5,145,664	4455 Days
50-Year Flood		$ -	$ -	$ -	0 Days
Reach 3A; Moorhead to Baseline					
500-year Flood	144	$ 4,918,883	$ 1,781,786	$ 6,700,668	2070 Days
100-Year Flood	43	$ 991,125	$ 302,847	$ 1,293,972	90 Days
50-Year Flood	7	$ 249,852	$ 79,161	$ 329,013	180 Days
Reach 3B; Baseline to DS Study Limit					
500-year Flood	70	$ 1,700,570	$ 624,577	$ 2,325,147	540 Days
100-Year Flood	5	$ 93,737	$ 32,540	$ 126,276	0 Days
50-Year Flood	1	$ 3,913	$ 1,878	$ 5,791	0 Days
Total Damages for Study Area by Return Period					
500-year Flood	412	$ 13,896,690	$ 4,840,317	$ 18,737,006	10485 Days
100-Year Flood	176	$ 5,343,763	$ 1,541,801	$ 6,885,564	4545 Days
50-Year Flood	8	$ 253,765	$ 81,039	$ 334,804	180 Days

The table displays losses by stream reach and sub-reach for the 50, 100, and 500 year flood events. There was no risk of structure flooding to the 10 year event risk within any reach, thus no losses are shown. All reaches have risk to the 100 and 500 year events. Only reach 3 has risk to the 50 year event. Total damages across all reaches for the 50 year event is estimated at $335,000; the 100 year and 500 year total estimated damages are $6.9M and $18.7M respectively.

Reach 1 has the lowest risk to flooding of the 3 reaches and does not result in flood loss from the 100 year event. The 500-year event affects 35 residential structures, with a total damage of $1.1M. While there is no modeled risk to the more frequent interval floods, it should be noted that debris and culvert blockage during the 2013 flood (estimated to be a 25 year event) caused flooding in the 500 year floodplain in this reach.

Reach 2A and 2B has the most buildings of the three reaches, including the most commercial structures. The commercial structures are associated with the Table Mesa Shopping Center at the intersection of Table Mesa and Broadway. This area has the greatest risk from the 100 and 500 year floods. The

majority of this damage is associated with reach 2B east of Broadway. The 100 year flood analysis results in less than $400k in damages between Lehigh and Broadway in reach 2A, and $1.1M associated with the 500 year event.

Reach 3A and 3B has 213 residential structures and a church at risk to flooding. This reach is the only reach to have some risk to the more frequent 50 year flood event (8 structures total). Reach 3A has substantial risk to the 500 year flood event.

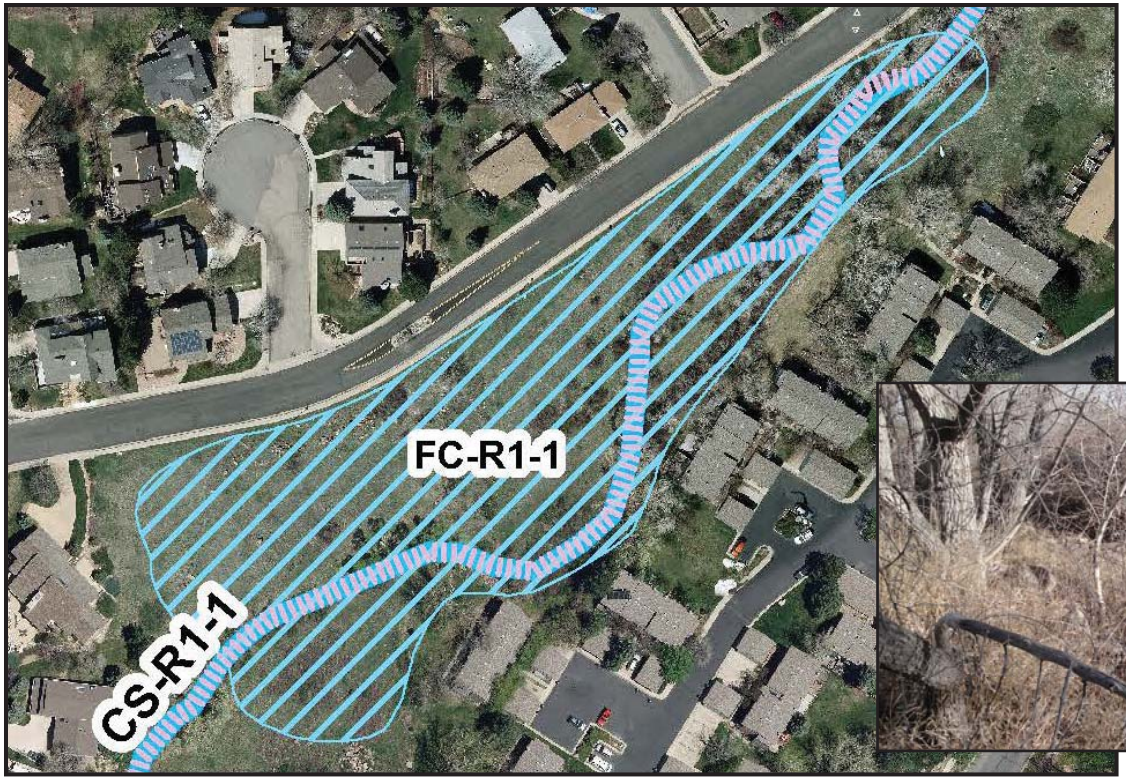
Income Related Losses and Debris Generation Estimates

Hazus has utility in estimating Income related losses and debris (building related as opposed to soil and woody debris), and these losses were calculated based on the Census block based inventory associated with a Level 1 Hazus flood run, but utilizing the user-defined depth grids. These losses were modeled to capture additional losses due to business interruption and debris estimates. Income related losses include a one-time flood disruption cost, rental income losses, and capital income losses. A single Hazus study area was created to encompass all three reaches. Total income losses were estimated at $130,000 for the 100 year and $146,000 for the 500 year event. Debris generation was estimated at 1,150 tons for the 100 year and 1,303 tons for the 500 year event. These values, in addition to the structure loss estimates previously discussed, can be used as a baseline for comparison as flood mitigation alternatives are modeled in future phases of the project.

Attachment C

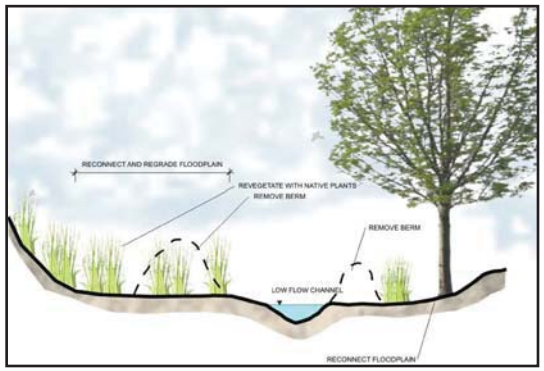
Open House Figure A

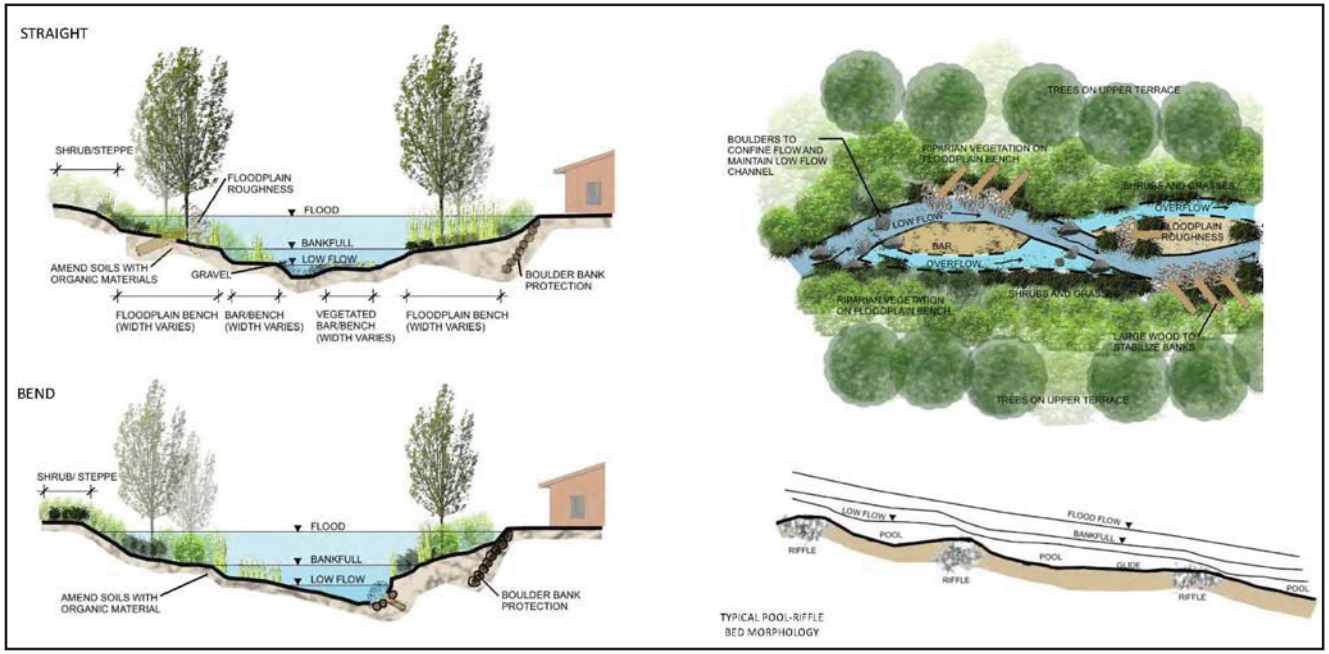
Bear Canyon Creek Mitigation Study - Reach 1
Rendering Compilation



Wildwood Road near Ithaca
Floodplain Connection FC-R1-1

Maintenance/Improvements:
- remove invasive species
- selectively regrade area to provide storage
- reconnect floodplain to improve channel stability
- revegetate with diverse, native species
- restore riparian ecosystem





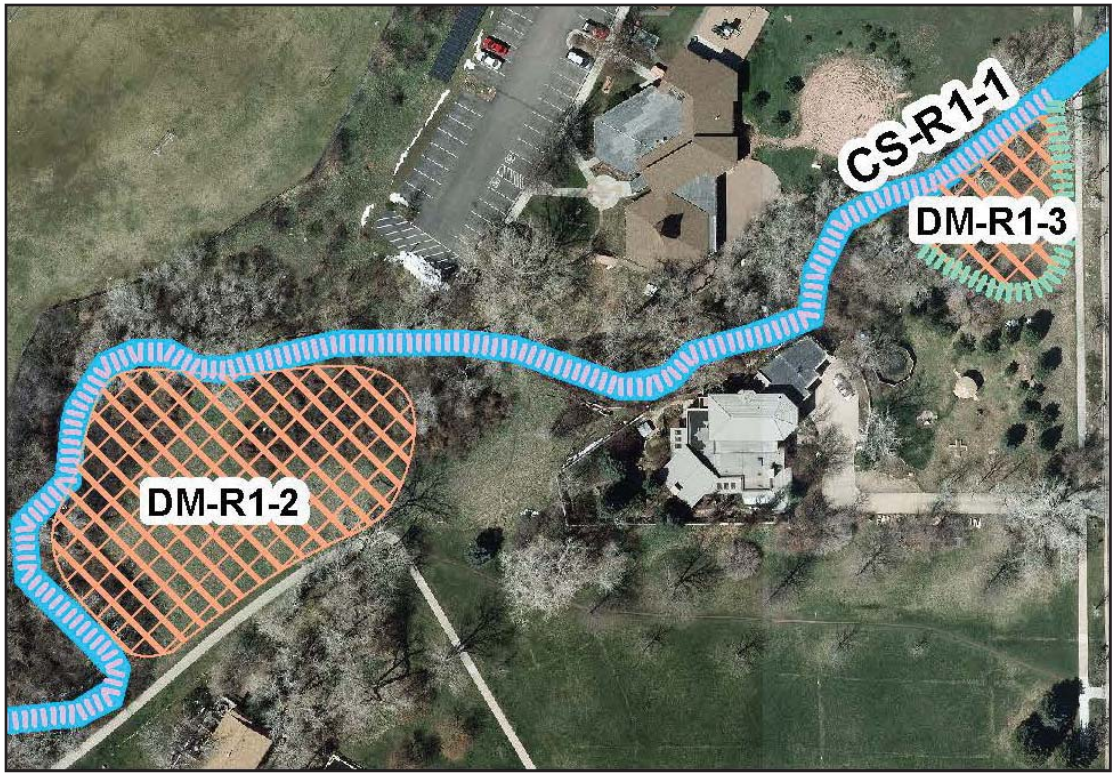
Wildwood Road near Ithaca
Channel Stabilization CS-R1-1

Improvements:
- restore stable channel gradient
- provide capacity for flood events
- restore aquatic ecosystem

Attachment C

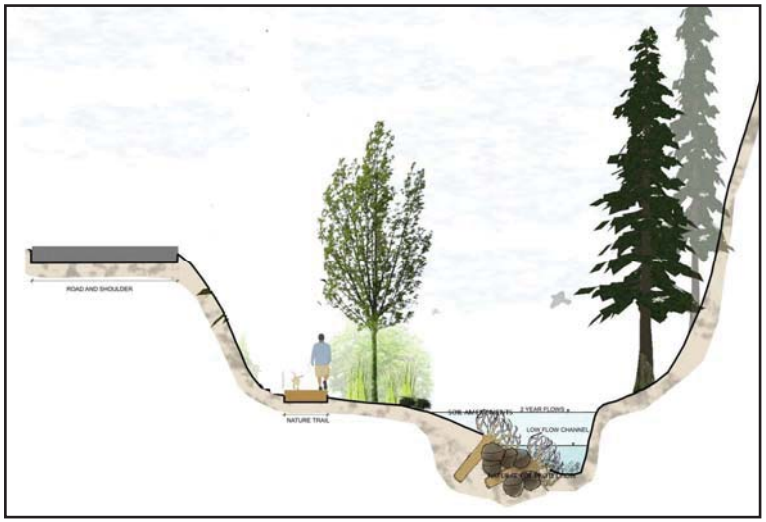
Open House Figure B

Bear Canyon Creek Mitigation Study - Reach 1
Rendering Compilation



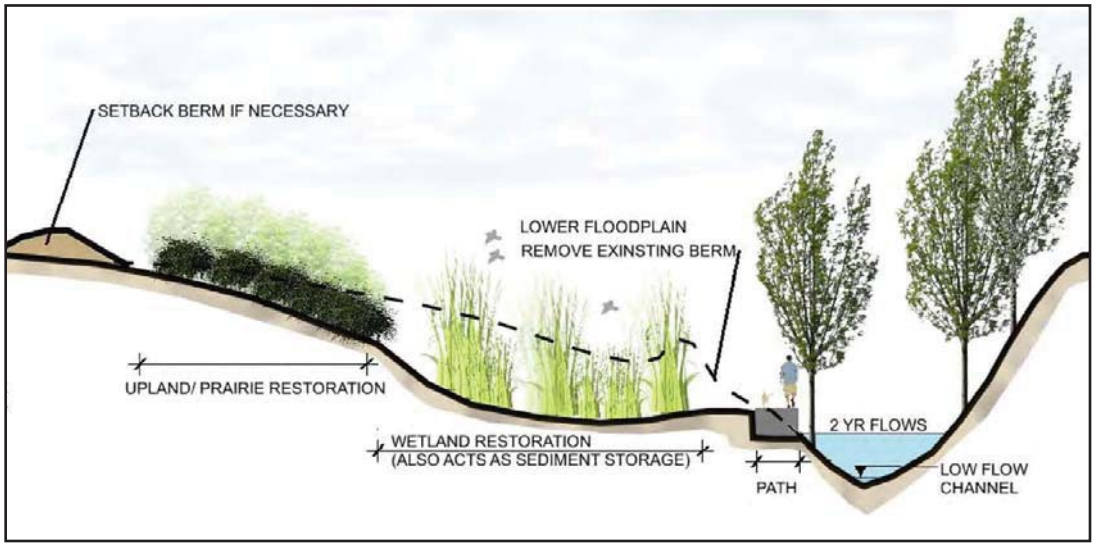
Upstream of Lehigh Debris Management DM-R1-3

Improvements:
- grade area to receive debris
- provide access for maintenance
- stabilize channel



Bear Creek Park Debris Management DM-R1-1, Channel Stabilization CS-R1-1

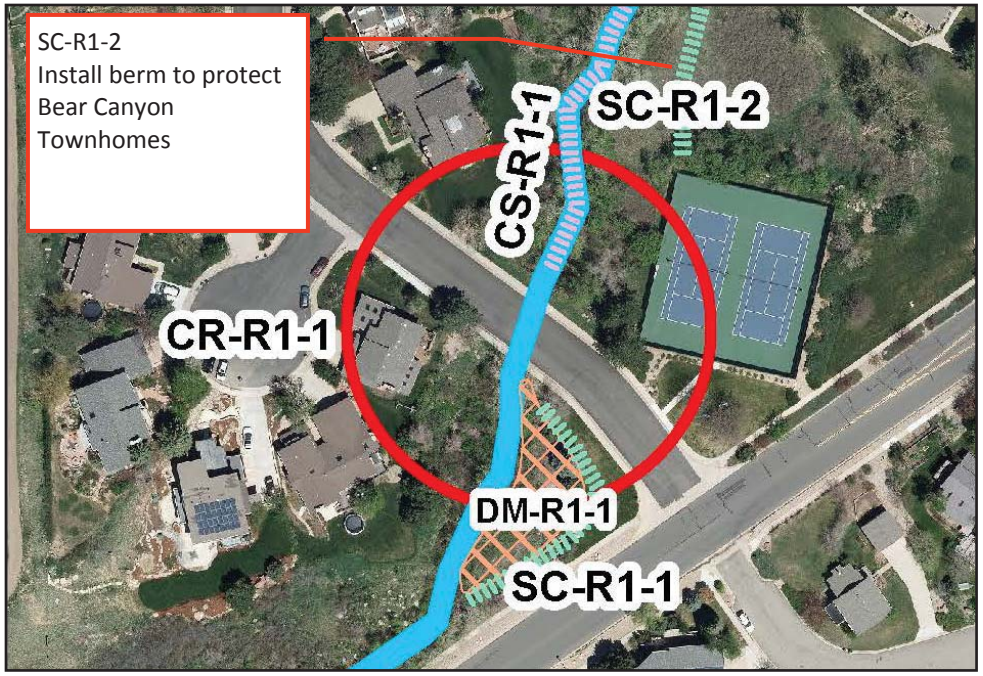
- restore stable channel gradient
- provide capacity for flood events
- selectively regrade area to provide storage
- reconnect floodplain to improve channel stability
- revegetate with diverse, native species
- restore riparian ecosystem



Attachment C

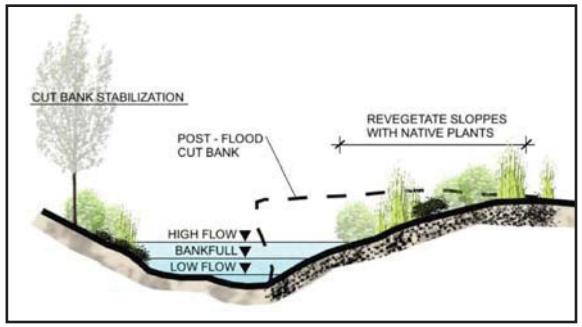
Open House Figure C

Bear Canyon Creek Mitigation Study - Reach 1
Rendering Compilation



Wildwood Road Culvert
CS-R1-1
Maintenance:
- clear blocked cell
- restore channel US and DS
Improvements:
- install fins upstream
- install debris deflector
- increase cell size

Wildwood / Bear Canyon
Debris Management Area DM-R1-1, Spill Control SC-R1-1:
Maintenance
- clear sediment debris from channel
- maintain vegetation upstream
Improvements:
- grade area to receive debris
- place berm to provide spill control
- provide access for maintenance
- stabilize channel



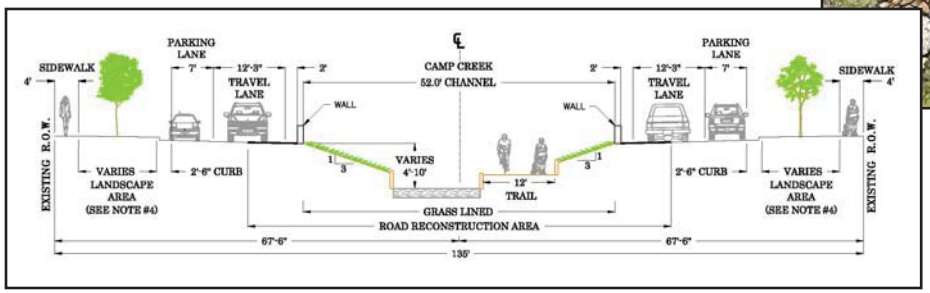
Attachment C

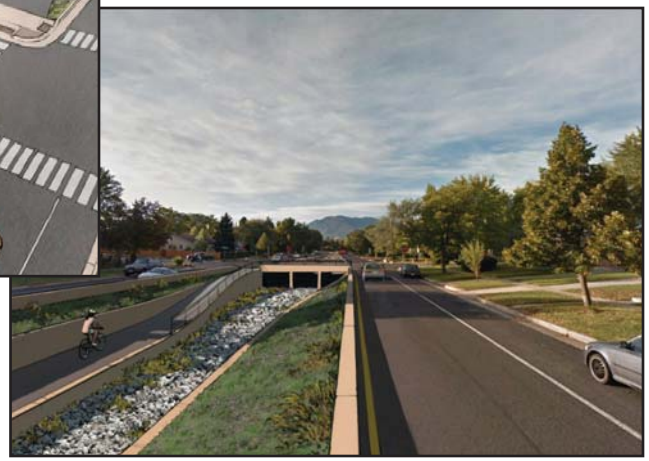
Open House Figure D

Bear Canyon Creek Mitigation Study - Reach 2
Rendering Compilation

Table Mesa Drive:
CS-R2-1-6, CR-R2-2-6

Improvements:
- break-away railing
- increase cell size
- improve inlet hydraulics
- widen / stabilize channel
- construct pedestrian path

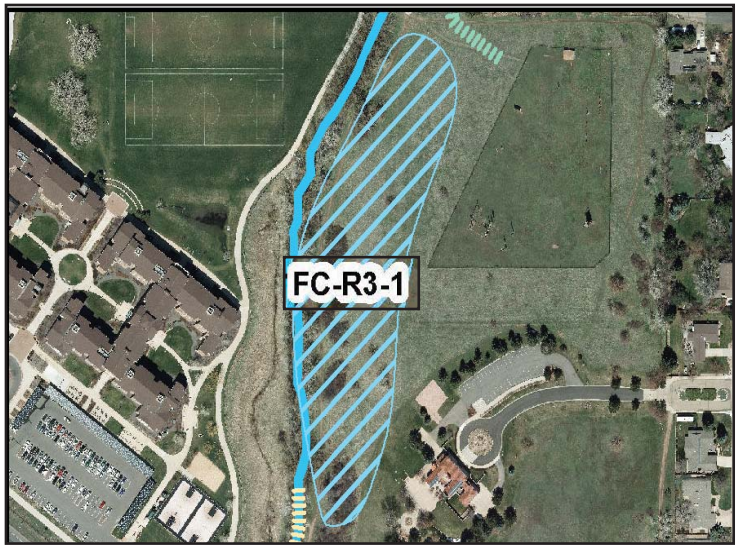


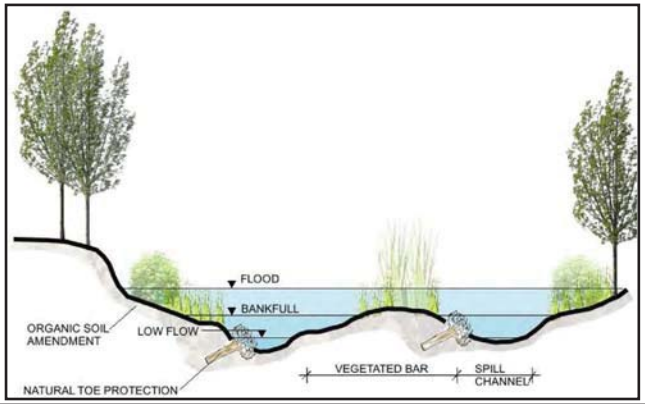


Attachment C

Open House Figure E

Bear Canyon Creek Mitigation Study - Reach 3
Rendering Compilation





CU South Campus:
Floodplain Connection FC-R3-1

Maintenance
- clear sediment debris from channel
- remove invasive vegetation

Improvements:
- grade to provide floodplain connection / storage
- stabilize channel
- provide access for maintenance
- place berm to provide spill control
- remove / upgrade crossings

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.

The intent of the flood mitigation plan is to mitigate flood damage 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 Bear Canyon Creek Mitigation Plan. The initial alternatives under consideration include structural improvements, debris management alternatives by improving the quality of the stream ecosystem and sediment control through various measures including improving and connecting floodplain configurations.