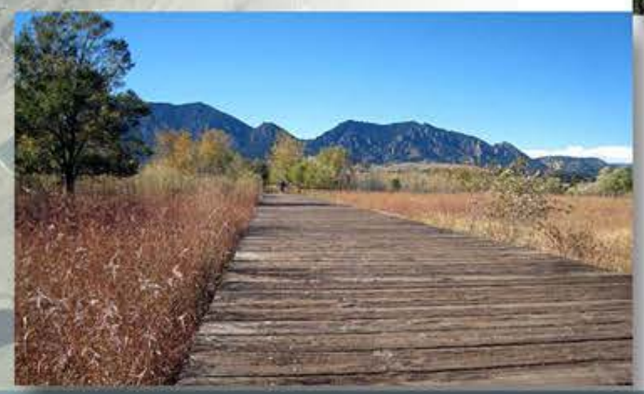
FINAL SOUTH BOULDER CREEK MAJOR DRAINAGEWAY PLAN–*ALTERNATIVES ANALYSIS REPORT*

Prepared for:

CITY OF BOULDER

URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

August 2015



CH2MHILL

9191 South Jamaica Street
Englewood, CO 80112-5946
Phone (303) 771-0900
Fax (720) 286-9250

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Transmittal Letter

9193 South Jamaica Street
Englewood, CO
80112
Tel 303-771-0900
Fax 720.286.8637

August 13, 2015

Project Number: 240043

City of Boulder
Public Works Department
Utilities Division
Mr. Kurt Bauer, P.E.
Project Manager
P.O. Box 791
Boulder, CO 80306

Subject: Final South Boulder Creek Major Dranageway Plan – Alternatives Analysis Report

Dear Mr. Bauer

CH2M HILL is pleased to submit the Final South Boulder Creek Major Drainageway Plan – Alternatives Analysis Report.. The South Boulder Creek Alternatives Analysis report focused on alternatives to alleviate flooding through the West Valley North of US-36.. This watershed was previously studied in the *Major Drainageway Planning – Phase A Report (*Taggert Engineering, Inc., 2001) and subsequently during the *South Boulder Creek Flood Mapping Study* (HDR, DHI, CH2M HILL, 2003 – 2008). This report builds on the South Boulder Creek Flood Mapping Study that included the following reports:

1. *Climatology and Hydrology Repor*t (HDR, CH2M Hill and DHI, February 6, 2007);
2. *Hydraulic Modeling Report* (HDR, CH2M Hill and DHI, December 30, 2008);
3. and the *Risk Assessment Report (*HDR, CH2M Hill, and DHI, May 2009*)*

The Final South Boulder Creek Major Drainageway Plan – Alternatives Analysis Report presents the conceptual design to address the flooding problems through the West Valley as defined by the reports listed above. This report provides conceptual level guidance and recommendations for the phasing, location, and rough budgets for flood control facilities that aid in the elimination of flood threats through the West Valley. This report is intended as an informational guide to help the City in long-term planning, stakeholder coordination, and further community involvement, as the concepts laid out in this report are further refined and designed. We appreciate the opportunity to complete this important mitigation project for the City.

Sincerely,

Alan Turner, P.E. No. 38982
Project Manager

Aaron Cook, P.E. No. 45916
Project Engineer

CH2M HILL

c: Shea Thomas, P.E. / Urban Drainage and Flood Control District

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Acronyms

AC	Acre
AF	Acre-feet
AG	Agricultural Landuse
BCA	Benefit Cost Analysis
BSDS	Basin Specific Design Storm
BVCP	Boulder Valley Comprehensive plan
BVSD	Boulder Valley School District
CB	Community Business Landuse Designation
CDEM	Colorado Department of Emergency Management
CDOT	Colorado Department of Transportation
CFS	Cubic Feet per a Second
CMP	Corrugated Metal Pipe
CU	University of Colorado
DC	Dry Creek No. 2 Ditch Reach
DFIRM	Digital Flood Insurance Rate Map
DHI	Danish Hydrologic Institute
DRCOG	Denver Regional Council of Governments
EA	Each
EIS	Environmental Impact Statement
EPA	United States Environmental Protection Agency
ES	Executive Summary
FEMA	Federal Emergency Management Agency
FFA	Flood Frequency Analysis
FIS	Flood Insurance Study
FT	Foot
GIS	Geographic Information System
G Storm	General Storm
HAZUS-MH	Hazards United States Multi Hazard
HD	High Density Residential and Mobile Home Landuse
HEC	Hydrologic Engineering Center
HWY	Highway
LD	Low Density and Rural Residential Landuse
LF	Linear Foot
LS	Lump Sum
MD	Medium and Mixed Density Residential Landuse
MP	Master Plan
NA	Not Applicable
NAD	North American Datum
NAVD88	North American Vertical Datum of 1988
OHWM	Ordinary High Water Mark
OSBT	Open Space Board of Trustees
OSMP	Open Space and Mountain Parks
PAL	Provisionally Accredited Levee
PKWY	Parkway
PMJM	Preble's Meadow Jumping Mouse
PU	Public Landuse
RB	Regional Business Landuse
RCBC	reinforced Concrete Box Culvert
RCP	Reinforced Concrete Pipe
RP	Return Period

Acronyms (Continued)

RTD	Regional Transportation District
SBC	South Boulder Creek
SF	Square Foot
SFHA	Special Flood Hazard Area
SWMM	Storm Water Management Model
SY	Square Yard
T Storm	Design Thunder Storm
U.S.	United States
UDFCD	Urban Drainage and Flood Control Distirct
USACE	United States Army Corps of Engineers
USDCM	Urban Stormwater Drainage Criteria Manual
USFWS	Untied States Fish and Wildlife Service
VH	Very Heavy Riprap (D50 = 24")
W	West
WRAB	Water Resources Advisory Board
WV	West Valley Reach Designation

ES. Executive Summary

Purpose and Scope

This Major Drainageway Planning Study was initiated in early 2010 by the City of Boulder. The Urban Drainage and Flood Control District (District) was a financial participant in the project and assisted in providing oversight during the project execution.

South Boulder Creek is a major drainageway that conveys stormwater runoff from Eldorado Canyon southwest of the City of Boulder through the eastern portions of the City of Boulder. After leaving Eldorado Canyon and crossing Hwy 93 and US-36, South Boulder Creek follows several flow paths before reaching Boulder Creek. Development and other anthropogenic features subject the lower parts of the basin to periodic flooding because of overflows that propagate to one of the various flow paths. These overflows contribute to the flood hazard at areas far removed from the mainstem. In particular, much of the area known as the West Valley of South Boulder Creek (West Valley) lies along one of the historic low points and is subject to periodic flooding because of spills out of the main channel. The focus of this study is to address flooding problems in the lower portions of the basin within the City of Boulder, with a particular emphasis on the flooding problems through the area of the West Valley located within current incorporated City limits.

The project builds on the Flood Mapping Study (Mapping Study) completed by HDR Engineering, Inc. (HDR) in late 2008. That study produced floodplain maps. A Risk Assessment Report (HDR, May 2009) was also prepared that identified approximately $8.7 million dollars in annual damage from South Boulder Creek flooding and the addition of approximately 700 structures not previously identified as flood prone.

The focus of the Study is to define alternatives that address the flood problems in the West Valley, an area generally bounded by US-36 on the south, Mohawk Drive on the west, 55th Street on the east and Arapahoe Avenue on the North (Study Area). This area had been omitted from earlier flood maps prepared for the City. As such, much of the area was developed without consideration of the large flood threat from South Boulder Creek. The Study identifies drainage improvements that, in combination, provide the most beneficial means of addressing the identified flooding problems.

Planning Process

The process used to prepare the Study was designed to build a comprehensive master drainage plan using existing information, a suite of viable alternative elements and an evaluation of several alternative plans.

Existing information regarding the South Boulder Creek watershed was reviewed and stakeholders were engaged and asked to provide concerns and constraints. This information was used to develop a screening matrix to assess the effectiveness of the suite of potential solution approaches to address the identified problems. Alternatives elements that were patently infeasible, either for reasons of technical issues, cost, environmental issues, or public input were eliminated and the remaining elements were then assembled into alternative plans.

Fifteen alternative plans were developed to address the identified problems in a holistic way, recognizing the benefits of certain upstream improvements to control downstream flood threats. These alternatives included a Status Quo alternative that proposed no improvements but did include the enforcement of the City's floodplain management and development regulations. Other alternatives included various structural components that provided improved storage, collection, or conveyance of the flood flows, thereby reducing the flood threat. Sizing, alignments, and costs were determined for each of the alternatives for a variety of discharges. Benefits were estimated using information developed previously in the Risk Assessment. Other considerations important to the City, such as preservation of Open Space and habitat areas, minimizing disruption to the community or conforming to broader City Policies were included in the evaluation of the alternatives. This information allowed a direct comparison among the alternatives and provided a foundation for the selection of Best Alternative Plans.

The nine Best Alternative Plans, described in Table ES-1, represent those plans from among the studied alternative plans that were able to address the flood hazard the most effectively. In many cases, these plans were not necessarily the least costly or the ones with the fewest environmental or public issues; rather, they were the plans that provided the greatest benefit for the investment and were felt to have other issues that could be mitigated.

TABLE ES-1

Best Alternative Plans

Alternative	Description
1	Status Quo
2	High Hazard Zone containment with critical structure flood proofing
3	Regional Detention at US-36 with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch
4	Regional Detention near Hwy-93 with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch
5	Distributed Regional Detention with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch
6	Mainstem flow containment with local West Valley improvements
7	Dry Creek No. 2 Ditch pipeline
8	Bear Canyon Creek pipeline
9	Nuisance – Level Flood Improvement Protection

The evaluations conducted for these early alternatives were summarized and presented to key stakeholders representing major landowners and public infrastructure within the basin as well as the public, City Open Space and Mountain Parks Board of Trustees (OSBT), and the Water Resources Advisory Board (WRAB).

Based on recommendations from the Water Resources Advisory Board (WRAB) and Open Space and Mountain Parks (OSMP) staff, the Best Alternative Plans were reduced to five Best Alternate Plans that were to be refined based on additional interests and issues that were identified as being important in the selection and implementation of a selected alternative. The five alternatives identified for further evaluation include:

- Status Quo
- High Hazard Zone Mitigation
- Regional Detention at US-36
- Distributed Regional Detention
- Bear Canyon Creek Pipeline

The evaluation of each of the Best Alternative plans included many considerations. In addition to the financial and flood control elements implicit in the evaluation of the alternatives, the stakeholder involvement identified a number of other considerations that were assessed during the evaluation process. These issues are summarized below. Table ES-2 presents a summary of the findings of the Best Alternative Plan evaluation.

Benefit-Cost Analysis - The aggregated costs for each of the Best Alternative Plans were compared to the computed flood reduction benefits to determine a Benefit-Cost relationship for the alternative. This ratio provides a simple numeric measure of the return on investment but is not the sole basis for recommendation of a particular alternative.

Water Quality - All of the alternatives will continue to incorporate the ongoing measures already in place within the City to control impacts to water quality. In general, alternatives employing natural channels and detention storage will provide greater water quality benefits.

Natural Environment – Boulder has a longstanding tradition of protecting and enhancing natural areas. Impacts on the natural environment have been evaluated as part of this analysis and a conceptual mitigation plan was developed for the engineering recommendation. Further analysis of impacts and refinement of corresponding mitigation measures would need to be conducted during design of the flood mitigation measures. In addition, areas of high groundwater are known to exist along South Boulder Creek. A groundwater analysis would also likely be required during design of the flood mitigation measures.

Threatened and Endangered Species – The locations of threatened and endangered species consisting primarily of the orchid and the Preble's Meadow Jumping Mouse were investigated. The flood control measures proposed in the various Alternative Plans have been formulated to avoid these areas to the extent possible.

Open Space Lands - The alternatives identified in these plans were formulated to minimize the impacts to Open Space lands. However, since many of these lands fall in or near the conveyance areas of the channel, all impacts were unavoidable. The type and function of Open Space lands was considered in the layout of improvements associated with the Alternative Plans to limit physical improvements to the extent possible.

Social Impacts - Each of the projects, other than the Status Quo, has associated construction impacts that can generally be mitigated in the design and construction process. Efforts were made to minimize the potential permanent disruption to mature vegetation and existing sight lines.

The alignments identified for the various alternative plans were chosen to try to minimize the impact on private properties. Unfortunately, not all impacts to private property could be avoided. The costs for each of the plans include provisions for the purchase of easements or outright purchase of the property. The estimates are based on costs derived from the City's recent experience.

City Policies - During past studies of South Boulder Creek, the City identified guidelines that could be used as guidance in the development and evaluation of alternatives. Many of these reflect sound flood control principles while others reflect the collective interests of the community and its leadership. These issues, include avoiding channelization of South Boulder Creek, limiting the amount of private property necessary for the implementation of the alternatives, minimizing the use of large mainstem dams to control flooding, and a continued commitment to floodplain management are all incorporated to the extent possible.

TABLE ES-2

Best Alternative Plan Evaluation Summary

Alternative	Total Implementation Cost ($millions)	Present Worth of Benefits ($millions)	Benefit-to-Cost Ratio[1]	Plan Elements	Significant Considerations
Status Quo	$0.00	$0.00	0	Maintains systems and processes as they are today.	Provides no enhanced flood protection anywhere in the system.
High Hazard Mitigation	$0.14	$0.00	0	Includes grading changes to eliminate structures from the designated High Hazard Zone.	Provides no substantive enhancement to level of flood protection anywhere in the system.
Regional Detention at US-36	$46.91	$77.30	1.65	Detention pond at US-36 reduces US-36 overtopping threat and eliminates 100-year floodplain within West Valley. Local improvements in West Valley and at Arapahoe Avenue address local flood issues.	Meets defined objective of eliminating 100-year floodplain in West Valley. Some encroachment of facilities onto City-owned Open Space lands.
Distributed Regional Detention	$48.10	$75.90	1.58	Three detention ponds reduce US-36 overtopping threat to eliminate 100-year floodplain within West Valley and mitigate increased mainstem flows in channel downstream of US-36. Local improvements in West Valley and at Arapahoe Avenue address local flood issues.	Meets defined objective of eliminating 100-year floodplain in West Valley. Significant encroachment of facilities onto Open Space lands and into identified habitat areas.
Bear Canyon Creek Pipeline	$46.80	$58.00	1.24	Inlets and pipelines to capture and convey overflows from US-36. Local improvements in West Valley and at Arapahoe Avenue address local flood issues.	Generally addresses the objective of eliminating 100-year floodplain in West Valley with the exception of Apache Drive. Nominal impact to Open Space lands and identified habitat areas. Significant disruption to residential properties is expected during construction.

[1] These benefit to cost ratios were developed prior to the 2014 and 2015 refinements.

Recommended Plan

The Engineer's Recommended Plan is based on the described criteria and evaluations, and represents the Engineer's best judgment. However, the Engineer may not be aware of issues or objectives that transcend the flood control objectives defined at the project's outset. As such, the Engineer's Recommended Plan should be viewed as a starting point to help the City understand the flood control issues, objectives and solutions and to allow City decision makers to refine, revise and modify the plan as necessary to achieve the broader community interests of the project.

Based on the refined analysis of the selected Best Alternative Plans, the Regional Detention at US-36 Best Alternate Plan with Downstream Improvements was selected as the Engineer's Recommended Plan. The recommended plan includes a series of improvements to address the overtopping of US-36 and the flood concerns through the West Valley. This plan was selected because it removes approximately 411 structures and 1,721 dwelling units from the 100-year floodplain, achieving the goals set at the onset of the project. In addition, this alternative has the highest Benefit-Cost Ratio of any of the alternatives reviewed.

A review of a conceptual version of the Engineers Recommended Plan with the City of Boulder Staff, coordination with stakeholders including CDOT and Open Space and Mountain Parks (OSMP), indicated that a more in depth look at the location and design of the US-36 flood control facility was required. As a result, the US-36 detention berm was refined in early 2014 to understand the constraints, opportunities, and cost of this keystone element of the Engineers Recommended Plan. Specifically, the following items were addressed:

1. Options to minimize impacts to OSMP property
2. Ensure the flood control facility was compatible with the CDOT Phase I and Ultimate conditions construction plans for US-36
3. Understand and provide a conceptual mitigation plan for environmental impacts
4. Review geotechnical requirements for the site
5. Understand requirements for design and construction related to the Colorado State Engineers Office (SEO)
6. Refine the cost / benefit analysis to reflect refinements

A staff recommendation was presented in August 2014 to both WRAB and the OSBT and to City Council at a Study Session. The recommended plan included moving forward with regional detention at US-36 with downstream improvements, with the following phases:

I. A regional stormwater detention facility at US-36;

II. West Valley improvements including a stormwater detention facility at or near Manhattan Middle School, a small stormwater detention storage area at the intersection of Foothills Parkway and Baseline Road, and enlarging the capacity of Dry Creek No. 2 Ditch; and,

III. A stormwater detention facility located at Flatirons Golf Course.

Both Boards made motions to recommend that City Council accept the second and third phases of the recommended plan but did not support the Phase I regional detention concept without first evaluating other options to reduce impacts on OSMP property and other environmental impacts. In response to the direction given by council, six new options for detention at US-36 have been developed. The options include variations of single and dual berm detention systems. From a technical aspect, all options function to effectively mitigate flooding from South Boulder Creek in the same capacity. All of the options would eliminate overtopping of US-36 and subsequent flooding in the West Valley during a 100-year FEMA theoretical design storm (short duration flash flood event) and all of the options reduce impacts to environmental resources and to Open Space compared to the 2014 recommended plan. It should be noted that a longer duration storm might result in greater stormwater volumes that could exceed the capacity of the detention facility.

Three options have been developed that modify the single berm system presented in 2014. These options vary in the degree of fill and excavation. It should be noted that only the 2014 option would impact federally designated Preble's Meadow Jumping Mouse (PMJM) critical habitat along South Boulder Creek. However, all other options would impact habitat occupied by PMJM with the exception of the recommended option (impacts to PMJM habitat from this option have already been mitigated by CDOT).

Three dual berm options have been developed that also include varying degrees of fill and excavation. The dual berm detention system would require breaching the existing CU South levee and constructing an open channel segment within the CU South parcel. City staff has concerns with these options because debris could block the breach in the levee, which would then prevent water from reaching the secondary detention basin.

City staff recommends moving forward with the single berm on CDOT ROW and CU South Campus property as the concept for providing regional stormwater detention to prevent floodwaters from overtopping of US-36 during a 100-year design storm. This alternative, estimated to cost $22 million to construct, is expected to have minimal direct impact to OSMP lands and environmental resources from berm construction. The remaining options for US-36 regional detention are not being recommended at this time, as they all have similar or greater berm and associated environmental impacts to OSMP lands. All other options, except for the option presented in 2014, have a greater impact on CU's property. Additionally, all of the dual berm options carry a higher cost and a lower benefit to cost (B/C) ratio than the single-berm options (the recommended option has a B/C ratio of 1.2).

CDOT representatives have stated that should the ultimate US-36 configuration be constructed, additional lanes could be built on the north side of the existing highway and within their existing ROW. This would eliminate the need to remove and replace the path a second time, and would leave the berm unaffected. CDOT has also indicated in writing that they are agreeable to the city's request to consider developing an agreement to use a portion of the US-36 Phase 2 Bikeway located within CDOT ROW to function as a berm. CU staff has stated they are willing to consider use of a portion of the CU South Campus for flood mitigation, with the understanding that significant further analysis is required in order to assess the full impacts to their property.

The recommendations for downstream improvements did not change from 2014 and include Improvements in the West Valley and Stormwater Detention at Flatirons Golf Course.

Recommended Plan Elements

The following section presents the elements of the Engineers Recommended Plan. The Engineers Recommended plan is depicted in Figure ES-1, Engineers Recommended Plan.

US-36 Stormwater Detention Facility

The selected US-36 detention pond alignment and configuration is the ***US-36 Zoned Earthen Berm combined with the US-36 Ultimate Conditions ROW.*** The US-36 Detention facility provides 100-year protection from the overtopping flows of South Boulder Creek to downstream properties in the West Valley. The alternative combines excavation and fill to produce a configuration that minimizes the impacts to Open Space land and the University of Colorado (CU) South Campus and to minimize the potential visual impact by integrating the detention berm into existing Foothills Parkway overpass berm that is outside both the Ultimate Conditions ROW and the Phase 1 ROW. The recommended option would modify the multi-use path that CDOT is currently constructing within land it owns. CDOT has already mitigated for environmental impacts for use of this land and therefore staff anticipates little or no additional mitigation would be required. The multi-use path would need to be modified including constructing walls and raising the path to a maximum height of 9' above US-36 (it is currently being constructed at grade to approximately 2' lower than the highway). Conceptually the path and berm could fit within the existing CDOT ROW and CU South Campus. Future design would confirm this assumption and identify any possible temporary impacts that would need to be mitigated during construction.

Arapahoe Avenue Detention

The detention pond and associated outfall structures at Arapahoe Avenue take advantage of the Flatirons Golf Course to provide 58 AF of storage that reduces the impact to downstream industrial and commercial properties. This facility also helps to collect shallow floodwaters that overtop Arapahoe Avenue from the main stem of South Boulder Creek and the West Valley and convey them through two outlet channels below Arapahoe Avenue. The proposed west outfall will discharge flows to an existing flood channel that has adequate capacity while the east flood channel will require the construction of an outfall conveyance to return water to the South Boulder Creek mainstem. Both of these outfalls will

work in tandem with the detention to store and attenuate flows helping to alleviate flooding issues downstream of Arapahoe Avenue. There are some unavoidable impacts to City regulated wetlands that will require mitigation and the alternative requires the acquisition of some private property.

Improvements in the West Valley

Although the proposed detention at US-36 would eliminate the overtopping of US-36, flood mitigation measures are required within the West Valley. Recommended improvements in the West Valley are either in the form of small detention facilities that are used to capture and attenuate flows or improvements to existing conveyance infrastructure. These facilities and/or upgrades are required to convey the detained stormwater from the US-36 detention facility and to accommodate stormwater flows originating from the surrounding area (local basin contributions). The recommended improvements include:

- 25 AF of detention at or near Manhattan Middle School to capture locally generated flows that can be discharged to the existing downstream infrastructure minimizing additional downstream system improvements.
- 9 AF of detention at the intersection of Foothills Parkway and Baseline Road to collect flood flows at this intersection and discharge them to the channel parallel to Baseline Road, taking advantage of the capacity of the downstream system.
- 2 foot Extension of the concrete retaining wall of along Baseline Road east of Foothills Parkway to increase the conveyance capacity of the channel and thereby preventing overflow from entering the lower West Valley.
- Conveyance improvements to the New Anderson Ditch to prevent overflows from entering the West Valley and to convey additional flow that results from the increased hydraulic head generated by the storage above US-36.
- A turnout structure for the Wellman Canal, east of Foothills Parkway to allow flood flows from Bear Canyon Creek that enter the Wellman canal to be discharged back into the Bear Canyon Creek historic channel. This improvement is required to help eliminate flood flows overtopping the Wellman Canal from causing additional flood hazards through the West Valley.
- Increase the conveyance capacity of Dry Creek No. 2 Ditch channel in order to convey 420 cfs of flows down the Dry Creek No. 2 Ditch corridor.

Recommended Phasing

Phasing of the elements of the Recommended Plan provides an opportunity to distribute the cost of implementation over a longer time and allows the community to realize benefits from the individual aspects of the improvements without full plan implementation. The elements of the Recommended Plan do allow for a phased implementation. The discussion below summarizes a possible phasing approach. It should be noted that the estimated benefit to cost ratios presented are based on the phasing presented below. The benefit to cost ratio would need to be recalculated if a different phasing scenario is selected.

Priority 1 – US-36 detention:

US-36 Detention is the recommended first element to be implemented. This project element fulfils an important purpose of the project (reduce the flood hazard due to US-36 overtopping in the West Valley) without the need for extensive further investment. In doing so, the flood insurance burden associated with the South Boulder Creek 100-year flood for those properties in the West Valley is reduced and the residual flood threat in the West Valley is limited to flows generated from local storm basin contributions in the West Valley and flows discharged from the proposed US-36 Detention outfalls. The proposed US-36 Detention facility has a benefit-cost ratio of approximately 1.2 and an approximate capital cost of $22 million. Implementation of Phase I would result in an estimated 199 structures and 1,273 dwelling units to no longer be located within the 100-year floodplain.

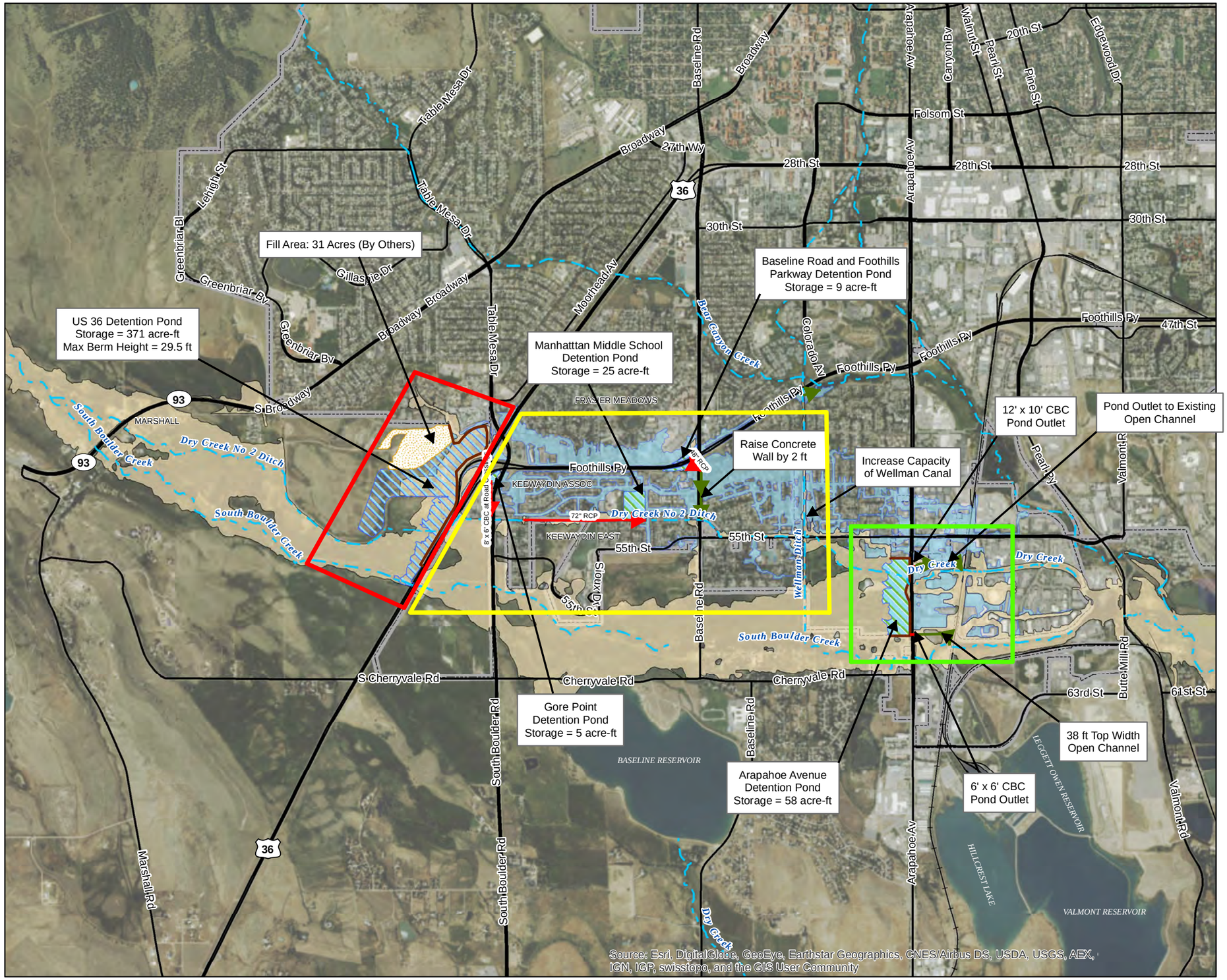
Priority 2 – Local West Valley Improvements

The improvements proposed in the West Valley address a number of different flood-related issues and are comprised of several smaller elements. These include local detention at Manhattan Middle School, Dry Creek No. 2 Ditch pipeline improvements, local detention at Baseline Road and Foothills Parkway, floodwall improvements along Baseline Road, improvements to the New Anderson Ditch and improvements to the Wellman Canal. The improvements to the other irrigation ditches are intended to prevent overflows and contain those flows in the original system. The West Valley Improvements can be constructed independently of any other improvements. In aggregate, these improvements are expected to cost $11.0 million to implement and result in a benefit-cost ratio of 3.2. Implementation of Phase II would result in an estimated 134 structures and 386 dwelling units to be removed from the 100-year floodplain.

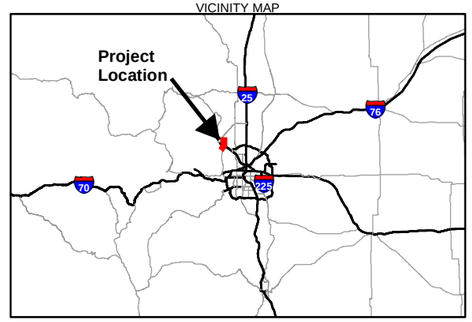
Priority 3 – Arapahoe Avenue Detention

The Arapahoe Avenue detention pond and associated downstream improvements provide considerable flood relief to those properties below Arapahoe Avenue however; the floodplain reduction associated with these improvements is localized making this the last of the suggested implementation priorities. The improvements are estimated to cost $11.9 million and result in a benefit-cost ratio of 1.3. Implementation of Phase III would result in an estimated 42 structures and 6 dwelling units to be removed from the 100-year floodplain.

It should be noted that the City's Community Environmental Assessment Process (CEAP) for recommended Phases II and III might change the priority and sequencing of these phases. Implementation of the entire project would result in an estimated 411 structures and 1,721 dwelling units to be removed from the 100-year floodplain.



VICINITY MAP



LEGEND

Conveyance Alignment

Category

- Open Channel Improvement
- Pipeline/Culvert Improvement
- US-36_Embankment
- Area of Fill (By Others)
- Streams, Creeks and Ditches
- Detention at US-36
- Local Detention
- Post Project Floodplain
- Existing Floodplain

Notes:

1. Phase 1 Improvements
   US-36 Detention
   B/C Ratio = 1.2
2. Phase 2 Improvements
   West Valley Improvements
   B/C Ratio = 3.2
3. Phase 3 Improvements
   Arapahoe Avenue Detention
   B/C Ratio = 1.3

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Figure ES-1
Engineers reccomended Plan
Detention At US-36

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I. Introduction

The purpose of this report is to present the findings of the Major Drainageway Planning Study for South Boulder Creek. South Boulder Creek is a major drainageway that conveys stormwater runoff from Eldorado Canyon west of Boulder through the eastern portions of Boulder. The drainageway passes through areas outside the city limits within Boulder County. The focus of this study is to address flooding problems in the lower portions of the basin within the Boulder city limits, with a particular emphasis on the flooding problems through the area of the basin known as the West Valley.

Authorization

This Major Drainageway Planning Study was prepared as part of the *South Boulder Creek Flood Mitigation Study* (Study) authorized by the City of Boulder (Boulder) through a Purchase Order on December 23, 2009. The Urban Drainage and Flood Control District (District) was a financial participant in the project and provided oversight during the project execution. The Agreement authorizes CH2M HILL to develop a mitigation plan to address flooding along South Boulder Creek.

Purpose and Scope

The scope of the project builds on the Flood Mapping Study (Mapping Study) completed by HDR Engineering, Inc. (HDR) in late 2008. That project had a carefully developed scope that focused on the identification of flood issues along South Boulder Creek. Two important reports were developed during the Mapping Study, a *Climatology/Hydrology Report* (HDR, February 6, 2007) and a *Hydraulic Modeling Report* (HDR, December 30, 2008), both of which are important foundations for the development of the floodplain maps that were the ultimate product of the Mapping Study. In addition to the Mapping Study, HDR produced a *Risk Assessment Report* (HDR, May 2009) that assessed the flood risk caused by South Boulder Creek. This analysis identified approximately $8.7 million dollars average annual damage from South Boulder Creek flooding for all return periods studied and the addition of approximately 240 structures not previously identified as flood prone for a total of 700 individual structures located within the 100-year floodplain. This Study builds on the previous effort, identifies, and evaluates a number of alternatives to address the flood problems.

The focus of the Study is to define an alternative that will address the flood problems in the area known as the West Valley of South Boulder Creek (West Valley). This area is generally bounded by US-36 on the south, Mohawk Drive on the west, 55th Street on the east and Arapahoe Avenue on the North (Study Area). This area is the focus of the study because earlier studies did not identify a flood threat. As such, much of the area was developed without consideration of the large flood threat from South Boulder Creek. The Study identifies drainage improvements that, in combination, provide the most beneficial means of addressing the identified flooding problems. In some cases, the improvements identified provide benefits that extend beyond the limits of the West Valley and provide a broader benefit to other properties impacted by South Boulder Creek.

Planning Process

The process used to prepare the Study is to build a comprehensive master drainage plan using existing information, a suite of viable alternative elements, and an evaluation of several alternative plans. Engineering, economic, and public interest evaluations were then considered before arriving at a recommended plan.

The planning process began with a careful review of the large body of existing information available regarding the South Boulder Creek watershed. Stakeholders were engaged and asked to provide concerns and constraints that they believed should be incorporated into the Study. This information provided a strong foundation of understanding of the flood hazard and its source. It also helped establish basic objectives against which all alternatives would be measured.

A screening matrix was developed that was used to assess the effectiveness of a suite of potential solution approaches to address the identified problems. This screening matrix was used to eliminate from further consideration the alternatives that were patently infeasible, either for reasons of technical issues, cost, environmental issues, or public input. The alternative elements that remained after the screening process were then assembled into alternative plans.

The alternative plans were built based on the screening process. The assembled elements were intended to address the identified problems in a holistic way, realizing the benefits of certain upstream improvements to control downstream flood threats. Sizing, alignments, and costs were determined for each of the alternatives for a variety of discharges.

Benefits were estimated using information developed previously in the *Risk Assessment Report* (HDR, May 2009). This information provided a foundation for the comparison of the various alternatives and the selection of Best Alternative Plans.

The Best Alternative Plans represent those plans from among the studied alternative plans that were able to address the flood hazard the most effectively. In many cases, these plans were not necessarily the least costly or the ones with the fewest environmental or public issues; rather, they were the plans that provided the greatest benefit for the investment and were felt to have other issues that could be mitigated. These plans were refined to reflect a more detailed investigation of size, alignment, cost, and potential mitigation requirements. Detailed hydraulic simulations were performed to generate a more refined estimate of the potential benefits associated with the various plans.

Using this information, a Recommended Plan (Plan) was identified. This Plan represents the plan that was deemed the most appropriate approach for the city to address the flood threat, particularly in the West Valley. The plan does not address every problem but does provide significant benefit relative to the estimated investment.

Public input was solicited and considered at each major step along the way. Key stakeholders representing major landowners and public infrastructure within the basin as well as Water Resources Advisory Board (WRAB) representatives were involved in periodic workshops that were used to review the various evaluation steps and support the selection of alternatives for future consideration.

In addition to the input from the city and Stakeholders, two public meetings were conducted to gather input and better understand the interests of the community. During the first public meeting, conducted on March 3, 2010 and attended by approximately 50 people, problem areas were identified and potential solutions were brought forward by members of the public. These comments generally identified areas where recurring flood problems had been observed and potential solutions that should be considered in the alternative development phase. The areas of concern and the potential solutions were both considered in the Study. A detailed summary of the first public meeting can be found in Appendix A.

The second public meeting was held on September 2, 2010. Staff presented a summary of the study progress to date and presented eight conceptual alternatives for public comment. Alternatives ranged from maintaining the status quo, constructing improvements to mitigate nuisance-flooding, protection of High Hazard Zone structures and critical facilities to constructing improvements to provide 100-year flood protection. Concept-level costs along with estimated benefits for each alternative were presented but it was emphasized that none of the alternatives have been ranked and no one alternative is currently recommended. One hundred seven (107) members of the public attended the meeting and 63 comment sheets were submitted. As a recommendation from this public meeting, a ninth alternative was introduced to include detention along the South Boulder Creek Mainstem from US-36 to Baseline Road. This alternative was proposed to prevent the impacts to private property at Highway 93 and at the Cu South Campus. A summary of this meeting with attached comment sheets can be found in Appendix A.

After the second public meeting and subsequent creation and refinement of the ninth alternative, identified in the second public meeting the first of Two WRAB meetings was conducted. At this meeting, the nine alternatives were presented to WRAB. After public comment and feedback from staff at the City of Boulder, WRAB recommended that four alternatives be moved forward for additional refinement before returning to WRAB with an Engineers recommended plan. The four alternatives selected for further refinement include:

- Status Quo Alternative
- High Hazard Mitigation and Flood Proofing
- Regional Detention at US-36
- Distributed Regional Detention

Upon the recommendations of OSMP a fifth alternative was added for additional refinement. This alternative is:

- Bear Canyon Creek Pipeline

OSMP wanted this alternative carried forward because it had the least impact to open space lands.

In response to public review and recommendations from WRAB, OSMP and city staff , the five alternatives carried forward for analysis by WRAB were further refined. This refinement called for a more detailed evaluation so the elements of the plans could be refined with greater resolution and the plans could be more clearly communicated to the public. The refinements to the five alternatives included a more detailed engineering evaluation to better define the characteristics of the plan elements including conceptual grading and layout, the associated costs, and proposals for the most logical implementation sequence.

Upon the completion of the analysis, the alternatives were ranked and phased and an Engineers Recommended Plan was developed to carry forward to WRAB in August 2014 for approval. The Engineers Recommended Plan was the Regional Detention at US-36 with Downstream Improvments After discussion by the WRAB, the West Valley Improvements and the Arapahoe detention elements of the Engineers Plan were met favorably and the WRAB gave staff the direction to continue working with Open Space and Mountain Parks, CU and CDOT to look at alternatives and environmental issues related to the US-36 stormwater detention facility to minimize or eliminate environmental impacts to OSMP property.

The refined alternatives and alignment analyses for the US-36 alignment was completed in early 2015 and the results of those refinements produced a recommended berm alternative that eliminated permanent impact s to OSMP property. Staff presented the refined analysis to WRAB and the OSBT in early 2015, including the recommended alternative. Both Boards motioned to recommend City Council accept the South Boulder Creek Flood Mitigation Major Drainageway Master Plan including all components of the recommended mitigation plan.

The US-36 Regional Detention at US-36 preferred alternative and WRAB recommendations will be going to the Boulder City Council in August 2015 for consideration.

Mapping

The mapping used in this study builds on the mapping developed as part of the Flood Mapping Study. One foot contour interval mapping surveyed in the North American Vertical Datum of 1988 (NAVD88) and the North American Datum of 1983 (NAD83) Colorado State Plane North Coordinates was developed in 2003 by Merrick and Company. Field surveys of major structures such as bridges and large culverts were provided by Merrick as part of the Mapping Study and were used in this work. Denver Regional Council of Governments (DRCOG) aerial photographs acquired in 2008 were used for this planning study.

Data Collection

Project data used for this study was provided by a number of different sources. Most of the data was obtained from the city's GIS databases and proved very useful in identifying constraints. Much of the city's data related to environmental overlays such as wetlands, Open Space, and habitat areas. Similar data was obtained from Boulder County's (County) GIS database and supported the understanding of environmental conditions and constraints on County lands. The city's GIS databases were also used to obtain information related to the city's infrastructure as well as to update the property information used to estimate the financial implications of floods.

Other project stakeholders also provided information that was used in the formulation and evaluation of the various plans and plan elements. In particular, several past studies were reviewed as part of the flood Mapping Study. While some of these provided important background for the Flood Mapping Study, their application was limited for this project. However, the South Boulder Creek Major Drainageway Planning Phase A Report, (Taggert, 2001) completed by Taggert Engineering Associates (Taggert) in 2001 for the District provided important historical context for a better understanding of past planning efforts. Similarly, the US Army Corps of Engineers' (USACE) Reconnaissance Study, Flood Risk Management and Ecosystem Restoration Study (USACE, January 2010), provided some background on potential alternatives to address flooding along South Boulder Creek's mainstem and through the West Valley. Colorado Department of Transportation's (CDOT) US-36 Corridor Final Environmental Impact Statement/Final Section 4(f) Evaluation (EIS) (CDOT, October 2009), information related to the University of Colorado (CU) South campus planning efforts (South Campus Plan) were also provided and reviewed. A summary of data collected is given in Table 1-1, List of Gathered Data.

The collected data and information was used to understand the constraints that influence potential alternatives. In addition to the information described above that the city and the other Stakeholders provided, several meetings, primarily in the form of workshops, were conducted during which considerable discussion took place that was helpful in formulating plans and directing the project. These meetings proved to be invaluable in better understanding the information already collected and in securing additional information that supplemented the publically available information. Detailed summaries of these meetings are included in Appendix A. Several individual meetings were also held where project team members met with stakeholders to clarify and enhance the information provided.

In response to feedback received about one of the alternatives (a flood detention alternative that used private property near Hwy-93), staff was directed to develop and evaluate a ninth alternative for a flood detention facility that uses city Open Space property or private property with owners willing to sell.

TABLE 1-1
List of Gathered Data

Name	Author
South Boulder Creek Climatology/Hydrology Report February 2007	HDR Engineering, Inc.
South Boulder Creek Hydraulics Report 2008	HDR Engineering, Inc.
South Boulder Creek Risk Assessment 2009	HDR Engineering, Inc.
City of Boulder Stormwater Master Plan 2007	HDR Engineering, Inc.
1' Interval Topographic Map 2003	Merrick and Company
Structure Field Surveys 2003	Merrick and Company
Aerial Photography 2008	DRCOG
City of Boulder Greenways master Plan 2001	City of Boulder
City of Boulder Wetlands Maps	City of Boulder , GIS Mapping Services
City of Boulder Habitat Areas	City of Boulder , GIS Mapping Services
Critical Facilities	City of Boulder , GIS Mapping Services
Storm and Sanitary Sewer System Maps	City of Boulder , GIS Mapping Services
Boulder County Wetlands Maps	Boulder County , Geographic Information Services
Boulder County Habitat Areas	Boulder County , Geographic Information Services
Preble's Meadow Jumping Mouse Critical Habitat	Boulder County, Land Use Department
Cost Estimator for Master Planning 2010	Urban Drainage and Flood Control District
FEMA Benefit-Cost Analysis Software Version 4.5	Federal Emergency Management Agency
South Boulder Creek Phase A 2001	Taggert Engineering Inc.
South Boulder Reconnaissance Study 2010	USACE
US-36 Corridor EIS 2009	CDOT
South Campus Conceptual Master Plan	CU – Facilities Management

Planning Context, Laws, Regulations and Criteria

Other plans, laws, regulations, and criteria that governed the development of the proposed alternatives included the following:

- *Boulder Valley Comprehensive Plan*
- *Boulder Revised Code*
- *Comprehensive Flood and Stormwater Master Plan- 2004*
- *Urban Drainage and Flood Control District (UDFCD) Urban Stormwater Drainage Criteria Manual (USDCM) (Volumes 1, 2, and 3),*
- *City of Boulder Comprehensive Flood and Stormwater Master Plan*
- *City of Boulder Design and Construction Standards*
- *City of Boulder Open Space and Mountain Parks Regulations*

South Boulder Creek and the riparian areas adjacent to the stream have been identified as having a number of wetland areas, many of which have been determined to be high functional. Work in these areas must be done in accordance with the city's Stream, Wetland, and Water Body Protection Ordinance. Any work done along drainages that result in fill being placed below the Ordinary High Water Mark (OHWM) is required to be permitted by the United States Army Corps of Engineers (USACE) under Section 404 of the Clean Water Act. Any impacts to threatened and endangered species are governed by requirements from the U.S. Fish and Wildlife Service (USFWS), the Colorado Division of Wildlife (CDOW) and city.

Finally, one of the Boulder Valley Comprehensive Plan (BVCP) general policies states that the City of Boulder is committed to the preservation of Open Space and the use of Open Space buffers to define the community. Lands owned by the City of Boulder Open Space and Mountain Parks (OSMP) include restrictions and requirements for improvements that will need to be carefully considered and incorporated in the alternatives analysis and conceptual design.

Acknowledgements

This Study was completed with support and input from a variety of city staff representing many different city departments and public and private stakeholders, including the District, CU, CDOT, and USACE. In addition, WRAB was represented throughout the project. Many of the key participants are shown in Table 1-2, Project Contributors.

TABLE 1-2
Project Contributors

Project Team Members	Affiliation	*Role*
Kurt Bauer	City	*Project Manager*
Bob Harberg	City	*Project Coordinator*
Jeff Arthur	City	*Director of Public Works for Utilities*
Ned Williams	City	*Former Director of Public Works for Utilities*
Annie Noble	City	*Greenways Coordinator*
Don D'Amico	City	*Open Space Representative*
Chuck Howe	City	*WRAB Representative*
Shea Thomas	District	*Project Sponsor*
Ken MacKenzie	District	*Project Sponsor*
Dave Webster	Boulder County	*Boulder County Floodplain Administrator*
Jeff Lipton	CU	*Stakeholder*
Steve Griffin	CDOT	*Stakeholder*
Bob Hays	CDOT	*Stakeholder*
Kayla Eckert Uptmor	USACE	*Stakeholder*
Mark Nelson	USACE	*Stakeholder*
Chris Fassero	USACE	*Stakeholder*
Mark Glidden	CH2M HILL	*Project Manager*
Alan Turner	CH2M HILL	*Assistant Project Manager*
Aaron Cook	CH2M HILL	*Staff Engineer*
Alan Taylor	Alan Taylor Consulting	*Sub-Consultant*
Eric Fontenot	DHI	*Sub-Consultant*
Mark Taylor	Architerra Group	*Sub-Consultant*

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II. Study Area Description

Study Area

The South Boulder Creek basin is located in southern Boulder County and crosses the southern and eastern edges of the City of Boulder. The watershed covers approximately 136 square miles, starting at the Continental Divide, and extends over 27 miles to the confluence with Boulder Creek. Gross Reservoir lies in the basin and collects runoff from the upper 90 square miles. The basin below Gross Reservoir does not contain a similar major control structure but is crossed by several roadway corridors and numerous active irrigation canals that affect the flow patterns in the basin. Figure 2-1, Basin Delineation, depicts the watershed and the Study Area.

The basin flows out of the mountains and foothills near Eldorado Springs and enters a broad alluvial valley. Here flows work their way to the north to the confluence with Boulder Creek. The channel has followed several historic flow paths before reaching its current alignment. Development and other anthropogenic features have resulted in less channel migration but have subjected the lower parts of the basin to periodic flooding because of overflows that propagate to one of the historic flow paths. These overflows contribute to the flood hazard at areas far removed from the mainstem. These areas are generally in the lower parts of the watershed and extend across much of the alluvial valley below US-36. In particular, much of the area known as the West Valley lies along one of the historic low points and is subject to periodic flooding because of spills out of the main channel.

South Boulder Creek lies adjacent to Bear Canyon Creek and is often impacted by overflows from that basin. Undersized infrastructure along Bear Canyon Creek results in flows spilling out of the channel and flowing along other flow paths to join South Boulder Creek. These flows, while not native to South Boulder Creek, do cause impacts.

After the completion of the Flood Mapping study by HDR and subsequent delineation of the revised floodplain boundaries for South Boulder Creek, many additional residences were identified as being located within the Special Flood Hazard Area (SFHA). The delineation of the South Boulder Creek Floodplain indicated that over 1,200 dwelling units (700 structures) along South Boulder Creek were being inundated by the revised 100-year flood plain. Currently there are approximately 460 identified structures in the existing 100-year floodplain (approximately 500 dwelling units). The South Boulder Creek Flood Study identified approximately 240 additional structures that were previously unidentified as being within the 100-year floodplain. Figure 2-2, Revised Regulatory Floodplain, depicts the 100-year revised floodplain for South Boulder Creek and includes the structures impacted by the revised floodplain.

The Mitigation Study focuses on the watershed below Hwy-93 within the city limits and, in particular, the areas subjected to flooding through the West Valley.

Land Use

The upper parts of the South Boulder Creek basin are undeveloped and relatively rugged. Rocky outcrops, trees, and forest vegetation dominate the watershed above Gross Reservoir. In fact, the area below Gross Reservoir but above Eldorado Springs has similar characteristics.

Once below Eldorado Springs, the character of the watershed changes dramatically. Either large tracts of Open Space exist, in the form of agricultural lands or city owned Open Space, some of which is being leased for agricultural purposes. There are also areas of very low-density residential development.

Highway 93 marks a shift from agricultural and Open Space to more traditional urban development. The segment between Highway 93 and US-36 is transitional with large areas of Open Space along the channel, more dense residential developments along the floodplain fringe and the University of Colorado South Campus immediately adjacent to US-36. The channel has been generally left undisturbed but the overbanks exhibit the effects of past development.

Downstream of US-36, the floodplain is almost fully covered with residential properties or designated Open Space areas. The residential areas, with minor pockets of commercial and industrial development, are generally along the western portion of the floodplain and include the West Valley. This area has formal drainage conveyance via storm drain systems that are sized to convey local “nuisance” flows with major flood flows being conveyed along streets and irrigation canals such as the Dry Creek No. 2 Ditch.

The areas adjacent to the mainstem of Boulder Creek have a much lower level of development and are dominated by publically owned Open Space lands. A few enclaves of development, largely in unincorporated areas of Boulder County, encroach into the mainstem floodplain.

There is a shift from residential to commercial and industrial development near Arapahoe Avenue. Immediately upstream of Arapahoe Avenue is the Flatirons Golf Course and adjacent residential developments. On the downstream side (north) is an area of commercial and industrial development that extends across much of the floodplain and down to the confluence with Boulder Creek almost a mile downstream.

The city and county have both made significant investments in acquisition of Open Space lands and the development of an extensive network of trails and other recreational facilities. While representing a small fraction of the overall lower basin area, these Open Space lands do dominate the floodplain near the mainstem.

Figure 2-3, Lower Basin Land Use, depicts the lands uses across the floodplain of South Boulder Creek through the Study Area.

Reach Descriptions

The Study Area has been subdivided into several reaches representing differing flood hazards and land use conditions. Figure 2-4, Reach Designation, shows these various reaches in the Study Area.

Reach 1

The mainstem channel between Highway 93 and US-36 is designated Reach M1. The overbanks of the floodplain are largely undeveloped with the exception of a small trailer park adjacent to Marshall Road downstream of Highway 93 and several single family homes around Marshall Road. Much of the land along this reach has been designated as Open Space. In the area immediately upstream of US-36, the University of Colorado has a large parcel of land designated as the South Campus. The area sits on the reclaimed site of a former gravel mining operation and is protected from the mainstem by a currently Provisionally Accredited Levee (PAL).

In addition, several threatened and endanger species have been identified on land south of US-36. These include an important occurrence of the federally threatened plant species, *Spiranthes diluvialis* or Ute lady's tresses orchid; an important population of the federally threatened animal species, Preble’s Meadow Jumping Mouse (PMJM); a population of an amphibian under status review by the U.S. Fish and Wildlife Service for listing as a federally threatened species, Northern Leopard Frog; a population of two native fish species believed in decline in Colorado, Plains Topminnow and Orange-Spotted Sunfish; and a population of a declining grassland nesting bird, Boblink.

Finally, one of the Boulder Valley Comprehensive Plan (BVCP) general policies states that the City of Boulder’s commitment to the preservation of Open Space and the use of Open Space buffers to define the community. Lands south of US-36 include lands with high ecological resources and land owned by the City of Boulder OSMP. These properties include an important remnant of the plains cottonwood riparian ecosystem; relicts of the tall grass prairie ecosystem; and wetlands that are considered to be among the best preserved and most ecologically significant in Boulder Valley. Careful design and restoration would be required to minimize environmental impacts and mitigate for impacts should an alternative that would affect these resources be selected.

Reach 2

Below US-36, three parallel alignments convey flow to the confluence with Boulder Creek. These three alignments are acknowledged in the reach designation. Reach WV2 represents the West Valley flows from US-36 to Baseline Road. This area is generally west of Foothills Parkway and is characterized by flow down existing residential streets. The primary conveyance is Thunderbird Drive where flow collects and is conveyed to the north. Numerous residential properties, both single and multifamily are subject to flooding because of flows in Reach WV2.

Reach DC2 is centered on the Dry Creek No. 2 Ditch. This represents one of the historic flow paths and serves as both a collection for, and a source of, flooding in the area. The reach consists of both open channel sections, closed conduits, and crosses several roadways, including South Boulder Road and Tenino Avenue. Flooding along this reach is primarily to single family residential structures and is caused by both mainstem South Boulder Creek flooding as well as overflows from Dry Creek No. 2 Ditch during more frequent local floods

The final alignment is the Mainstem, Reach M2. This reach is largely natural with a well-defined main channel and a broad undeveloped overbank area. A crossing of South Boulder Road and the South Boulder Community Center are the only two material improvements along this reach. The floodplain, while broad through this area, has little impact on developed properties.

Reach 3

The area between Baseline Road and the Wellman Canal (approximately Colorado Avenue extended) also has three relatively distinct alignments. West Valley Reach 3 (WV3) crosses Foothills Parkway and Baseline Road near that intersection and flows to the north along McIntyre Street and Brooklawn Drive. There is limited flood conveyance infrastructure and the majority of the flow is conveyed on the surface of the street system. Structures along this reach are primarily single family residential.

Reach DC3 follows the alignment of Dry Creek No. 2 Ditch through residential areas, eventually reaching Arapahoe Avenue to the north. The conveyance through this reach is primarily through an open channel with large culverts at major crossings such as 55th Street. Once again, the flood threat to the adjacent properties comes from both South Boulder Creek flows and local runoff captured and conveyed that exceed the available capacity in the ditch and local storm drain system.

The channel through reach M3 is natural and areas of Open Space lands lie to the west of the main channel and provide considerable overbank conveyance. However, the area immediately to the east of the mainstem consists of residential structures along Gaptor Road that are subject to periodic flooding from even relatively small events with residences experiencing flooding during 10-year storm events. Anecdotal evidence from residents of the area has indicated that damage from the 1969 flood occurred from both channel flooding and groundwater flooding. The South Boulder Creek channel through this area has a very limited capacity with homes located against the banks.

Reach 4

The channel between the Wellman Canal (approximately Colorado Avenue extended) and Arapahoe Avenue comprises Reach 4. In this reach, the three conveyance paths remain, but they tend to be less distinct and flooding from one path has a tendency to affect the others.

Reach WV4 extends to the north and east, eventually reaching Eisenhower Drive and Arapahoe Avenue. Once again, there is limited infrastructure to convey flood flows, so they flow on the surface of the street and across grassed areas. The southern portion of the reach is dominated by single-family residential properties while those areas closer to Arapahoe Avenue are generally multifamily.

Reach DC4 follows 55th Street north to Centennial Trail and then extends northwest across Flatirons Golf Course to Arapahoe Avenue just west of the entrance to the golf course property.

Flows in the mainstem, Reach M4, travel north following an alignment parallel to the eastern boundary of the golf course but between Old Tale Road and Cherryvale Road. Much of the flood hazard is contained within the golf course but properties along both Old Tale Road and Cherryvale Road are subject to periodic flooding from the 100-year flood event.

Reach 5

Below Arapahoe, the West Valley Reach (WV5) extends north through commercial and industrial properties and joins Boulder Creek considerably upstream of the confluence of the South Boulder Creek mainstem with Boulder Creek. These flows follow an undersized conveyance, and are largely conveyed across the surface of the ground on streets, and paved parking areas.

Reach DC5 is a well-defined channel with mature vegetation that crosses the railroad track and several local roads along the western boundary of Flatirons Industrial Park before joining the mainstem of South Boulder Creek at the north end of the Flatirons Industrial Park.

The mainstem of South Boulder Creek (Reach M5) crosses under the railroad track and then follows the west boundary of Flatirons Industrial Park before extending to the north under Valmont Road and then joining the floodplain of Boulder Creek. This channel is very well defined and has mature vegetation along the invert.

Flood History

Flooding along South Boulder Creek has not been common over the last 100 years. However, the floods that have occurred were widespread and had significant impacts ranging from structure damage in Eldorado Springs to residential flooding and roadway overtopping in the city and the West Valley. The three events that appear to have caused the most disruption occurred in 1938, in the 1950s, 1969 and again in 2013. Each has been attributed to a different source.

The 1938 flood generated the highest recorded peak flow at the Eldorado Springs Stream gage. The HDR *Climatology/Hydrology Report (HDR, February 6, 2007)* characterized this storm as one with subtropical origins. This flood was the result of an estimated 5 – 7 inches of rainfall over a 6-hour period. The resulting flood caused great damage in Eldorado Springs and resulted in flooding that damaged several bridges downstream through Boulder.

The floods in the 1950s were described by Taggert in the *South Boulder Creek Major Drainageway Planning Phase A Report*. In that characterization, it was noted that no major flood events were recorded at the Eldorado Springs Stream gage, but that the West Valley experienced floods on numerous occasions. These floods were attributed to development in the lower basin and the impacts from the resulting flow increases on existing drainage infrastructure, including irrigation ditches serving as drainage channels. Large flows that overwhelmed drainage facilities on Bear Canyon Creek had similar impacts and caused localized flooding.

In 1969, a flood resulting from what the HDR *Climatology/Hydrology Report (HDR, February 6, 2007)* described as a long duration, low intensity general rain. This storm was widespread across the basin and resulting in up to 13 inches of rain over 72 hours. Flood flows at US-36 backed up and eventually overtopped the highway, spreading into the West Valley. Taggert, in the *South Boulder Creek Major Drainageway Planning Phase A Report* indicated that local drainage from many of the local tributaries to South Boulder Creek was likely to have contributed to the overflow and West Valley flooding.

During the initial phases of the Refinement of the US-36 Flood Control Facility, historic rainfall and flooding event hit the northern front range of Colorado. This flooding event was focused on the City of Boulder and extensive flooding and damage was experienced throughout the city including South Boulder Creek.

A slow moving storm collided with humid air over the Colorado Front Range Starting on September 9, 2013 and continuing through September 13, 2014. The storm was most intense between September 11 and September 12 with up to 6.4 inches of rain falling over 24 hours on September 11 and 7.9 inches falling over 24 hours on September 12. Both of these 24-hour precipitation events represent close to back-to-back 100-year recurrence interval general storms as defined by the South Boulder creek Hydrologic Study Completed in 2008.

Between September 14, 2014 and September 20, 2014, The City of Boulder asked CH2M HILL to collect high watermarks from the flooding events and to delineate approximate flood extents from the storm event. Figure 2-5, Figure 2-6 and Figure 2-7, 2013 Flood Extents depicts the approximate flooding extents as defined by high water marks for South Boulder Creek. The approximate floodplain replicates the 100-year floodplain for South Boulder Creek very closely especially for the flooding corridor along Thunderbird Lane and along South Boulder Creek. These figures highlight potential flooding sources for all of South Boulder Creek and highlight the sources that are addressed by the Refined Recommended Plan.

This flooding event reinforced the need for flood mitigation along South Boulder Creek. This was emphasized at a public meeting held to discuss the South Boulder Creek Flooding from the September event that was held November 21, 2014. An informal poll was taken at this meeting to gauge the public interest in constructing flood mitigation along South Boulder Creek. The results of this poll indicated that approximately 79% of respondents felt strongly about mitigating flood hazards from South Boulder Creek while 90% of respondents indicated that constructing a flood control facility on OSMP property would be acceptable. Results of this poll can be found in Appendix I.

Wetland and Riparian Zones

The Study Area has a number of designated wetland and riparian zones. These identified areas contain important functional values that warrant special consideration. It is the intent of the city to preserve, protect, restore, and enhance the quality and diversity of wetlands and water bodies. Streams, wetlands, and water bodies are indispensable and fragile natural resources with significant development constraints due to high groundwater, flooding, erosion, and soil limitations. Development activities in and around these wetlands may pose a threat these resources. The preservation of

streams, wetlands, and water bodies under the *Streams, Wetlands, and Water Body Protection Ordinance (9-3-9)* is consistent with the goal of wetland protection set forth in the Boulder Valley Comprehensive Plan.

The city has defined two wetland and water body designations as adopted on regulatory maps. These two designations are High Functioning and Low Functioning and are defined below:

- High Functioning: The additive value of all adopted functional value ratings, excluding recreation, equals twenty-six or more; or at least one function, excluding recreation, is rated high or very high.
- Low Functioning: The additive value of all adopted functional value ratings, excluding recreation, equals twenty-five or below.

The functions of all regulated stream, wetland, and water bodies within the city limits have been evaluated and are described in the *City of Boulder, Comprehensive Wetlands Remapping Project* by Land Stewardship Consulting, October 18, 2004. The *Streams, Wetlands, and Water Body Protection Ordinance (9-3-9)* outlines buffer areas for all regulated streams, wetlands, and water bodies. These buffer zones vary based on stream wetland or water body designation as defined above. Buffer widths for each designation are defined below:

- The buffer area width for High Functioning streams, wetlands, and water bodies shall be fifty feet and shall include an inner and outer buffer area.
  - The inner buffer area width shall be twenty-five feet from each point on the stream, wetland, or water body boundary.
  - The outer buffer area width shall be twenty-five feet from each point on the inner buffer area boundary.
- The total buffer area width for Low Functioning streams, wetlands, and water bodies shall be twenty-five feet from each point on the stream, wetland, or water body boundary and shall be considered an outer buffer area.

High and low functioning wetlands are depicted on Figure 2-8, Wetland and Riparian Zones, and specific requirements for projects involving these areas have been established. Wetlands identified on Figure 2-8 impacted by any proposed alternative would have to provide the following:

- The proposed alternative shall not result in a significant change to the hydrology affecting the stream, wetland or water body. Percolation of storm runoff on-site through vegetated swales, permeable paving materials or other similar methods to slow and clean runoff being discharged directly into the wetland, stream or water body may be required.
- The proposed activity shall demonstrate that the alternative is designed and located to minimize direct or indirect impacts to the adjacent wetland, stream or water body.
- The alternative shall demonstrate that if unavoidable direct and indirect impacts to vegetation, pervious surface or hydrology affecting the adjacent stream, wetland or water body then the direct and indirect impacts can be successfully mitigated through design of the alternative or by compensating for the impact. Alternative shall demonstrate protection of species and demonstrate that the alternative will not jeopardize the continued existence of habitat for the following species:
  - Plant, animal or other wildlife species listed as threatened or endangered by the United States Fish and Wildlife Service;
  - Plant, animal or other wildlife species listed by the State of Colorado as rare, threatened or endangered, species of special concern;
  - Plant, animal or other wildlife species listed in the Boulder County Comprehensive Plan as critical; and
  - Plant, animal or other wildlife species listed in the Boulder Valley Comprehensive Plan as a Species of Local Concern.

All wetlands within the Project Area are category A or category B and would be required to be mitigated or enhanced if disturbed by the recommended plan.

Flora, Fauna and Threatened and Endangered Species

South Boulder Creek has many areas that are identified as important habitat areas. In some cases, these areas have been formally designated. In others, these areas have been preserved and protected by Open Space through habitat conservation areas or habitat conservation easements as defined in Figure 2-9, Identified Preble's Jumping Meadow Mouse Habitat and Proposed Conservation Corridor and Figure 2-10, Designated Habitat Conservation Areas.

As discussed previously, many of the areas along the mainstem of South Boulder Creek have been identified as areas of known habitat for several threatened and endanger species. These species include Ute lady's tresses orchid; Preble's Meadow Jumping Mouse (PMJM); Northern Leopard Frog; two native fish species believed in decline in Colorado, Plains Topminnow and Orange-Spotted Sunfish; and a grassland nesting bird, the Boblink. Lands south of US-36 include lands with high ecological resources and land owned by the City of Boulder OSMP. These properties include an important remnant of the plains cottonwood riparian ecosystem; relicts of the tall grass prairie ecosystem; and wetlands that are considered to be among the best preserved and most ecologically significant in Boulder Valley. Specific mapped areas for all of the endangered species are currently not available. However, an understanding of the presence of these habitat areas dictates that any potential improvements must carefully consider potential impacts. In many case, the city and County have been proactive and have identified general areas of critical habitat and has designated these for special oversight. These areas are shown in Figure 2-10, Designated Habitat Conservation Areas.

Both the city and County also recognize that lands within the Study Area offer great benefit for a number of other natural uses. This recognition has resulted in a considerable amount of land having an Open Space designation. These lands are commonly owned by the city and are intended to be left in their natural state to preserve the important natural functions already identified. These functions may range from providing a natural buffer between riparian corridors and adjacent developed properties to preserving important floodplain functions such as flood storage and providing habitat to important plant and animals. Open Space lands have been identified in Figure 2-11, Open Space Lands.

In addition to the areas specifically designated as having important habitat or Open Space values, or even designated wetland areas, the Study Area has other amenities that are found to be of great value to the community. This area of Boulder has a long history of development and environmental stewardship by landowners and numerous aesthetic enhancements have been incorporated over the years. The most obvious among these is the mature vegetation that lines many of the area's drainageways.

Previous Studies

The South Boulder Creek basin has been the subject of many studies. Most have focused on the definition of the flood threat. The most recent of these is the HDR Flood Mapping Study. Several studies have attempted to identify mitigation measures to address the flood threat along South Boulder Creek.

US Army Corps of Engineers *Boulder Creek and South Boulder Creek Floodplain Information, Volume II, Boulder Metropolitan Area* 1969 was among the first to look at the watershed comprehensively. This proved to be the foundation for much of the early planning. This study acknowledges the broad floodplain and even notes that once flows leave the mainstem, they often flow in parallel channels that are below the elevation of the mainstem. However, the study failed to fully capture the high flow rates or the nature or extent of the threat to the West Valley.

The Wright McLaughlin Engineers *South Boulder Major Drainageways* (1970) looked at drainageways in the South Boulder area but not at the South Boulder Creek mainstem. The report did look at Viele and Bear Canyon Creek. The Viele Channel is an important tributary to South Boulder Creek. The report included a number of recommended improvements to the channel. The report also included proposed improvements along Bear Canyon Creek. While not intentionally tributary to South Boulder Creek, Bear Canyon Creek overflows do affect Sought Boulder Creek flooding.

R.W. Beck *Major Drainageway Planning Study, South Boulder Creek Volume II*, prepared for the District in 1973, defined the floodplain along the mainstem and proposed improvements, including several large detention ponds. This report also did not identify the significant flood threat through the West Valley.

Simons Li & Associates *Major Drainageway Planning Boulder Creek and South Boulder Creek Confluence Area*, prepared in 1983 focused on the area below Arapahoe Avenue. The report concluded there was little flood threat in this area based on improvements around the Flatirons Industrial Park area that were deemed adequate at the time. Subsequent interpretations of the adequacy of the facilities suggest a greater flood threat.

The Greenhorne & O'Mara *South Boulder Creek Flood Hazard Area Delineation* 1996 was the basis for the regulatory floodplain until the recent HDR studies. This study correctly identified the overflows of Hwy-93 and the limited capacity of the Dry Creek No. 2 Ditch system. They carefully delineated the resulting floodplain associated with these spills. However, the study did not include any overtopping of US-36 and the subsequent flood hazard to the West Valley. The flow rates used for this study closely resemble those of previous studies but there were slight variations in the final flow rates.

A *Floodplain Analysis of South Boulder Creek at the Flatiron Property in Boulder County, Colorado* 1996, prepared by Love and Associates was commissioned by the University of Colorado to provide a review of impacts on South Boulder Creek by the levee constructed to protect the property acquired by the University. This study was the first to identify and evaluate the significant spills that occur into the West Valley.

Taggert Engineering Associates was engaged to conduct a comprehensive evaluation of the flood threat along South Boulder Creek and to prepare a series of alternative mitigation measures for consideration. The reports *South Boulder Creek Interim Hydrology Study* 2000 and *South Boulder Creek Major Drainageway Planning Phase A Report* 2001, present the findings of these studies. These documents identify the hazard along the mainstem as well as that in the West Valley. The studies also identified a number of alternatives to address the flood threat. The report was never fully accepted by the city and the recommendations were not implemented.

The recommended plan from the Taggert Study of South Boulder Creek Completed in January of 2012 included the following improvements.

- Relocation of 90 Residences in Marshall out of the South Boulder Creek Floodplain
- Stream restoration and spill stabilization above Highway 93
- Culvert replacement with a multiple cell box at Highway 93 with drainage improvements to convey flow through the downstream property
- South Boulder Creek Spill Structure upstream of U.S. 36 along the west bank of South Boulder Creek to force additional flows to remain in the South Boulder Creek channel
- Flood storage at US-36 using a 10 - 13 foot high embankment and excavation on the CU south campus property
- Construction of a large storm drain from Thunderbird Lane and discharging to an open waterway at Flatirons Crossing Golf Course
- Construction of a 7,000 linear foot meandering wetlands waterway from South Boulder Creek at 1,500 feet upstream of Baseline Road to the Flatirons Crossing Golf course. This channel will be constructed primarily on City of Boulder Parks and Open Space property and would require multiple culverts under Baseline Road and a new flume at the Wellman Canal.

The estimated total cost of the Taggert flood mitigation alternative was estimated at $135,600,000 in 2001. This included land purchase costs, residual flood damages, flood hazard management, operation and maintenance costs and capital costs.

HDR recently completed the comprehensive Flood Mapping Study that includes three reports, *Climatology/Hydrology Report* (HDR, February 6, 2007), *Hydraulic Modeling Report* (HDR, December 30, 2008) and *Risk Assessment Report* (HDR, May 2009). These studies provided a comprehensive summary of the most recent hydrologic studies and the resulting floodplain and are currently being accepted by the Federal Emergency Management Agency (FEMA) as the regulatory flood studies for South Boulder Creek. These reports affirmed some of the flood threat along the mainstem and further defined the flood threat in the West Valley described earlier by Taggert and Love.

The US Army Corps of Engineers recently completed a *Reconnaissance Study Section 905(b) Preliminary Analysis Report, South Boulder Creek Boulder, Colorado, Flood Risk Management and Ecosystem Restoration Study*, 2010. This study focused on possible mitigation measures to address the flood issues along the mainstem and through the West Valley. This study was commissioned to determine the potential Federal interest in constructing one or more flood control projects along South Boulder Creek. This report heavily utilized the Taggert 2001 study as the primary source for evaluation alternatives and development of costs. The USACE evaluation of the Taggert report determined that Alternative 4 from the Taggert report could be economically feasible. This plan features the following flood control improvements:

- Additional storage in Gross Reservoir
- The construction of a 1,950 acre foot reservoir with a 54 foot high dam at Highway 93
- Channel improvements to South Boulder Creek from Highway 93 to downstream of Marshal Road
- South Boulder Creek Spill Structure upstream of U.S. 36 along the west bank of South Boulder Creek to force additional flows to remain in the South Boulder Creek channel
- A flood easement on the CU South Campus property for extreme floods
- Construction of a large storm drain from Thunderbird Lane and discharging to an open waterway at Flatirons Crossing Golf Course

The total cost of Alternative 4 is $124,600,000. The USACE has completed an initial "Maximum Supportable Cost." This cost is estimated to be $185,000,000. This report concluded there would be a Federal interest in construction a flood control project focusing primarily on storage.

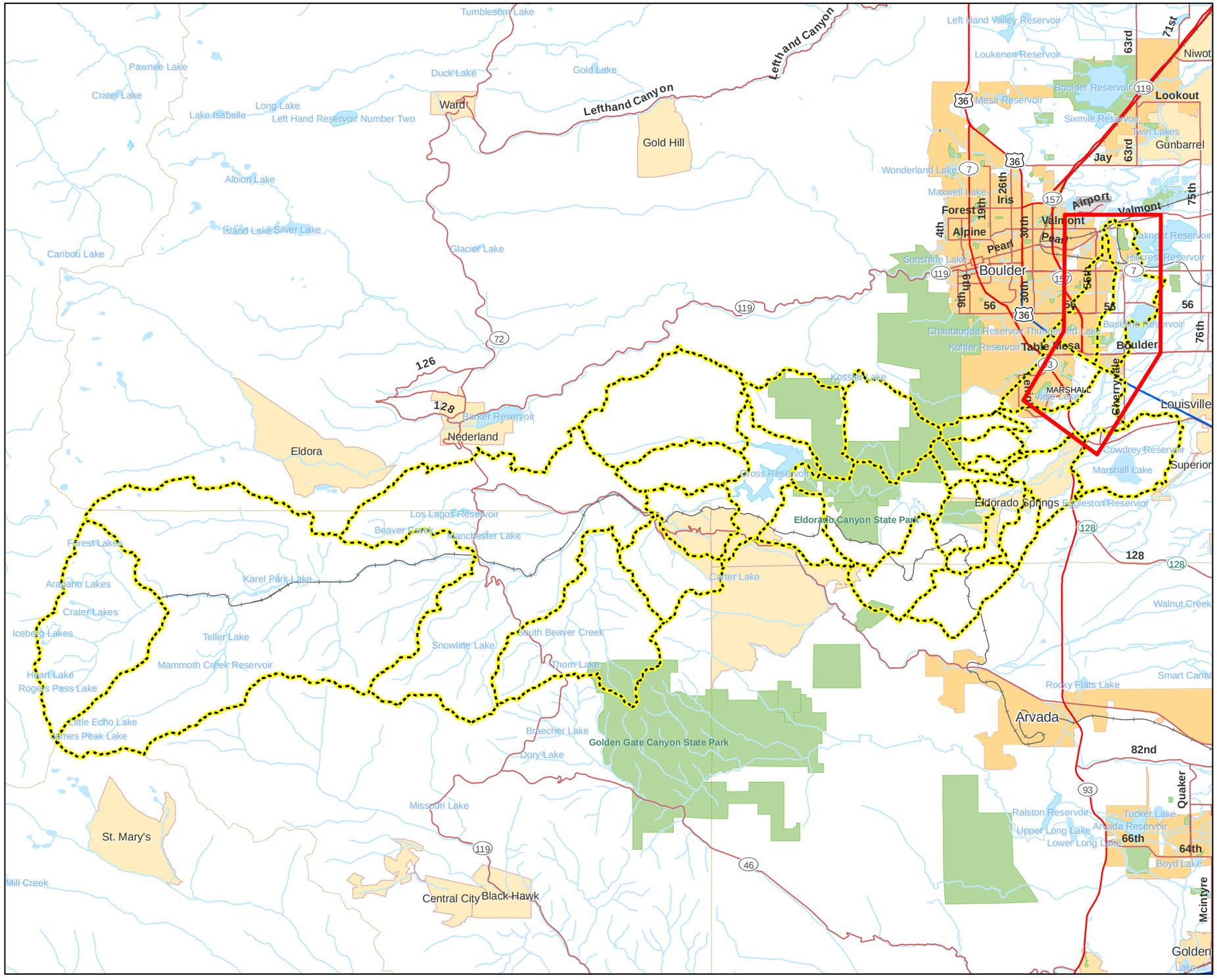


FIGURE 2-1
Basin Delineation
South Boulder Creek Flood Mitigation Report

VICINITY MAP

LEGEND

Structures within Revised Regulatory Floodplain

Revised Regulatory Floodplain

Streams, Creeks and Ditches

Streams, Creeks and Ditches

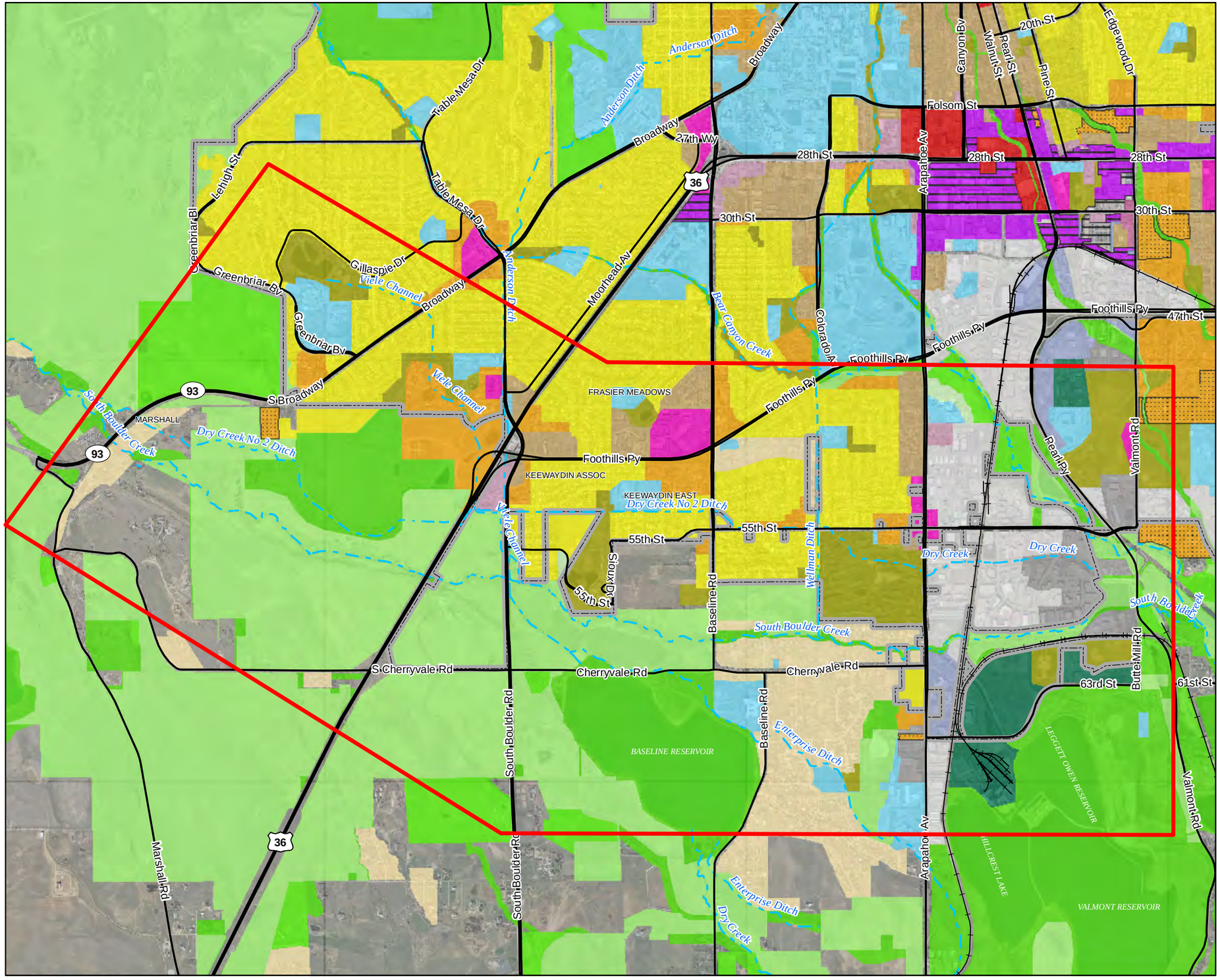
Boulder County

Notes:
1. Area of Interest
2. Revised regulatory floodplain impacts 1,253 structures

N

0 1,000 2,000 3,000 4,000 5,000
Feet

FIGURE 2-2
Revised Regulatory Floodplain
South Boulder Creek Flood Mitigation Report
South Boulder Creek Flood Mitigation Project



LEGEND

- Streams, Creeks and Ditches
- Boulder County Boundary

Residential
- Very Low Density Residential
- Low Density Residential
- Manufactured Housing
- Medium Density Residential
- Mixed Density Residential
- High Density Residential

Business
- Community Business
- General Business
- Service Commercial
- Transitional Business
- Regional Business

Industrial
- Community Industrial
- General Industrial
- Light Industrial
- Performance Industrial

Mixed Use
- Mixed Use Business
- Mixed Use Industrial
- Mixed Use Residential

Open Space and Mountain Parks
- Open Space, Aquired
- Open Space, Development Rights
- Open Space, Other

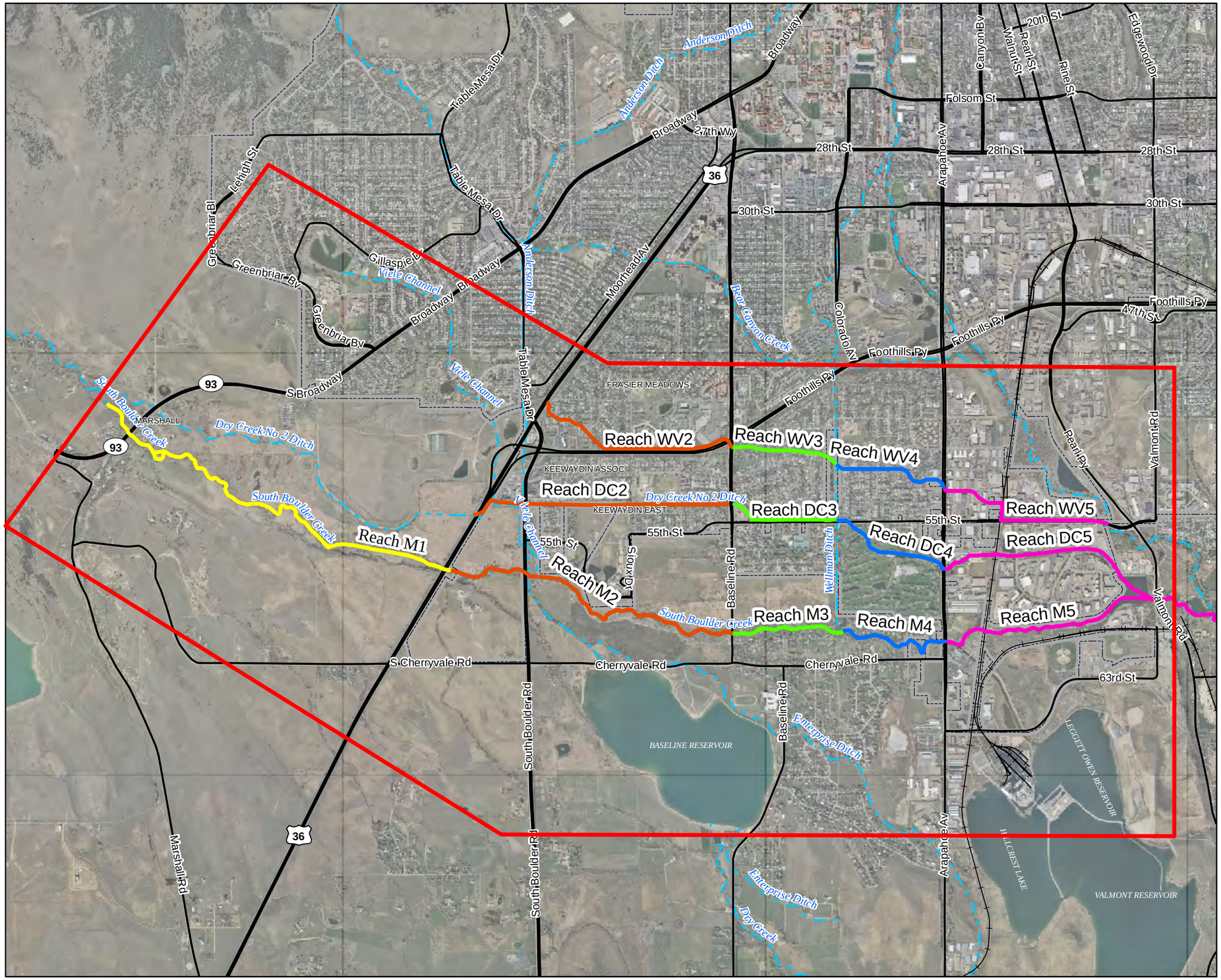
Other
- Agricultural
- Park, Urban and Other
- Public
- Environmental Preservation

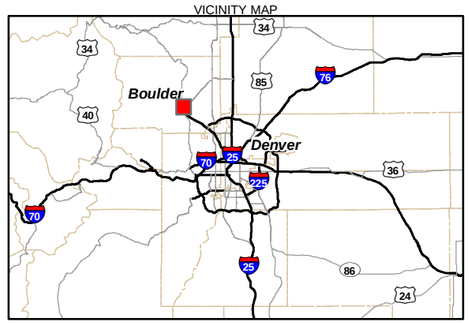
Notes:
1. Area of Interest

N

0 1,000 2,000 3,000 4,000 5,000
Feet

FIGURE 2-3
Lower Basin Land Use
South Boulder Creek Flood Mitigation Report
From the Boulder Valley Comprehensive Plan, 2009





LEGEND

- SBC Reach 1
- SBC Reach 2
- SBC Reach 3
- SBC Reach 4
- SBC Reach 5
- Main Road
- railroad
- Streams, Creeks and Ditches
- Boulder County

Notes:
1. Area of Interest

N

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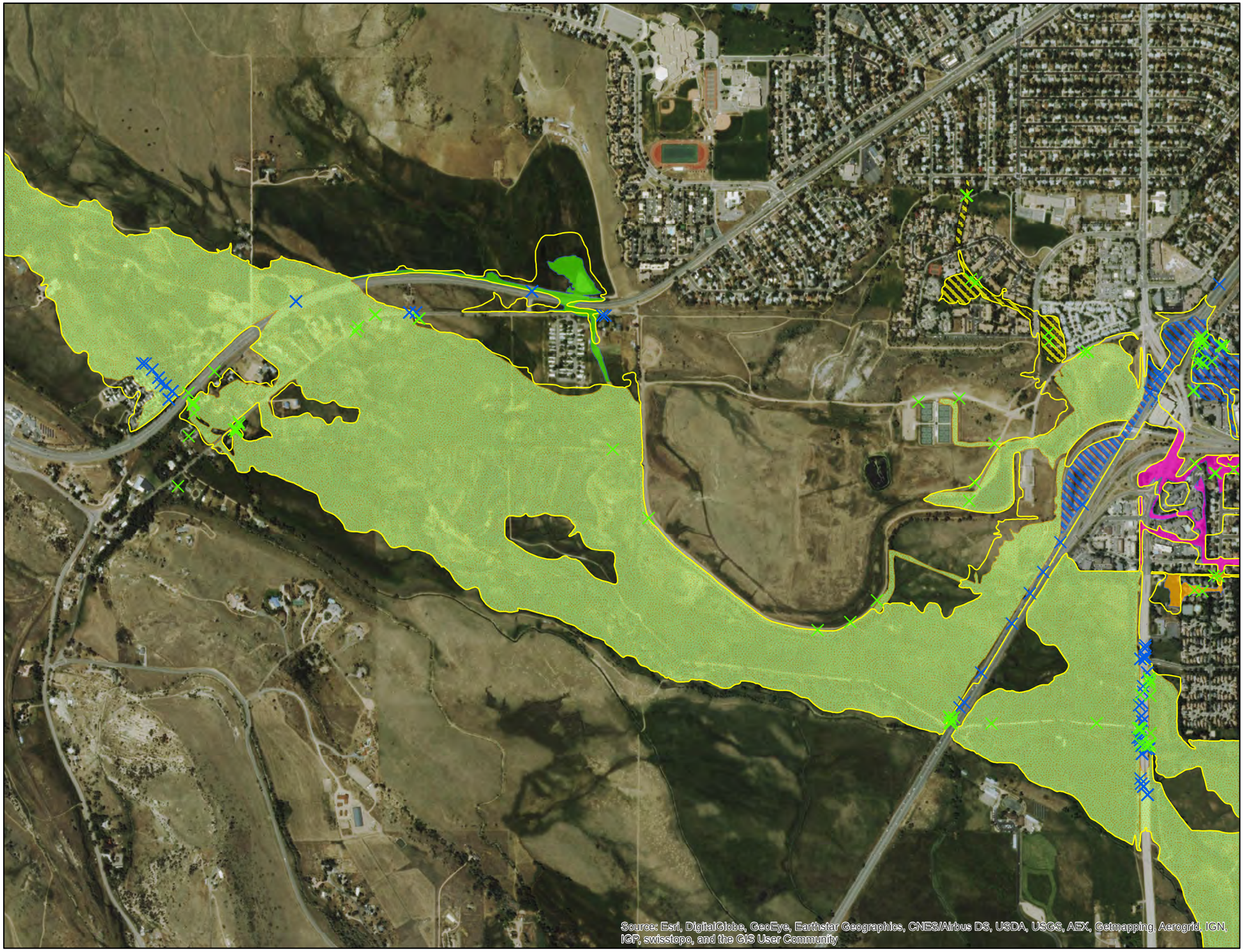
Feet

FIGURE 2-4
Reach Designation
South Boulder Creek Flood Mitigation Report



LEGEND

- CH2M HILL Assessment Photos
- Waterview Property Photos
- DHI Assessment Photo
- Regulatory 100-YR Floodplain

2013 Approximate Flood Limits

Estimated Flooding Source

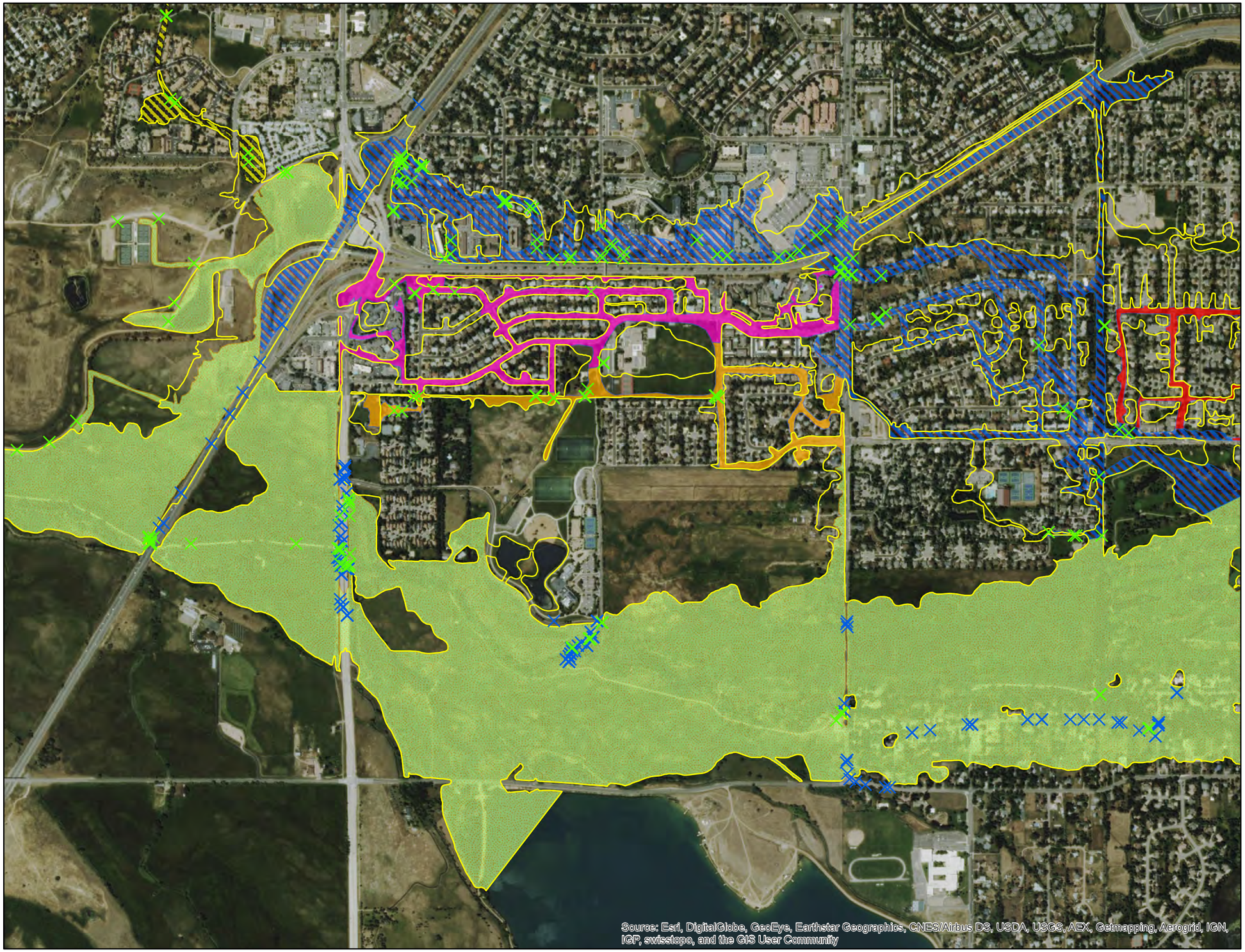
- Dry Creek #2 Ditch
- Local Basin
- Local Basin / South Boulder Creek
- New Anderson / C2 Basin / Groundwater
- South Boulder Creek
- US-36 Overtopping / Local C2 Basin / Groundwater
- Viele Channel

Notes:
1. Approximate flood plain based on High Water Marks Collected the Week of September 16, 2013 by DHI, and CH2M HILL

N

0 255 510 1,020 1,530 2,040
Feet

FIGURE 2-5
Approximate 2013 Flood Extents
Hwy-93 to US-36
South Boulder Creek Flood Mitiagtion Report



LEGEND

- CH2M HILL Assessment Photos
- Waterview Property Photos
- DHI Assessment Photo
- Regulatory 100-YR Floodplain

2013 Approximate Flood Limits

Estimated Flooding Source

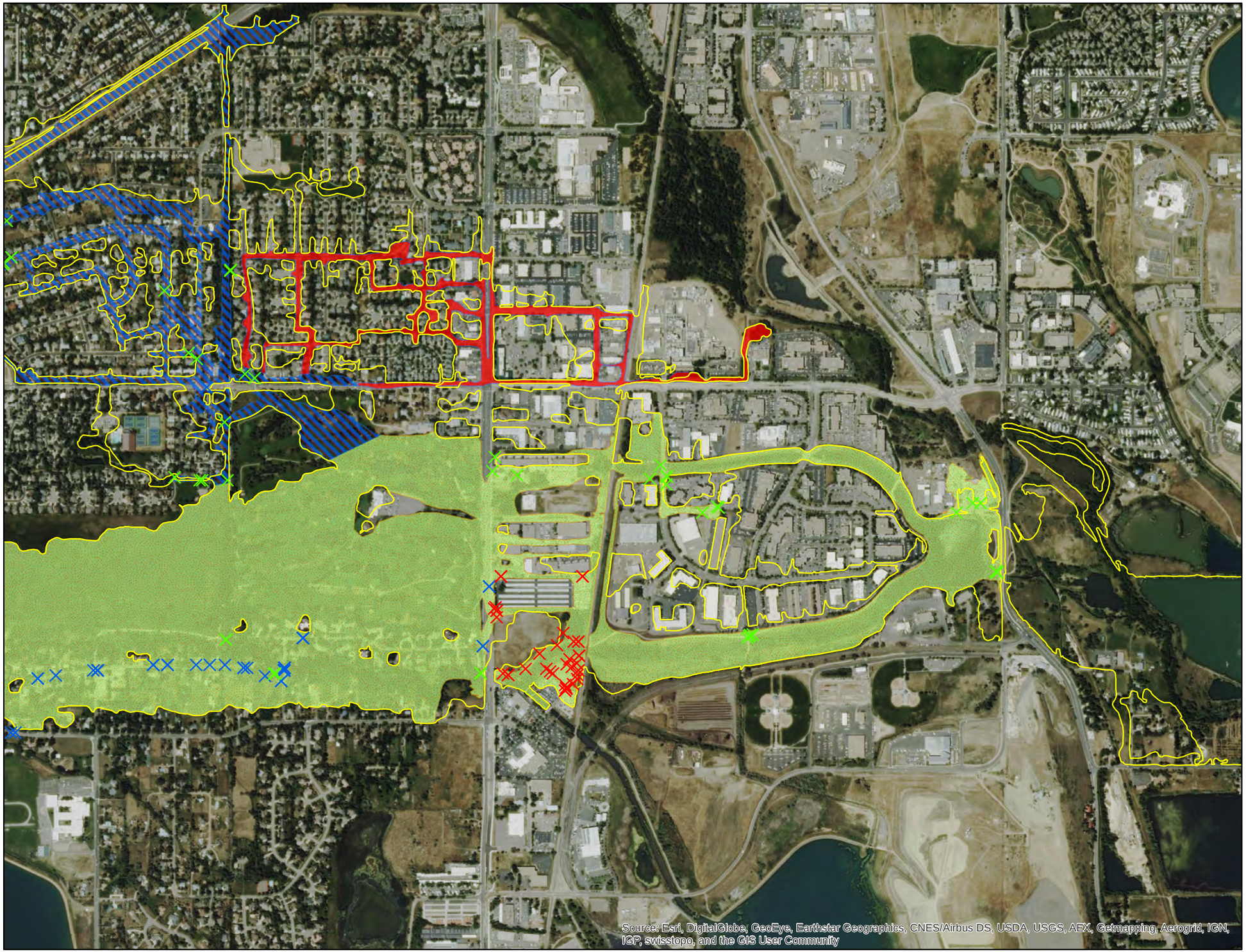
- Dry Creek #2 Ditch
- Local Basin
- Local Basin / South Boulder Creek
- New Anderson / C2 Basin / Groundwater
- South Boulder Creek
- US-36 Overtopping / Local C2 Basin / Groundwater
- Viele Channel

Notes:
1. Approximate flood plain based on High Water Marks Collected the Week of September 16, 2013 by DHI, and CH2M HILL

N

0 255 510 1,020 1,530 2,040
Feet

FIGURE 2-6
Approximate 2013 Flood Extents US-36 to the Wellman Canal
South Boulder Creek Flood Mitiagtion Report



LEGEND

- CH2M HILL Assessment Photos
- Waterview Property Photos
- DHI Assessment Photo
- Regulatory 100-YR Floodplain

2013 Approximate Flood Limits

Estimated Flooding Source

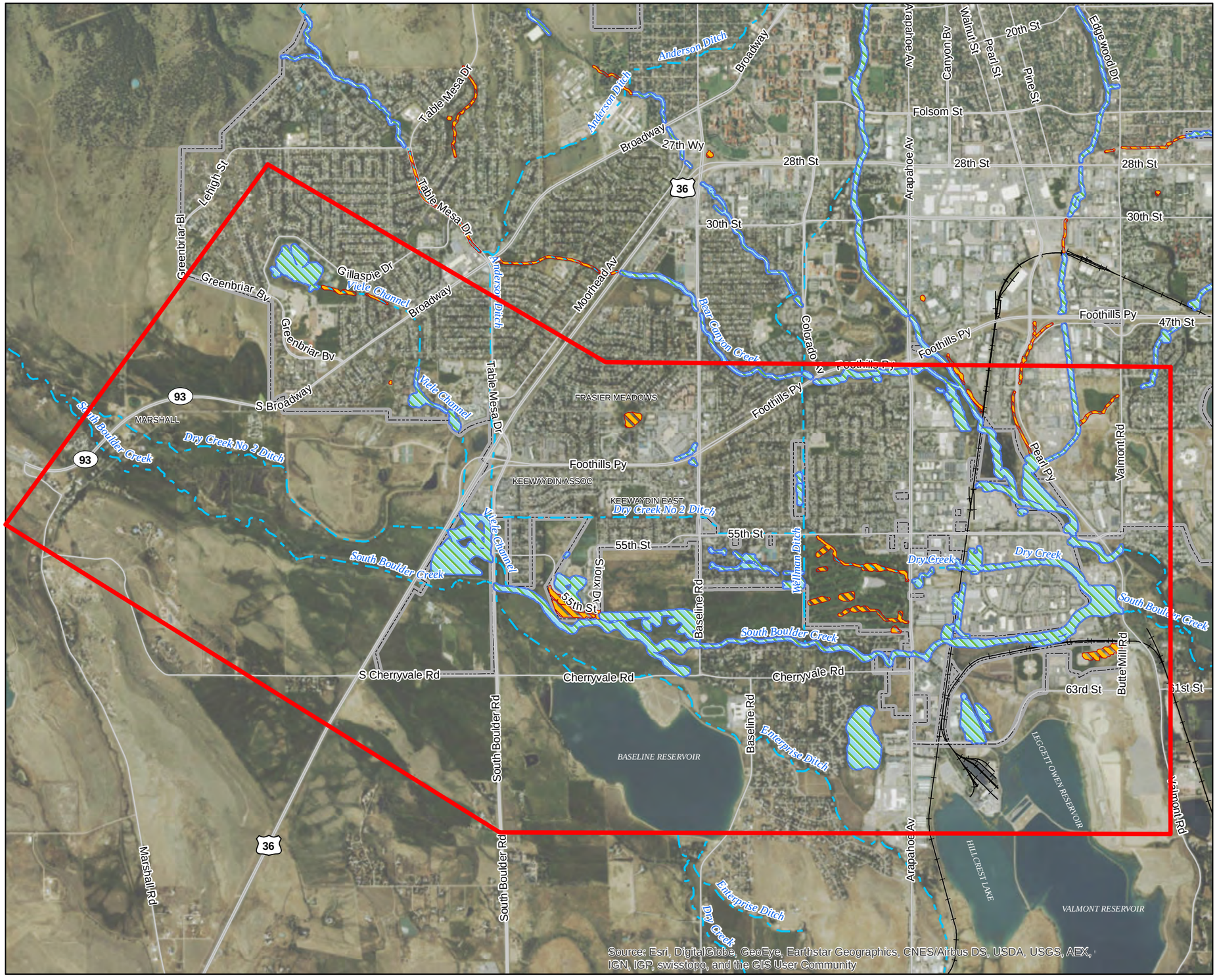
- Dry Creek #2 Ditch
- Local Basin
- Local Basin / South Boulder Creek
- New Anderson / C2 Basin / Groundwater
- South Boulder Creek
- US-36 Overtopping / Local C2 Basin / Groundwater
- Viele Channel

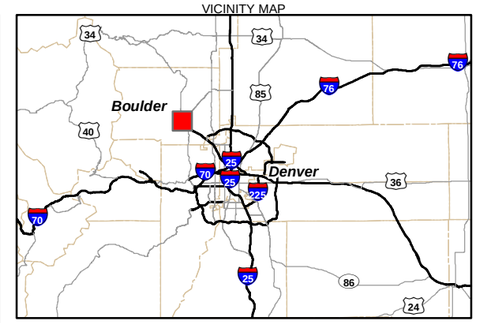
Notes:
1. Approximate flood plain based on High Water Marks Collected the Week of September 16, 2013 by DHI, and CH2M HILL

N

0 255 510 1,020 1,530 2,040
Feet

FIGURE 2-7
Approximate 2013 Flooding Extents Wellman Canal to Confluence with Boulder Creek
South Boulder Creek Flood Mitiagtion Report





LEGEND

City of Boulder Wetlands

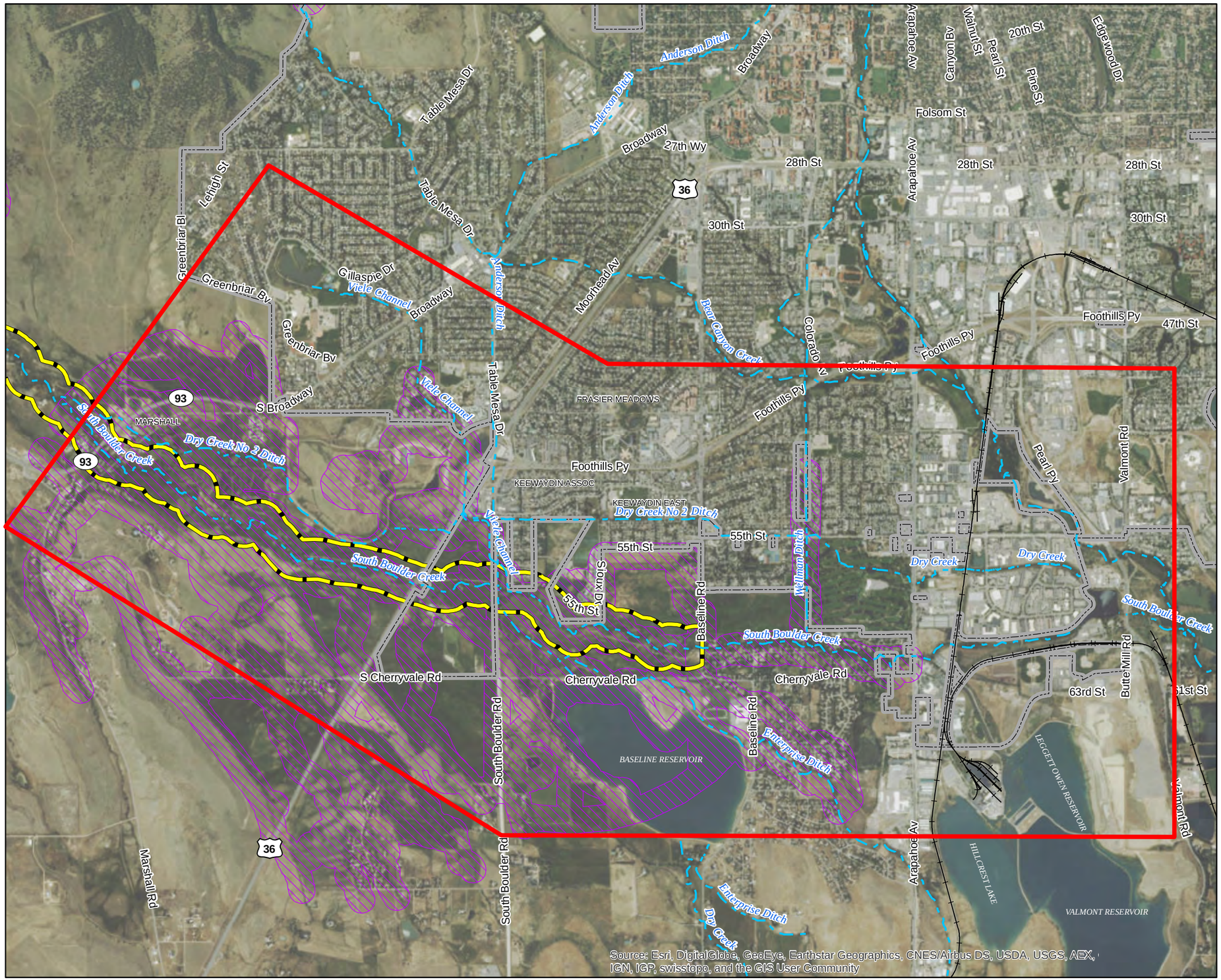
Wetlands Catagory

- High Functioning
- Low Functioning
- Streams, Creeks and Ditches
- Boulder County

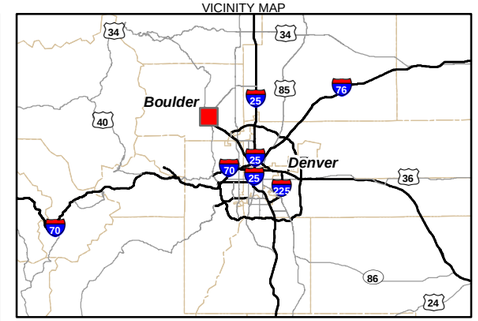
Notes:
1. Area of Interest

0 1,000 2,000 3,000 4,000 5,000
Feet

FIGURE 2-8
Wetland and Riparian Zones
South Boulder Creek Flood Mitigation Report



VICINITY MAP



LEGEND

- Streams, Creeks and Ditches
- Boulder County
- PMJM Critical Habitat 12/14/2010
- PMJM Occupied Range

Notes:

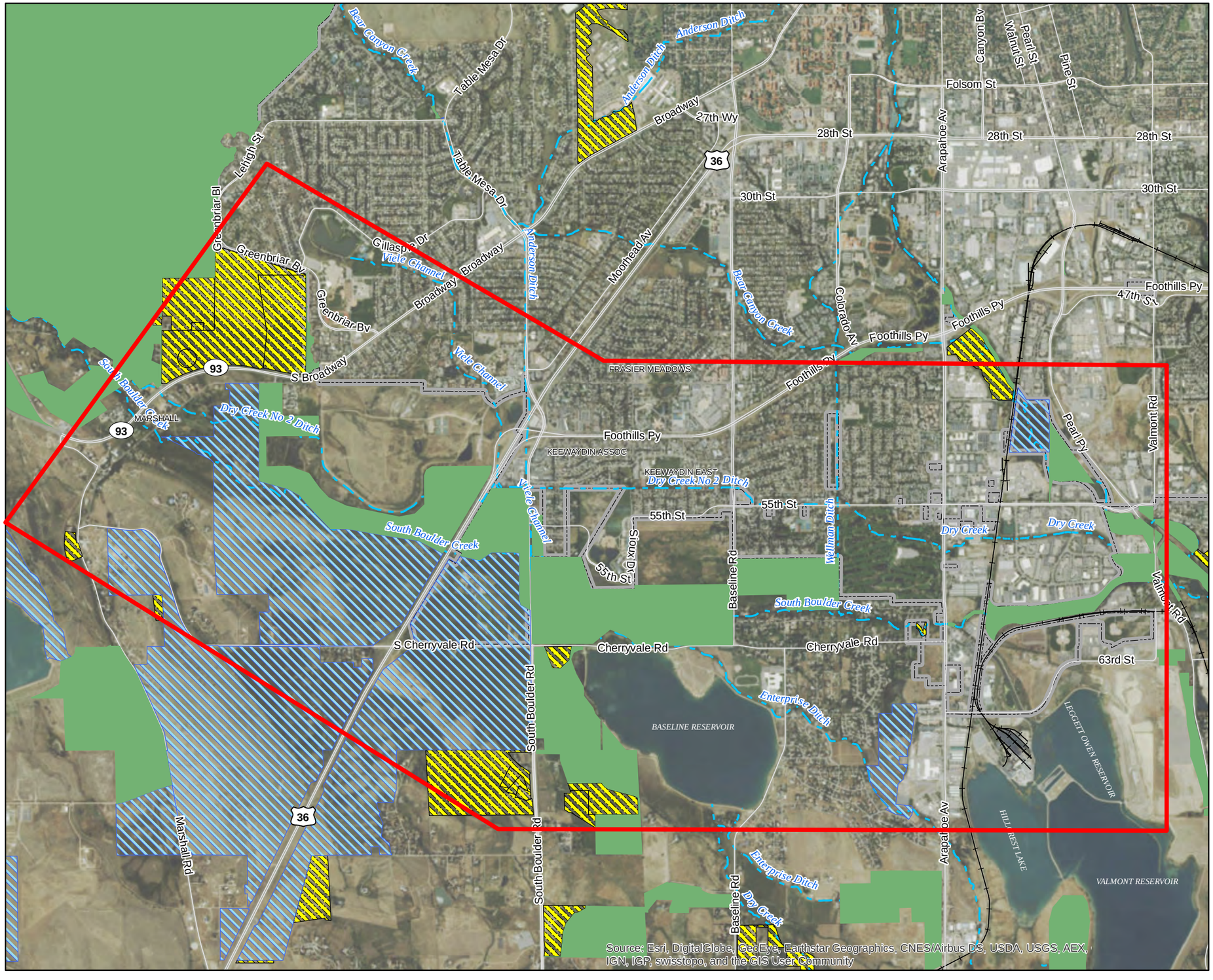
1. Area of Interest

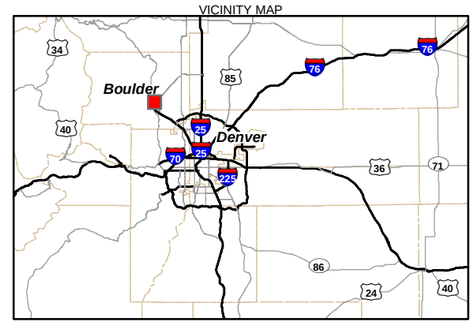
2. PMJM Critical Habitat Area from the U.S. Fish and Wildlife Service
3. PMJM Occupied Area from the Colorado Department of Wildlife

N

0 1,000 2,000 3,000 4,000 5,000
Feet

FIGURE 2-9
Preble's Meadow Jumping Mouse Habitat Areas
South Boulder Creek Flood Mitigation Report





LEGEND

- Boundary County
- Streams, Creeks and Ditches

Boulder County Management Areas

- Habitat Conservation Area
- Natural Area

Boulder OSMP Conservation Areas

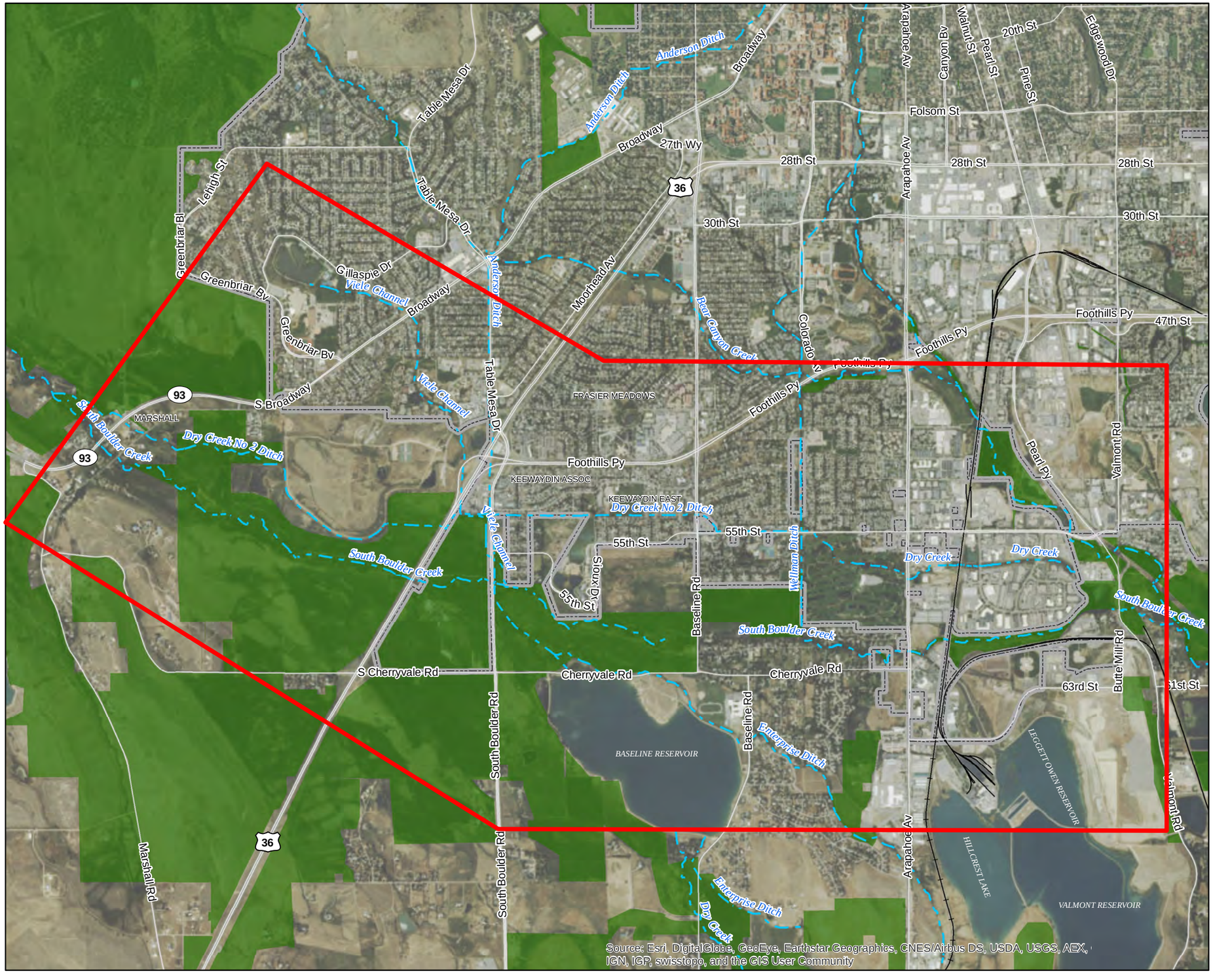
- Conservation Easement

Notes:
1. Area of Interest

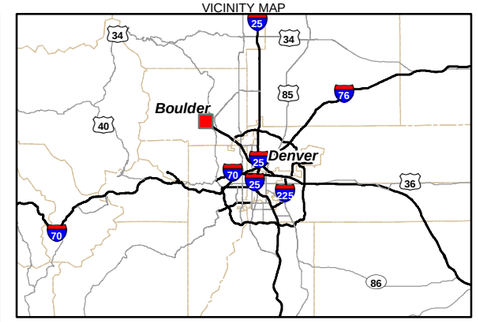
N

0 1,000 2,000 3,000 4,000 5,000
Feet

FIGURE 2-10
Designated Habitat Conservation Areas
South Boulder Creek Flood Mitigation Report



VICINITY MAP



LEGEND

- Main Road
- neighborhood
- railroad
- Streams, Creeks and Ditches
- LAKES
- Boundary County
- City of Boulder Open Space

Notes:
1. Area of Interest

N

0 1,000 2,000 3,000 4,000 5,000
Feet

FIGURE 2-11
Open Space Lands
South Boulder Creek Flood Mitigation Report

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III. Hydrologic Analysis

Overview

An extensive hydrologic analysis for the Study Area was conducted as part of the Mapping Study. This analysis was based on a comprehensive scope of services developed by the city with the input of a number of city staff and members of the public. The Mapping Study included hydrologic analyses based on recorded stream gage data, paleohydrologic flood estimates and a comprehensive rainfall/runoff computer model.

The rainfall/runoff computer model was developed using a proprietary software package developed by DHI called MIKEFLOOD. This model provided a vehicle to conduct exhaustive simulations of various basin conditions and various rainfall inputs to represent the complex hydrologic response of the watershed. The model incorporated a sophisticated algorithm to compute infiltration losses and simulates the runoff from a number of sub-basins. The model assembles the runoff from these individual sub-basins using a simplified routing algorithm that accounts for minor storage and attenuation of the individual hydrographs. The model also uses a sophisticated approach to routing and combining flow from individual sub-basins by accounting for floodplain storage and the impacts of drainage features within the watershed.

Another important differentiator between the hydrologic studies done for this study and the standard approach is the careful attention to calibration. The results of the stream gage analysis and the paleohydrologic flood study were used to adjust model parameters to assure that the simulated results reflected actual recorded basin responses.

The Mapping Study included a Climatology/Hydrology Report (HDR, February 6, 2007) that looked at the nature of rainfall in the South Boulder Creek watershed. That study concluded that two distinct types of storms were common in the watershed, a general storm and a thunderstorm. The Mapping Study reported the thunderstorm resulted in the highest flows along the mainstem of South Boulder Creek.

The focus of the hydrologic evaluation was on the flows in the mainstem of South Boulder Creek. The combination of rainfall and basin assumptions used in the Mapping Study produced the most critical conditions and resulted in the highest flows along the mainstem. However, that study, as well as the current Study, recognizes that other rainfall events may result in higher flood flows and a higher consequent hazard to areas within the tributary basin. This Study relies on other work to identify those other critical storms and the resulting flows and to assess the potential effectiveness of proposed improvements to address the flood threat associated with those flows. These other investigations include the flows reported in an HDR memorandum (Lower Storm Center memorandum) developed during the Mapping Study that addressed the lower basin storms. A subsequent study, also prepared by HDR that focused on the local stormwater collection system, the City of Boulder Stormwater Master Plan (Stormwater MP) was published in 2007. The Lower Storm Center Memorandum and the Stormwater MP provided estimates of local tributary flows for the South Boulder Creek Watershed that were utilized to complete initial sizing of stormwater and flood control facilities throughout the West Valley and to allow for the preliminary comparison of the various alternatives.

Design Rainfall

The South Boulder Creek Flood Mapping Study was unique among projects in the District in that a Basin Specific Design Storm (BSDS) was developed. The development of the storm is described in detail in the HDR *Climatology/Hydrology Report* (HDR, February 6, 2007). In fact, two such storms were developed that reflected differing climatologic conditions a thunderstorm and a general storm. The regulatory floodplain for South Boulder Creek is based on the BSDS Thunderstorm.

Basin Specific Design Storm Thunderstorm

An exhaustive evaluation of historic rainfall events was initiated as part of the Mapping Study. The evaluation concluded that climatologic conditions in South Boulder Creek are such that the typical assumption of a uniform spatial distribution of rainfall across the entire watershed was not appropriate. Rather, a rainfall event having a defined spatial footprint and with a defined spatial distribution of rainfall intensities and depth was more appropriate. The study defined three unique distributions based on the probabilities for a particular storm. In general, the footprint of the rainfall and the point precipitation values increased as the probability of the storm decreased.

The adopted 100-year BSDS Thunderstorm for South Boulder Creek had a spatial footprint of approximated 75 square miles, a six hour storm duration, and a maximum rainfall depth of 3.89 inches. Rainfall events smaller than the 100-year design thunderstorm, had a smaller footprint and lower rainfall depths. Larger storms had larger footprints and depths. All thunderstorms were six hours in duration. Rainfall intensities over the six-hour storm duration differed between the various storms events but generally followed a pattern similar to the distribution recommended by the District in the USDCM Volume 1 and 2. A summary of the size and maximum point precipitation for each of the study storms is presented in Table 3-1, South Boulder Creek (SBC) Basin Specific Design Storm Return Frequency Values and Table 3-2, South Boulder Creek Basin Specific Design Storm Thunderstorm Spatial Distribution summarize the important design thunderstorm characteristics that the flood hydrology is based upon.

TABLE 3-1
South Boulder Creek Basin Specific Design Storm Return Frequency Values
Taken from Table 5, Climatology and Hydrology Report, HDR February 6, 2007

Return frequency	SBC 6-hr Total Rainfall (in)
2-yr	1.65
5-yr	2.23
10-yr	2.57
25-yr	3.06
50-yr	3.46
100-yr	3.89
200-yr	4.25
500-yr	4.78

TABLE 3-2
South Boulder Creek Basin Specific Design Storm Thunderstorm Spatial Distribution
Taken from Table 11, Climatology and Hydrology Report, HDR February 6, 2007

Rainfall Depth[1] (in)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00
Spatial Distribution Area (Sq. MI.)	74.57	69.32	64.30	58.16	33.15	15.00	7.41	2.96	0.00

[1]Note: Peak rainfall depth is 3.89"

Another unique quality of the BSDS Thunderstorm adopted for the South Boulder Creek basin was its spatial orientation. The climatologic studies determined that wind patterns and other conditions would result in a storm location that was generally centered over the lower portion of the watershed. This location is shown in Figure 3-1, 100-year South Boulder Creek Basin Specific Design Thunderstorm Location. To assure that this storm resulted in the most critical flood threat, the storm was simulated in the hydrologic model in critical locations across the basin. The resulting analysis showed that the mainstem flows resulting from the BSDS Thunderstorm represented the highest predicted discharges.

General Storm

The evaluation of historic floods on South Boulder Creek noted there was also a flood threat from a large regional storm that had a longer duration but lower intensity than the BSDS Thunderstorm. Once again, the analysis described in the *Climatology/Hydrology Report* (HDR, February 6, 2007) indicated that the characteristics of this storm differed from the normal assumption of a uniformly distributed rainfall event lasting 24-hours. Instead, the General Storm had a duration of 72-hours with a maximum rainfall depth of 6.54 inches. The climatologic evaluations identified a spatial distribution of

rainfall depths across the basin that reflected some decrease in peak intensity and depth farther away from the storm center and recognized a similar decrease as elevation increased. Moreover, the evaluation concluded that precipitation falling above elevation 8000 feet was likely to fall as snow and not contribute directly to immediate storm runoff.

Sub-watershed Characteristics

Details of the sub-watersheds comprising the South Boulder Creek basin can be found in the *Climatology/Hydrology Report* (HDR, February 6, 2007). In general terms, the watershed was sub-divided into 27 sub-basins as shown on Figure 3-2, South Boulder Creek Basin Delineation. The sub-basins lower in the watershed are generally smaller to better capture the response to high intensity rainfall events.

The upper portions of the watershed have minor development, few roads or structures, are generally above 10,000 feet in elevation, and extend to the continental divide. These basins (Sub-watersheds C26 and C27) are characterized by HDR as Mountainous – High basins. Paleoflood studies conducted as part of the Mapping Study indicated that runoff from this area is characterized by snowmelt runoff and that there is minor potential for flooding.

Below the upper watersheds described above, exist The Mountainous – Low the watershed that can be divided into two regions. The upper part of the watershed (that include Sub-watersheds C18, C20-25) lies at elevations above about 8000 feet and The lower part of the Mountainous – Low region (that include Sub-watersheds C9-C10, C13-C15, C17, and C19) lie above Eldorado Springs and the mouth of Eldorado Canyon. These sub-watersheds have minor development, few roads or structures and are tributary to Gross Reservoir. Heavy precipitation over these sub-watersheds generally falls as snow and there is a minor danger of flooding. In addition, these sub-watersheds also have an extensive network of irrigation ditches. This part of the watershed often includes steep, narrow tributary watersheds that have a high potential for flooding. Moreover, it is over this area of the watershed where the highest intensity precipitation occurs during the BSDS Thunderstorm.

The plains portion of the watershed sits between Eldorado Canyon and the developed parts of the city. These sub-watersheds (C4 – C8) still have minor development although the extent of structural development immediately adjacent to the channel increases lower in the watershed. This area is subject to moderate to low intensity rainfall and does represent an increased flood hazard, although the limited extent of development minimizes the threat.

The main channel of South Boulder Creek throughout the upper reaches of the basin as described above is generally capable of conveying flood flows. There may be localized areas where water gets out of the main channel and enters the overbank, but these are limited and flow quickly returns to the channel.

The lower portion of the watershed (Sub-watersheds C1 – C3) is the area of the watershed that is most highly developed. Sub-watersheds C1 and C2 in particular are fully developed with much urban land. At the western edge of these sub-watersheds, major roadways such as Hwy-93 and US-36 cross South Boulder Creek. There is considerable development adjacent to and downstream of the crossing of these roadways over the creek. A number of diversion channels divert water from the creek and cross the floodplain, often influencing the flow characteristics of the channel and the overbanks.

The channel through the lower portion of the basin is often overtopped with water entering the overbank floodplain. The broad nature of the floodplain causes the flood flows to inundate property and roadways not in the immediate vicinity of the channel. The extensive network of irrigation ditches furthers the spread of the water away from the channel. The channel through this area is perched on an alluvial floodplain and the channel is often higher than the land adjacent to the channel. As such, water leaving the channel sometimes travels great distances downstream along Alternative flow paths before it reenters the mainstem. These Alternative flow paths are often down residential streets or through developments for which no significant flood control facilities exist.

Table 3-3, South Boulder Creek Sub-watershed Characteristics, contains the important basin characteristics that define the runoff characteristics input in to the hydrologic model to determine the rainfall runoff response of the South Boulder Creek watershed.

TABLE 3-3
South Boulder Creek Sub-watershed Characteristics
Taken from Table 18, Climatology and Hydrology Report, HDR February 6, 2007

Sub-basin ID	Sub-basin Area (Acres)	Elevation Zone Range (ft)	Predominant Land Cover	Sub-basin Slope (%)
C1	1,800	5,000-5,500	Highly developed, urbanized land use	0.88
C2	2,700	5,000-6,000	Highly developed, urbanized land use	2.48
C3	1,710	5,500-6,000	Moderate development, borders the City of Boulder	3.56
C4	2,300	5,500-6,000	Minor development, a large pond comprises majority of sub-basin	1.35
C5	1,330	5,500-6,000	Moderate development, homes in floodplain of South Boulder Creek	4.28
C6	480	5,500-8,500	Minor development present, roads, isolated homes and structures	19.30
C7	630	5,500-8,500	Minor development present, roads, isolated homes and structures	23.66
C8	230	5,500-7,000	Minor development present, roads, isolated homes and structures	15.11
C9	480	5,500-8,500	Minor development present, roads, isolated homes and structures	20.18
C10	1,060	5,500-8,000	Minor development present, roads, isolated homes and structures	23.48
C11	1,070	5,500-8,500	Minor development present, roads, isolated homes and structures	14.76
C12	630	5,500-6,500	Minor development present, roads, isolated homes and structures	4.49
C13	2,400	6,500-8,500	Minor development present, roads, isolated homes and structures	8.48
C14	3,380	6,000-9,000	Minor development present, roads, isolated homes and structures	2.48
C15	1,850	6,000-9,000	Minor development present, roads, isolated homes and structures	10.31
C16	1,490	6,000-9,000	Minor development present, roads, isolated homes and structures	15.94
C17	2,430	6,500-8,500	Minor development present, roads, isolated homes and structures	9.66
C18	2,320	7,000-9,000	Predominately Gross Reservoir, almost no development	9.88
C19	1,330	7,000-8,500	Minor development present, roads, isolated homes and structures	12.39
C20	4,550	7,500-9,000	Minor development present, roads, isolated homes and structures	5.72
C21	1,680	7,500-8,500	Minor development present, roads, isolated homes and structures	6.76
C22	1,730	7,500-9,000	Minor development present, roads, isolated homes and structures	10.83
C23	1,980	8,000-10,500	Minor development present, roads, isolated homes and structures	14.99
C24	14,280	8,000-11,000	Minor development present, roads, single homes, alpine lakes	6.35
C25	5,600	8,000-10,500	Minor development present, roads, single homes, alpine lakes	6.07
C26	21,820	8,500-13,500	Undeveloped alpine terrain, presence of alpine lakes	6.32
C27	5,710	9,000-13,500	Undeveloped alpine terrain, presence of alpine lakes	12.67

Hydrograph Routing

Hydrology for this project was developed as part of the Mapping Study. Details of that work effort are described in the *Climatology/Hydrology Report* (HDR, February 6, 2007). The hydrologic analysis consisted of three distinct approaches, a statistical evaluation, a paleoflood analysis, and a rainfall/runoff modeling effort. The statistical evaluation and the

paleoflood analysis both were used to support the model development and were not directly a part of the regulatory hydrologic model. The hydrologic modeling was performed using DHI's software MIKEFLOOD, but in two distinct phases.

The initial hydrologic model development was conducted using the MIKE 11 model. This model is described by HDR as:

> *"MIKE 11 is a conceptual model in that it represents the watershed with a series of sub-basins each represented by basin specific topography, soils and ground cover. The model applies rainfall to each sub-basin, computes losses resulting from vegetation evapotranspiration and infiltration, and estimates the water reaching the stream through a combination of surface flows and base flows. The model combines the runoff from various sub-basins to generate a complete representation of flow in the overall watershed. Flow is combined and routed down the channel in a series of channel segments each defined by specific cross sectional geometry, longitudinal channel slope, and surface roughness."*

MIKE 11 is a fully dynamic, 1-D hydrologic model. That is, the model generates and routes the full hydrograph through the watershed considering backwater effects from culverts and undersized channels but it does so using the assumption of one-dimensional flow. This approach differs from the District's prevailing standard of practice that generally assumes no backwater effects and less flood peak attenuation. The results of this modeling effort provided a preliminary estimate of the flood peaks and hydrograph that was used for calibration and verification for both the BSDS Thunderstorm and General Storm.

An updated hydrologic analysis was incorporated into the two-dimensional floodplain analysis using MIKEFLOOD. In this package, MIKE 11 runoff results are routed using both the 1-D channels captured by MIKE 11 and a 2-D representation of the flow in the floodplain using the MIKE 21 capability of MIKEFLOOD. HDR described the linked capability as follows:

> *"The MIKE 11 computer model is a part of an even more comprehensive package called MIKEFLOOD. MIKEFLOOD uses the information developed in the MIKE 11 model and combines it with a sophisticated two-dimensional floodplain model (MIKE 21) to provide a detailed representation of the watershed reflecting where water is generated, how it travels down well-defined channels, and how it moves out of the channel and across the broad floodplain. Flows move down the channel and are attenuated because of hydraulic features within the channel. The MIKE 11 model accounts for channel backwater and other localized phenomena, but cannot represent floodplain storage. However, the impacts of floodplain storage are obvious along South Boulder Creek and will be addressed within the MIKE 21 model that has the capability to simulate these conditions."*

The use of an approach with this kind of detail and resolution is uncommon in the District. However, the Mapping Study scope and execution were directed by the city and done to address specific concerns expressed by the community regarding the accuracy and detail of past studies. The Mapping Study and the MIKEFLOOD based hydrology has been adopted as the regulatory floodplain delineation document. FEMA anticipates the formal adoption of the revised mapping study through the Digital Flood Insurance Rate Map Modification (DFIRM) process in mid to late 2012.

While the use of the MIKEFLOOD model to generate flood flows is well founded and provides an uncharacteristic level of understanding of the development and propagation of the flood wave, it does present some complications for floodplain managers and administrators. Any physical changes in the upstream watershed, whether on channel or in the overbank areas, have the potential to significantly alter the flood flows because of the models sensitivity to not only peak flow but also flow volume. This complication requires extreme diligence when assessing the impacts of proposed improvements along the drainageway or in the floodplain.

Results of Analysis

The hydrologic study conducted as part of the Mapping Study generated two sets of results, related but with entirely different application. The first results were derived from the MIKE 11 analysis that generated runoff hydrographs from the sub-watersheds. These values were very important, became the hydrologic input into the MIKEFLOOD hydraulic model, and were useful in some of the initial calibration and validation efforts. In particular, the MIKE 11 analysis allowed a comparison of the BSDS Thunderstorm and General Storm to be compared with the statistical peak flow rates and volumes at the Eldorado Springs Stream gage calculated by the USACE Hydrologic Engineering Center (HEC)-Flood Frequency Analysis (FFA) program. A summary of the results of the MIKE 11 analysis and the statistical analysis of the stream gages computed by FFA are presented in Tables 3-4, MIKE 11 Model Peak Flow Results, and 3-5, MIKE 11 Model Volume Comparison.

TABLE 3-4
Mike 11 Peak Flow Results
Taken from Table 22, Climatology/Hydrology Report, (HDR February 6, 2007)

Event	FFA Discharge	Simulated Discharge (cfs)									
		Eldorado Gage		Hwy-93		US-36		Baseline Road		Confluence	
		TStorm	GStorm	TStorm	GStorm	TStorm	GStorm	TStorm	GStorm	TStorm	GStorm
2-yr	550	670	1000	870	1350	910	1420	1020	1580	1020	1610
5-yr	952	1060	1330	1300	1930	1390	2040	1680	2260	1680	2310
10-yr	1360	1310	1520	1770	2270	1950	2400	2400	2660	2440	2720
25-yr	1910	2280	1800	3270	2760	3510	2930	3980	3240	4020	3320
50-yr	2910	2640	2020	3770	3130	4030	3330	4560	3690	4620	3780
100-yr	3970	4520	2230	7120	3490	7690	3710	8770	4120	8910	4220
200-yr	5360	6210	2450	9520	3870	10090	4120	11090	4580	11100	4690
500-yr	7930	7400	2735	11360	4360	12030	4640	13170	5160	13130	5290

TABLE 3-5
Mike 11 Model Volume Comparison
Taken from Table 21, Climatology/Hydrology Report, (HDR February 6, 2007)

Recurrence Interval	Thunderstorm Volume (million cubic feet)	General Storm Volume (million cubic feet)	FFA Volume (million cubic feet)
2-yr	46.8	66.0	38.2
5-yr	58.2	81.0	56.7
10-yr	64.7	90.6	69.5
20-yr	NA	NA	81.9
25-yr	81.9	105.5	NA
50-yr	89.4	117.1	98.5
100-yr	121.6	128.3	111.0
200-yr	143.7	139.5	124.0
500-yr	163.0	154.2	142.0

The hydrologic analysis was refined using MIKE 21 within MIKEFLOOD to route the sub-watershed hydrographs and to reflect overland and floodplain storage. This was deemed important in the South Boulder Creek watershed because of the unique alluvial character of the drainageway below Eldorado Canyon and because of the public's demand for a comprehensive hydrologic study that reflected "actual" conditions in the watershed. As one would expect, the MIKE 21 representation resulted in a significant attenuation of flows. The MIKE 21 hydrologic analysis results are summarized in

Table 3-6, 100-year Routed Flow Summary Table. These flows reflect the regulatory flood flows and are the basis for planning studies.

TABLE 3-6
100 Year Thunderstorm Peak Hydrologic Discharges vs. Routed Hydraulic Peak Discharges (cfs)
Taken from Table 2, Hydraulic Modeling Report,(HDR December 30, 2008)

100 Year Thunderstorm Peak Hydrologic Discharges vs. Routed Hydraulic Peak Discharges (cfs)		
Location	**MIKE11 Hydrologic Model**	**MIKE21 Hydraulic Model**
Eldorado Springs	4520	4520
HWY-93	7120	6630
US-36	7690	7250
Baseline Road	8770	5010
Confluence	8910	4570

Alternate Hydrology

There have been several other studies completed recently that have developed hydrology for the West Valley. Because this Flood Mitigation Study focused on the West Valley flood problems, the focus of the review of these additional hydrologic studies was to compile flow rates for the C2 Basin. The C2 Basin is a large sub-basin to South Boulder Creek that primarily drains flow through the West Valley. Figure 3-2, South Boulder Creek Basin Delineation, displays the sub-basin location and shows the significance of the C2 Basin on the West Valley. The goal of reviewing the studies was to determine the most conservative flow rates for infrastructure design throughout the West Valley for storm flows ranging from the 5-year to the 500-year recurrence interval storms. The reports reviewed are listed below.

- *South Boulder Creek, Climatology/Hydrology Report*, HDR, CH2M HILL and DHI, February 6, 2007.
- *Technical Memorandum: South Boulder Creek Lower Urbanized Storm Center - 100 Year Flood Impacts, HDR, March 2007.*
- *City of Boulder Stormwater Master Plan*, HDR Engineering, June 2007

The South Boulder Creek *Climatology/Hydrology Report* (SBC Hydrology Report) developed a Basin Specific Design Storm (BSDS) thunderstorm centered over the South Boulder Creek watershed below Gross Reservoir in Eldorado Canyon that was used in the Flood Mapping Study. The location of the BSDS thunderstorm maximized the peak flow rates along the mainstem of South Boulder Creek. These flows were the focus of the alternatives outlined in this Master Plan Report. Flows in the C2 Basin for the BSDS Thunderstorm are relatively low because of the rainfall distribution pattern.

The Technical Memorandum*: South Boulder Creek Lower Urbanized Storm Center - 100 Year Flood Impacts*, (Lower Storm Center TM) presents a "Lower Storm Center" Design thunderstorm that moved an earlier iteration of the BSDS thunderstorm described above and centered it over the West Valley. This storm was only run for the 100-year storm event and was created to understand the impacts of a thunderstorm centered over the West Valley of South Boulder Creek and West Valley Neighborhoods. In general, the flow rates along the South Boulder Creek Mainstem generated by the Lower Storm Center Design Storm were less than the flows presented for the BSDS Thunderstorm. However, flow rates generated by the Lower Storm Center Design Storm were higher than the BSDS Thunderstorm for the C2 Basin. For the Lower Storm Center Design Storm, the C2 Basin flow rates were evaluated for use in this study.

Finally, the *City of Boulder Stormwater MP* developed a design storm based on Urban Drainage and Flood Control District criteria for the water quality, 2–year, and 5-year storms only. The Stormwater MP Design Storm was compared to the BSDS Thunderstorm. The design storms from both reports generally exhibited the same duration and developed similar runoff volumes to each other. However, the peak flows were different and the Stormwater MP flows were evaluated for use in this study.

West Valley and C2 Basin Hydrograph Loading

For the design of infrastructure improvements in the West Valley, the City has indicated that infrastructure needs to be adequately sized to convey the most conservative flow expected for the location. As described above, three studies were reviewed to determine the controlling hydrology specifically for the West Valley basin. This included the SBC Hydrology Study, the Stormwater MP, and the Lower Storm Center TM storms. Table 3-7 below identifies the flood recurrence interval that each study focused on.

TABLE 3-7
Recurrence Intervals Studied by Hydrologic Reports for the South Boulder Creek Watershed

Study	**Recurrence Interval Studied**							
	2-year	5-year	10-year	25-year	50-year	100-year	200-year	500-year
SBC Hydrology Report	NA	NA	X	X	X	X	X	X
Lower Storm Center TM	NA	NA	NA	NA	NA	X	NA	NA
City of Boulder Stormwater Master Plan,	X	X	NA	NA	NA	NA	NA	NA

Based on the review of the studies, the flow rates generated by the Regulatory MIKEFLOOD model, as reported in the SBC Hydrology Report, would control facilities related to mainstem flooding because there was insufficient information from the other studies to cover all the recurrence intervals required as part of this flood mitigation study. However, there were two additional specific conditions studied to determine the controlling flow rate.

1. Did the 5-year recurrence interval flow rates from the Stormwater MP exceed the flow rates from the Flood Mapping Study for the C2 Basin?
2. Did the 100-year recurrence interval flow rates from the Lower Storm Center TM exceed the 100-year flow rates from the Flood Mapping Study for the C2 Basin.

Comparable flow rates were taken directly from the Stormwater MP Hydrologic Models and the C2 Basin Loading points from the Flood Mapping Study. The Lower Storm Center TM developed one single flow for the entire C2 Basin. This flow was apportioned across the C2 Basin loading points utilizing ratios based on subwatershed areal contributions developed during the Flood Mapping Study.

Based on the review of the hydrology from the three studies for the C2 Basin the following rules were developed determining the use of hydrology for this Flood Mitigation Project.

1. If there was no overtopping of US-36, the flows from the Lower Storm Center TM controlled the 100-year flooding through the West Valley and C2 Basin. This essentially represented the local flood threat and was unrelated to the mainstem flows entering the West Valley.
2. If there was over topping of US-36, then the BSDS Thunderstorm from the Flood Mapping Study controlled the 100-year flooding through the West Valley and C2 Basin.
3. For recurrence intervals less than the 50-year flood, the 5-year flow rate from the Stormwater MP was found to be the largest controlling flow. Because it was the only published flow for small events in the West Valley, this 5-year recurrence interval C2 Basin flow loading was also used for the 10-, 25- and 50-year recurrence interval flows.

Hydrologic inflows, regardless of the study in which they were defined, were not the singular basis for facility sizing decisions in the Flood Mitigation Study. The hydraulics of the South Boulder Creek System was also considered in addition to the subbasin hydrologic loading. The hydraulic calculations are further described in Section 4; however, the interaction of floodwaters leaving the mainstem of South Boulder Creek and entering the West Valley can have a

profound effect on the peak flow rates and the sizing of infrastructure throughout the basin. This hydrologic analysis provided a foundation on which the hydraulics could be built and hydraulics and infrastructure sizing could begin.

Rather than recreate the rainfall/runoff computations, tributary hydrographs developed in both the Mapping Study and Stormwater MP were input into the hydraulic model. This reduced the computation time and assured that the inflow from the tributaries would remain unchanged from previous studies. Hydrographs were loaded into the main channel upstream of Hwy-93 and at five locations in the downstream watershed representing major sub-watersheds within the C2 basin. In addition, the overflows from Bear Canyon Creek that enter the basin via the new Anderson Ditch and the Wellman Canal were input into the hydraulic model.

An analysis of the tributary basin inflow hydrographs was completed to determine the most conservative peak flow loadings for each of the C2 Basin sub-loading points and overflows from Bear Canyon Creek. It was determined that for storms less than the 50 – year design storm for South Boulder Creek, the Stormwater MP flows were greater than the flows from the Flood Mapping Study and represented the most conservative flow estimate. For storms greater than the 50-year return period, the Mapping Study and Lower Storm Center tributary inflows controlled through the C2 Basin and were used for the 100-, 200- and 500-year return period. Figure 4-3, Tributary Basin Loading Points and Table 3-8, Tributary Basin Discharge Loading present the location of the C2 basin inflows and the peak values for a variety of storm events.

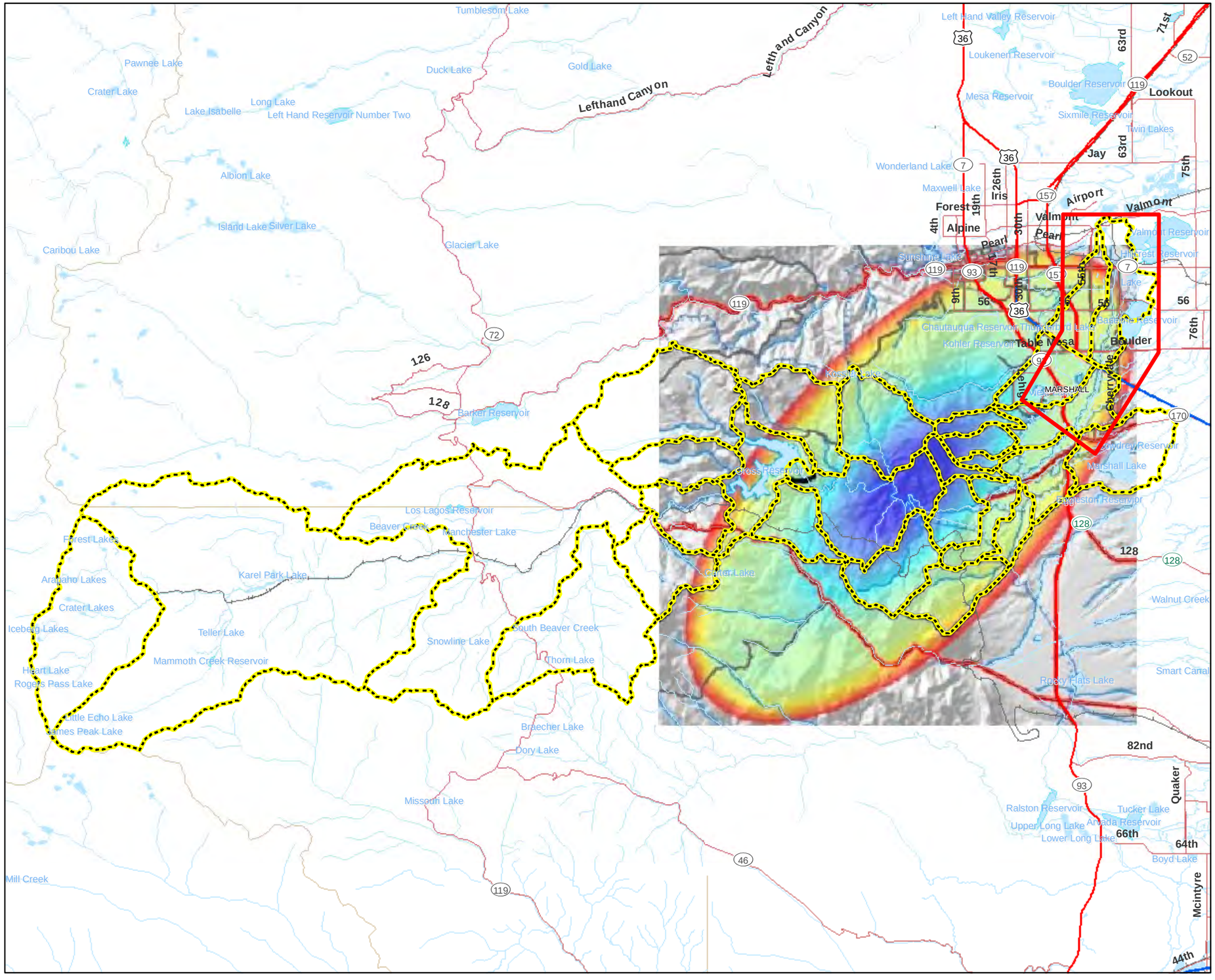
TABLE 3-8
Tributary Basin Discharge Loading

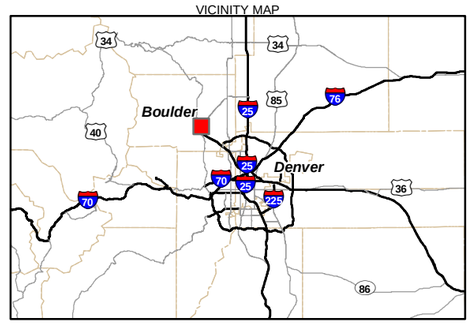
Sub-basin/ Loading Point	Intersection Location	[1]Q_2 (cfs)	[1]Q_5 (cfs)	[2]Q_{100} With US-36 Overtopping (cfs)	[2]Q_{100} Without US-36 Overtopping (cfs)	[2]Q_{200} (cfs)	[2]Q_{500} (cfs)
C2A	W. Moorehead Cir. and Viele Channel	70	110	700	920	700	700
C2B	Foothills Parkway and Baseline Road	120	180	140	190	140	140
C2C	Tenino Drive and Oneida Street	50	70	120	160	120	120
C2D	Arapahoe Avenue at Dry Creek Ditch No. 2	110	140	230	300	230	230
C2E	Dry Creek Ditch No. 2 South of Flatiron Parkway	100	130	70	90	70	70
Table Mesa Drive/ Bear Canyon Creek	Table Mesa Drive and South Loop Drive	50	80	110	110	110	110
Wellman Canal/ Bear Canyon Creek	Foothills Parkway and Colorado Avenue	60	80	200	200	200	200
C-2 Basin Total		450[3]	630[3]	1230[3]	1660[3]	1230[3]	1230[3]

[1] Values obtained from the *City of Boulder Stormwater Master Plan* completed by HDR in June 2007. These flow rates control for designs storms less than the 50-year recurrence interval for the West Valley.

[2] Values obtained from the *Climatology and Hydrology Report*, Completed by HDR, February 6, 2007

[3] Values do not include Bear Canyon Creek Discharges or any spills from the mainstem that will be considered in facility sizing





LEGEND

- South Boulder Creek Sub-Watersheds
- Primary Limited Access
- Primary US & State Highways
- Secondary State & County
- Railroads (150 to 50k)
- Rivers (150 to 50k)
- County Boundaries (150 to 50k)

South Boulder Creek Basin Specific Design Storm

Low: 0.00" of Rainfall

High: 4.00" of Rainfall

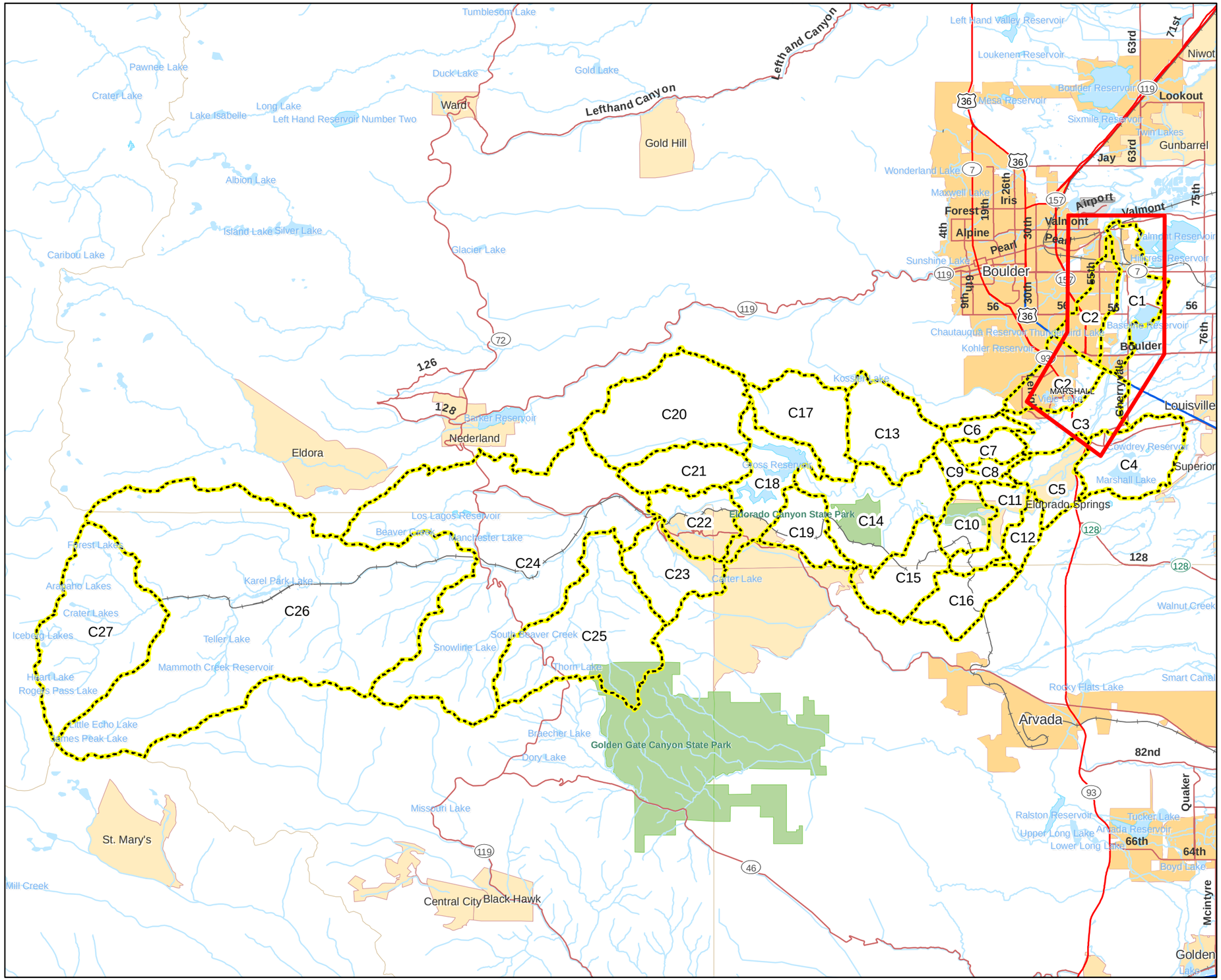
Notes:
1. Area of Interest

N

0 1 2 3 4
Miles

FIGURE 3-1
South Boulder Creek
Basin Specific Design Storm
South Boulder Creek Flood Mitigation Report

CH2MHILL



LEGEND

- South Boulder Creek Sub-Watersheds
- Primary Limited Access
- Primary US & State Highways
- Secondary State & County
- Railroads (150 to 50k)
- Rivers (150 to 50k)
- Airport Areas (150 to 50k)
- National Park - Forest
- State Park or Forest
- Local Park
- City Areas (5 to 3mil)
- County Boundaries (150 to 50k)

Notes:
1. Area of Interest

N

0 1 2 3 4
Miles

FIGURE 3-2
South Boulder Creek Basin Delineation
South Boulder Creek Flood Mitigation Report

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IV. Hydraulic Analysis

Hydraulic analyses were conducted along South Boulder Creek to determine the extent of the flood threat, the source of the threat and the performance of the existing infrastructure in response to large flood events. Much of the existing understanding of the flood hazard was established in the Mapping Study. The objective of the Flood Mapping Study was to define the flood problem, not solve it and included the development of a comprehensive two-dimensional floodplain model using MIKEFLOOD. This model is not only the basis of the regulatory floodplain but also serves as the foundation for the evaluations of various alternative flood mitigation measures.

The MIKEFLOOD analysis conducted as part of the Mapping Study used a coupled combination of a MIKE 11 one-dimensional (1-D) representation of major channels and culverts along the mainstem and its major tributaries and a MIKE 21 two-dimensional (2-D) representation of the overbanks and floodplain. This coupled model enables water to move between the channel and the overbank floodplain, simulating the actual hydraulic performance of the complete system. A more traditional simulation would limit the analysis to a 1-D representation of the channel and floodplain and may misrepresent the movement of water across the floodplain.

The 1-D analysis was limited to the channel and hydraulic structures along the mainstem and major tributaries where flow could reasonably be expected to flow parallel to the channel centerline. These areas were simulated using cross sections that were generally perpendicular to the direction of flow. While this approach is very consistent with the general standard of practice, the analysis in the Mapping Study did use the full hydrograph rather than the conventional steady state approach used in most studies. This was an important consideration along South Boulder Creek because of the significant interaction between the channel and the overbanks and the resulting floodplain storage. The more traditional steady state analysis does not consider the floodplain storage impacts that are so important in this watershed. The extent of the 1-D hydraulic analyses is shown on Figure 4-1, Area of Flood Mapping Study 1-D Hydraulic Model Analysis.

The 2-D analysis differs from the 1-D analysis in that it uses a network of pixels to represent the terrain rather than defining a series of predetermined flow paths. This 2-D grid consisted of over two million pixels, each representing an area four meters square. Figure 4-2, Graphic Extent of Flood Mapping Study 2-D Hydraulic Simulation Area. The 2-D hydraulic modeling approach addressed the concerns, expressed by the community during the Mapping Study, that the analysis not be skewed by preconceived notions of the problems and their cause. The use of the 2-D pixels enabled the model to predict the movement of water across the floodplain based on hydraulic and topographic conditions rather than being based on predetermined assumptions of how the water moved. The resulting floodplain delineation demonstrated a far more complex interaction between channel and floodplain than might have been predicted using a more conventional 1-D approach alone. The final MIKEFLOOD model used in the Mapping Study is commonly referred to as the Regulatory Model.

The analysis in the Mapping Study focused on the overall floodplain impacts based on the drainage system response and included the response of both the major 1-D elements that included drainage / irrigation ditches, streams and major culverts/bridges with a size greater than 36” in diameter, and the 2-D overbank areas outside of the 1-D elements. In addition, debris blockage was reviewed as part of the Mapping Study based on vegetative cover and potential for debris production for each stream reach. This was included in the MIKEFLOOD model and caused blockages of between 30% to 75% depending on structure and upstream conditions.

The city conducted a study of the existing drainage infrastructure to determine the ability of this system to handle minor floods. The Stormwater MP looked at minor storms and the capacity of the city’s infrastructure to handle these storms. The analyses and information provided in the Stormwater MP was not used directly in the hydraulic analysis but did provide a strong understanding of the minor system and the impacts on the larger flood events.

Evaluation of Existing Facilities

The hydraulic analysis used for this Study built on the foundation of the MIKEFLOOD analysis but limited the level of resolution and the geographic extent of the analysis. The details of the input necessary to execute a simulation are largely unchanged from the earlier study and are described in detail in the Flood Mapping Study *Hydraulics Report*. The primary change was to limit the extent of the analysis to that area included in the scope of this Study. The 1-D model was modified to limit the extent of the channels being evaluated to those below Hwy-93. The level of resolution and the details of the 1-D analysis were unchanged beyond the geographic extent. The 2-D simulation area was unchanged but the 2-D grid resolution was changed from a 4-meter grid to an 8-meter grid. This reduced the computational requirements by a factor of four, from nearly two-weeks for the 4-meter regulatory model to three days for the revised 8-meter grid model. Some minor changes in the linkage between the 1-D and 2-D models were required when the model gird was converted from the 4-meter grid to the 8-meter grid, but this did not materially affect the analysis. The resulting model (Coarse Grid Model) became the basis for all subsequent alternative evaluations including refinements to the recommended plan and creation of final benefit - cost ratio.

The hydraulic evaluation was initiated by using the Coarse Grid model to establish a new baseline flood condition that could be compared to the Regulatory Model. This assured that the difference in resolution between the 4-meter Regulatory Model and the 8-meter Coarse Grid model would not materially alter the representation of the floodplain. The reliability of the Coarse Grid model to represent the flood conditions was established. Some minor differences were noted but they generally tended to make the results of the Coarse Grid Model a bit more conservative. That is, the Coarse Grid model slightly overstated the flood hazard. This was determined to be appropriate for planning purposes.

South Boulder Creek Master Plan Hydraulic Evaluations

Hydraulic evaluations were conducted for each of the alternatives at each phase of project development. This included the Alternative Development Phase described in Section 5, the Conceptual Alternative Plan Development described in Section 6, and the development of the Best Alternative Plans described in Section 7. Given the varied nature of the alternatives and the different levels of evaluation used in each part of the planning process, a number of different techniques for conducting hydraulic analyses were used.

At the foundation, the hydraulic analysis is built on the regulatory MIKEFLOOD model developed during the Flood Mapping Study. This model provides a high level of detail and a clear understanding of the types of flood problems, their source, and the extent of the problem. Unfortunately, this model is extremely complex and unwieldy for use as a planning tool. The simulation times necessary to execute the regulatory MIKEFLOOD model run with its 4-meter gird size is approximately 2 weeks making the use of the tool for planning level evaluations impractical. The project team therefore developed alternative approaches to conduct hydraulic simulations of various stages of alternative evaluation.

A process was developed upon which project elements could be sized and evaluated outside of the MIKEFLOOD model. For the initial sizing and evaluation of independent project elements (Section 5 of this report) and the initial 15 Conceptual Alternative plans (Section 6 of this report), flows were obtained from the Regulatory 4-meter MIKEFLOOD Model as reported in the Hydrology Report, the Lower Storm Center TM and the Stormwater MP. These flows were evaluated to determine the most conservative flow rate for each return period and peak flow estimates along each of the main tributaries were developed. These peak flows were a combination of reported flows or summations of inflow peaks to create estimates of flow for the preliminary sizing of facilities. These initial flow rates are conservative in nature, as they do not reflect floodplain storage or the interaction of flood control elements. Although these flows are conservative, they provide a quick methodology for sizing alternatives and evaluating system performance outside of MIKEFLOOD. It was concluded this approximate approach was sufficient for the preliminary evaluation of alternatives and that a reasonable comparison of the alternatives could be conducted using this information.

A modified version of the MIKEFLOOD regulatory model was developed to support the analysis of the interaction between the various components of the 9 best alternative plans (Section 7 of this report). The regulatory MIKEFLOOD models used a 4-meter grid cell for the analysis. The modified model, named herein as the “Coarse Grid Model,” used an 8-meter grid cell in its analysis. The Coarse Grid Model was used to simulate the residual floodplain resulting from the various alternatives because the runtimes for this model were less than three days which was significantly less than the two week run times required by the regulatory model. The results of the Coarse Grid Model were reviewed and did not differ significantly from the flood plain depth and floodplain extents determined in the regulatory model. The Coarse Grid Model was also used to represent some of the other elements in the lower part of the watershed that might be influenced by flow from several sources including interchange between the mainstem and the West Valley that would have proven difficult to analyze using the more simplified tools.

Several alternatives rely on the storage and detention of floodwaters to control downstream flooding. A simplified version of MIKEFLOOD was developed to determine the volume of water required to be stored to eliminate the overtopping of US-36. This model herein named as the “Cut off Model “, was based on the 8 meter Coarse Grid Model and simulated the benefits of storage by computing the change in the inflow hydrograph above Hwy-93 as it moved downstream through the areas upstream of US-36 where regional detention might be practical. The model captured the complicated hydraulic flow pattern and timing and helped to size and refine possible storage locations but did not simulate flows below US-36.

Alternative Development Hydraulic Evaluations

In general, the flood control elements that were defined and sized as part of the Alternative Development were evaluated using simplified tools to establish the overall effectiveness of the alternative to address the flood threat in the West Valley. As such, specific elements of the alternative and the hydraulic performance and flow rates used to develop the alternatives might change with subsequent refinements and analyses. In fact, the complexity and interaction between some of the improvements and the floodplain suggest that further changes to specific assumed flow rates based on subsequent more detailed evaluations is inevitable. However, the level of the evaluation was determined to be sufficient to understand the overall element performance, to allow comparisons between alternatives and to make decisions about which alternatives should be taken forward for additional evaluation.

The United States Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) Version 5.0, Bentley CulvertMaster, and Bentley FlowMaster were used to conduct simplified hydraulic analyses of infrastructure downstream through the floodplain. SWMM and FlowMaster were used to simulate bridges and open channel systems that could be represented as simple 1-D flow elements. CulvertMaster was used to understand the performance of culverts and other roadway crossings. These tools lacked the resolution of the MIKEFLOOD simulation but served to determine facility size and the relative impacts of localized capacity improvements on the overall system.

The representation of underground conveyance systems and simple elements farther down in the watershed was accomplished using SWMM. SWMM has a similar hydraulic analysis engine to MIKEFLOOD. SWMM can simulate unsteady flow and provide the ability to link systems and elements and route flow more accurately than FlowMaster and CulvertMaster. SWMM also has the capability of routing flows through storage elements and determining the impacts to downstream flow that result. This capability in SWMM was used to test and evaluate some of the local detention facilities and proposed infrastructure identified.

Together, these tools facilitated the evaluation of alternative elements relatively quickly and efficiently. Using the evaluations of the various plan elements to better understand the floodplain impacts, the various components were assembled into Alternative Plans. These Alternative Plans were eventually incorporated into the Coarse Grid Model version of MIKEFLOOD to confirm performance consistent with earlier assumptions. In some cases, refinement of the alternatives was necessary to achieve the level of performance desired. This refined Coarse Grid MIKEFLOOD model became the basis for the determination of project benefits and the visual representation of the residual floodplain.

Conceptual Plan Hydraulic Evaluations

In general, Conceptual Alternative Plans were evaluated using the previously developed MIKEFLOOD evaluations for existing conditions, as well as the simplified modeling tools discussed in Section 5. The understanding of the existing conditions allowed the team to identify more simplistic tools to size the facilities and to estimate residual flood extents. The Coarse Grid MIKEFLOOD Model was used to establish the flow distribution across the floodplain.

Sizing of Conveyance Facilities

Because of the complex nature of the flooding along South Boulder Creek, it was necessary to combine and sum flow rates from the Coarse Grid MIKEFLOOD Model grid cells along existing flood prone conveyance channels to define a flow along each of the established sub-reaches. The results of this analysis are presented in Table 4-1, Design Flows by Sub-Reach. This table provides a summary of the 100-year design flow target for improvements along specific conveyance channels and corridors throughout the South Boulder Creek floodplain.

TABLE 4-1

Design Flow by Sub-Reach

Profile	Reach	100-Year Peak Flow
West Valley	US-36 to Baseline Road	1,259
West Valley	Baseline Road to Wellman Canal	1,137
West Valley	Wellman Canal to Arapahoe Avenue	1,350
West Valley	Below Arapahoe Avenue	371
Dry Creek No. 2 Ditch	US-36 to Baseline Road	695
Dry Creek No. 2 Ditch	Baseline Road to Wellman Canal	389
Dry Creek No. 2 Ditch	Wellman Canal to Arapahoe Avenue	2,844
Dry Creek No. 2 Ditch	Below Arapahoe Avenue	2,038

Sizing of Storage Facilities

Storage facilities were sized based on volume and discharge information determined during the development of the “Cut-off Model.” Storage facilities were evaluated for a variety of recurrence intervals. The Flow rates reported in Table 4-2, West Valley Peak Flow Rates For Preliminary Sizing of Storage Facilities, differ from those reported in Section 3 because they represent the summation of overflows from US-36, flows in Dry Creek No. 2 Ditch and overflows from the South Boulder Creek Channel that enter the West Valley between the Wellman Canal and Arapahoe Road. Overflows were estimated from the "Cut-off Model", but because it did not include areas below US-36, needed to be combined with the C2 Basin loading points. Both the overflows from the Cutoff Model and the Loading points from the C2 basin are summed in the downstream direction to produce conservative estimates of expected flows at the defined locations to size prospective detention facilities.

TABLE 4-2

West Valley Peak Flow Rates For Preliminary Sizing of Storage Facilities

	Peak Flow (cfs)				
Intersection Location	[1]Q_2 (cfs)	[1]Q_5 (cfs)	[2]Q_{100} (cfs)	[2]Q_{200} (cfs)	[2]Q_{500} (cfs)
W. Moorehead Cir and Viele Channel	120	190	810	810	810
Foothills Parkway and Baseline Road	120	180	1390	1810	2020
Tenino Drive and Oneida Street	280	370	1410	1970	2280
Arapahoe Avenue at Dry Creek No. 2 Ditch	690	890	4100	5360	6230
Dry Creek No. 2 Ditch South of Flatiron PKWY	790	1020	4170	5420	6300

[1] Values obtained from the 5-year storm event from the *City of Boulder Stormwater Master Plan* completed by HDR in June, 2007 and are summed with flow rates from the "Cut-Off Model". These produced conservative flow rates for detention facilities.

[2] Values obtained from the *Climatology and Hydrology Report*, Completed by HDR, February 6, 2007 and are summed with flow rates from the "Cut-Off Model." These produced conservative flow rates for detention facilities.

Each Alternative plan was evaluated for the potential benefits associate with the proposed improvements. The nature of flooding along South Boulder Creek, particularly in the West Valley, which was the focus of the mitigation efforts, is such that minimal damages occur throughout the West Valley during more frequent flood events. It is not until US-36 is overtopped that increased damages and flooding are experienced in the West Valley. Since this occurs around the 100-year event, the sizing of infrastructure for control of events less than that resulted in very small facilities that provided

little benefit during the larger storms. The resulting benefit to cost ratio was small and would render the improvements unattractive. As such, the Project Sponsors concluded that alternatives should be sized to control the 100-year flood and evaluate the benefits and effects on the larger 500-year storm, with the exception of the alternative specifically intended to provide the improvements identified in the Stormwater MP.

At this stage in the evaluation, the distinction between open channel conveyance and underground conveyance was not critical unless some other constraint drove the determination. Preliminary alignments were chosen based on available corridors using parcel data provided by the city and the County. Every effort was made to define alignments down public rights of way so that public impacts would be minimized.

The sizing of the flood storage facilities also relied on information derived from the Course Grid or Cut-Off MIKEFLOOD model results. Here, rather than merely determining the peak flow, it was also necessary to determine a hydrograph and total volume of flow to the area in question. This was specifically necessary when considering the alternatives that had storage upstream of US-36.

Best Alternative Plan Hydraulics

Best Alternative Plans were looked at more carefully than previous analysis of the alternatives described in the Alternative Development and Conceptual Alternative Analysis, both in terms of the refinement of system elements and in the hydraulic evaluations. The Best Alternative Plans utilize the MIKEFLOOD "Coarse Grid" model exclusively to model and optimize each plan. Using MIKEFLOOD analyses of the alternatives were more comprehensive and provided a more refined understanding of the system performance, flow rates expected for each flood mitigation system and the resulting floodplain extent. This proved to be particularly true for the detention alternatives where the MIKEFLOOD tool provided a much better understanding of the complex interaction between the South Boulder Creek channels, the floodplain, and the storage facilities. This more refined approach also provided data used to update and refine the size of facilities based on the routed flow rates from the model, refine the damage estimates, and allowed the team to refine and update the benefit cost analysis.

Storage facilities were simulated in MIKEFLOOD with a relatively high level of resolution. This was necessary because of the complex interaction of flows between the various sub-reaches of the system and because of the severe constraints that were identified around most of the storage options. While a conventional analysis of storage options would allow the simple development of stage, storage and discharge functions, MIKEFLOOD, and the site conditions around each of the storage elements made this typical evaluation process inadequate. Rather, a detailed grading plan was necessary at each site so that the facility could be adequately represented in the model. Grading plans for each site can be found in Appendix D

The storage facilities near Hwy-93 proved to be complex. These storage facilities capture overflows over Hwy-93 and delay their return to the mainstem. While these storage facilities are of considerable size, the value of the detention comes from the impacts on hydrograph routing and timing more so than the actual storage of water. The flow passing through the storage facility during the early stage of the hydrograph is returned to South Boulder Creek through a large weir un-detained. However, the storage facility near Hwy-93 begins to detain flow during the peak of the South Boulder Creek hydrograph. This detention prevents the overtopping of US-36 by reducing the peak flow at US-36. This storage area consists of two areas, which, in combination, provide the necessary control. The layout of these storage areas was based on some, but minimal, excavation and the construction of relatively high embankments. Concept Plans for this detention alternative can be found in Appendix D

Storage at US-36 was more straightforward but had some unique complexities. The layout was intended to maximize the storage and minimize impacts to CU property and to Open Space land. A combination of excavation and fill were incorporated into the storage footprint. The existing Viele Pond was incorporated into the refinements made at this stage of the evaluation to attempt to maximize the existing storage areas. The operation of this system proved to be very sensitive to outflow and several refinements were necessary to achieve the desired performance.

Lower basin storage such as the storage at Manhattan Middle School was incorporated into the MIKEFLOOD model with little difficulty. The outfall from these facilities was optimized to provide the maximum benefit and to minimize the need to replace existing downstream infrastructure.

The storage associated with the Distributed Regional Detention presented challenges similar to Hwy-93 storage. These facilities included a combination of mainstem and off channel storage that had complex interactions during flood events. A careful review of flood hydrographs from the Coarse Grid MIKEFLOOD model at key locations throughout the project area and a review of physical constraints allowed the modeling and optimization of the timing of capturing and releasing flows to downstream detention facilities. These facilities were used to mitigate and improve flooding conditions throughout the West Valley by preventing the overtopping of US-36 and controlling and reducing peak flows along the mainstem of South Boulder Creek.

The incorporation of underground pipes and large open channels into MIKEFLOOD is complex and time consuming. However, the benefits of these facilities needed to be characterized so that reasonable determinations of the reduction in flood threat could be conducted. The process for representing these facilities in the MIKEFLOOD model was to adjust the surface flow rate. This was done within MIKEFLOOD by creating a "sink" where flow leaves the system. A physical analogy for this would be that the "sinks" represent inlets that take flow from the surface of the model and into the pipe or large open channel. This simplification provided a realistic representation of the system and enabled the model to establish the character of residual overland flows that might cause flood damage.

The results of the more detailed hydraulic evaluations for the Best Alternative Plans resulted in considerable refinement of the storage areas but only nominal changes to the conveyance facilities. The model did provide a better understanding of the nature and extent of the residual floodplain, particularly in areas in the lower part of the watershed along the mainstem. Figures 7-1 through 7-9 include the results of the hydraulic evaluations conducted for each of the Best Alternate Plans using MIKEFLOOD.

Flood Hazards

Flood hazards in the South Boulder Creek watershed are clearly articulated in the reports prepared as part of the Mapping Study. These hazards were confirmed using the Coarse Grid model. Only very small storms stay confined to the channel, storm drain systems or within the street right of way. Other events quickly exceeded the capacity of the conveyance areas and spread into the overbank. The 2-D model effectively identified how much water left the channel and where it went.

The existing conveyance infrastructure throughout the West Valley includes both open channel conveyance and closed conduit conveyance. As described earlier the west valley can be broken down into three major flow profiles and existing irrigation ditch channels. During the flood mapping study, 1-D channels were selected for modeling based on one or more of four criteria.

1. channels with significant hydraulic capacity; in excess of 1,000 cfs,
2. channels with hydraulic capacity that were wholly or partially outside of the 2D model domain
3. channels which the resolution of the 2D topography did not resolve adequately or
4. channels that had hydraulic structures on them, i.e., bridges, culverts, or diversion gates.

For additional information on how 1-D elements were selected for modeling for the South Boulder Creek Flood Mapping Study please see Appendix C of the *South Boulder Creek Hydraulic Modeling Report, HDR, December 30, 2008.*

Irrigation Ditches/Channels

Several irrigation ditches cross the South Boulder Creek floodplain. These irrigation ditches are hydraulically linked to the South Boulder Creek floodplain and are still in use delivering water to customers throughout the West Valley. Figure 4-1 displays the 1-D modeling domain in MIKEFLOOD and the modeled 1-D channels.

Anderson Extension Ditch

This ditch parallels Table Mesa Drive and South Boulder Road to the south. The ditch originates on Bear Canyon Creek at the intersection of Table Mesa Drive and Broadway west of the project area. This ditch is currently operated by the Baseline Reservoir stakeholders and has an active decree flow of 50 cfs. This channel intercepts overflows from South Boulder Creek near the Table Mesa – Foothills Parkway Interchange for flood ranging from the 25-year recurrence interval through the 500-year recurrence interval and again north of the interchange from the overtopping of US-36

during flood greater than the 100-year flood. The capacity of the ditch is exceeded when the floodwaters enter the channel during the 100-year flood. This channel was not modeled in the 1-D model because it conveyed flow less than 1,000 cfs. However, the culverts along the Anderson Extension Ditch were determined to be hydraulically significant and were added to the 1-D modeling domain for the Mapping Study MIKEFLOOD model. A loading point was used at the southeast corner of the Table Mesa Drive and US-36 and was included in the 2-D modeling domain.

Dry Creek No. 2 Ditch

This ditch runs south to north roughly parallel to 55th Street through the West Valley. This channel is a remnant of the South Boulder Creek alluvial fan channel system prior to development. Currently the ditch diverts water near Eldorado Springs south of the project area, runs north through Marshall and the South CU Campus. The ditch is conveyed through a 6' x 4' Reinforced Concrete Box Culvert (RCBC) under US-36 and then enters the West Valley. Currently this ditch has three remaining shareholders north of US-36 that include Manhattan Middle School, Flatirons Golf Course, and a private owner in the Flatirons Industrial Park. The active decree for the ditch is 69 cfs. This ditches' capacity is overwhelmed during the 25 year and 50 year recurrence intervals due to local basin inflows including C2 basin loadings at Manhattan Middle School and inflows from the Wellman Canal. The 100-year overflow of US-36 by South Boulder Creek enters Dry Creek No. 2 Ditch and overwhelms the entire capacity of the ditch for storms greater than the 100-year storm.

Wellman Canal

The Wellman Canal is owned by Xcel Energy and flows from west to east from Boulder Creek south of Arapahoe Road to Valmont Reservoir. This ditch delivers decreed flows to the Xcel operated Valmont Power plant for cooling processes. The Wellman Canal was not modeled in the 1-D, due to the general lack of hydraulic structures and the low flow rates normally conveyed by the channel. This canal was captured in the 2-D model domain.

This ditch is aligned perpendicular to Bear Canyon Creek, South Boulder Creek, and Dry Creek No. 2 Ditch and intercepts flood flows from all of these channels, which quickly overwhelm the channel capacity from storms as small as the 25-year storm. The total decreed flow for the Wellman Canal is 819.2 cfs, which is the sum of the decreed flows from South Boulder Creek, Skunk Creek, and Bear Canyon Creek. Much of this water does not enter into the Wellman Canal and is delivered to the Valmont Reservoir through flow exchanges with various water holders throughout the basin. The total decreed flow from all water sources would exceed the capacity of the existing channel, which has a current capacity of approximately 80 cfs maximum. Xcel energy would prefer that the existing capacity of the ditch be maintained in review of any alternatives that impact the Wellman Canal

Viele Channel

The Viele channel runs generally from west to east parallel to Table Mesa Drive, crosses through culverts through the Foothills Parkway interchange and then parallels South Boulder Road on its way to South Boulder Creek. This channel intercepts South Boulder Creek floodwaters near South Boulder Road but is also the source of local sub-basin flows that contribute to the flooding of South Boulder Creek. This channel is not an irrigation channel but a natural conveyance channel and has an approximate capacity of 500 cfs. This channel did not meet the 1,000 cfs criteria for modeling in the 1-D MIKEFLOOD modeling domain. However, the culvert structures did meet the criteria and the Viele Channel culverts were added in as 1-D elements for the MIKEFLOOD regulatory model.

Enterprise Ditch

The Enterprise ditch has its head gates at South Boulder Creek just downstream of South Boulder Road. This ditch carries water northeast north of Baseline Reservoir. This ditch primarily crosses open space and is completely overwhelmed by the flood flows from South Boulder Creek. Flows that enter this ditch either spill from its banks back into South Boulder Creek or continue along the conveyance removing flow from the South Boulder Creek Floodplain. This ditch is primarily located in Boulder County and was not a focus of this current study.

Scherer Ditch

The Scherer Ditch runs generally northeast east of South Boulder Creek and crosses US-36 near Cherry Vale Road. The head gates of this ditch are located just north of HWY -93. Flows that enter this ditch are conveyed away from South Boulder Creek and do not have a chance to re-enter South Boulder Creek. Due to capacity-limited culverts near US-36 Land adjacent to the highway is expected to see shallow flooding during a 100-year event. This ditch is primarily located in Boulder County and was not a focus of this study.

Local Storm Drainage

Local storm drainage facilities through the West Valley generally flow from south to north and rely on existing irrigation ditches to help convey flood flows through the area. Below is a detailed description of the existing local storm drainage through each neighborhood within the Study Area as well as a reach-by-reach description of the local storm drainage infrastructure. For a detailed description of the local storm drainage infrastructure, please see the HDR Engineering, Inc. *Volume 1 - Final Report City of Boulder Stormwater Master Plan*. Boulder (2007).

Keewaydin Neighborhood

In this neighborhood east of Foothills Parkway and north of South Boulder Road, the existing storm sewer infrastructure generally takes water from the neighborhood west to the storm sewer trunk line that parallels Thunderbird Lane west of Foothills Parkway. Storm sewer in the area is generally less than 27" in diameter and conveys nuisance flows. This storm drain infrastructure was not included in the MIKEFLOOD model that was completed for the flood mapping study. The flood conveyance is generally south to north through this neighborhood and the existing storm sewer has little impact on the 100-year flood.

Frasier Meadows Neighborhood

The Frasier Meadows Neighborhood lies just to the west of Foothills Parkway. This neighborhood is impacted by the overflow of US-36 by South Boulder Creek. Existing storm sewer infrastructure leads to a trunk line under Thunderbird Lane. This trunk line accepts flows from both the Frasier Meadows Neighborhood and the Keewaydin Neighborhood. The maximum pipe diameter is 48" and discharges into detention ponds at the corner of Foothills Parkway and Baseline Road. These systems are overwhelmed by the overtopping flows from South Boulder Creek. This pipeline was not included the 1-D MIKEFLOOD model due to the limit capacity of the pipe and the potential for debris blockage.

Park East Neighborhood

The Park East Neighborhood is north of Baseline Road and East of Foothills Parkway. This neighborhood is flooded by the West Valley flooding from Baseline Road. There is not any storm sewer through this neighborhood except along Pennsylvania Avenue on the north edge of the neighborhood. This storm sewer intercepts flow and takes it east to Dry Creek No. 2 Ditch and the Wellman Canal. The maximum size of the storm sewer is 36" in diameter and is overwhelmed by the 100-year flood flows. This pipeline was not included the 1-D MIKEFLOOD model due to the limit capacity of the pipe and the potential for debris blockage.

Arapahoe Ridge Neighborhood

The Arapahoe Ridge Neighborhood is located north of the Wellman Canal and East of Foothills Parkway. This neighborhood is flooded by the West Valley flooding from the Wellman Canal. Storm sewers in the area generally take flow north across Arapahoe Avenue and Boulder Creek or east to the Flatirons Golf Course and Dry Creek No. 2 Ditch Drainage. The maximum size of the storm sewer is 45" and is on average 24" in diameter. The storm sewer is overwhelmed by the 100-year flood flows. This pipeline was not included the 1-D MIKEFLOOD model due to the limit capacity of the pipe and the potential for debris blockage.

Flatirons Industrial Park

This is the final area prior to South Boulder Creek discharging to Boulder Creek. This area is north of Arapahoe Road and east of Foothills Parkway. Storm sewers in this area are generally small and drain most of the flow to Dry Creek No. 2 Ditch that is the main stormwater conveyance through the area. Storm sewer mains can reach a maximum size of 60" x 36" RCBC but are on average 24" in diameter. This system helps alleviate flooding through the Industrial Park but still is overwhelmed by flooding from South Boulder Creek. This pipeline was not included the 1-D MIKEFLOOD model due to the limit capacity of the pipe and the potential for debris blockage.

Flooding Problems

Flooding problems through the West Valley are generally caused by uncontrolled overtopping of US-36 into the West Valley as identified in the Flood Mapping Study. However, additional sources of flooding also occur within the West

Valley. A reach-by-reach description of flooding issues follows, and Figure 2-4, Reach Description, graphically displays each reach described below.

Reach 1

South Boulder Creek exceeds the conveyance capacity of its channel at the very upstream of this study reach near Hwy-93. Here, both the channel and the Hwy-93 crossing of the South Boulder Creek mainstem are undersized. Flood flows in excess of the 10-year flood spread to the west and north behind Hwy-93, overtop the highway, and inundate Marshall Road, eventually reaching the CU levee and being directed back toward the mainstem. The CU levee effectively protects the area of the South Campus and, in combination with the mainstem and Dry Creek No. 2 Ditch conveys flows toward US-36.

The channel upstream of US-36 is inadequate to convey the full flood flows under US-36. While the bridge is adequate to convey the full 100-year flood, only a small fraction of that flow remains in the channel. Flows in excess of the upstream channel capacity spill to the west and flow along the south side of the US-36 right of way toward the Viele Channel and the Foothills Parkway interchange. The water spreads out behind US-36, inundating portions of the CU property and spilling into the pond on the Viele Channel. For storms smaller than the 50-year event, the flood flows are generally confined to the upstream side of US-36. Storms in excess of the 50-year overtop US-36 and spill into the West Valley, flowing north along Foothills Parkway.

Reach 2

Flows from the local tributary sub-watershed contribute to the flood hazard along South Boulder Creek. The primary sub-watershed of concern (Sub-watershed C2) is to the west of the mainstem and consists of highly urbanized areas of South Boulder. During the Mapping Study, the C2 sub-watershed was further subdivided into five areas and the inflows were added into the hydraulic model at points that represent the natural drainage patterns as shown on Figure 4-3. Inflows from the Bear Canyon Creek watershed are also accounted in the model. These tributary inflows create a flood hazard that is independent of the mainstem flood issues. It was the intent of this study to mitigate the effects of flooding from the South Boulder Creek mainstem only and not address localized flooding caused by local basin inflow flooding. While smaller in nature than the large floods associated with the mainstem, these have the potential to create damages. As is expected, the extent of the flooding associated with these tributary inflows increases as the storm intensity increases. Most of the flooding within the areas west of the mainstem associated with these inflows is localized and the result of undersized street and drainage system capacity.

Reach WV2

The flood threat in the West Valley is greatest when US-36 overtops during events in excess of the 50-year flood. The overflows from US-36 generally follow the alignment of Foothills Parkway, initially concentrated on the west side of the Foothills Parkway roadway. These flows are significant and would cause extensive damage along Thunderbird Drive all the way to Baseline Road. In addition to the flooded areas, there are two structures located within the city's designated High Hazard Zone in this reach. Some buildings and facilities designated by the city as critical are also in the floodplain in this reach.

Reach DC2

The Dry Creek No. 2 Ditch corridor is the source of considerable flooding below US-36. This conveyance is part of the primary outlet for the ponded water above US-36. As the water from larger floods passes under the highway through Dry Creek No. 2 Ditch, the Anderson Extension, and Viele Channel, it exceeds the combined capacity of these systems at South Boulder Road. Water overtops South Boulder Road and flows through the neighborhoods west of Dry Creek No. 2 Ditch. Water generally follows the street corridors and causes some localized flooding when street and drainage system capacity are undersized.

Reach M2

Mainstem flows that make their way under the US-36 crossing continue to exceed the capacity of the South Boulder Creek channel. This water spreads out above South Boulder Road and overtops the road, creating two flow paths, one along the mainstem and another along the alignment of the New Anderson Extension and Enterprise Ditch. These two flow paths recombine at Baseline Road. There are additional overflow paths from the mainstem just north of the East Boulder Recreation Center that continues to the north across undeveloped land. A portion of the flood flows are diverted out of the basin and flow toward Baseline Reservoir. The details of that flow are provided in the Mapping Study *Hydraulic Modeling Report* (HDR, December 30, 2008)

Reach 3

Between Baseline Road and the Wellman Canal (approximately Colorado Avenue extended) the flood hazard continues to be most significant for properties located along roadways used as the primary conveyance and for areas adjacent to the mainstem.

Reach WV3

The flows from the upstream reaches of the West Valley are exacerbated by inflows from portions of the C2 basin joining at Baseline Road and Foothills Parkway. The combined flows overtop Baseline Road and flow through the neighborhood along McIntyre Street and Brooklawn Drive. Homes along these streets and the adjacent and interconnecting roadways are subject to flood threats as the capacity of the street and drainage system is exceeded. A portion of the flow remains west of Foothills Parkway and is diverted over to the Bear Canyon Creek watershed. These flows are generally confined to the road right of way and do not pose a significant hazard to residential or commercial properties.

Reach DC3

Dry Creek No. 2 Ditch in this reach is generally adequate to convey all but the most extreme flows. There are a few locations where the ditch capacity is exceeded and minor inundation occurs adjacent to the channel. The lower part of the reach, there is an inflow from the West Valley overflow that occurs near 55th Street and Pennsylvania Avenue that cause flooding of Dry Creek No. 2 Ditch into the surrounding neighborhood and the Wellman Canal.

Reach M3

The mainstem floodplain is broad in this reach extending from Gaptor Road on the east across Open Space land, almost reaching Meadow Glen Drive. Fortunately, with the exception of homes along Gaptor Road, there is very little hazard to properties other than Open Space.

Reach 4

Below the Wellman Canal (approximately Colorado Avenue extended) the floodplain from the various tributaries begin to converge. At Arapahoe Avenue, the minor storms continue to have distinct areas of flooding but as the flood flows increase, the flood flows join and form one large area of ponding above Arapahoe Avenue.

Reach WV4

There is limited infrastructure along this reach and flows quickly exceed the capacity of the roadway and the minor drainage system. Residential flooding along the street is common and the properties adjacent to Arapahoe Avenue are subject to considerable hazard for all but the smallest events. The portion of the flow that remains west of Foothills Parkway and is diverted over to the Bear Canyon Creek watershed begins to spread outside the right of way to the west before reaching Boulder Creek. Flood flows near the confluence of Bear Canyon Creek and Boulder Creek do not pose a significant hazard to residential or commercial properties.

Reach DC4

Dry Creek No. 2 Ditch in this reach enters the Flatirons Golf Course where flood flows spread out over the golf course in shallow overland flooding. These flood flows have limited impact to the structures on the property. The Clubhouse is elevated above the 100-year flood. Minor damage and the resulting repair to the golf course would be expected during large floods. Flood flows spread out west of the channel and affect a few properties along Arapahoe Avenue. Once flows reach Arapahoe Avenue, they combine with flows from the West Valley and the mainstem to form a large pool upstream of the roadway.

Reach M4

The mainstem floodplain is broad in this reach extending from the back yards of homes along Gaptor Road across the Flatirons Golf Course to the west. Much of the flood flows are confined to the channel but also extend to the golf course

and can begin doing damage to residences along Old Tale Road and Gaptor Road during the 10-year flooding event. Damages across the golf course are negligible. Once flow reaches Arapahoe Avenue, the floodwaters combine with the flow from the West Valley and Dry Creek No. 2 Ditch to form a large pool upstream of Arapahoe Avenue.

Reach 5

South Boulder Creek below Arapahoe Avenue is characterized by large tracts of commercial and industrial properties with a broad floodplain but significant conveyance capacity. Nevertheless, there is considerable flood hazard as flood waters flow overland before reaching these large channels.

Reach WV5

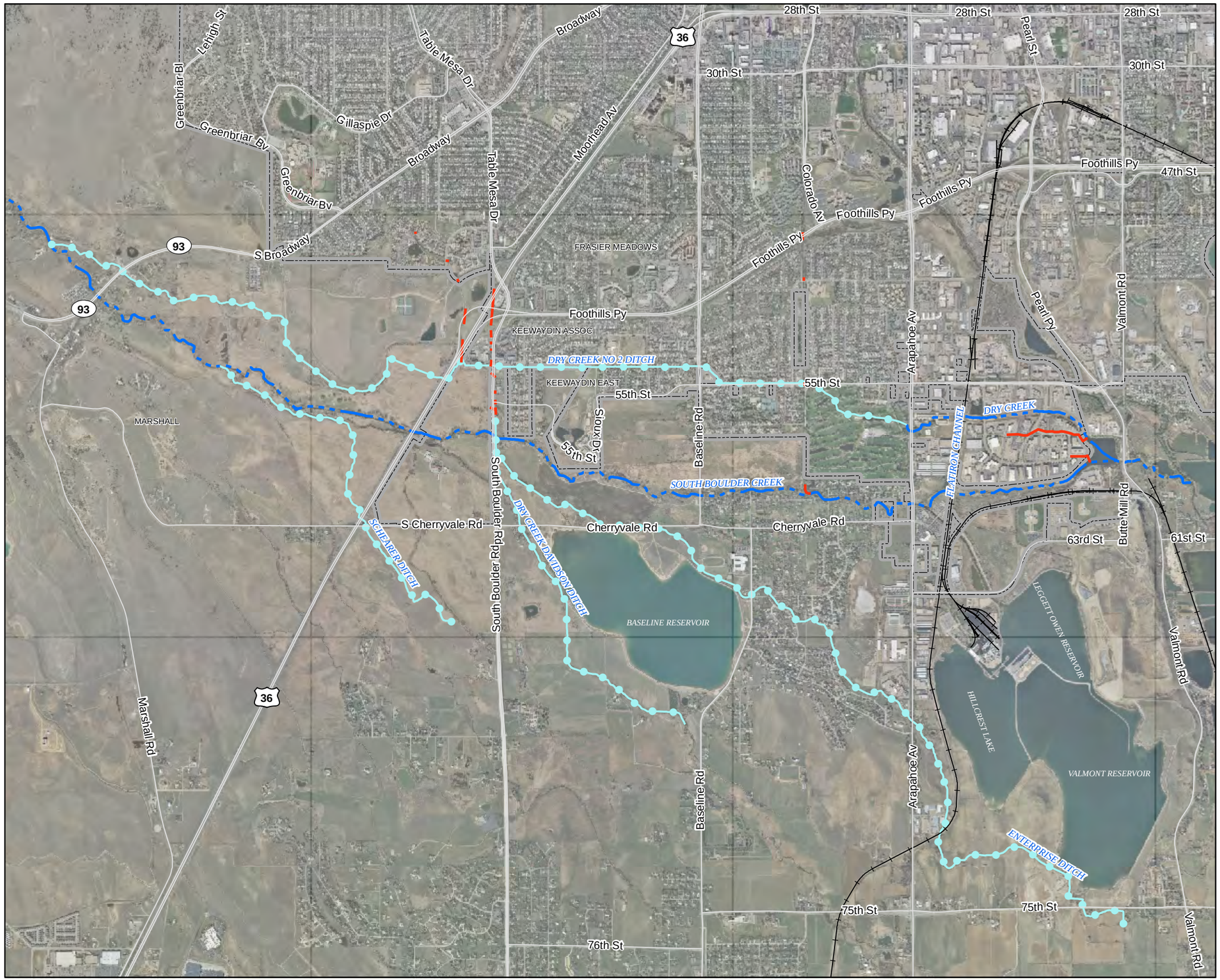
There is limited infrastructure along this reach and flows never return to South Boulder Creek. Rather, they flow north down roadways and through developed properties south of the railroad tracks. Once at the tracks, the flow diverts and flows directly to Boulder Creek west of the Roche property or along 55th before reaching Boulder Creek.

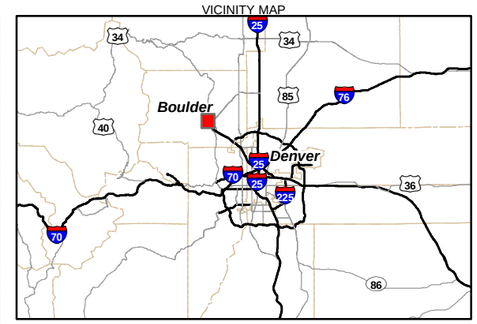
Reach DC5

Dry Creek No. 2 Ditch in this reach has a somewhat limited capacity between Arapahoe Avenue and the railroad. There is a relatively broad floodplain extending both east and west from the channel and inundating several properties. Once the Dry Creek Ditch No. 2 channel has crossed the Burlington Northern railroad, the channel capacity increases dramatically over upstream capacity and flood flows entering the channel are conveyed to Boulder Creek without exceeding the capacity of the channel. The railroad serves to concentrate and collect flow and the floodplain downstream is smaller. Areas within the Flatirons Industrial Park are subject to some elevated flood threat during events that exceed the capacity of the channel.

Reach M5

The mainstem of South Boulder Creek between Arapahoe Avenue and the railroad is similar to that of DC2 in that it has a limited capacity but there is limited impact because of undeveloped parcels. The overtopping of Arapahoe Avenue does create a broad flood threat to the business and industrial area to the north of Arapahoe Avenue. At the railroad, flow is once again concentrated and flows under the tracks and into the main channel. A cross channel between Dry Creek No. 2 Ditch and the mainstem is undersized and cannot effectively balance flows between the two conveyance channels. This results in flows during larger events flowing into the Flatirons Industrial Park. At Valmont Road, South Boulder Creek, flows join those in Boulder Creek.





LEGEND

1-D Modeled Channels

- 1-D Modeled Streams
- 1-D Modeled Irrigation Ditches
- 1-D Modeled Culverts & Storm Sewers
- Boundary County

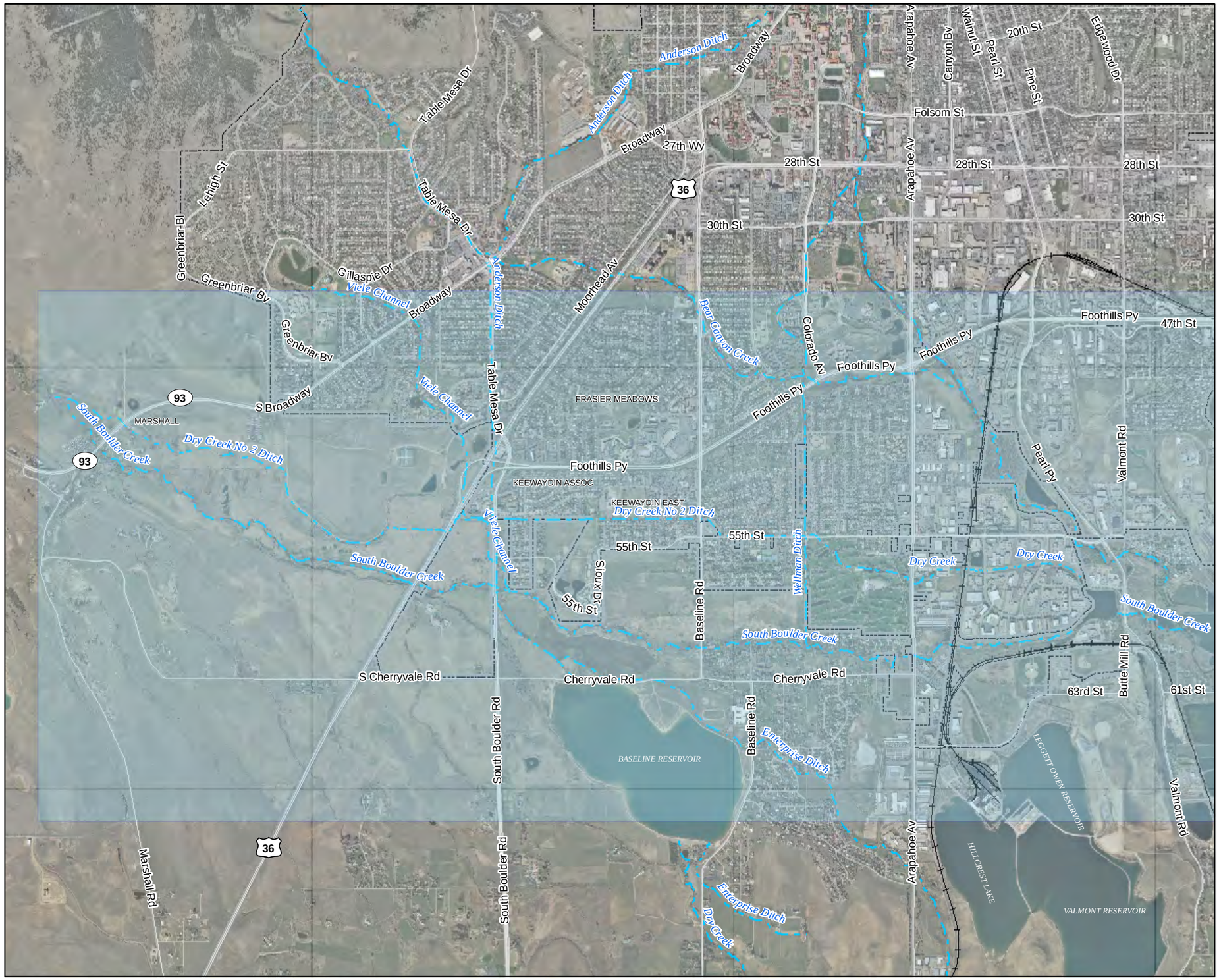
N

0 1,000 2,000 3,000 4,000 5,000

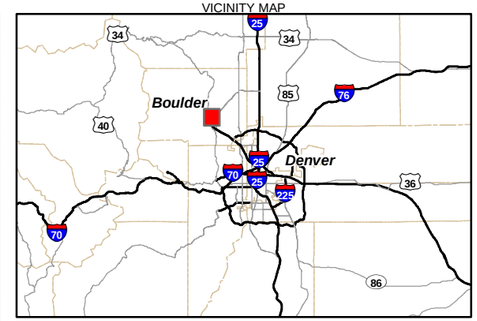
Feet

FIGURE 4-1
Graphic Extent of Flood Mapping Study 1-D Hydraulic Simulation Channels
South Boulder Creek Flood Mitigation Report

CH2MHILL



VICINITY MAP



LEGEND

- 2-D Model Domain
- Streams, Creeks and Ditches
- Boulder County

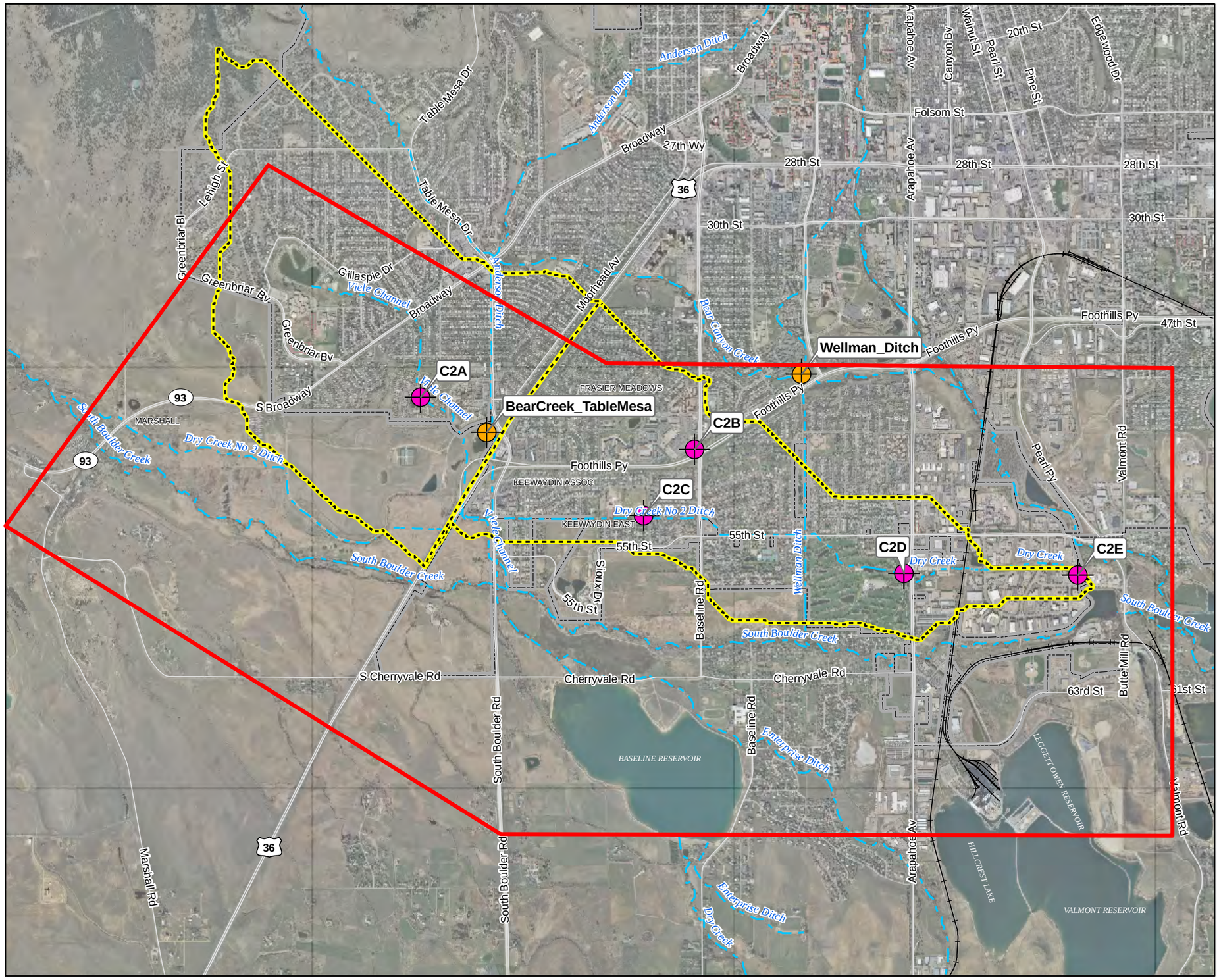
N

0 1,000 2,000 3,000 4,000 5,000

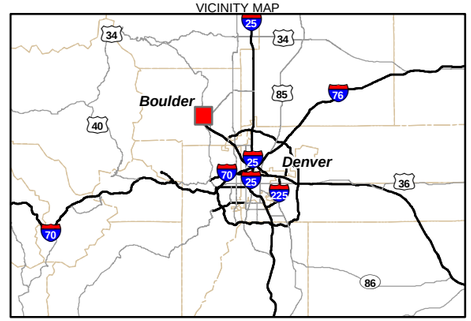
Feet

FIGURE 4-2
Graphic Extent of Flood Mapping Study 2-D Hydraulic Simulation Area
South Boulder Creek Flood Mitigation Report

CH2MHILL



VICINITY MAP



LEGEND

- Bear Canyon Creek Overflow Loading Points
- C2 Sub-Basin Hydrograph Loading points
- South Boulder Creek C2 Basin Boundary
- Streams, Creeks and Ditches
- Boulder County

Notes:
1. Area of Interest

N

0 1,000 2,000 3,000 4,000 5,000
Feet

FIGURE 4-3
Tributary Basin Loading Points
South Boulder Creek Flood Mitigation Report

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V. Alternative Development

Sections V, VI, VII, VIII, IX and X describe the process of developing and refining alternatives to address flooding issues through the West Valley from South Boulder Creek from initial problem identification through the selected plan.

Section V presents the process for initial problem identification, identified problem solutions, and screening of the initial identified problem solutions. This initial screening process was accomplished through interactive workshops with stakeholders, an initial public meeting, and with the use of basic hydrologic and hydraulic tools.

Section VI presents the formulation of the 15 Conceptual Plans and the method of evaluation. This secondary screening process was accomplished through interactive workshops with stakeholders and was further screened by utilizing MIKEFLOOD to optimize the concept design, develop the alternative benefits and cost, and to estimate the benefit cost analysis of each alternative.

Section VII presents the review and selection process for the 9 Best Alternative Plans from the 15 identified plans described in Section VI. These alternatives were further screened by utilizing MIKEFLOOD to optimize the concept design, develop the alternative benefits and cost, and to estimate the benefit cost analysis of each alternative. After presentation of the 9 Best Alternative Plans to WRAB on December 14, 2011, WRAB along with subsequent discussions with OSMP selected 5 Alternative Plans to be refined further. The 5 alternatives selected for further refinement were the:

- Status Quo Alternative
- High Hazard Zone Mitigation Alternative
- Regional Detention at US-36 Alternative
- Distributed Regional Detention Alternative
- Bear Canyon Creek Pipeline Alternative

Section VIII presents the refinements to the 5 plans selected by WRAB and discussions with OSMP. This section presents a more detailed evaluation so that the elements of the plans could be refined with greater resolution and the plans could be more clearly communicated to the public.

Section IX presents the refinements of the proposed US-36 Detention facility. The US-36 detention concept was refined to focus on additional alternatives to minimize impacts to Open Space and Mountain Parks (OSMP) property, incorporate the Phase 1 CDOT construction along US-36, and to continue to understand and develop potential environmental mitigation plans for the proposed berms. This alternatives analysis focused on earthen berms that followed both the CDOT Phase 1 ROW and proposed Ultimate ROW and included both earthen embankments and concrete walls to minimize or eliminate impacts to OSMP property

Section X describes the process and reasoning behind the Engineers Recommended Plan that will be presented to city staff for further review through public input, WRAB and OSBT and City Council meetings. This section includes the final benefit - cost ratio and final configurations, and conceptual elements of all flood control facilities recommended by the engineer.

Alternative Development Process

The development and evaluation of alternatives is a sequential process that takes a broad range of options and systematically reduces them into a manageable number of alternatives. The process defined by the District and articulated in the approved Scope of Work follows this approach.

The initial screening of options builds on an understanding of the problems within the watershed and the identification of various types of improvements to address the identified problems. The general problem understanding builds on the insights gained in the Flood Mapping Study and Risk Assessment. In this, several broad issues that caused much of the flood threat within the West Valley were identified:

- **Overtopping of US-36** – Overtopping creates a number of flood hazards downstream, including overwhelming the existing conveyance system, which, in many cases, consists exclusively of surface conveyance via roadways, or small undersized storm sewer systems.
- **Overflows from existing pipe and channel conveyance systems** – The undersized systems often cause flooding along the channel banks or the pipe alignment due to overflows from the pipes and channels. However, in many cases, the undersized open channel conveyance systems often back up water behind existing structures and embankments causing additional flood damage because of upstream inundation and roadway overtopping.
- **Overflows from surcharged irrigation ditches** – Similar to the undersized channels, undersized ditches present a flood hazard as the result of potential overtopping. When undersized ditches exceed their flow capacity and convey additional flood flows from South Boulder Creek, adjacent properties may be subjected to flooding. Moreover, irrigation ditches provide a means for flows from the South Boulder Creek drainageway to reach areas that may be isolated from the direct flooding effects of South Boulder Creek. In the case of ditches conveying flood flows from South Boulder Creek and other surrounding watersheds, these ditches exacerbate the flood hazard by conveying flows to flood prone properties.
- **Overflows from the mainstem that worked their way into the West Valley** - In areas where the mainstem of South Boulder Creek is inadequate, flow leaves the mainstem and flows overland toward the West Valley. These flows reach areas where the existing infrastructure is not intended to capture and convey those flows and quickly becomes surcharged, increasing the flood risk.
- **Transbasin inflows from Bear Canyon Creek** – Flows from Bear Canyon Creek enter the South Boulder Creek watershed, in multiple locations, because of undersized drainage conveyance in the Bear Canyon Creek watershed. Control structures are subject to overtopping with the excess discharge flowing down streets or irrigation channels to South Boulder Creek.
- **Local C2 Basin Inflows** – Flows originating from the local C2 basin within the South Boulder Creek watershed, in multiple locations, result in additional local flooding issues. The flows from the C2 basin, which enter the West Valley North of US-36, fill the capacity of local drainage systems eventually overwhelming the local drainage systems prior to South Boulder Creek Flooding the West Valley. Excess discharge from the overwhelmed local drainage system ends up flowing down streets or irrigation channels to South Boulder Creek causing flooding damage through the West Valley.

Within each of the above-described identified flooding triggers, a number of more specific issues were identified within the various study reaches. Because of the preliminary nature of this evaluation, the study reaches were more generally defined into two reaches, one following the alignment through the West Valley and the other along the Dry Creek No. 2 Ditch. Since the focus of the evaluation was limited to addressing problems in the West Valley, issues of concern along the mainstem were not explicitly addressed. Similarly, a detailed evaluation of the specific problems within each of the previously described sub-reaches along both the West Valley and the Dry Creek No. 2 Ditch alignments was premature for screening purposes.

The project also defined a number of potential mitigation measures that were included in the evaluation process. These alternatives formed the suite of potential options that would be considered to address the identified problems. The alternatives ranged from large structural improvements such as pipes, channels, or detention ponds to flood-proofing and non-structural floodplain management measures to maintaining the status quo. Specific measures to be considered include:

- **Installation of Major Underground Conduits** – Major underground conduits are those that have the capacity to convey large quantities of flow. For this analysis, they were assumed capable of conveying flows in excess of the 10-year flood. These conduits would generally follow existing street alignments but may, in some cases, follow other undeveloped corridors.
- **Limited Structural Improvements or Additions** – Limited improvements are generally identified to address a specific problem that stems from a very well defined and isolated source. These may include the culvert enhancements that relieve an obstruction caused by an undersized bridge or culvert. In other cases, these improvements may consist of an addition of another conveyance element that improves the hydraulic conditions at the identified location.

- **Improvements to Existing Channels** – These improvements generally consist of the expansion of existing channels to provide greater conveyance capacity. In many areas, this will require the widening of the existing channel because groundwater or grade constraints preclude the significant lowering of the channel bottom.
- **Regional Detention Facilities** – These are large flood storage facilities that capture significant portions of the flood flows and store them for later release when there is available capacity in the downstream facilities. These facilities often consist of earthen embankments or excavated areas that capture floodwaters and relatively small outlet pipes that meter the water slowly back into the natural drainage course.
- **Local Detention Facilities –** In contrast to large regional detention facilities, these local detention facilities are much smaller and are intended to address inflows from a much smaller drainage basin. In many cases, properly located and sized local facilities can significantly reduce the infrastructure required to handle inflows from the lower tributary areas along South Boulder Creek.
- **Flood Proofing of Critical Facilities** – In some cases, the nature of the flooding is so distributed that extensive stretches of the stream cannot be economically addressed. In these cases, it is sometimes advisable to focus on isolated structures to mitigate flood hazard. In the case of flood proofing, modifications to specific structures can be made to reduce the impacts of flood flows by preventing them from entering and damaging the structure or by reducing the expense to repair the structure after a flood.
- **Non-Structural Methods** – Non-structural methods have long been embraced in Boulder. These include measures such as flood warning or floodplain management to the preservation of the natural flood storage found on Open Space lands.
- **Flow Diversion** – Flow diversion takes advantage of the potential available capacity in adjacent waterways to convey flood flows out of the areas of greatest impact. Flow diversions allow the residual flow to be reduced and often significantly reduce the flood threat.

A screening matrix approach was used to evaluate the suite of identified problems and identified solutions. The more specific problems defined one axis of the Potential Solutions Screening Matrix while the suite of potential mitigation measures defined the other axis. This screening matrix provides a quick summary of the full suite of potential solutions and allows a quick assessment of the viability of any solution to address the identified problem area.

Alternative solution elements were screened by determining the viability of a particular option. In all cases, the options were generally assumed viable unless some particularly significant constraint was identified or the option was not applicable to the problem. Constraints were generally deemed significant if they would impose an extraordinary mitigation burden or that would require significant cost to address. These might include significant impacts to Open Space where the proposed uses were in direct conflict with known Open Space values. An example might be the construction of a large culvert that would drain an Open Space area acquired for its wetland habitat thereby changing the natural community, intended use of the land and ecological function. Similarly, an alternative that proposed the enlargement of a small, naturally vegetated open channel with a large, prismatic landscaped open channel might have unacceptable impacts to threatened and endangered species along the alignment. Alternative elements that were considered not applicable were ones, which would not address the identified flood hazard problem in any meaningful way. None of the evaluation standards were absolute and alternative elements were sometimes carried forward even in the face of substantial flaws if it was felt that they may be important elements of a future plan that would address the overall hazard in a meaningful way.

Two Potential Solutions Screening matrices were developed, one for each of the two study reaches. Within the screening matrix, each potential solution was assessed to determine if it could be part of a broader solution effort that resolved each of the identified issues. A high-level screening matrix was developed for each reach and is presented as Figure 5-1, Potential Solutions Matrix. In this matrix, large dots represent feasible options that received further attention.

The content of Figure 5-1, Potential Solutions Matrix was discussed and developed during the first of several workshops conducted during the study. Workshop Number 1 focused on the identification of significant constraints that would render a particular solution element infeasible. The workshop, conducted on January 27, 2010, was attended by most of the project stakeholders. A number of other major constraints were identified during the workshop including the consideration of past public objection and the lack of an existing defined drainageway that would preclude the construction of a new open channel.

Following Workshop Number 1, a second series of Potential Solutions Screening matrices were developed that looked more carefully at specific elements to address specific problem areas. In this matrix, presented as Figure 5-2, Refined Potential Solutions Matrix, more detail regarding the specific elements that could be used to address a problem area is provided.

The various elements presented in the refined matrix provide a better understanding of the type of improvements envisioned. For example, rather than merely identifying that channel improvements are reasonable, the refined matrix describes a general location and type of channel that will address the identified problem. All evaluations used to refine the matrix were qualitative, based on the input received during the Workshop, and are located in Appendix A. In most cases, the capacity of the improvements, the specific alignment, or the exact geometry was not specified. Sizing and specific alignments were defined in general terms. With this better understanding of potential elements that could address specific problems it was possible to begin a more detailed evaluation and then assemble the elements into viable plans.

Constraints and Criteria

In order to guide the evaluation of the various elements, several overlaying objectives were identified. These objectives provided some framework that would shape the formulation of plans.

The primary focus of the study remained the protection of properties in the West Valley. This previously articulated objective is consistent with direction received subsequent to the past planning efforts and during the Flood Mapping Study. The protection of these properties that were constructed prior to a clear understanding of the flood threat remains the primary focus of the study.

Constraints

Containment of the High Hazard Zone so that no structures are impacted by this floodplain zone designation is a broad objective established by city Council during past planning studies. This past direction was imposed on this study. Efforts would be made to contain the High Hazard Zone so that future determinations would not include these structures. The existing defined High Hazard Zone includes a large area of street flow. While these areas pose a significant hazard during large floods, the focus of the containment measures would be limited to the removal of structures.

During the course of discussion related to the High Hazard Zone, the city also indicated that it would be desirable to provide a greater level of protection to Critical Facilities within the 100- and 500-year floodplain. These facilities are more distributed and do not generally lend themselves to economical removal using conveyance improvements. However, the desire to provide an enhanced level of protection demanded that some action be taken. The option of flood proofing these Critical Facilities will be incorporated into the alternative plan development process.

In June of 2007, HDR published a Stormwater MP that described the types of improvements necessary to address localized flooding associated with minor floods (2- and 5-year) and to provide guidance on water quality enhancement measures. The systems defined in the Stormwater MP establish a base level of protection against nuisance flooding problems but does not materially affect the threat associated with major floods. However, the consideration of the Stormwater MP recommendations also reiterated the potential of flood hazard throughout the watershed resulting from storms that were more localized than the design storm used to define the 100-year flood theat. Therefore, additional objectives included the potential for any identified improvements to provide protection against the major flood threat associated with a localized storm falling over the lower watershed and to consider the value-identified facilities would have to support the objectives of the Stormwater MP.

The City of Boulder has a very well established system of Open Space lands. Many of these areas are within or adjacent to the delineated floodplain of South Boulder Creek. While many communities view flood control as a compatible use of Open Space land, the city has very specific guidelines that regulate the use of Open Space. In general, these regulations restrict the use of these lands to uses that are consistent with the intended function for that particular parcel. When looking at flood control options along South Boulder Creek, careful attention was given to assuring that any proposed actions would be compatible with the city's Open Space regulations.

The acquisition of land is frequently a necessity to successfully implement a particular alternative. Many of the elements identified in the screening matrix would require additional land to be effectively implemented. Past studies that looked at flood control raised the issue of land acquisition. During those earlier studies, the general direction was that only properties for which there are willing sellers should be considered as part of any specific alternative. When properties were identified, the fair market cost for that land, based on recent sales or assessments, should be the basis for the development of cost estimates. At the early stages of project, alternative formulation the availability of land was not yet determined. Properties were all assumed available if fair market prices are paid. As the alternative plans become more refined, more site-specific assessments of individual properties will be conducted to determine if alternative plans using private parcels remain desirable alternatives.

Wetlands and habitat for threatened and endangered species are common along South Boulder Creek. Particular care needed to be exercised to assure that no unintended impacts to these areas resulted from any of the proposed improvements. Because of the abundance of wetlands and habitat areas along the corridor, it may not be possible to avoid all impacts. In cases where facilities cannot avoid impacts, mitigation measures, as defined by the City of Boulder's Stream, Wetland and Waterbody Protection Ordinance, to minimize the adverse impacts on wetlands need to be considered. The specific nature of the disturbance will determine the type and extent of the mitigation approach.

One of the most important constraints identified during the evaluation process was that of the public interest. This was qualitative at this stage of the evaluation and incorporated the past input gathered during public meetings on South Boulder Creek projects as well as other projects around the city. Much of what has been heard has already been incorporated into the other identified constraints, but several other issues were brought forward against which all alternatives would be measured. These included concerns related to construction impacts, aesthetics, use of eminent domain to secure land from unwilling sellers, and broader community development interests and policies. While too numerous to mention individually, whenever these constraints become the basis for an action related to a particular alternative, it will be identified and discussed in detail.

Criteria

The city has formally adopted a set of design standards for drainage related improvements. These include Chapter 7 of the City of Boulder Design and Construction Standards and Section 9-3-2 through 9-3-9 of the Boulder Revised Code. The city also relies on the requirements of the District as articulated in the Urban Storm Drainage Criteria Manual, Volumes 1 – 3 for guidance in the layout and design of drainage and flood control facilities. The governing design criteria used in the design of the components making up the improvements in the alternative plans are summarized in Table 5-1, Design Standards. Together, these tools facilitated the evaluation of alternative systems and elements relatively quickly and efficiently. Using the evaluations of the various plan elements to better understand the floodplain impacts, the various components were assembled into Alternative Plans. These Alternative Plans were eventually incorporated into the Coarse Grid Model version of MIKEFLOOD to confirm performance consistent with earlier assumptions. In some cases, refinement of the alternatives was necessary to achieve the level of performance desired. This refined Coarse Grid MIKEFLOOD model became the basis for the determination of project benefits and the visual representation of the residual floodplain. The alternatives assembled and evaluated as part of this process are depicted in figures located in Appendix B, Alternative Development Figures and listed in Table 5-2.

TABLE 5-1

Design Standards

Regulation	Description
Culvert Sizing Criteria	Manning's n for CMP, n = 0.024
Culvert Sizing Criteria	Manning's n for concrete, n = 0.013
Open Channel Criteria	Maximum velocity in open channels = 7 ft/s
Open Channel Criteria	Maximum depth in open channels = 4 ft
Open Channel Criteria	Slope = 0.4%
Open Channel Criteria	Freeboard = 1 ft
State Engineers Office Dam Criteria	Reservoir with a capacity greater than 100 Acre-Feet
State Engineers Office Dam Criteria	Reservoir with a surface area greater than 20 Acres
State Engineers Office Dam Criteria	Reservoir with a berm higher than 10-feet measured from the lowest point of the natural surface to the spillway crest.
State Engineers Office Dam Criteria	Minor Dam, is a jurisdiction dam that does not exceed 20 feet in height and or 100 acre-feet in capacity
State Engineers Office Dam Criteria	Small Dam, is a jurisdiction height greater than 20 feet in height but less than 50 feet in height or a reservoir with greater than 100 acre-feet in capacity but less than 4,000 acre-feet in capacity.

TABLE 5-2

Appendix B: Alternative Development Figures

Figure Number	Title
5-3	Summary of Flow Rates
5-4	High Hazard/Critical Facility Alternative
5-5	High Hazard Purchase/Critical Facility Alternative
5-6	Upstream Storage Dry Creek Ditch No. 2 Alternative
5-7	Upstream Storage Bear Canyon Creek Alternative
5-8	Upstream Storage Bear Canyon Creek Alternative 2
5-9	Upstream Storage Bear New Conveyance Alternative
5-10	Upstream Storage Bear New Conveyance Alternative 2
5-11	100-Year Regulatory Dry Creek Ditch No. 2 Alternative
5-12	100-Year Regulatory Bear Canyon Creek Alternative
5-13	100-Year Regulatory Bear Canyon Creek Alternative 2
5-14	100-Year Regulatory New Conveyance Alternative
5-15	100-Year Regulatory New Conveyance Alternative 2

			Potential Solutions									
			Routine Maintenance of Existing Configuration	Development of Naturalistic Historic Channel	Installation of Major Underground Conduits	Lined Flood Channels	Limited Structural Improvements Or Additions	Existing Channel Improvements	Detention Facilities	Acquisition of Flood Prone Properties	Non-Structural Methods	Relocation of Channel
Identified Problem Areas	1	S. Boulder Rd. Inundation from Viele Channel/Dry Creek No. 2 Ditch	●	×[4]	●	●	●	●	●	×	×	×
	2	Businesses/Residences Inundated between US-36 and Baseline Road	●	×[4]	●	●	●	●[4]	●[4]	●	●	●[4]
	3	Inundation of Baseline Road	●	×[4]	●	●	●	●[4]	●[4]	×	×	●[4]
	4	Residences Inundated between Baseline Rd. & Wellman Ditch	●	×[4]	●	●[4]	●	●[4]	●[4]	●	●	●[4]
	5	Bear Canyon Creek / Wellman Ditch Flow Inundating West Valley	●	×[4]	●	●[4]	●	●[4]	●[4]	×	×	●[4]
	6	Residences Inundated between Wellman Ditch & Arapahoe Avenue	●	●[4]	●	●[4]	●	●[4]	●[4]	●	●	●[4]
	7	Inundation of Arapahoe Avenue	●	×[4]	●	●	●	●[4]	●[4]	×	×	●[4]
	8	Residences Inundated between Arapahoe Avenue & BNSF RR	●	×[4]	●	●	●	●[4]	●[4]	●	●	●[4]
	9	Flooding associated with BNSF RR Inundation	●	×[4]	●	●	●	●[4]	●[4]	×	×	●[4]
	10	Businesses Inundated Downstream of BNSF RR	●	×[4]	●	●	●	●[4]	●[4]	●	●	●[4]

Notes:
1 - Potential solution conflicts with known uses of City of Boulder Open Space
2 - Potential solution conflicts with a known habitat conservation area or endangered species habitat
3 - Potential solution has pas public opposition
4 - Potential solution has right of way constraints
5 - Channel or structure currently does not exist

FIGURE 5-1
Potential Solutions Matrix
Reach 1 – 55th Street/ Dry Creek No. 2 Ditch
South Boulder Creek Flood Mitigation Report

			Potential Solutions									
			Routine Maintenance of Existing Configuration	Development of Naturalistic Historic Channel	Installation of Major Underground Conduits	Lined Flood Channels	Limited Structural Improvements Or Additions	Existing Channel Improvements	Detention Facilities	Acquisition of Flood Prone Properties	Non-Structural Methods	Relocation of Channel
Identified Problem Areas	1	Flooding Associated with US-36 Overflow	●	×[4]	●	●	●	●	●	●	●	●[4]
	2	Businesses/Residences Inundated between US-36 and Baseline Road	●	×[4]	●	●[4]	●	×[5]	●[4]	●	●	●[4]
	3	Inundation of Foothills Parkway and Baseline Road Intersection	●	×[4]	●	●[4]	●	●	●[4]	×	×	×[4]
	4	Inundation of Foothills Parkway North of Baseline Road	●	×[4]	●	●[4]	●	●	●[4]	×	×	×[4]
	5	Residences Inundated between Baseline Rd. & Wellman Ditch	●	×[4]	●	●[4]	●	×[5]	●[4]	●	●	●[4]
	6	Bear Canyon Creek / Wellman Ditch Flow Inundating West Valley	●	×[4]	●	●[1]	●	●	●[4]	×	×	●[4]
	7	Residences Inundated between Wellman Ditch & Arapahoe Avenue	●	×[4]	●	●[4]	●	×[5]	●[4]	●	●	●[4]
	8	Inundation of Arapahoe Avenue	●	×[4]	●	×[5]	●	×[5]	●[4]	×	×	●[4]
	9	Residences Inundated between Arapahoe Avenue & BNSF RR	●	×[4]	●	×[5]	●	×[5]	●[4]	×	●	●[4]
	10	Flooding associated with BNSF RR Inundation	●	×[4]	●	×[5]	●	×[5]	●[4]	×	×	●[4]

Notes:
1 - Potential solution conflicts with known uses of City of Boulder Open Space
2 - Potential solution conflicts with a known habitat conservation area or endangered species habitat
3 - Potential solution has pas public opposition
4 - Potential solution has right of way constraints
5 - Channel or structure currently does not exist

FIGURE 5-1
Potential Solutions Matrix
Reach 2 – West Valley FIS Profile
South Boulder Creek Flood Mitigation Report

			Potential Solutions							
			Installation of Major Underground Conduits	Limited Structural Improvements Or Additions	Existing Channel Improvements	Regional Detention Facilities	Local Detention Facilities	Flood Proofing Critical Facilities	Non-Structural Methods	Flow Diversion
Identified Problem Areas	1	South Boulder Road inundation from Dry Creek No. 2 Ditch	Pipe all Dry Creek No. 2 Ditch	Enlarge Dry Creek No. 2 Ditch Culvert	Enlarge Dry Creek No. 2 Ditch / Crossing Structure	Storage Upstream of US-36 (Regional)	**X** - Habitat Impacts	NA	Flood Warning, Road Closure, Etc.	X - Habitat Impacts
			Pipe South to Regional Storage Pond	Waste way from Dry Creek No. 2 Ditch to Viele Channel	Raise South Boulder Road					
				Gate/SCADA at South Boulder Road to move water to Viele Channel / Anderson Ditch Extension						
	2	South Boulder Road Inundation from Viele Channel	**X** - Habitat Impacts	Enlarge Viele Culvert	**X** - Habitat Impacts	Storage Upstream of US-36 (Regional)	**X** - Habitat Impacts	NA	Flood Warning, Road Closure, Etc.	Divert Flow to South Boulder Creek
	3	South Boulder Road inundation from Anderson Ditch Extension	Pipe all of New Anderson Ditch to Viele Channel	Broadway & Table Mesa - Enlarged Culvert under Table Mesa	Enlarged New Anderson Ditch/ Crossing	Storage Upstream of US-36 (Regional)	Storage at Table Mesa & US-36	NA	Flood Warning, Road Closure, Etc.	Divert Flow to Viele Channel/ South Boulder Creek
	4	Structures inundated between US-36 and Baseline Road	Increase size of existing 42" RCP Dry Creek No. 2 Ditch at Tenino Avenue - Outfall at North of Aztec Drive	Improved conveyance structure at Baseline Road at South Boulder Creek to prevent back water flows	Replace Dry Creek No. 2 Ditch culvert at Manhattan Middle School & Oneida Street with enlarged open channel	Storage Upstream of US-36 (Regional)	Local Storage at Manhattan Middle School	Flood Proof Manhattan Middle School and Montessori School	Flood Warning, Road Closure, Etc.	Flow Diversion from Dry Creek No. 2 Ditch East to East Boulder Recreation Center ponds via existing irrigation ditch
			Place Dry Creek No. 2 Ditch in a conduit from South Boulder Road to Baseline Road		Channelization from South Boulder Road to Baseline Road just east of Foothills Parkway					Pipe from Manhattan Middle School to open space north of East Boulder Rec. Center
			Collect flow in a major conduit at SBR & Foothills Parkway to Baseline Road and Crescent Avenue							
	5	Structures inundated between Baseline Road & Wellman Ditch	Pipe Dry Creek No. 2 Ditch	Culvert improvements at 55th Street & Tennis Courts	Conveyance improvements / enlarge Wellman	Storage Upstream of US-36 (Regional)	**X** - Right of Way constraints	Flood proof / acquire school	Flood Warning, Road Closure, Etc.	Flow diversion from Dry Creek No. 2 Ditch to South Boulder Creek at Tennis Courts
			Pipe flow from Pennsylvania to Golf Course	Culvert improvements at Pennsylvania Avenue	Conveyance improvements / enlargement of Dry Creek No. 2 Ditch			Flood proof fire station		Flow diversion from 55th street to South Boulder Creek via Wellman
	6	Structures inundated between Wellman Ditch & Arapahoe Avenue	Large conduit along 55th street	Culvert improvements at Arapahoe Avenue	Conveyance improvements through golf course	Storage Upstream of US-36 (Regional)	Local storage in golf course	NA	Flood Warning, Road Closure, Etc.	Diversion to golf course
	7	Structures inundated between Arapahoe Avenue & BNSF RR	Large conduit along 55th street to Boulder Creek	NA	New channel along existing alignment behind buildings	Storage Upstream of US-36 (Regional)	Store flows in Leggett Reservoir	NA	Flood Warning, Road Closure, Etc.	Divert flows to Leggett Reservoir

Notes:
1. Routine maintenance of existing configuration will be a stand along alternative for all problems and will be analyzed as the "No Action" alternative moving forward. Maintenance will be a key component of all alternatives considered for this project.
2. Developing a naturalistic channel was not considered as a solution for problems in the planning study. Due to the developed nature of the West Valley profile and 55th Street/Dry Creek No. 2 Ditch profile, a naturalistic channel is infeasible.

FIGURE 5-2
Refined Potential Solutions Matrix
Reach 1 – 55th Street / Dry Creek No. 2 Ditch
South Boulder Creek Flood Mitigation Report

			Potential Solutions							
			Installation of Major Underground Conduits	Limited Structural Improvements Or Additions	Existing Channel Improvements	Regional Detention Facilities	Local Detention Facilities	Flood Proofing Critical Facilities	Non-Structural Methods	Flow Diversion
Identified Problem Areas	1	Flooding Associated with US-36 Overflow	Enlarge New Anderson Extension Crossing	Enlarge Dry Creek No. 2 Ditch Culvert	Levees to Force all flow through US-36 Bridge along Mainstem	Storage upstream of US-36 (Regional)	Store Table Mesa overflows from Bear Canyon Creek at Foothills Interchange and Drain to New Anderson Extension	NA	Flood Warning, Road Closures, Etc.	Divert overflows to South Boulder Creek via New Anderson Extension
	2	Structures Inundated between US-36 and Baseline Road	Large Pipe to carry over flows from US-36 to Foothills Parkway	**X** - Habitat Impacts	Create new open channel between Foothills Parkway and Thunderbird Drive	Storage upstream of US-36 (Regional)	**X** - Right of Way Impacts	Flood proof Frasier Meadows Manor	Flood Warning, Road Closures, Etc.	Divert flow to South Boulder Creek
					Extend noise barrier wall along Foothills Parkway					
	3	Inundation of Foothills Parkway and Baseline Road Intersection	Large underground pipe in the direction of the existing profile	Increase capacity of culverts through Baseline Road and Foothills Parkway	NA	Storage upstream of US-36 (Regional)	Localized storage at intersection of Foothills Parkway and Baseline Road	NA	Flood Warning, Road Closures, Etc.	Divert flow through underground pipe to Dry Creek
	4	Inundation of Foothills Parkway North of Baseline Road	Large underground pipe parallel to the existing flow path	Increase capacity of existing culverts through Baseline Road / Foothills Parkway so that overtopping does not occur	NA	Storage upstream of US-36 (Regional)	Localized storage at intersection of Foothills Parkway and Baseline Road	NA	Flood Warning, Road Closures, Etc.	Divert flows through underground pipe to South Boulder Creek
			Pipeline parallel to Foothills Parkway							
	5	Structures Inundated between Baseline Rd. & Wellman Ditch	Large underground pipe parallel to the existing flow path	**X** - Right of Way Impacts	Conveyance improvements / enlarge Wellman	Storage upstream of US-36 (Regional)	Localized storage at intersection of Foothills Parkway and Baseline Road	NA	Flood Warning, Road Closures, Etc.	Divert flows through underground pipe to South Boulder Creek
										Flow diversion from 55th Street to South Boulder Creek via Wellman
	6	Structures Inundated between Wellman Ditch & Arapahoe Avenue	Replace Wellman Ditch with underground pipe	SCADA system on the Wellman / Bear Canyon Creek diversion structure	Increase capacity of Wellman Ditch extending to South Boulder Creek	Storage upstream of US-36 (Regional)	Localized storage at intersection of Foothills Parkway and Baseline Road	Flood proofing of critical facilities	Flood Warning, Road Closures, Etc.	Diversion to Golf Course
			Large underground pipe parallel to the existing flow path	Culvert improvements through Arapahoe Avenue			Local storage at Eisenhower Elementary School			
				Limited structural improvements along the Wellman to improve capacity						
	7	Structures Inundated Below Arapahoe Avenue	Large conduit along 55th Street to Boulder Creek	Culvert Improvements at Arapahoe Avenue	New open channel along existing alignment behind buildings	Storage upstream of US-36 (Regional)	Store flows in Leggett Reservoir	NA	Flood Warning, Road Closures, Etc.	Large underground pipe to South Boulder Creek

Notes:
1. Routine maintenance of existing configuration will be a stand along alternative for all problems and will be analyzed as the "No Action" alternative moving forward. Maintenance will be a key component of all alternatives considered for this project.
2. Developing a naturalistic channel was not considered as a solution for problems in the planning study. Due to the developed nature of the West Valley profile and 55th Street/Dry Creek No. 2 Ditch profile, a naturalistic channel is infeasible.

FIGURE 5-2
Refined Potential Solutions Matrix
Reach 2 – West Valley FIS Profile
South Boulder Creek Flood Mitigation Report

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VI. Conceptual Alternative Plans

Conceptual Alternative Plan development came during the second workshop that was held on March 17, 2010 to present and discuss the Refined Potential Solutions Matrix. Based on the feedback from the first and second workshops and the Refined Potential Solutions Matrix, the plan elements were assembled into a series of Conceptual Alternative Plans.

The plans were built using various combinations of several common elements. Using this approach provided an appropriately broad range of alternatives and resulted in a reasonable assurance that the best alternatives were considered. Common elements that were assembled into the plans included:

- Regional Detention at US-36 – This element included off-channel storage along the upstream side of the embankment along US-36 and considered storage on Open Space land, private property, and CU property.
- Regional Detention near Hwy-93 – This element included off-channel storage near Hwy-93 and considered storage on both Open Space land and private property in the area.
- Downstream conveyance along Dry Creek No. 2 Ditch – This element included a series of conveyance improvements along the Dry Creek No. 2 Ditch corridor and looked at both pipes and open channels for flow rates ranging from the 10-year flood through the 100-year flood.
- Downstream conveyance through the West Valley – This element included a series of conveyance improvements through the West Valley generally along Foothills Parkway and then through utility easements and roads through the East Foothills Neighborhood to Boulder Creek. This alternative included both pipes and open channels for flow rates ranging from the 10-year flood through the 100-year flood.
- Mainstem Containment – This element included measures to reduce the threat of overflows across US-36 by constructing a series of improvements to contain flow within the channel above the US-36 crossing. It also included various mitigation elements downstream of US-36 to mitigate the impacts of increased flows in the mainstem including using Baseline Reservoir to store flood flows.
- Diversion to Bear Canyon Creek/Boulder Creek – These elements convey excess flows from the West Valley to the adjacent watershed using a series of pipes and channels.
- Downstream Storage – These elements were investigated to try to control flooding during both the US-36 overtopping events and those of lesser frequency that generate flooding below US-36. Small-localized downstream storage locations included Manhattan Middle School and the Flatirons Golf Course.

These elements, in various combinations, were the basis for the formulation of alternative plans. The intent of the formulation process was to identify elements from the options above and combine them in ways that formed complete systems to address the identified problems. With this, it was possible to look at the lower basin holistically and determine if benefits were realized in areas beyond the specific issue the particular option addressed.

Alternative Plan Formulation

A total of 15 different alternative plans were developed for further consideration. These plans were intended to address the full suite of issues by defining a full system of improvements. For example, in this evaluation, the benefits of upstream detention configurations were seen in the required sizing of the downstream facilities.

Not only was the analysis conducted using combinations of the various elements but the level of protection was also evaluated. For each alternative, all of the infrastructure elements were looked at across a broad range of flow rates so that the relative impact on benefits and cost could be considered. The determination of flow rates in the analysis was complicated by the 2-D nature of the floodplain determination, the basin specific design storm and the impacts associated with the overtopping of US-36.

The 2-D analysis used a process by which the flood hydrograph was routed through the stream system and overbanks and takes into account floodplain storage throughout the basin. While this represents a realistic determination of the flood hazard along South Boulder Creek, the model is very sensitive to change due to changes in floodplain storage. Any physical changes to the system, using culverts, detention, or improved channels, were likely to result in a change to flooding depths, flow rates, and inundation elsewhere in the system. For the purposes of this analysis, a simplified approach that added flow rates in the downstream direction was employed. If the improvements such as detention at an upstream location reduced the discharge, it was assumed that reduction would apply from that point downstream. Similarly, if an improvement such as a culvert enlargement increased a flow rate downstream, the resulting increase in discharge was assumed to apply to every other point downstream. This provided a simple and conservative methodology to quickly review the effectiveness of individual alternatives in solving flooding problems throughout the basin without employing MIKEFLOOD.

The analysis conducted for this Study recognizes that the focus is on flooding generated from a flood that maximizes the flow along the mainstem of South Boulder Creek. During the Flood Mapping Study, it was noted that the potential for small-localized storms falling below the Basin Specific Design Storm location could result in higher flows along some of the areas tributary to the mainstem. The area of the West Valley, because it is hydraulically disconnected from the mainstem flood for smaller events, may be one area where this potential exists. However, after considerable deliberation, it was concluded that the focus of this study should remain to address the flood threat associated with the mainstem and that localized events would not be explicitly evaluated. However, the improvements incorporated into the various alternative plans are sized to convey the lower storm center hydrology or Stormwater MP hydrology if US-36 does not overtop, resulting in an increased level of protection for smaller localized storms.

Finally, the overtopping of US-36 dramatically influences the flood response in the West Valley. Unlike a typical riverine system where the flood threat increases in a general linear relationship with flow rates, the West Valley is generally free of a significant flood threat for all events until US-36 overtops at around the 100-year flood. At that time, a considerable hazard is created. While the benefit of the protection below the 100-year flood is considerable, the result is that improvements in the West Valley intended to address local floods more frequent than the 100-year event will be overwhelmed by the overtopping of US-36 and will not materially reduce the flooding impacts from the 100-year storm.

Alternative Plan Identification

The 15 specific alternatives identified are described as follows. Figures for each Conceptual Alternative Plans can be found in Appendix C.

- **Status Quo** – This option represents the existing condition. While the name suggests no additional actions are to be taken, the status quo actually reflects a considerable amount of attention to the control of flood hazards. The city has an extensive body of floodplain and floodway protections built into the zoning, land use, and development regulations. Physical infrastructure to warn citizens of an impending flood threat exists through sirens and other warning mechanisms and an impressive body of master planning exists for many of the city's drainageways. Figure 6-1, Status Quo can be found in Appendix C.
- **High Hazard Zone containment with critical structure flood proofing** – This option focuses on the control of the flood hazard to the two existing structures located in the High Hazard Zone. It is expected that there will be minor improvements required to remove structures located in the High Hazard Zone. Measures to address the flood threat to Critical Structures will largely be limited to flood proofing the existing structures, Figure 6-2; High Hazard Zone Containment with Critical Structure Protection can be found in Appendix C.
- **US-36 detention with downstream conveyance along Dry Creek No. 2 Ditch** – Detention at US-36 eliminates the overflow of US-36 and provides a substantial benefit to downstream properties in the West Valley. The detention pond is configured to maximize the use of existing flood prone areas, to minimize the impacts to Open Space land and the University of Colorado South Campus and to minimize the potential visual impact by integrating into existing roadway improvements in the area. To address the flood threat downstream of US-36, improvements are proposed along the alignment of Dry Creek No. 2 Ditch. These improvements will generally consist of enlarged channels or pipes to minimize the potential for residual flooding in the area. Figure 6-3, US-36 Detention with Downstream Conveyance along Dry Creek No. 2 can be found in Appendix C.
- **US-36 detention with downstream conveyance through West Valley** – This alternative includes the detention facility at US-36 described above and to address the flood threat downstream of US-36, improvements are proposed along a new conveyance alignment through the West Valley. These improvements will generally consist

of enlarged channels or pipes to minimize the potential for residual flooding in the area. Figure 6-4, US-36 Detention with Downstream Conveyance through West Valley can be found in Appendix C.

- **US-36 detention with downstream storage and conveyance through West Valley and along Dry Creek No. 2 Ditch** –The cornerstone of this alternative is the detention at US-36. To address the flood threat downstream of US-36. This alternative differs from previous alternatives by handling downstream flood threats through both storage and conveyance improvements. The proposed improvements are located in the West Valley and along the alignment of Dry Creek No. 2 Ditch. The storage component of the downstream improvements allows for locally generate flood peaks to be attenuated and results in a decrease in the size of the required infrastructure downstream. The combination of conveyance improvements along both drainage corridors reduces the amount of overland flooding that poses a threat once floodwaters leave either corridor. These improvements will generally consist of enlarged channels or pipes to minimize the potential for residual flooding in the area. Figure 6-5, US-36 Detention with Downstream Storage and Conveyance through West Valley can be found in Appendix C.
- **US-36 detention with downstream diversion to Bear Canyon/Boulder Creek** – This alternative again begins with the detention facility at US-36. This alternative differs in the approach to addressing the flood threat downstream of US-36. Improvements downstream of US-36 are proposed that divert flows from the West Valley out of the South Boulder Creek System and move them along Foothills Parkway into the Bear Canyon Creek channel where they eventually outfall to Boulder Creek. These improvements will generally consist of enlarged channel with culvert improvements at roadway crossings. No improvements are proposed along the Dry Creek No. 2 Ditch corridor so some residual impacts may still be seen. Figure 6-6, US-36 Detention with Downstream Diversion to Bear Canyon/Boulder Creek can be found in Appendix C.
- **US-36 detention with downstream diversion to mainstem** – The focus on this alternative is diversion of floodwaters from the West Valley to the mainstem coupled with Detention at US-36. To address the flood threat downstream of US-36, improvements are proposed that divert the excess flows through the West Valley back to the mainstem of South Boulder Creek. These improvements will generally consist of enlarged channels or pipes that carry water from the West Valley and the Dry Creek No. 2 Ditch corridor, east back to the mainstem. Figure 6-7, US-36 Detention with Downstream Diversion Main Stem can be found in Appendix C.
- **Detention near Hwy-93 with downstream conveyance along Dry Creek No. 2 Ditch** – Detention near Hwy-93 provides an a similar benefit to that of detention closer to US-36 but avoids the challenges associated with coordination with CU, CDOT and other stakeholders in the vicinity of the US-36 corridor. The detention near Hwy-93 is an off-stream facility that captures overflows from Hwy-93 and releases them later during the flood. This delay allows the mainstem flows around US-36 to decrease and reduces the overflows from the main channel that fill the existing inadvertent detention near US-36 and Foothills Parkway. In doing so, overflows of US-36 can be avoided. The detention facility near Hwy-93 would require the purchase of two privately held properties from unwilling sellers. To address the flood threat downstream of US-36, improvements are proposed along the alignment of Dry Creek No. 2 Ditch. These improvements will generally consist of enlarged channels or pipes to minimize the potential for residual flooding in the area. Figure 6-8, Detention near Hwy-93 with Downstream Conveyance along Dry Creek No. 2 Ditch can be found in Appendix C.
- **Detention near Hwy-93 with downstream conveyance through West Valley** – This alternative combines the detention near Hwy-93 with the conveyance improvements through the West Valley that will consist of enlarged pipes to minimize the potential for residual flooding in the area. Figure 6-9, Detention near Hwy-93 with Downstream Conveyance through West Valley can be found in Appendix C.
- **Detention near Hwy-93 with downstream storage and conveyance through West Valley and along Dry Creek No. 2 Ditch** – This alternative combines the detention near Hwy-93 with, both storage and conveyance improvements that would include enlarged pipes or channels through the West Valley and along the alignment of Dry Creek No. 2 Ditch. The storage component allows for locally generate flood peaks to be attenuated and results in a decrease in the size of the required infrastructure downstream. The combination of conveyance improvements along both drainage corridors reduces the amount of overland flooding that poses a threat once floodwaters leave either corridor. Figure 6-10, Detention near Hwy-93 with Downstream Storage and Conveyance through West Valley can be found in Appendix C.
- **Detention near Hwy-93 with downstream diversion to Bear Canyon/Boulder Creek** – Detention near Hwy-93 becomes a cornerstone for this alternative and is combined with improvements that divert flows from the West Valley along Foothills Parkway over to the Bear Canyon Creek channel where they eventually outfall to Boulder Creek. These improvements will generally consist of enlarged channel with culvert improvements at roadway crossings. No improvements are proposed along the Dry Creek No. 2 Ditch corridor so some residual impacts may still be seen. Figure 6-11, Detention near Hwy-93 with Downstream Diversion to Bear Canyon/Boulder Creek can be found in Appendix C.
- **Detention near Hwy-93 with downstream diversion to mainstem** – This alternative combines detention near Hwy-93 with improvements that divert the excess flows back to the mainstem of South Boulder Creek. These improvements will generally consist of enlarged channels or pipes that carry water from the West Valley and the Dry Creek No. 2 Ditch corridor to the east back to the mainstem. Figure 6-12, Detention near Hwy-93 with Downstream Diversion Main Stem can be found in Appendix C.
- **No upstream detention with downstream conveyance along Dry Creek No. 2 Ditch –** This alternative does not control the overflow of US-36. The impacts upstream are relatively limited and the overflow of US-36 does little immediate damage downstream of US-36. However, as the flood wave progress to the north, considerable damage is seen. This alternative collects and captures the overflow downstream of US-36 and provides a large, stabilized conveyance to move those flows along the Dry Creek No. 2 Ditch corridor. The improvements are larger pipes or channels and the associated inlets. No improvements are proposed though the West Valley. As a result, some potential for damage during local floods remains. Figure 6-13, No Upstream Detention with Downstream Conveyance along Dry Creek No. 2 Ditch can be found in Appendix C.
- **No upstream detention with downstream conveyance through West Valley –** This alternative is similar to the alternative ***No upstream detention with downstream conveyance along Dry Creek No. 2 Ditch***, but capture the overflow in a large, stabilized conveyance to move those flows through the West Valley along Foothills Parkway, Thunderbird Land and eventually 55th Street. The improvements are larger pipes or channels and the associated inlets. No improvements are proposed along the Dry Creek No. 2 Ditch corridor so some residual damage is expected as overflows from the mainstem work their way to the west. Figure 6-14, No Upstream Detention with Downstream Conveyance along through West Valley can be found in Appendix C.
- **No upstream detention with downstream diversions** – This alternative does not control the overflow of US-36 but collects and captures the overflow and provides a large, stabilized conveyance to move those flows east to South Boulder Creek or the west toward channels that have adequate capacity. In general, overflows reaching the West Valley will be captured and diverted north and west to the Bear Canyon Creek system along Foothills Parkway downstream of Baseline. Flows that reach the Dry Creek No. 2 Ditch corridor will be captured and moved east back toward the mainstem where adequate capacity exists. The improvements are larger pipes or channels and the associated inlets. Figure 6-15, No Upstream Detention with Downstream Diversions can be found in Appendix C.

Conceptual Alternative Plan Evaluation

The evaluation process was a sequential effort that built on the earlier assessments by adding progressively more detail and filtering out projects or options that proved to be infeasible or otherwise flawed. The intent was to develop a common understanding of the different alternatives and compare them against one another. Subsequent evaluations built more detail into the alternative and allowed a more refined comparison.

The intent of the evaluation of the Conceptual Alternative Plans was to provide a clearer understanding of the costs, benefits, and constraints of the alternatives and to identify the most workable alternatives for further evaluation. Each of these plans was developed at a conceptual level reflecting this step in the overall process.

Residual floodplains were not quantitatively determined during this phase of the evaluation. Rather, general estimates of the physical extent of the floodplain were determined using information from the earlier MIKEFLOOD Coarse Grid

simulations. Since the majority of the improvements were intended to provide protection from the 100-year flood, the elimination of the 100-year flood hazard was assumed. For those alternatives that had a different level of protection, the residual floodplain was estimated by determining the residual surface flow rate and correlating that to a modeled flood event from the *Risk Assessment Report* (HDR, May 2009). Figures depicting the residual floodplains are located in Appendix C. Table 6-1 describes the location of each figure.

TABLE 6-1

Summary of Conceptual Alternative Plans

Alternative	Description	Figure Location
1	Status Quo	Appendix C, Figure 6-16
2	High Hazard Zone containment with critical structure flood proofing	Appendix C, Figure 6-17
3	US-36 detention with downstream conveyance through West Valley	Appendix C, Figure 6-18
4	Detention near Hwy-93 with downstream storage and conveyance through West Valley	Appendix C, Figure 6-19
5	Mainstem Flow Containment With Distributed Regional Detention	Appendix C, Figure 6-20
6	Mainstem Flow Containment With Local West Valley Improvements	Appendix C, Figure 6-21
7	No upstream detention with Bear Canyon Creek Conveyance Improvements	Appendix C, Figure 6-22
8	No upstream detention with Dry Creek No. 2 Ditch Conveyance Improvements	Appendix C, Figure 6-23
9	Stormwater Master Plan Improvements	Appendix C, Figure 6-24

Flood Damages

Flood damage assessments for both the existing condition and post flood conditions are necessary to determine the economic benefits of a particular alternative. The District has published guidelines that were used in the evaluations conducted for the study. It is also the city's intention to look at alternative funding opportunities such as FEMA grants and all financial investigations were conducted in accordance with FEMA guidelines as described in FEMA's Benefit Cost Analysis (BCA) Version 4.5.5 tool. This is a software tool that performs project financial benefit-cost evaluations based on FEMA approved standards. Unfortunately, the tool was developed for more traditional riverine systems and did not lend itself to direct application to the information available using MIKEFLOOD. However, manual input methodologies embedded in the tool can be used to define flood damages based on the FEMA Hazards U.S. Multi Hazard (HAZUS-MH) methodology that are consistent with the methodologies used in the South Boulder Creek *Risk Assessment Report*.

A meeting was held with the Colorado Department of Emergency Management (CDEM) and FEMA. During this meeting, the FEMA representative accepted the proposal of calculating damages outside of the FEMA BCA tool by using the HAZUS-MH methodology for flood damage estimation and manually importing those results into the BCA tool for further analysis.

In addition to reviewing the BCA tool, the CDEM and FEMA representatives reviewed the Risk Assessment damage methodology, which utilized the HAZUS-MH depth damage curves similar to the BCA tool, to determine if it is appropriate and acceptable for the purposes of applying for FEMA grants. It was decided that the Risk Assessment methodology for damage estimates would be carried forward into this planning phase.

Most of the information necessary to determine the damages under existing conditions (baseline damages) was obtained using the information derived from the Risk Assessment. In that document, the damage for various recurrence interval storms was reported. The values were refined in this analysis to reflect updated assessed values and the depths reported in the Course Grid model. There were slight changes between the reported damages in the Risk Assessment and those computed as part of this analysis. These differences were investigated. The primary difference was attributed to a slight increase in the assessed value of the properties flooded since the Risk Assessment was completed. This difference was approximately 10%. A careful review of the damage spreadsheet in the Risk Assessment also identified duplication in the accounting of damages for some structures. This error was corrected and accounted for a decrease of approximately 5% in damage estimates from the Risk Assessment. Finally, the impact of the difference between the Regulatory 4 meter grid model and the Course Grid 8 meter model was investigated. It was found that the difference in computed water surface between the 4–meter grid model and the 8-meter grid model showed a slight increase in the depth of flooding in the 8-meter grid model. The difference in computed damages based on the increased water surface elevations increased the damage estimates by approximately 7.5%. Overall, the current damage analysis is slightly higher when compared to the Risk Assessment due to the changes made to the analysis to make it FEMA compliant.

The damages were also sub-divided to provide estimates of the damages along the various project reaches. Specific structures were assigned to a particular reach and the damages for each storm were aggregated. The estimated damages for each storm were then integrated over the full spectrum of probabilities to compute an average annual damage estimate. Average annual damages were converted using the FEMA approved discount rate of 7% into an equivalent capital cost. This discount rate is higher than the discount rate reported in the Risk Assessment. The Risk Assessment utilized a discount rate of 3.5% and the effect of the increased discount rate was to decrease the average annual damages compared to the Risk Assessment Damages. These updated damage estimates are summarized in Table 6-4, Baseline Damage Estimates.

Project Benefits

An estimation of conceptual alternate plan benefit calculations was necessary to allow a useful comparison between the alternatives. A relationship between flow rate and damages was established for each of the project study reaches reported in Table 6-4. An example of these curves is presented as Figure 6-1, Damage-Discharge Relationship for Dry Creek No. 2 Ditch from the Wellman Canal to Arapahoe Avenue. As this curve demonstrates, when the flow rates increase, the overall damages increase. This information proved valuable in the sizing of facilities and the evaluation of the relative benefit of those sizing strategies.

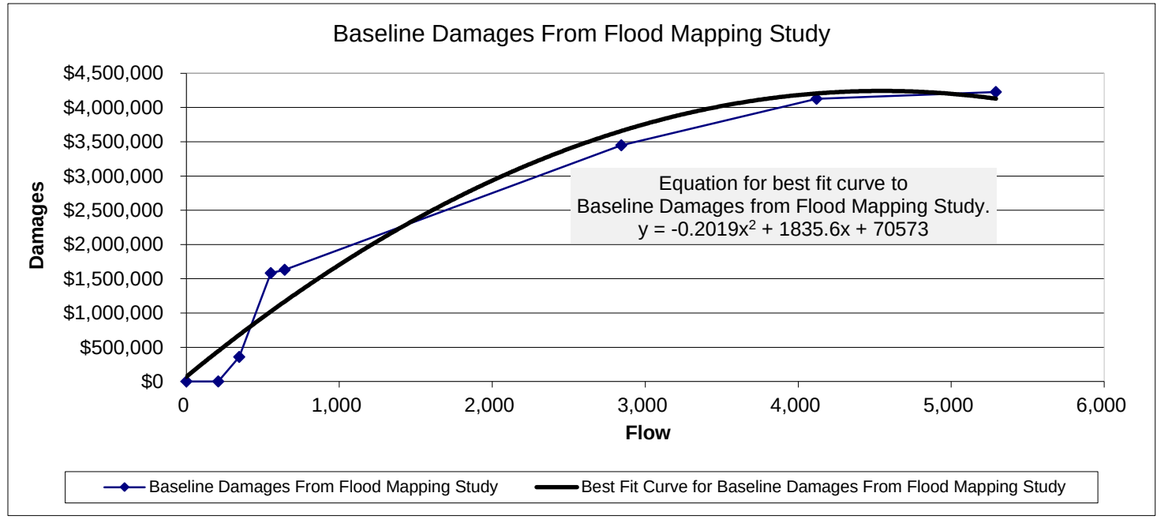

FIGURE 6-1: DAMAGE DISCHARGE RELATIONSHIP FOR DRY CREEK NO. 2 DITCH, WELLMAN CANAL TO ARAPAHOE AVENUE

These curves were used to estimate the residual damages for each of the specific alternatives studied. Residual damages were not explicitly computed for any of the alternatives. Rather, an estimate of the residual surface flow (original flow rate minus alternative improvement flow capacity) was computed. This residual flow rate was then used to enter the Damage-Discharge Relationship curve to determine the associated damage. A parallel curve was generated that represented the residual damages that would be expected with the incorporation of a specific alternative.

The estimated residual damage formed the basis for the determination of project benefits. Project benefits were estimated for each of the alternatives by developing a damage estimate with the improvements in place for each recurrence interval storm and subtracting them from pre-project damages. The reduction in damages was determined to be the project benefit. The estimated benefits for each storm return period were then integrated over the probability of recurrence for any given year, to compute an average annual project benefit. Average annual benefits were developed using the FEMA approved discount rate of 7% and converting the average annual benefits into an equivalent capital cost. Other potential project benefits such as the intangible benefit associated with peace of mind or the more tangible reduction in flood insurance premiums were not included at this stage of project formulation. This consistent estimate of the benefit of project implementation allowed for a direct comparison between the various alternatives. Table 6-2 reports the baseline damages reported in the Risk Assessment Report, the revised damage analysis based on the Flow Damage Curves and the estimated project benefit, which is the difference between the Baseline Damages (annual damages expected from the regulatory flood in today's dollars) and the residual damages.

TABLE 6-2

Baseline Damage Estimates

	Baseline Average Annual Damage[1]	100-Year Residual Average Annual Damage[2]	Average Annual Benefit[3]	Capital Equivalent[4]
West Valley US-36 to Baseline Road	$1,400,000	$400,000	$1,000,000	$14,000,000
West Valley Baseline Road to Wellman Canal	$300,000	$50,000	$300,000	$4,100,000
West Valley Wellman Canal to Arapahoe Avenue	$300,000	$40,000	$300,000	$4,100,000
West Valley Below Arapahoe Avenue	$1,600,000	$0	$1,600,000	$22,500,000
Dry Creek US-36 to Baseline Road	$300,000	$100,000	$200,000	$2,700,000
Dry Creek Baseline Road to Wellman Canal	$100,000	$10,000	$60,000	$900,000
Dry Creek Wellman Canal to Arapahoe Avenue	$100,000	$20,000	$10,000	$1,700,000
Dry Creek Below Arapahoe Avenue	$1,000,000	$70,000	$1,100,000	$14,900,000

1. Baseline Average Annual Damages – Annual damages expected from the regulatory flood in today's dollars.

2. 100-Year Residual Average Annual Damages – Annual damages expected from the proposed improvements in today's dollars

3. Average Annual Benefit – Difference between the Baseline and 100-Year Residual Average Annual Damages

4. Capital Equivalent – Estimated cost of the improvements justified by the reduction in annual average damages by implementing improvements

Alternative Costs

Once the alignments were established and general capacities for the elements understood, cost estimates were prepared. These estimates were developed based on general cost development information using cost estimating tools provided by the District and updated to reflect some critical site specific data such as Boulder area land costs. The various project elements were aggregated to develop an overall project implementation cost.

Planning level cost data was developed to allow a comparison between the various alternatives. The costs were developed using a general estimating spreadsheet that incorporated some uniquely developed unit costs along with costs embedded in the District's UD-Cost tool. The combination was deemed appropriate because of the indeterminate nature of the work elements. Rather than estimating specific type, size, and grade of the improvements, more general costs per unit discharge or size were used. These were based on summaries of past projects. Table 6-3, Conceptual Unit Costs summarizes the major cost elements.

The unit costs were combined with estimated facility sizes and quantities to develop an approximate cost for each of the identified alternatives. These costs use the District's spreadsheet with the modifications described but also have some additional modifications that reflect the nature of this project. Of greatest significance is the incorporation of a higher contingency reflecting the uncertainties associated with the complex nature of flooding along South Boulder Creek. This complexity is likely to result in some additional refinement of project elements beyond what might ordinarily be expected on District projects. Other factors and standard allowances remain unchanged.

Benefit-Cost Analysis

With both the costs for an alternative and the benefit expressed as a capital value, the benefit-cost ratio could be determined. The aggregated costs for each of the Conceptual Alternative Plans were compared to the computed benefits to determine a Benefit-Cost relationship for the alternative. This ratio provides a simple numeric measure of the approximate return on investment for a specific alternative. Ratios over one indicate the project benefits outweigh the necessary investment and are a financially justifiable use of public money. However, a ratio in excess of one does not necessarily suggest that the projects are the best use of public funds nor is a favorable ratio an indication that the project is not flawed in other ways.

Other Considerations

Other considerations such as environmental or community impacts, alignment with the city's defined objectives or general financial viability were also considered. The evaluation of the various alignments was initially conducted to determine if any constraints existed, that would render the alternative infeasible. This included consideration of land uses (both existing and anticipated future uses) that might render the alternative extremely costly or incompatible. Political constraints were generally defined as issues or concerns presented during past studies, and identified during stakeholder and public meetings that would not be compatible with public concerns or Council direction. Environmental factors were also considered and qualitative assessments were made on the impacts that might result from project implementation. Avoidance or mitigation was factored into the evaluation of the alternative plans.

Field visits were conducted to validate the information and assumptions made during the screening and alternative development process. These visits were intended to define other considerations that may not be obvious from available data such as property owner improvements, mature vegetation or physical or topographic constraints.

Table 6-4, Summary of Conceptual Alternative Plans Evaluation presents the findings of the evaluation. In this table, each alternative cost, benefit, benefit-cost ratio and some of the other considerations are presented for easy comparison and evaluation. This table provides the foundation for the decisions that were made in selecting the Best Alternative Plans. The results of this evaluation were presented at a workshop to the Project Sponsors and Stakeholders on May 11, 2010. During this workshop, the stakeholders discussed the elements of the various alternative plans and focused on the broader considerations and impacts associated with each of the plans. At the meeting, the stakeholders and Project Sponsors identified eight alternatives that were to be taken forward for further evaluation. These alternatives are collectively known as the Best Alternative Plans.

During the evaluation and refinement of these alternatives it was determined that a ninth alternative should be considered among the Best Alternative Plans. This alternative was identified in late September 2010 and the project team was directed to conduct evaluations on this alternative in addition to the previously identified eight.

TABLE 6-3

Conceptual Unit Costs

Item	Unit Cost	Unit of Measurement
36 - 48" RCP	$126.81 - $169.08	LF
90 - 120" RCP	$459.79 - $865.20	LF
Flared End Sections for 36 - 48" RCP	$1,545 - $2,060	EA
Headwalls for 90 - 120" RCP	$2,853 - $3,777	EA
Wingwalls for 90 - 120" RCP	$19,294 - $28,633	EA
Manhole, 6' Diameter	$5,407.50	EA
Type B Manhole	$10,300.00	EA
Storm Inlet	$3,605	EA
Box Culvert	$473.58 - $1,443.57	LF
Headwalls and Toewalls for Box Culvert	$454.92 - $1,123.08	EA
Wingwalls for Box Culvert	$6,865.01 - $26,895.69	EA
Sloping Drop Structures	$116,000.00	EA
Detention Ponds	$46,968	AC-FT
Roadway Reconstruction	$50.00	SY
Open Channel Improvements	$0.20	LF/Q
Regional Detention Ponds	Cost ($M) = (1+0.00215*AC-FT)	AC-FT
Channel O&M	$27.60	LF
Pond O&M	$1,380.00	AC-FT
Utility Relocation Costs	0.32*Construction Total	LS
Acquisition of Open Space Property	$0.83	SF
Acquisition of Private Property in City of Boulder	$17	SF
Acquisition of Private Property in Boulder County	Assessed Value	LS
Mobilization	5% Capital Improvement Costs	
Stormwater Management/Erosion Control	5% Capital Improvement Costs	
Engineering	15% Capital Improvement Costs	
Legal/Administrative	5% Capital Improvement Costs	
Contract Administration/Construction Management	10% Capital Improvement Costs	
Contingency	50% Capital Improvement Costs	

TABLE 6-4

Summary of Conceptual Alternative Plans

Alternative	Description	Estimated Construction Cost	Estimated Benefit	Benefit to Cost Ratio	Environmental Impacts	Social Impacts
1	Status Quo	$0	-	-	• No Impacts	• No reduction in flood risk
2	High Hazard Zone containment with critical structure flood proofing	$11,500,000	$1,150,000	0.10	• Limited Impacts	• No reduction in flood risk • Flood proofing reliability concerns
3	US-36 detention with downstream conveyance along Dry Creek No. 2 Ditch	$24,600,000	$46,700,000	1.90		
4	US-36 detention with downstream conveyance through West Valley	$28,000,000	$46,700,000	1.67		
5	US-36 detention with downstream storage and conveyance through West Valley and along Dry Creek No. 2 Ditch	$24,200,000	$46,700,000	1.93	• Habitat and wetland impacts • Periodic inundation of Open Space	• Requires formal agreement with CU • Provides 100-year protection in West Valley
6	US-36 detention with downstream diversion to Bear Canyon/Boulder Creek	$25,500,000	$46,700,000	1.83		
7	US-36 detention with downstream diversion to mainstem	$25,600,000	$46,700,000	1.82		
8	Detention near Hwy-93 with downstream conveyance along Dry Creek No. 2 Ditch	$24,100,000	$46,700,000	1.94		
9	Detention near Hwy-93 with downstream conveyance through West Valley	$27,500,000	$46,700,000	1.70		
10	Detention near Hwy-93 with downstream storage and conveyance through West Valley and along Dry Creek No. 2 Ditch	$23,700,000	$46,700,000	1.97	• Habitat and wetland impacts • Periodic inundation of Open Space	• Requires purchase of currently developed private property or OSMP • Provides 100-year protection in West Valley
11	Detention near Hwy-93 with downstream diversion to Bear Canyon/Boulder Creek	$25,000,000	$46,700,000	1.87		
12	Detention near Hwy-93 with downstream diversion to mainstem	$25,100,000	$46,700,000	1.86		
13	No upstream detention with downstream conveyance along Dry Creek No. 2 Ditch	$39,100,000	$46,700,000	1.19		• Construction traffic, road closures, and noise near homes • Traffic disruption on major roads including possible closures • Utility disruption during construction • Requires easement coordination with ditch companies • Provides 100-year protection in West Valley
14	No upstream detention with downstream conveyance through West Valley	$47,900,000	$46,700,000	0.97	• No water quality enhancement opportunities • Limited wetland impacts	
15	No upstream detention with downstream diversions	$38,900,000	$46,700,000	1.20		

VII. Best Alternative Plans

The Best Alternative Plans represent those that were felt to achieve the project objectives while also having the most favorable return of the capital investment and the fewest undesirable community impacts. The alternatives spanned the range of the alternatives considered and included a Status Quo alternative, protection for high hazard and critical facilities, conveyance alternatives and storage alternatives.

The original 15 alternatives were reviewed based on benefit - cost analysis, staff and OSMP feedback and public meeting comments and feedback on alternatives. Based on this analysis, 6 of the 15 conceptual alternative plans from Section 6 were moved forward. The alternatives moved forward are reported in Table 7-1 and include Alternative 1 (Alternative 1 from Section 6), 2 (Alternative 2 from Section 6), 3 (Alternative 5 from Section 6), 4 (Alternative 10 from Section 6), 7 (Alternative 13 from Section 6), and 8 (Alternative 14 from Section 6).

Based on recommendations from staff and public feedback three additional alternatives were added. These included looking at Baseline Reservoir as a potential storage facility to mitigate increased flood flows through the US-36 Bridge to avoid overtopping. In addition, an alternative was added that looked at providing distributed detention storage at facilities near US-36 east of the CU South campus, at South Boulder Road, and at Baseline Road, and providing local flood improvements along Dry Creek No. 2 Ditch to address the remaining hazard. These alternative detention facilities eliminated the need for detention on private property at Hwy-93 or detention on the CU South Campus. Finally, a flood protection alternative to handle nuisance flows was added to address issues related with the flood threat generated by local runoff. This alternative was based on the recommendations included in the Stormwater MP completed by HDR. The nine alternatives selected as Best Alternative Plans are summarized in Table 7-1, Best Alternative Plans and are presented as Figures 7-1 through 7-9.

TABLE 7-1

Best Alternative Plans

Alternative	Description
1	Status Quo
2	High Hazard Zone containment with critical structure flood proofing
3	Regional Detention at US-36 with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch
4	Regional Detention near Hwy-93 with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch
5	Distributed Regional Detention with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch
6	Mainstem flow containment with local West Valley improvements
7	Dry Creek No. 2 Ditch pipeline
8	Bear Canyon Creek pipeline
9	Nuisance – Level Flood Improvement Protection

The alternatives are generally described as follows:

1. **Status Quo** –. This alternative remains unchanged from the Conceptual Alternative Plan. Figure 7-1 in Appendix D presents the existing floodplain conditions that would result from maintain the status quo.

   High Hazard Zone containment with critical structure flood proofing –25 structures are proposed to be flood proofed with this alternative and include hazardous materials facilities, schools, essential government offices, public safety and emergency medical facilities and at risk population facilities as outlined in the City of Boulder's Critical Facilities and Mobile Populations Ordinance. A facility was identified if it was within the 500- or 100-year floodplain. The structures identified for flood proofing and the structures in the High Hazard Area are shown on Figure 7-2, High Hazard Zone Containment with Critical Structure Flood Proofing in Appendix D. This alternative remains unchanged from the Conceptual Alternative Plan.

3. **Regional Detention at US-36 detention with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch** – The proposed 560 AC-FT Detention at US-36 prevents the overflow of US-36 and provides 100-year protection from the overtopping flows from South Boulder Creek to downstream properties in the West Valley. The detention pond combines excavation and fill to produce a configuration that minimizes the impacts to Open Space land and the University of Colorado South Campus and to minimize the potential visual impact by integrating into existing roadway improvements in the area. The Remainder of the alternative includes improvements along Dry Creek No. 2 as described in the Conceptual alternatives Plan. Figure 7-3 US-36 Detention in Appendix D presents the proposed improvements.

4. **Regional Detention near Hwy-93 with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch** – Detention near Hwy-93 provides detention on approximately 40 acres of land (420 acre-feet of storage). This alternative reduces impacts of city owned Open Space and isolates the detention onto two large privately owned parcels, avoiding the challenges associated with coordination with CU South Campus, CDOT and other stakeholders in the vicinity of the US-36 corridor but would require the purchase of currently developed private property from unwilling sellers.

   This alternative has other constraints that make its implementation difficult. This alternative relies on uncontrolled overflows of Hwy-93 to function. There is no guarantee that the specific natural conditions that currently cause this overflow to occur would continue in perpetuity. These conditions include the geometry of Hwy-93, which will likely change in the future, upstream conditions including irrigation diversions, changes to upstream vegetation and land use, and the location of any specific design storm. If any of the above-mentioned conditions change, it could affect the overflow at Hwy-93 and the function of the proposed detention structure potentially changes the flow conditions and storage capacity of the alternative.

   The Remainder of the alternative includes improvements along Dry Creek No. 2 as described in the Conceptual alternatives Plan. Figure 7-3 US-36 Detention in Appendix D presents the proposed improvements. Figure 7-4, Detention near Hwy-93 in Appendix D presents the proposed improvements.

5. **Distributed Regional Detention with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch** – This alternative was developed in response to feedback opposing Alternative 4. The objective of this alternative is to provide 100-year flood protection within the West Valley area using lands owned by the city OSMP or through the purchase of currently undeveloped private land. This represents a derivative of the Mainstem Containment option but incorporates some of the features of the detention alternatives. The intention of this plan is to provide mainstem containment but to mitigate the impacts associated with the increased flows through the US-36 Bridge by providing storage both upstream and downstream of US-36. Detention to mitigate the impacts of increased flows through the US-36 bridge were accomplished using the following detention locations:

   – Approximately 130 acre-feet of detention storage (38 acres surface area) at US-36. Floodwaters would be stored behind a berm constructed along the south side of US-36 on the west side to South Boulder Creek. The berm would begin at the bridge, reach a maximum height of 13 feet near the Foothills Parkway interchange and be constructed entirely on OSMP lands, avoiding construction on CU property.

   – Approximately 130 acre-feet of detention storage (49 acres surface area) at South Boulder Road. Flood waters would be stored behind a berm constructed along the south side of South Boulder Road, have a maximum height of six feet above South Boulder Road and be constructed entirely on OSMP lands.

   – Approximately 295 acre-feet of detention storage (38 acres of surface area) at Baseline Road. The water would be stored behind a berm constructed along the south side of Baseline Road that would have a maximum height of approximately 13 feet above Baseline Road. The berm would be constructed on OSMP land but would also require the purchase of privately owned parcel. Construction of this detention facility would require relocating

an OSMP trail head and access parking lot from the south side of Baseline Road likely to the west side of Cherryvale Road.

To address the flood threat downstream of US-36, both storage and conveyance improvements are proposed through the West Valley and along the alignment of Dry Creek No. 2 Ditch. The storage component of the downstream improvements allows for locally generate flood peaks to be attenuated and results in a decrease in the size of the required infrastructure downstream. The combination of conveyance improvements along both drainage corridors reduces the amount of overland flooding that poses a threat once floodwaters leave either corridor. These improvements will generally consist of enlarged channels or pipes to minimize the potential for residual flooding in the area. Figure 7-5, Mainstem Containment with Storage in Appendix D presents the elements of this alternative.

6. **Mainstem flow containment with local West Valley improvements** – This alternative does not control the overflow of US-36 using storage. Rather, it provides a berm parallel to the existing CU South Campus Berm to contain the flow in the main channel and forces more water through the US-36 Bridge. Localized improvements through the West Valley and along the Dry Creek No. 2 Ditch corridor are still required to manage locally generated flows. Both storage and conveyance improvements are proposed through the West Valley and along the alignment of Dry Creek No. 2 Ditch. The storage component of the downstream improvements allows for locally generate flood peaks to be attenuated and results in a decrease in the size of the required infrastructure downstream. The combination of conveyance improvements along both drainage corridors reduces the amount of overland flooding that poses a threat once floodwaters leave either corridor. These improvements will generally consist of enlarged channels or pipes to minimize the potential for residual flooding in the area. The impacts associated with higher flows along the mainstem would be mitigated by providing additional storage capacity in Baseline Reservoir. Currently, some of the mainstem flows reach Baseline Reservoir. This alternative proposes to formalize this flow path and add additional flow capacity and storage in Baseline Reservoir to mitigate impacts to downstream properties. On July 30, 2010, the project team met with Staff from the Baseline Reservoir Company and City of Lafayette to discuss the use of Baseline Reservoir for storage of flood flows. From this meeting several issues regarding the alternative were brought to light.

   – Baseline Reservoir is a drinking water storage reservoir and Lafayette has concerns that adding additional flood flows to the reservoir could detrimentally affect the quality of the drinking water for Lafayette. The City of Lafayette would require water quality enhancements to mitigate the effect of the additional flood flows to the water quality in Baseline Reservoir.

   – There was concern that adding additional flood flows to the reservoir could affect the spillway and embankment of the reservoir requiring a lengthy and expensive retrofit or upgrade to the reservoir embankment and spillway to accept additional flood flow waters.

   These issues are significant factors to the successful implementation of this alternative and are reflected in the benefit cost ratio for the alternative.

   Figure 7-6, Mainstem Flow Containment in Appendix D shows the proposed improvements.

7. **Dry Creek No. 2 Ditch pipeline –**. This alternative remains the same as the alternative described in the Conceptual Alternative Plan. It should be noted however that no improvements are proposed though the West Valley. As a result, some potential for damage during local floods remains. Figure 7-8, Dry Creek No. 2 Ditch Conveyance in Appendix D presents the proposed improvements.

   This alternative has the potential to create significant disruption to both local neighborhoods and arterial roadways throughout Boulder. Potential impacts could include disruption or closure of both local residential streets and major arterials including Baseline Road and 55th Street to accommodate the construction of the Pipelines. In addition, there could be additional disruptions to utilities as utility conflicts with water, sewer gas, electricity and telecommunications are resolved during construction.

8. **Bear Canyon Creek pipeline** – This alternative remains the same as the alternative described in the Conceptual Alternative This alternative collects and captures the overflow and provides a large, conveyance to move those flows to the west toward channels that have adequate capacity. In general, overflows reaching the West Valley will be captured and diverted north and west to the Bear Canyon Creek system along Foothills Parkway downstream of Baseline Road. Remaining flows that reach the Dry Creek No. 2 Ditch corridor will be captured and moved east back toward the mainstem where adequate capacity exists. Improvements include larger pipes or channels and associated collection facilities and inlets. Figure 7-7, Diversion to Bear Canyon Creek in Appendix D presents the proposed improvements.

   This alternative has the potential to create significant disruption to both local neighborhoods and arterial roadways throughout Boulder. Potential impacts could include disruption or closure of both local residential streets and major arterials including Baseline Road and 55th Street to accommodate the construction of the Pipelines. In addition, there could be additional disruptions to utilities as utility conflicts with water, sewer gas, electricity and telecommunications are resolved during construction.

9. **Nuisance – Level Flood Improvement Protection** – This alternative considers the improvements proposed in the Stormwater MP. This alternative does not explicitly address the hazards of the 100-year flood but focuses on the minor floods that cause considerable nuisance but little major damage. The primary purpose of this alternative was to assess the potential flood damage reduction if these lower events were controlled. The facilities proposed in the Stormwater MP are the basis for this alternative and are generally smaller pipes that collect local runoff. This alternative does not significantly alter or reduce the 100-year floodplain as the proposed pipe systems will be surcharged during a 100-year event. However, during smaller local basin storms this alternative will address local basin and small flooding events helping to eliminate repetitive damages in the basin during small storms. Figure 7-9, Stormwater MP, in Appendix D shows the proposed facilities.

Project Benefits

Benefits associated with the various alternatives were derived directly from the results of MIKEFLOOD. Unlike the earlier evaluations that required an estimation of the damage to flooded structures, the MIKEFLOOD model results defined a depth of flooding at each structure in the floodplain for each recurrence interval event. Similar to the original estimate of the flood damages, it was possible to aggregate these damages estimates and determine the residual flood damage for each simulation.

The resulting flood damages, when subtracted from the baseline flood damage, provide an estimate of the project benefits. Residual damages for each event were computed and average annual residual flood damage was determined. The difference between the baseline average annual flood damage and the residual average annual flood damage was the computed project benefit. Average annual benefits were converted to an equivalent capital cost using the processes defined by the District and FEMA using the FEMA approved discount rate of 7%.

Alternative Costs

The planning level cost estimating tools developed during Conceptual Alternative Plan evaluations were generally applied to develop costs for the Best Alternative Plans. The higher level of resolution of the alternatives allowed for an improved cost estimate for each of the alternatives. In particular, the resolution used to define the storage facilities provided a better understanding of the earthwork and of the outlet control structures. This greater level of resolution was incorporated into the planning cost estimates.

Unit cost was not changed in the revised alternative evaluations. Land costs were reviewed and clarifications were added. Purchase or easements on property outside of the City of Boulder's corporate limits were valued based on the assessed value of both the land and structures as found in the Boulder County Assessors data. Land within the City of Boulder's Corporate Limits was conservatively valued based on zoning designations within the city's boundaries as shown in Table 7-2.

TABLE 7-2
Land Value Data for South Boulder Creek Flood Mitigation Project
Source: City of Boulder Utilities

Zoning Code	Description	Price per Square Foot ($)
AG	Agricultural	0.80
PU	Public	19.00
RB	Regional Business	180.00
CB	Community Business	39.00
HD	High Density Residential and Mobile Home	50.00
MD	Medium and Mixed Density Residential	36.00
LD	Low Density and Rural Residential	22.00
IND	Industrial	15.00

Benefit-Cost Analysis

The refined aggregated costs for each of the Best Alternative Plans were compared to the refined computed benefits to determine a Benefit-Cost relationship for the alternative. This ratio provides a simple numeric measure but does not necessarily suggest that the projects with the best ratios are the best use of public funds nor is a favorable ratio an indication that the project is the most favorable project without the consideration of social, political, and environmental constraints. The results of this analysis are presented in Table 7-3.

Other Considerations

Decisions regarding which alternatives should be taken forward for additional investigation and consideration are not made solely based on the financial impacts. While these financial impacts are an important consideration that will profoundly affect the implementation potential, many financially viable projects are in other ways flawed. The consideration of these other issues often drives decisions on the real potential for a project to successfully address the flood control objectives while conforming to other community standards.

Water Quality

The city has a strong history of efforts that demonstrate a commitment to water quality enhancement. All of the alternatives will continue to incorporate the ongoing measures already in place within the city such as the National Pollutant Discharge Elimination System (NPDES) Stormwater Discharge permit program. In this program, the city has identified and implemented measures that collectively will improve the quality of stormwater runoff within the city. While these control measures are generally focused on minor, first flush events that convey the majority of pollutants of interest, they provide broad benefit, and considerations for major floodwater quality were taken into account.

Water quality impacts and the measures necessary to address those impacts generally fall into two categories, temporary and permanent. Temporary impacts are often associated with construction activities and focus primarily on the disturbance to natural ground cover during construction activities. While the general extent of these impacts often varies with the nature of the construction, mitigation measures required by the NPDES Stormwater Discharge Permits held by the city and Boulder County will be imposed on any construction activities. As such, there is not likely to be any difference in the temporary water quality impacts associated with the various improvements.

Permanent impacts to water quality are likely to differ among the alternatives. In general, alternatives employing natural channels will provide greater water quality benefits than those, which include conveyance mechanisms such as pipes or lined channels that accelerate flow and eliminate the natural filtration provided by the natural systems. Similarly, detention storage has water quality benefits due to the water being detained allowing large particles to settle out of suspension. These particles are common carriers of many pollutants in stormwater and, after being removed from the flow, result in reduced concentrations of many of the most significant constituents impairing water quality.

Stormwater inherently conveys pollutants. Flood control improvements that convey this stormwater to areas not typically receiving these flows have the potential to create adverse impacts if not carefully considered. Efforts were made to understand the potential impact of water quality changes on receiving waters such as Baseline Reservoir.

Natural Environment

Boulder has a longstanding tradition of nurturing, protecting and integrating the natural environment into the community. Flood control projects are no exception. Whether greenways, Open Space lands, buffers, wetlands or other habitat areas; identification, protection and preservation of these areas must be incorporated into flood control projects.

The projects identified as Best Alternative Plans are mindful of the city's interest in the natural environment and have been laid out to minimize impacts. Areas containing high functioning wetlands have been avoided to the extent possible. In some cases, minor impacts to the fringes of these areas may have been unavoidable but the level of encroachment has been minimized.

While not an element directly incorporated at this level of study, enhancement of the natural environment is often an element of flood control improvements. These can be incorporated as trails that provide the public with better access to natural areas or in may be the enhancement of natural spaces. Ponds and open channels are frequently revegetated with native plant materials that provide aesthetic means of stabilization integrate into the surrounding environment and provide habitat and other functions often found in natural environments. As the alternatives identified for further study are refined, specific measures to enhance the natural environment will be incorporated.

The natural environment also includes the groundwater resource in the area. Drainage improvements often affect the natural flow of groundwater. In many cases, the construction of these drainage improvements lowers groundwater tables by providing improved and lowered drainage channels. That is likely to be the case where open channel improvements are proposed. However, a high groundwater table also constrains some alternatives. High groundwater complicates construction activities and may limit the effectiveness of facilities such as detention ponds by occupying some of the intended flood storage capacity. Along South Boulder Creek, there are numerous areas where the groundwater table supplies an important water source for wetlands. Every effort was made to understand the nature of the groundwater near the proposed improvements. Further investigations are likely to be required if specific alternatives move forward for additional consideration.

Threatened and Endangered Species

Numerous resources from Boulder County, OSMP and the City of Boulder were referenced that identify the locations of threatened and endangered species within the South Boulder Creek watershed. These consist primarily of *Spiranthes diluvialis* or Ute lady's tresses orchid and the Preble's Meadow Jumping Mouse (PMJM), which have been mapped as having habitat along the mainstem, primarily upstream of US-36. Figure 2-5 through Figure 2-8, presented earlier in this report provide a summary of the habitat areas along the study alignment.

The flood control measures proposed in the various Alternative Plans have been formulated to avoid these areas to the maximum extent possible. Any projects that move forward toward implementation will be required to look at these habitat areas more carefully and provide assurance that no adverse impacts to threatened and endangered species occur.

Open Space Lands

Numerous areas of designated Open Space land exist within the South Boulder Creek watershed. These areas serve many important functions, any of which may be unique to a given property. The alternatives identified in these plans were formulated to minimize the impacts to Open Space lands. However, since many of these lands fall in or near the conveyance areas of the channel, all impacts were unavoidable.

The Project Stakeholders group included representatives from city OSMP. Numerous discussions were held to understand the types of Open Space lands being impacted and to identify any possible measures that might be allowable on a particular Open Space parcel. In general, the layout of improvements associated with the Alternative Plans limited physical improvements on Open Space lands to the extent possible and required several iterations of concept designs.

Operation and Maintenance

The costs identified for the various alternatives include an allocation for the long-term maintenance of the component facilities. These costs are generally mowing and cleanup costs. For the purposes of comparing the various Alternative Plans, the maintenance costs have been converted to an equivalent capital cost and rolled into the total improvement cost for a specific plan.

The design criteria developed by the District and adopted by the city also include considerations that minimize the long-term cost of maintenance of drainage facilities. Measures have been incorporated into the layout of alternatives that assure there is adequate access for routine maintenance or for emergency repairs if required. Other design standards have been developed to limit future erosion and to provide stable slopes with appropriate vegetation.

Social Impacts

Impacts to the community pose a particular constraint on many types of improvement options. These impacts include disruptions during construction, visual or aesthetic impacts, and many other impacts that were expressed during the public involvement process on this project. These must be included in the final consideration of the various alternative plans.

Each of the projects, other than the Status Quo, will have associated construction impacts. While these are temporary, they have the potential to disrupt business activity, make travel from home to office and other destinations more difficult and create noise and dust. Typical construction specifications impose conditions on the contractor that require the mitigation of these impacts. It can be assumed that such conditions will be included in any improvements that are associated with the selected plan.

Much of the character of the community is defined by the maturing of the landscaping along many of the streets and parcels on which improvements have been identified. Considerable feedback was provided during the public meetings about the desirability to maintain the large mature trees that line many of the drainage corridors in the city. Any impact to this vegetation would create considerable disruption and would be looked upon with skepticism by the community. Efforts were made to minimize the potential disruption along the mature drainageways whenever possible.

Other visual impacts were also considered. In particular, the construction of embankments for flood control storage would obstruct existing sight lines. Moreover, the construction of an embankment often gives the appearance of creating an entirely new landscape that is very imposing. Efforts were made to understand the impact of these new facilities and to minimize the visual impact by aligning them with existing features of similar geometry.

The implementation of flood control improvements often requires new rights – of - way. The alignments identified for the various alternative plans were chosen to minimize the impact on private properties. Not all impacts to private property, however, could be avoided. The costs for each of the plans include provisions for the purchase of easements or outright purchase of the property. The estimates are based on costs derived from the City of Boulder assessor's data.

City Policies

During past studies of South Boulder Creek, the city identified priorities that could be used as guidance in the development and evaluation of alternatives for this study. Many of these reflect sound flood control principles while others reflect the collective interests of the community and its leadership. Among these were issues discussed earlier such as the avoidance of alteration to Open Space or the consultation and approval should any impacts be necessary and the preservation of habitat and riparian areas.

Other objectives include an interest in avoiding channelization of South Boulder Creek. Because the corridor had many areas of designated habitat and wetlands and because the corridor was home to long reaches of mature vegetation, these areas were generally avoided in the formulation of the alternative plans. Minor improvements were identified along the mature drainageways within South Boulder Creek but they were limited to the extent necessary to provide the necessary flood protection.

The city has expressed an interest in minimizing the impacts to the community and that includes the potential purchase of property for flood control facilities. The intention of the identification and selection of the alternatives was to minimize disruption to the community, including limiting the amount of private property necessary for the implementation of the alternatives. The facilities were located so that the number of private property impacts would be minimized. In the case of the Distributed Regional Detention, that meant aligning the alternative so that the impacts would be borne by a single property owner rather than several. While the impacts to that property owner were indisputably higher as a result, the position taken during alternative development and evaluation was that the impact would be mitigated by payment of fair market value for any impacts.

The city has expressed a strong interest in minimizing the use of large mainstem dams to control flooding along South Boulder Creek. That interest was reflected in the development of these alternatives. The alternatives selected generally try to provide storage off channel, although on-channel detention facilities were included to limit disturbances to private property. All Detention structures focused on minimizing excavation and minimizing the impacts to habitat areas and wetlands that are most commonly along the mainstem. In many cases, the storage areas that are proposed are in areas already impacted by flood flows so there is little additional impact to habitat areas.

In all cases, the city's commitment to floodplain management is maintained. Each of the alternatives continues the city's ongoing efforts to protect the community from the hazards of flooding along South Boulder Creek and from its tributaries. The practices such as flood warning systems, education and floodplain regulations provide a strong foundation that is complementary to the structural measures identified as part of most of these alternatives.

Best Alternative Plan Evaluation Summary

The evaluation of the Best Alternative Plans is summarized in Table 7-3, Best Alternative Plan Evaluation Summary.

TABLE 7-3

Best Alternative Plan Evaluation Summary

Alternative	Description	Estimated Construction Cost	Benefit-to-Cost Ratio	Environmental Impacts	Social Impacts
1	Status Quo	$0	0.00	• No impacts	• Flood risk still remains
2	High Hazard Zone containment with critical structure flood proofing	$10,700,000	2.20	• Flood proofing of critical facilities reduces the potential exposure of flood waves to toxins	• Flood limits do not change • Flood proofing reliability concerns • Provides emergency egress to homes within the high hazard zone
3	Regional Detention at US-36 with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch	$28,800,000	2.68	• Impacts to Environmental Conservation Area Land • Impacts to wetland • Periodic inundation of Open Space lands • Groundwater impacts still to be determined	• Requires formal agreements with CU, Boulder Valley School District (BVSD), OSMP, CDOT, ditch companies, and city Parks • Provides 100-year protection in West Valley Area • Includes enhancements to Manhattan Middle School play fields and includes enhanced bike/pedestrian trail at Arapahoe Avenue
4	Regional Detention near Hwy-93 with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch	$31,100,000	2.49	• Habitat and wetland impacts • Periodic inundation of Open Space lands • Groundwater impacts still to be determined	• Requires purchase of currently developed private property • Requires formal agreement with CU, BVSD, OSMP ditch companies and city Parks • Provides 100-Year protection in West Valley Area • Includes enhancements to Manhattan Middle School play fields and includes enhanced bike/pedestrian trail at Arapahoe Avenue
5	Distributed Regional Detention with downstream storage and conveyance improvements through West Valley and along Dry Creek No. 2 Ditch	$29,200,000	2.60	• Habitat and wetland impacts • Periodic inundation of Open Space lands • Impacts Boulder county Critical Wildlife Area at Baseline Road • Groundwater impacts still to be determined	• Requires formal agreements with BVSD, OSMP, CDOT, ditch companies, and city Parks • Provides 100-year protection in West Valley Area • Includes enhancements to Manhattan Middle School play fields and includes enhanced bike/pedestrian trail at Arapahoe Avenue • Requires purchase of undeveloped private property
6	Mainstem flow containment with local West Valley improvements	$39,200,000	1.94	• Impacts to Open Space and Environmental Conservation lands downstream of South Boulder Road • Impacts Boulder County Critical Wildlife Area at Baseline Road • Groundwater impacts still to be determined	• Requires approval from State Engineers Office • Requires formal agreements with City of Lafayette, BVSD, CDOT, OSMP, ditch companies, and city Parks • Provides 100-year protection in West Valley Area • Includes enhancements to Manhattan Middle School play fields and includes enhanced bike/pedestrian trail at Arapahoe Avenue
7	Dry Creek No. 2 Ditch pipeline	$45,700,000	1.24	• No water quality enhancement opportunities • Wetland impacts at Baseline Road/ Foothills Parkway intersection	• Extensive disruption during construction • Requires easement coordination with ditch companies • Provides 100-year protection in West Valley Area • Significant utility relocation costs
8	Bear Canyon Creek pipeline	$46,300,000	1.25	• No water quality enhancement opportunities • Wetland impacts at Baseline Road/ Foothills Parkway intersection	• Extensive disruption during construction – Construction traffic, road closures, and noise near homes – Traffic disruption on major roads including possible closures – Utility disruption during construction • Requires easement coordination with ditch companies • Provides 100-year protection in West Valley Area • Significant utility relocation costs
9	Nuisance – Level Flood Improvement Protection	$14,000,000	0.10	• No impacts	• Limited reduction in flood risk

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VIII. Refinement of Best Alternative Plans

Introduction

The refinement of five of the Best Alternative Plans was authorized by an amendment dated May 18, 2011. The need for the refinements to these alternatives came because of City of Boulder staff's discussions with the Water Resources Advisory Board (WRAB) and Open Space and Mountain Parks (OSMP) staff. During those discussions, additional interests and issues were identified that were beyond the scope of the original planning study. The selected five alternatives were deemed the most viable and the only alternatives among the previous nine that warranted further consideration. All other alternatives were eliminated from further consideration.

The scope of the amendment called for a more detailed evaluation so that the elements of the plans could be refined with greater resolution and the plans could be more clearly communicated to the public. The five alternatives identified for further evaluation include:

- Status Quo Alternative
- High Hazard Zone Mitigation Alternative
- Regional Detention at US-36 Alternative
- Distributed Regional Detention Alternative
- Bear Canyon Creek Pipeline Alternative

The focus of the evaluations continued to be on cost effective ways to address the 100-year flood threat in the West Valley. The refinements continued to rely on the representation of the flood threat as defined by the 8-meter grid MIKEFLOOD model. The refinements included more detailed engineering evaluations to better define the characteristics of the plan elements including conceptual grading and layout, the associated costs, and proposals for the most logical implementation sequence. In addition, renderings of select components of the plans were developed to communicate the details to the public more clearly. These more refined evaluations provide the necessary information to allow the city to put forward a single recommendation for formal consideration and adoption.

Alignment Refinements

The refinements looked more carefully at identified environmental constraints and existing public easements and utilities. The alignment and geometry of the improvements were revised to reduce impacts and costs.

Costs Refinements

One of the key objectives was to better define the likely implementation costs for each of the Best Alternative Plans. In addition to the higher resolution of the various plan elements, other items affecting cost such as utility relocations, easement and right-of-way acquisition, and environmental mitigation were identified and incorporated. A more detailed summary of the cost estimate refinements is presented in Appendix F, Cost Summary.

Unit costs for the various work elements and estimating contingencies were also reviewed and updated as required. The unit costs used were generally based on the default values found in the Urban Drainage and Flood Control District's (District) program UD-MP COST Version 1.1. While this proved to be a useful starting point, the nature of some of the improvements proposed along South Boulder Creek necessitated the modification of some of these values. The refined analysis included a more detailed grading plan for each of the ponds proposed in the alternatives and resulted in a better estimate of the embankment fill, impervious core, and impervious key. The evaluation also concluded that a concrete spillway would probably be required by the State Dam Safety staff in order to assure the stability of the embankment during the spillway design flood.

The utility relocation costs continued to be handled using a factor applied to the capital cost of all infrastructure. During the refinement process, it was concluded that the proposed ponds would have very little impact on existing utilities; therefore, the utility relocation cost factor applied to these costs was removed. Facility locations were adjusted to avoid impacts to individual single-family residential properties in favor of the purchase of larger easements from undeveloped or commercial and industrial properties.

The earlier alternatives recognized that there would be impacts to environmentally sensitive areas and anticipated that the cost of mitigation could reasonably be included in the project contingency. After discussions with OSMP staff, it was concluded that environmental mitigation should be estimated separately. A per acre cost based on the market price for creation of comparable wetlands for wetland areas that are regulated by the city or USACE was the basis of environmental mitigation costs.

The early estimates of Best Alternative Plan costs used a 50 percent construction contingency instead of the District's default value of 25 percent. These contingencies are above the engineering, legal, administrative and management contingencies that add another 30 percent. The higher factor was deemed appropriate because the nine alternatives were schematic in nature. The refined plans looked at various elements in greater detail than the original nine alternatives but are still not at the level of conceptual design drawings, so a construction contingency value of 35 percent was utilized for the refined costs.

Refined Benefits

The refinements to the various plan elements did not result in any substantive changes to the estimated benefits. The refined benefit-cost ratios reflect changes to the cost estimates discussed above.

Other Considerations

The refinement of the Best Alternative Plans allowed the team to gain a better understanding of the various project impacts and to assess the proposed plans against a broad range of considerations. Details of many of the identified impacts are discussed in a memorandum that updated the earlier assessment conducted by the OSMP staff. The memorandum is included in Appendix G, OSMP Impact Memorandum Update. These considerations included:

- Water Quality
- Natural Environment
- Threatened and Endangered Species
- Open Space Lands
- Operations and Maintenance
- Social Impacts
- Other city Departments

The refinements did not create any substantive changes in expected water quality benefit from those identified during the earlier evaluations.

Because of the refined analysis and discussions with OSMP staff, several environmental considerations and impacts were analyzed. Most of the improvements proposed reduce or avoid impacts to the main channel of South Boulder Creek that represents the majority of the natural areas.

Impacts to threatened and endangered species are expected as part of some of the alternative plans being considered. The two species noted are the PMJM and the Ute Ladies' Tresses Orchid. The Northern Leopard Frog is also a species of interest, and impacts to its habitat areas have been identified. While every effort was made to reduce the impact of construction footprints and permanent facilities, some impacts were unavoidable. The proposed plans include costs to mitigate the impacts through the development of compensatory mitigation or the purchase of land. In addition, all disturbed lands will be restored to the extent possible. Some impacted areas can be enhanced during the restoration process through the establishment of more suitable vegetation types or densities and grading changes to create more suitable habitat.

Many impacts to both privately owned and city-owned Open Space lands, including permanent improvements such as embankments and temporary impacts were not materially changed during the refinement. These areas will be restored.

All of the facilities will require routine maintenance to assure correct performance. Permanent access was incorporated during the refinement to facilitate operations and maintenance.

Social impacts were considered in the refinement process. This includes minimizing the visual impacts of any proposed improvements. This included concerns over the impacts to mature vegetation that currently serves as a visual barrier, as well as impacts to unvegetated areas that provide unobstructed views. The proposed facilities generally avoid direct

impact to the recreational corridor and do not preclude access to Open Space. There will inevitably be temporary impacts to residents along the areas of proposed construction, regardless of which alternative may be identified as the Selected Alternative. Final design and construction should include measures to assure that business and residential impacts are addressed.

Phasing Recommendations

The implementation of the Best Alternate Plans will require a capital investment of somewhere between $30 million and $50 million. It is quite likely that the city, even with a funding partner such as the District, will not be able to commit sufficient funds to construct the improvements for all elements of the plan concurrently. A more probable scenario is that the improvements will be phased to better align capital outlays with revenue streams.

In many drainageway improvement projects, facilities are implemented in an upstream direction. That is, the facilities farthest downstream are constructed first so that improvements will not increase the flood hazard to facilities further down in the system. This implementation strategy is often modified in the event of detention storage, which is commonly upstream in the system. Along South Boulder Creek, the definition of these implementation priorities is further complicated because of the unique flood threat that results from the overtopping of US-36. Many downstream improvements have little impact on the floodplain and are intended to capture and convey locally generated flows. Without detention to control the overtopping of US-36, the downstream improvements offer little flood threat reduction.

The challenge in providing phasing recommendations is that various considerations must be balanced in order to define the most reasonable order of implementation. This is a highly subjective process and one in which different people could reach different conclusions. In this case, the phasing recommendations are the product of interests expressed by the project team, the interested public during the various public meetings held on the project, and the direction and input received from WRAB and other city staff.

The process used to determine the recommended phasing for the various Best Alternative Plan elements is built upon several different criteria, including:

- Hydraulic Considerations
- Estimation of Residual Damage
- Capital Cost
- Element Benefit-cost Ratio
- Flood Control and Life Safety Issues
- Broader Public Interest Issues

For the phasing analysis, elements of the various plans that resulted in the lowest residual damages were determined to be more desirable than those with higher residual damages. Because the available funds to implement any of the identified plans are limited, the overall cost of the plan and the individual elements of the plan is an important consideration. In general, a higher benefit-cost ratio indicates a greater return on the community's investment and would suggest a higher priority. However, in some cases, the capital cost may be too high to warrant a high implementation priority. The comparison of the relative benefit-cost ratios assumes each phase might be implemented independently. By using this approach, the order of implementation can vary without the need to refine the benefit-cost ratio.

The primary objective of the Flood Mitigation Planning Study was to define a plan that would reduce the flood hazard in the West Valley. Alternative plan elements that helped to achieve this objective were accorded high priority when determining phasing recommendations.

Status Quo Alternative Refinements

This remains an important baseline against which all other alternatives will be measured and is unchanged from the earlier analysis. Figure 8-1, located in Appendix E, depicts the status Quo Alternative.

High Hazard Zone Mitigation Alternative Refinements

This alternative now focuses only on mitigation of High Hazard Zone conditions affecting two multi-family residential structures (Fig. 8-2, High Hazard Zone Mitigation Located in Appendix E) and no longer includes physical measures to floodproof Critical Facilities, as defined in the city's new Critical Facilities and Mobile Populations Ordinance. However, floodproofing schemes were identified and are discussed for informational purposes, but no specific floodproofing improvements are incorporated into the plan. More detailed suggestions of the possible floodproofing measures that could be employed for these structures are presented in Appendix H, Floodproofing.

The grading and structural improvements necessary to remove these two structures from the High Hazard Zone have been more clearly defined. A short structural floodwall adjacent to each structure and creation of a swale to improve conveyance along the emergency access lane and combined driveway north of Pima Court could be constructed. These improvements will prevent high-velocity flows from affecting the buildings and will effectively remove the structures from the designated High Hazard Zone. In addition to addressing the life safety threat, the elimination of the High Hazard Zone designation offers regulatory relief to property owners who seek to make modest improvements on the property that would have been disallowed in this zone. Figure 8-3, High Hazard Grading Improvements, located in Appendix E, shows the adopted concept for addressing the High Hazard Zone mitigation.

The High Hazard Mitigation Plan costs have been modified substantially. As part of the refinements to the High Hazard Plan, the properties identified as critical facilities as part of the Cities Critical Facilities ordinance were further reviewed. The originally identified critical facilities were further filtered based on the following criteria:

- Remove facilities that are outside the 100-year floodplain
- Remove hazardous chemical facilities
- Identify city owned facilities

Based on the refined filtering of the critical facilities, three non-hazardous materials critical facilities located within the 100-year floodplain were identified and none of the facilities is city owned. The three remaining critical faculties identified are:

- RTD Parking Structure at Foothills parkway and US-36
- Frasier Meadows Manor
- The Friends School

Because the three remaining critical facilities are not city owned, the Project Sponsors concluded that the cost of floodproofing of these critical facilities, as well as any flooded residential structures, should be borne by the property owner. As a result, it was also concluded that any benefits from floodproofing activities should not be included in the Plan benefits. The High Hazard Mitigation Plan now has no identified benefits because the grading work described above would not produce any material reduction in flood damage.

The implementation of this alternative does not lend itself to phasing. The improvements are relatively low cost and must be done in aggregate to provide the necessary changes to the High Hazard Zone. As such, this alternative plan must be implemented in its entirety.

Regional Detention at US-36 Alternative Refinements

US-36 Detention Pond

The grading for the detention pond adjacent to US-36 was refined to make sure that there was sufficient room for the incorporation of future transportation corridor improvements identified in the US-36 Corridor Environmental Impact Statement (EIS). The improvements specified in the EIS were generally limited to the addition of acceleration lanes east of the Foothills Parkway /US-36 interchange and the addition of a regional recreational trail along the south side of the existing highway. The proposed grading for the US-36 Detention Pond embankment is presented in Figure 8-4, US-36 Detention located in Appendix E. To provide a buffer between the proposed flood control facilities, provide right-of-way for the regional trail and allow for potential alterations to the US-36 EIS as design proceeds, a 20-foot shift of the embankment to the south and away from the existing roadway was incorporated. This created a slight increase in the amount of embankment material required to provide the necessary storage as well as slight additional impacts to OSMP property.

The public expressed considerable concern over the height and alignment of the embankment for the detention pond. The project team looked at this very carefully to minimize the footprint and the visual impact while maintaining the

desired flood storage capacity of 560 acre-feet (AF). Some visual impacts, however, were unavoidable. A rendering was developed to depict the view of the embankment across its highest point, as shown in Figure 8-5, US-36 Detention Pond Embankment Rendering, located in Appendix E. To capture the perspective that featured the greatest obstruction, the rendering was produced looking from the Table Mesa Drive crossing of US-36 toward the southeast with and without the embankment in place.

The project team also looked very closely at the identified environmentally sensitive areas near the embankment. Impacts to areas of special environmental interest including the South Boulder Creek Natural Area, the PMJM Critical Habitat Area identified by the USFWS, the PMJM conservation area, and riparian and wetlands impacts were re-evaluated. The embankment was designed to minimize impacts to environmental resources and was successful in not affecting regulated wetlands. However, 1.0 acres of PMJM habitat would be impacted and the purchase of land and construction of compensatory mitigation would be required. The embankment would encroach onto property owned by CU for its future South Campus expansion. The CU-Boulder South Conceptual Framework Plan developed by the University was incorporated into the earlier investigations and was not updated during the refinement period.

The refinement also included a review of the various structural elements that are incorporated into the detention facilities at US-36. These include structures draining the pond, at either existing irrigation facilities or new outlet works, and the emergency spillway. The outlet facilities were found to be reasonable and were not modified. However, the emergency spillway erosion protection was expanded as a result of the refinement process. The extent of the riprap erosion protection was enlarged to provide a higher degree of assurance that flows in excess of the 100-year flood could be safely conveyed over the embankment and onto the US-36 right-of-way.

Arapahoe Avenue Detention

The pond, as originally conceived, was located adjacent to Arapahoe Avenue, and took advantage of the Flatirons Golf Club golf course. The overall geometry of the facility and the infrastructure upstream of Arapahoe Avenue was largely unchanged during the refinement process, and the pond maintained a capacity of 58 AF.

The east outlet channel below Arapahoe Avenue has been realigned to minimize the impact on the existing development and to minimize future disruption to any new development. The realignment resulted in slightly more extensive downstream improvements and an increase in the associated right-of-way needs. The refinement to the outfall affected 0.14 acre of city-regulated wetlands that will require mitigation. The cost of mitigation for these impacts is now explicitly included in the cost estimate.

West Valley Improvements

Improvements along Dry Creek No. 2 Ditch are critical to the success of this alternative. The project team was asked to evaluate the potential of using a pipe to convey the 420 cfs flow down the Dry Creek No. 2 Ditch corridor in lieu of the open channel included in the original plan. The evaluation determined that a closed conduit pipeline 72 inches in diameter could be used instead of the previously identified open channel. The pipeline alignment was modified to take full advantage of existing publically owned lands, minimize the number of individual property owners impacted, and minimize the conflicts with known utility lines.

Cost Refinements

The costs increased by approximately 20 percent over the earlier estimate but are generally within the range of anticipated variation. Proposed costs for the Regional Detention at US-36 have been updated to $36.2 million. Alternative costs are summarized in Table 8-1, Alternative Plan Summary, located in the Summary of Refined Alternatives section at the end of this Chapter.

The changes in the cost of the pond construction represent about 75 percent of the total overall change in cost of the Regional Detention at US-36 cost. The updated grading plan provided a much higher degree of resolution of the embankment materials necessary to provide desired flood storage. The updated geometry also allowed a better estimate of the amount of material necessary to construct the impervious core and fill the key trench.

The spillway costs have been refined to reflect the better understanding of the nature of flood flows when they exceed the 100-year event. Because this is not a mainstem pond, the spillway lining material is still assumed to be Type VH riprap, but the extent of the spillway protection on the downstream embankment face was expanded because the pond footprint was shifted away from US-36.

The capital cost of the West Valley improvements is largely unchanged, but the required footprint for the construction and long-term maintenance now reflects the adjustments made so that utility conflicts and single-family residential property acquisition costs are minimized. Annual operation and maintenance costs have been revised.

The environmental mitigation costs for the West Valley improvements have been included as a single line item. These costs were built into the project contingency in the earlier plans because specific impacts had not yet been quantified. The refined plan better describes the impacts to environmentally sensitive areas, and the cost of mitigation for those impacts is included in the estimated costs.

More right-of-way will need to be acquired to accommodate future channel construction downstream of the Arapahoe Avenue Detention pond. The new alignment also requires the enlargement of an existing channel that flows through city-designated wetland areas. The cost of mitigation for these impacts is now explicitly included in the cost estimate.

Refined Benefits

The refinements to the various plan elements did not result in any substantive changes to the estimated benefits. The average annual benefit expected to result from these improvements is estimated to be $77.3 million. Because the costs for this alternative have changed, the benefit-cost ratio has also changed. The revised value is now 2.14.

Other Considerations

Based on the plan refinements, there will be about 5.4 acres of impact to the South Boulder Creek State Natural Area because of the Regional Detention at US-36 alternative. This represents 0.5 percent of the total area of the State Natural Area.

Impacts to the PMJM habitat areas were determined based on a comparison of the project footprint and a 15-foot-wide access area to the USFWS Critical Habitat Area as well as the city's Conservation Zone. The Regional Detention at US-36 alternative affects about 1.6 acres of Critical Habitat Area and 7.1 acres of Conservation Zone. A majority of this impact is on Open Space lands, but some falls on the US-36 right-of-way. The Regional Detention at US-36 embankment will affect approximately 5.5 acres of Open Space lands.

An Operations and Maintenance (O&M) Plan may be required for areas designated as compensatory mitigation. In most cases, constructing new wetlands and habitat areas for compensatory mitigation will require a long-term commitment to operations to assure the facilities actually reestablish lost function and are sustainable. An operations plan should be developed and included in the design of any compensatory mitigation areas.

Phasing

This alternative is made up of three broad elements: US-36 detention, West Valley improvements, and Arapahoe Avenue detention. The overall plan implementation cost is about $36.2 million, making implementation of the full alternative at one time improbable. The following presents an alternative implementation strategy. The computed benefit-cost ratio for each element described below, reflects damage reductions that are associated with those improvements only and do not reflect the additional benefits that accrue as a result of the implementation other flood mitigation elements.

Priority 1 – US-36 Detention

US-36 detention is the recommended first element to be implemented. In addition to having an element benefit-cost ratio of approximately 2.0, the capital cost of $13.3 million may be low enough to be funded as a single project. The relatively high benefit-cost of this alternative makes it an attractive candidate for funding from other sources. Because this is a stand-alone element that provides significant flood control benefit, it may be possible to secure funding from other sources such as the Federal Emergency Management Agency (FEMA) or the USACE.

In the event that the US-36 detention is built prior to other improvements downstream, there would need to be several minor temporary improvements to existing culverts that drain the US-36 detention facility at Dry Creek No. 2 Ditch, the Viele Channel, and the New Anderson Ditch. These culverts, in the absence of the interim controls will be under higher head and will convey more water. As such, they will require gates or structures to reduce the flow exiting from these culverts after the construction of this pond to pre -construction flow rates until the downstream improvements are in

place. This will help to reduce potential flooding impacts through the West Valley. They may be a slight reduction in the capacity of the detention pond that could slightly increase the potential for overtopping of US-36 in comparison to the performance when the entire system is in place.

This project element fulfills the defined purpose of the project (reduce the flood hazard due to US-36 overtopping in the West Valley) without the need for further investment. In doing so, the flood insurance burden associated with the South Boulder Creek 100-year flood for those properties in the West Valley is eliminated and the real flood threat reduced to that of locally generated runoff flooding. The elimination of the overtopping of US-36 means this important transportation corridor remains open.

Priority 2 – Local West Valley Improvements

The proposed improvements in the West Valley address a number of different issues and comprise several smaller elements, including local detention at Manhattan Middle School, Dry Creek No. 2 Ditch pipeline improvements, local detention at Baseline Road and Foothills Parkway, floodwall improvements along Baseline Road, improvements to the New Anderson Ditch, and improvements to the Wellman Canal. In aggregate, these improvements are expected to cost $11.0 million to implement and result in a benefit-cost ratio of 3.2. While this is a high benefit-cost ratio, the benefits are largely seen at lower frequency events when smaller flood flows are handled by the smaller capacity local improvements. There is limited benefit during the 100-year flood and higher events.

The localized detention storage should be implemented early in the process to fully exploit the flow reduction realized through these facilities. Then the flood control measures such as the pipeline improvements along Dry Creek No. 2 Ditch and along Baseline Road should be implemented to provide adequate conveyance of the remaining flows. The improvements to the other irrigation ditches are intended to prevent overflows and contain those flows in the original system. These can often be done independently of any other improvements and can be implemented as needed or as opportunities arise.

Priority 3 – Arapahoe Avenue Detention

The Arapahoe Avenue detention pond and associated downstream improvements provide considerable flood relief to those properties below Arapahoe Avenue. The improvements are estimated to cost $11.9 million and will result in a benefit-cost ratio of 1.3. The majority of the benefits accrue to the commercial and industrial properties below Arapahoe Avenue. This element has been ranked as the last priority in part because the improvements benefit only commercial and industrial properties.

Distributed Regional Detention Alternative Refinements

The three regional detention pond embankments were refined to reduce impacts to Open Space lands, environmental resources, right-of-way, and utilities. In addition, grading refinements, outlets, control structures, and emergency spillways were all reviewed and refined if necessary. Refinements to proposed facilities within the West Valley and at Arapahoe Avenue were similar to those considered for the other alternatives. Figure 8-6 presents the Distributed Regional Detention option, located in Appendix E.

US-36 Detention Facility

The alignment of the detention pond embankment along US-36 was reviewed to better understand impacts to Open Space lands and other properties in the area. The revised alignment is shown on Figure 8-7, Distributed Regional Detention – US-36 Pond, located in Appendix E. The western arm of the embankment has been relocated to avoid any contact with the existing levee protecting the CU South Campus property while still maintaining the desired 130 AF of storage. It was determined that a free-standing structure provided greater flexibility in future implementation and minimized the coordination issues with both the University and Federal regulators that may arise as a result of modifications to the levee system.

The northern and eastern portions of the embankment were moved slightly to minimize impacts to Open Space lands and to the riparian corridor along the South Boulder Creek mainstem. While these refinements helped to reduce the impacts, including the elimination of impacts to city-regulated wetlands, some encroachment into Open Space areas, PMJM Critical Habitat Area, and other habitat areas were unavoidable. Mitigation would be required to compensate for these 9.6 acres of unavoidable impacts.

The control structure that controls the flow of water from the South Boulder Creek mainstem into the detention pond at US-36 was modified during the refinement process. The earlier control strategy was to prevent overtopping of the US-36 embankment during the 100-year flood by pushing more of the flood flows through the US-36 Bridge using a berm and box culverts across the mainstem of the creek. This control strategy created unacceptable impacts to the riparian corridor upstream of US-36.

A revised strategy was developed that uses a more passive control structure that splits higher flows off and leaves low flows in the main channel, separating them from those in the overbank. The mainstem would continue to convey flows up to about 1,000 cfs without any water being directed to the detention pond. The structure would capture flows in excess of the first 1,000 cfs and convey them through the pond by creating a physical barrier across the section that captures and separates the overbank flows. A schematic of the cross section modifications that are proposed to create this control structure is presented in Figure 8-8, Distributed Regional Detention – US-36 Pond Control Structure, located in Appendix E. As the image shows, the overbank will need to be modified slightly to force more flow into the overbank during higher flow events.

Once the flows in excess of the 1,000 cfs threshold are separated from the channel flows, they flow into the pond. The storage-discharge relationship can be controlled by varying the shape and size of the outlet structure. The refinements allowed the performance of the outfall structure to be similar to that of earlier evaluations and helped minimize the storage in the overbank during flows less than the 100-year peak. Only during very large floods would the storage pool above the top of the pond outlet structure be used.

South Boulder Road Detention Facility

This 130 AF pond is an important element in controlling the impacts associated with the increased flow through the US-36 Bridge. The embankment alignment was modified to avoid encroachment into the South Boulder Road right-of-way and to minimize impacts to Open Space lands (Figure 8-9, Distributed Regional Detention - South Boulder Road Embankment, located in Appendix E). The shift of the embankment to the south would require reconstruction of portions of the Viele Channel. The portion of the channel flowing along the west side of the pond embankment was not changed because a concrete wall was used in lieu of an earthen embankment for this part of the pond. However, as the channel and embankment parallels South Boulder Road, the toe of the refined embankment encroaches into the existing channel, requiring realignment of the channel. This area may contain Ute Ladies' Tresses Orchids. A more exhaustive investigation may be required to determine if it is possible to mitigate these impacts. Regardless, at a minimum it is estimated that a total of 3.6 acres of regulated wetlands will need to be mitigated.

The pond has a mainstem embankment requiring the full flood hydrograph to pass through the pond. As a result, the emergency spillway required some refinements not considered in the earlier layout. The full spillway design flood must pass over the embankment because the topography at the site does not lend itself to a spillway over one of the overbank areas. To assure the long-term integrity of the embankment, it was decided the spillway should be constructed of concrete with the concrete extending down the full face of the embankment and all the way to South Boulder Road.

Baseline Road Detention Facility

The proposed detention facility at Baseline Road was modified to avoid encroachment into the road right-of-way and to minimize impacts to Open Space lands. (Figure 8-10, Distributed Regional Detention - Baseline Road Pond Embankment, Located in Appendix E). The southern embankment has been moved to the south resulting in some minor additional impacts to the Open Space lands. The east end of the embankment covers the existing trailhead and parking area. This impact has been mitigated through the proposed relocation of the trailhead parking off Cherryvale Road rather than from Baseline Road. A trail connection back to the regional trail system is proposed as part of the plan. In addition to the relocation of the trailhead, 3.4 acres of city-regulated wetlands were impacted by berm refinements that would need to be mitigated. This pond also has a mainstem embankment. The emergency spillway here has been modified to consist of a concrete overflow spillway as described for the South Boulder Road pond. Based on the refinements to the berm and continued modeling of the alternatives through the 8-Meter MIKEFLOOD model, the volume of the pond was increased

from 295 AC-FT to 375 AC-FT to accommodate additional flood flows and to ensure that there was not an increase in existing flood discharges downstream from the facility.

The proximity of the pond embankment to local roadways created some concern about the aesthetic impacts during the public meetings. As a result, an architectural rendering of the embankment as seen from the corner of Baseline Road and Cherryvale Road (Figure 8-11, Baseline Road Detention Pond Embankment Rendering, and Located in Appendix E) was prepared. This image shows that the embankment has a relatively minor impact on the view of the Open Space lands to the south and west.

Arapahoe Avenue Detention Facility

The refinements at Arapahoe Avenue are similar to those identified during the evaluation of the Regional Detention at US-36 alternative plan. The primary difference between the earlier proposed plan details and those subsequent to refinement are downstream of Arapahoe Avenue.

West Valley Improvements

The facilities in the West Valley associated with this alternative are very similar to those identified for the Regional Detention at US-36 alternative. The most substantial refinement was the change from open channel to pipe for the improvements along Dry Creek No. 2 Ditch and the realignment of those improvements to minimize right-of-way acquisition costs. Improvements to the New Anderson Ditch are no longer required in the West Valley because the detention above US-36 no longer extends across to the New Anderson Ditch culverts passing under US-36.

The evaluation determined that the flows being conveyed in open reaches of Dry Creek No. 2 Ditch could effectively be conveyed in a closed conduit.

Cost Refinement

The refinement of the Distributed Regional Detention alternative resulted in a much better understanding of the plan elements and an increase in the estimated plan implementation cost of approximately 40 percent to $48.1 million. This cost variability is at the upper end of the anticipated range of expected costs at this level of resolution, but the refinements are expected to result in less variability for future refinements.

The refinements in the pond spillway structure accounted for almost 40 percent of the change in estimated cost. The mainstem ponds at South Boulder Road and Baseline Road now have concrete emergency spillways to address potential concerns from the State's Dam Safety Officer. The US-36 pond inlet control structure refinements resulted in some additional right-of-way acquisition, as well as earthwork and protection not originally included in the estimate. These modifications resulted in an additional 10 percent increase in cost.

A better definition of the environmental mitigation costs was possible during the refinement process. The refined design built upon the OSMP evaluations and incorporated refinements to address many of the concerns. However, it was not possible to completely avoid compensatory environmental mitigation. The estimated costs for property acquisition, largely to address the mitigation needs at the three ponds and the other improvements proposed as part of this alternative, account for about 30 percent of the change in the estimated implementation cost.

Refined Benefits

The refinements to the various plan elements did not result in any substantive changes to the estimated benefits. The average annual benefit expected to result from these improvements is estimated to be $75.9 million. Because the costs for this alternative have changed, the benefit-cost ratio is also changed. The revised value is now 1.58.

Other Considerations

The refinement of the alternatives allowed the team to better understand the various project impacts and to assess the proposed plans against a broad range of considerations.

Impacts to city-regulated wetlands and PMJM Critical Habitat will need to be mitigated at a ratio of two to one. It is expected that acceptable mitigation will replace the type and function of the lost areas. There will be over 30 acres impacted by the Distributed Regional Detention plan, representing 2.5 percent of the total area of the State Natural Area. Impacts to PMJM and Ute Ladies' Tresses Orchid habitats are expected, as are impacts to Northern Leopard Frog habitat areas. These impacts were generally in the vicinity of mainstem embankments and along the improvements to the Viele Channel. The Distributed Regional Detention alternative plan has 16.9 acres and 29.7 acres of impact to the Critical Habitat Areas and Conservation Zone, respectively. A total of 17.3 acres of Northern Leopard Frog habitat are impacted. The project costs include the purchase of the Granite property or a similar parcel with the hope that this land can be used as mitigation for impacts to the Conservation Zone. It is believed that this area is already suitable for habitat and that, with minor enhancements; it could serve to replace any potential loss due to the implementation of the project.

Impacts to Open Space lands will include permanent improvements such as embankments, as well as temporary impacts that will be restored. The Distributed Regional Detention plan embankments will affect approximately 34.8 acres of Open Space lands.

Phasing Strategies

This alternative is also made up of three broad elements: Arapahoe Avenue detention; detention at US-36, South Boulder Road, and Baseline Road; and improvements within the West Valley. The overall plan implementation cost is about $48.1 million, making the implementation of the full alternative at one time improbable. The following presents an alternative implementation strategy.

Priority 1 – Local West Valley Improvements

The proposed improvements in the West Valley address a number of different issues and comprise several smaller elements, including local detention at Manhattan Middle School, Dry Creek No. 2 Ditch pipeline improvements, local detention at Baseline Road and Foothills Parkway, floodwall improvements along Baseline Road, and improvements to the Wellman Canal. These improvements in aggregate are expected to cost $9.6 million to implement and result in a benefit-cost ratio of 3.6. While this is a high benefit-cost ratio, the benefits are largely seen at lower frequency events when smaller flood flows are handled by the smaller-capacity local improvements. There is limited benefit during the 100-year flood and higher events.

Detention should be implemented early in the process to fully exploit the flow reduction realized through these facilities. Then, the flood control measures such as the pipeline improvements along Dry Creek No. 2 Ditch and along Baseline Road should be implemented to provide adequate conveyance of the remaining flows. The improvements to the other irrigation ditches are intended to prevent overflows and contain those flows in the original system. These can often be done independently of any other improvements and can be implemented as need or opportunities arise.

Priority 2 – Arapahoe Avenue Detention

The Arapahoe Avenue detention pond and associated downstream improvements provide considerable flood relief to those properties below Arapahoe Avenue. The improvements are estimated to cost $11.9 million and will result in a benefit-cost ratio of 1.3.

The floodplain reduction associated with these improvements remains relatively localized. The detention facility ponds water above Arapahoe Avenue onto Flatirons Golf Club property, controlling the discharge across Arapahoe Avenue and reducing widespread flooding downstream. The less frequent overtopping of Arapahoe Avenue reduces the threat to life and minimizes the disruption to traffic along Arapahoe Avenue.

Priority 3 – Detention at US-36, Baseline Road, and South Boulder Road

These three detention ponds, in combination, address the overtopping of US-36 but only have a benefit-cost ratio of 0.9, meaning that the $26.6 million investment does not provide a reduction in average annual flood damages by an equal amount. Moreover, these three ponds need to be constructed in unison to assure that the flood control benefits are realized and that no adverse impacts occur within the system.

This project element fulfills the defined purpose of the project (reduce the flood hazard due to US-36 overtopping in the West Valley) without the need for further investment. In doing so, the flood insurance burden associated with the South Boulder Creek 100-year flood for those properties in the West Valley is eliminated, and the real flood threat is reduced to that of locally generated runoff flooding. The elimination of the overtopping of US-36 means this important transportation corridor remains open.

The construction of three ponds, two of which have mainstem embankments, does require properly sized and constructed emergency spillways to assure that the potential of embankment failure is properly mitigated. The use of the distributed detention creates a greater impact to Open Space lands. These impacts are related to both the embankment and the upstream flow control structure. While alignments were adjusted to the extent possible, the site topography required encroachment. Mitigation would be required for this phase. .

Bear Canyon Creek Pipeline Alternative Refinements

The refinements to the Bear Canyon Creek Pipeline alternative focused primarily on the development of a more detailed strategy to capture overflows from US-36 and identification of areas where the proposed pipeline could be aligned to minimize impacts to properties and utilities.

Pipeline Alignment Refinement

A careful review of the proposed alignment of the Bear Canyon Creek Pipeline indicated that an alternative route would result in fewer right-of-way acquisition issues and would reduce the number of potential utility conflicts. The earlier alignment had followed the alignment for upgraded storm sewer lines identified in the Stormwater Master Plan. That alignment generally followed the lowest point of the floodplain from Apache Drive downstream to Baseline Road. The revised alignment takes the 114-inch-diameter line east to Thunderbird Road and then north (Figure 8-12, Bear Canyon Creek Pipeline, located in Appendix E). The revised alignment rejoins the original alignment at Baseline Road and follows that alignment to the outfall into Bear Canyon Creek just below Foothills Parkway and Colorado Avenue.

The mainstem pipeline and the lateral lines were sized based on the computed inlet capacity. In this way, the size of the pipelines was more closely aligned with the likely flow rates, rather than relying on the earlier assumption that all flow needed to be conveyed along the entire pipeline length. Pipeline sizes are also reported on Figure 8-13, Bear Canyon Creek Pipeline – Thunderbird Pipeline Alignment, located in Appendix E.

Inlet Location and Layout Refinement

The layout of the inlets necessary to capture the overflow of US-36 was refined. City of Boulder Type R inlets were selected rather than the combination inlets because of their smaller encroachment into the street surface. The chosen inlets have a slightly lower capacity but were deemed to be less disruptive to pedestrian and bicycle traffic through these residential areas. The inlet location was limited by the spread of the overtopping flows. The hydraulic capacity of the inlets also was limited by the depth of flow and the gradient of the streets.

The inlet layout intercepts the maximum amount of water possible before the overflows reach structures. Much of the frontage of Apache Drive west of Pima Court (approximately 300 feet) was committed to inlets to collect as much of the 1,250 cfs of overflow as possible (Figure 8-14, Bear Canyon Creek Pipeline Collection System, located in Appendix E). These are in areas where flooding is expected to be well in excess of 1 foot at the gutter flow line. As such, a simplified sizing methodology was employed that assumed the hydraulic performance would be similar to a sump inlet, with a single foot of head and a capacity of approximately 1.67 cfs per linear foot of opening. The estimated capacity included the City of Boulder required blockage. East of Pima Court along Apache Drive, the 130 feet of Type R inlets are assumed to have a capacity of approximately 0.80 cfs per linear foot of opening because the depth of flooding was slightly lower. These inlets capture about 100 cfs.

Another 380 feet of Type R inlets are proposed along both the east and west sides of Pima Court to capture additional flow not captured at Apache Drive. The street gradient down Pima Court is relatively flat, and the street section is not capable of conveying the full flow without considerable depth at the flow line. Once again, to simplify sizing, a capacity of 0.80 cfs per linear foot was assumed. The result is an assumed capture of an additional 300 cfs.

A final bank of Type 13 inlets (36 square feet) is located in the sump at the mouth of the drainage swale just off the driveway off Pima Court to capture an additional 40 cfs. These pick up a majority of the overflow, but additional inlets are required farther downstream near the intersections of Osage Drive and Qualla Drive with Thunderbird Drive. A review of the topography in the area suggests flows are likely to split. As such, it was concluded that approximately 300 feet of inlets would be provided along both roadways to capture the remaining overflows. The gradient along both streets as they approached Thunderbird Drive was approximately 0.6 percent resulting in an approximate capacity of 0.5 cfs per linear foot of opening.

The location and extent of these inlets is based on early estimates of the overflow and are likely to be refined if this alternative moves forward. During final design, other options to collect the overflow that reflect a more thorough understanding of the overflow characteristics can be explored.

The lateral pipelines conveying water from the inlets to the Bear Canyon Creek Pipeline were laid out to minimize potential utility impacts. The upstream end of the mainstem pipe at the overflow location of US-36 and Apache Drive provides a conveyance for the uppermost inlets, and the remaining inlets along Apache Drive can be discharged directly into the 114-inch-diameter pipeline. The inlets along Pima Court require the construction of a 72-inch-diameter lateral line. While a pipeline that follows the surface gradient would be preferable, the utility conflicts would have presented considerable challenges. It was therefore concluded that a pipeline from the inlets at the northeast end of Pima Court and from the Type 13 inlets to the Apache Drive pipeline would minimize utility conflicts. The length of the pipeline draining against the surface gradient is relatively short, approximately 200 feet, and does not create an abnormally deep pipeline.

West Valley Refinement

The facilities in the West Valley associated with this alternative differ from those in the other alternatives because of the US-36 overflow. The flow that crosses US-36 near the Park-n-Ride facility influences the New Anderson Ditch. The improvements proposed to convey the 720 cfs overflow were realigned to avoid utility corridors and to minimize easement acquisition costs (Figure 8-15, Bear Canyon Creek Pipeline - Dry Creek No. 2 Ditch Pipeline Alignment, Located in Appendix E). The increased flows captured by the pipeline discharge into the 90-inch-diameter pipeline along Dry Creek No. 2 Ditch. This pipeline alignment has been modified slightly to avoid known utilities and to minimize easement acquisition costs to the extent possible.

Arapahoe Avenue Detention Refinement

The refinements at Arapahoe Avenue are similar to those identified during the evaluation of the Regional Detention at US-36 alternative plan and are focused on one of the two outlet channels downstream of Arapahoe Avenue.

Cost Refinements

The refinement of the Bear Canyon Creek Pipeline alternative provided a much better understanding of the plan elements but resulted in a nominal change in the estimated plan implementation cost of approximately 1 percent to $46.8 million. The improvements proposed through the West Valley resulted in changes to the required property acquisition and operation and maintenance costs. The costs now reflect a pipeline rather than the originally proposed open channel. The capital cost of this facility is largely unchanged, but the required footprint for the construction and long-term maintenance now reflects the adjustments so that utility conflicts and single-family residential property acquisition costs are minimized. Annual operation and maintenance costs were updated.

The refined plan better describes the impacts to environmentally sensitive areas, and the cost of mitigation for those impacts is included in the estimated costs.

More right-of-way will be needed to accommodate future Arapahoe Avenue outfall channel construction. The new alignment also requires the enlargement of an existing channel that flows through city-designated wetland areas. The cost of mitigation for these impacts is now explicitly included in the cost estimate.

The estimated costs of this plan are summarized in Table 8-1 located in the Summary of Refined Alternatives section at the end of this Chapter.

Refined Benefits

The average annual benefit resulting from the refined improvements is estimated to be $58.0 million with a revised benefit-cost ratio of 1.24.

Other Considerations

The refinement of the alternatives allowed the team to better understand the various project impacts and to assess the proposed plans against a broad range of considerations.

The proposed alternatives were refined to minimize the impact to mature vegetation so that the long-standing character of the watershed was minimally impacted. The construction of the proposed improvements will have a significant local disruption. Large areas of residential neighborhoods will be disturbed during the construction of the inlets and pipelines. Final design and construction should include measures to assure that business and residential impacts are addressed. This may require temporary access, traffic control, or other measures.

Underground facilities like pipelines and culverts are generally designed with an expected service life in excess of 50 years. However, periodic inspections are necessary to confirm that there are not unexpected failures and that no debris or sediment has been deposited that might affect hydraulic capacity. Surface facilities such as curb opening inlets require more frequent cleaning and debris clearing so that their full capacity remains consistent with the design assumptions. Some debris clogging has been incorporated into the hydraulic assumptions in accordance with the city's drainage guidelines. A schedule of routine maintenance should be developed and enforced to assure correct function of these important hydraulic features.

Phasing Strategies

This alternative is also made up of three broad elements: the Arapahoe Avenue detention, inlets and pipeline improvements to capture US-36 overflows, and the improvements within the West Valley. The overall plan implementation cost of $46.8 million makes the implementation of the full alternative at one time improbable. The following presents an alternative implementation strategy.

Priority 1 – Local West Valley Improvements

The proposed improvements in the West Valley address a number of different issues and comprise several smaller elements, including Dry Creek No. 2 Ditch pipeline improvements and improvements to the New Anderson Ditch and the Wellman Canals. These improvements in aggregate are expected to cost $12.8 million to implement and result in a benefit-cost ratio of 1.2. In contrast to the improvements for the other alternative plans, these will be a necessary element to address the 100-year floodplain as they capture and collect some of the overflow of US-36 but, without the proposed pipeline improvements, do not fully address the 100-year floodplain threat.

The improvements to the Wellman Canal can be done independently as funds and interest permits. These improvements address the potential overflow of water in the ditch and do not rely on improvements in the systems above or below.

The improvements to the New Anderson Ditch and to Dry Creek No. 2 Ditch are intended to be complementary. The New Anderson Ditch improvements collect overflows of US-36 and convey them to Dry Creek No. 2 Ditch, which must be enlarged to convey the increased flow safely. Pipeline improvements should be implemented by first providing downstream conveyance capacity before proceeding upstream to increase collection capacity.

Priority 2 – Arapahoe Avenue Detention

The Arapahoe Avenue detention pond and associated downstream improvements are recommended as the next highest priority. The improvements are estimated to cost $11.9 million and will result in a benefit-cost ratio of 1.3. The implementation of this alternative has a direct benefit to the 100-year floodplain at a lower cost than the other elements that reduce the floodplain footprint and it has the added benefit of reducing the frequency of overtopping of Arapahoe Avenue.

Priority 3 – Bear Canyon Creek Pipeline

Construction of the pipeline and inlet systems has an estimated implementation cost of $22.2 million and a 1.2 benefit-cost ratio. The benefits are considerable but the cost is too high to be considered a top priority. However, it does meet the primary project objective of addressing the 100-year flood threat in the West Valley by capturing and controlling the overflow of US-36.

Summary of the Refined Alternatives

The five alternatives that were evaluated more carefully during the refinement process present a range of different approaches to address the flood threat along South Boulder Creek. They vary in cost and, in some cases, the level of protection provided, but they offer city staff, the various stakeholders, and city Boards and Council an array of options from which to choose. Table 8-1, Alternative Plan Summary, presents the costs, benefits, and a brief description of the plan.

TABLE 8-1

Alternative Plan Summary

Alternative	Total Implementation Cost ($millions)	Present Worth of Benefits ($millions)	Benefit-to-Cost Ratio	Plan Elements	Significant Issues
Status Quo	$0.0	$0.0	0.00	Maintains systems and processes as they are today.	Provides no enhanced flood protection anywhere in the system.
High Hazard Mitigation	$0.14	$0.0	0.00	Includes grading changes to eliminate structures from the designated High Hazard Zone.	Provides no substantive enhancement to level of flood protection anywhere in the system.
Regional Detention at US-36	$36.2	$77.3	2.14	Detention pond at US-36 reduces US-36 overtopping threat and eliminates 100-year floodplain within West Valley. Local improvements in West Valley and at Arapahoe Avenue address local flood issues.	Meets defined objective of eliminating 100-year floodplain in West Valley. Some encroachment of facilities onto city-owned Open Space lands.
Distributed Regional Detention	$48.1	$75.9	1.58	Three detention ponds reduce US-36 overtopping threat to eliminate 100-year floodplain within West Valley and mitigate increased mainstem flows in channel downstream of US-36. Local improvements in West Valley and at Arapahoe Avenue address local flood issues.	Meets defined objective of eliminating 100-year floodplain in West Valley. Significant encroachment of facilities onto Open Space lands and into identified habitat areas.
Bear Canyon Creek Pipeline	$46.8	$58.0	1.24	Inlets and pipelines to capture and convey overflows from US-36. Local improvements in West Valley and at Arapahoe Avenue address local flood issues.	Generally addresses the objective of eliminating 100-year floodplain in West Valley with the exception of Apache Drive. Nominal impact to Open Space lands and identified habitat areas. Significant disruption to residential properties is expected during construction.

IX. US-36 Detention Alternatives Review and Refinement

Introduction

The Engineer's Recommended Plan to address the identified flooding issues within the South Boulder Creek study area includes Regional Detention at US-36. In 2013, the US-36 detention alternative was refined to focus on additional alternatives to minimize impacts to Open Space and Mountain Parks (OSMP) property, incorporate the Phase 1 CDOT construction along US-36, and to continue to understand and develop potential environmental mitigation plans for the proposed berms. This alternatives analysis focused on earthen berms that followed both the CDOT Phase 1 ROW and proposed Ultimate ROW and included both earthen embankments and concrete walls to minimize or eliminate impacts to OSMP property. These alternatives were presented in 2014 to the City of Boulder Water Resources Advisory Board (WRAB), Open Space Board of Trustees (OSBT) and at a study session with City Council. . There was general concurrence with the proposed West Valley improvements and Arapahoe Avenue detention but staff was directed to work with the University of Colorado (CU) to reduce impacts to OSMP property and sensitive environmental habitat that would occur from the proposed US-36 stormwater detention facility. This additional alternatives analysis was completed in early 2015 and created six additional options for the US-36 stormwater detention facility. These options were presented to the OSBT and WRAB in early 2015 and both boards unanimously motioned to recommend City Council accept the master plan along with the staff recommendation for detention at US-36. A presentation to City Council is scheduled for August 2015. This chapter presents a summary of both the 2013 and 2015 refinements to the proposed US – 36 stormwater detention facility.

2013 US-36 Flood Control Facility Refinement Analysis

Goals

As mentioned previously the refinement of the US-36 Flood Control Facility was focused on minimizing impacts to OSMP property and ensuring compatibility with current and future US-36 widening proposed by CDOT.

To accomplish the goals of the refinement alternative berm configurations and alignments were considered to minimize impacts to open space and ensure compatibility with current and future plans to widen US-36.

There were three berm or wall configurations considered as well to help to provide options for achieving the goals of refining the berm. The berm configurations are described below and Figure 9-1, depict the three berm/wall configurations.

1. Traditional zoned earthen berm with a bentonite slurry cutoff wall
2. Concrete wall with a moment slab, piles and bentonite slurry cutoff wall
3. Concrete structural wall tied into structural concrete cutoff wall

Each alternative reviewed does create some unavoidable impacts to either OSMP or CDOT ROW. In addition, additional unavoidable impacts to areas defined by the city as environmentally sensitive will also occur. This includes city regulated wetlands and some areas that may include critical habitat. The refinements to the US-36 berm as part of this analysis also include a conceptual level analysis of the potential impacts to wetlands and critical habitat as well as a conceptual level mitigation plan that is discussed below.

Design Assumptions

Several design assumptions were made in the further refinement of the alternative analysis in order to facilitate the analysis of the possible detention facility configurations and to develop costs. Although these assumptions have been refined to reflect design requirements and modeling of the system, as design progresses these values will continue to be refined as new design information is included like additional geotechnical information, further refinement based on State Engineers Office requirements and further environmental analysis.

- The top of berm elevation is 5370'
- The spillway elevation is 5367' and is 1350 feet long
- The top of the berm is a 15 feet wide
- A 2' thick layer of Type M soil riprap will be placed on the upstream face of the dam
- The downstream face of the dam will be covered by a 1' thick layer of seeded topsoil, except near the spillway where a 2' thick layer of Type M riprap will be placed
- A 30' tall slurry cutoff wall designed to intersect bedrock and minimize seepage will be required under the berm
- For alternatives in which a concrete wall is used, the concrete wall is 2' wide and extends as a structural concrete cutoff wall 30' to bedrock

Geotechnical analysis and berm refinement

As part of the refinement of berm locations, a closer look at the geotechnical requirements of the flood control facility was looked at to further refine the berm and refine the cost to construct. Two sources were consulted to understand the soils in the area of the South Boulder Creek Flood Control Facility

1. Natural Resources Conservation Services (NRCS) Soil Survey for Boulder County
2. RTD Pedestrian Overpass of US-36 Geotechnical Report

Both reports indicated that the majority of soils in the area are made up of sandy to cobbley alluvium with a high groundwater table. The RTD report indicates that bedrock is located approximately 30 feet below the surface. To prevent unwanted and destabilizing seepage through and under the proposed detention facility, a 30' deep bentonite slurry cutoff wall will be required under the earthen berm and a 30' deep structural concrete cutoff wall under the concrete wall alternatives. This will help provide structural stability and eliminate seepage when the facility is storing water. These new cutoff walls are reflected in the revised cost analysis. This analysis was cursory in nature and a more in-depth analysis of the geotechnical conditions at the site will be required to design the final detention facility.

Alternative Alignment Refinement

The refinement of the recommended alternative focused on the US-36 Detention facility to address concerns related to US-36 expansion and impacts to OSMP. The detention pond still combines excavation and fill to produce a configuration that minimizes the impacts to OSMP land and the University of Colorado (CU) South Campus but included options to further reduce the impacts to OSMP and ensure coordination with future expansion plans of US-36. The following sections describe the alternatives reviewed.

The top elevation of any of the alternative configurations is required to be 5370'. This was determined by running the MIKEFLOOD Model with the berm in place and identifying the maximum 100-year water surface elevation (WSEL) and adding an assumed 5 feet for freeboard and spillway requirements. The 100-year water surface elevation determined from the MIKEFLOOD model was 5365 feet. Freeboard requirements will be further evaluated as design progresses based on an incremental damage assessment with the Probable Maximum flood (PMF) as required by the Colorado State Engineer's Office (SEO). Freeboard requirements may need to be increased to safely pass the PMF as the South Boulder Creek flood control facility will be classified as a High Hazard Dam.

US-36 Detention Berm Centered on the US-36 Median Barrier

The concept of the median barrier alignment was to eliminate all impacts to OSMP property, while not affecting the potential to widen US-36 in the future. The east end of the median wall berm location is elevation limited. The maximum elevation of US-36 at the west end of the alignment is 5365'. With the existing median barrier, elevation of 5368' (assuming 3' tall median barrier) this alternative will only achieve 3 feet of free board and would violate criteria for a high hazard dam.

The proposed wall for this alternative would begin on the east with the wall tying into the median barrier of US-36 at the South Boulder Creek Bridge. At this location, the wall would be the height of the existing median barrier. The wall would extend westward along US-36 at an elevation of 5368'. This wall would be required to extend east to the approximate intersection of Mohawk Drive and US-36 east of Table Mesa Drive. The wall would extend approximately 6,000' with the greatest height of the wall, approximately 21', occurring at Foothills Parkway. At Foothills Parkway and Table Mesa Drive, the wall would extend to the low cord of both bridges.

In addition to the median barrier wall, two berms would need to be constructed on the south side of US-36 east and west of Table Mesa Drive to an elevation of 5368' to protect residential and commercial properties. The western berm would extend east along the US-36 ROW from the approximate intersection of Hamilton Court and US-36 wrapping around the

Table Mesa on ramps and terminating west of the intersection of Moorhead Avenue and Table Mesa Drive. The eastern berm would extend from the east side of Moorhead Avenue and Table Mesa Drive east along south Loop Drive and terminating on high ground on the CU South Campus. See Figure I-1 in Appendix I for plan view of the alternative.

Ultimately, this alternative was not carried forward as feasible. This alternative would formalize flood storage on the eastbound lanes of US-36. The original goals of the project were to prevent and maintain access along US-36 during a flooding event. It was also determined that this alternative would not be acceptable to CDOT. In addition, the length of the berm and wall system (approximately 9,000 feet) as well as the structural requirements would cause this alternative to have a benefit cost ratio less than one

US-36 Detention Berm Maximizing use of CDOT Phase I ROW

This alternative berm configuration focused on minimizing the impacts to OSMP property by utilizing to the extent possible the US-36 Phase I ROW. In general, this would move the regional bike trail being constructed by CDOT to the top of the US-36 flood control berm and place the flood control berm approximately 12' off the shoulder of the widened US-36 currently under construction.

The proposed berm for this alternative would begin on the east with the berm tying into US-36 at the South Boulder Creek Bridge. At this location, the berm would be the height of the existing US-36 embankment. The berm would extend westward along US-36 at an elevation of 5370'. This berm would then tie into the Foothills Parkway to US-36 eastbound on ramp berm. The berm would then extend along the northern edge of the CU south Campus and South Loop drive before tying into high ground in the CU south Campus and would be approximately 6000' long. See Figure I-2 for a plan view of the proposed alternative and Figure I-3 for a typical cross section in Appendix I. The potential impacts to CDOT ROW and OSMP property are defined below.

1. Approximately 2.2 Acres on CDOT ROW (This assumes the berm will replace the bike trail but will not impact CDOT ditch to the north of the bike trail)
2. Approximately 5.1 Acres on OSMP property for the US-36 Flood Control Berm
3. Approximately 0.8 Acres on OSMP property for a 15 foot wide maintenance and access easement at the southern toe of the berm
4. Total impact to OSMP would be 5.9 acres

At the time this alternative was not carried forward as feasible as CDOT did not agree to allow the city of Boulder to use its Phase 1 ROW (required the concept to be located outside of the US 36 ultimate configuration ROW as shown in the US - 36 Environmental Impact Statement (EIS).

US-36 Detention Berm South of CDOT Phase I ROW

The following four conceptual alignments and berm configurations are similar as they focus on alignments that do not impact the CDOT US-36 ultimate configuration. In addition, two berm configuration alternatives, traditional zoned earthen berm and a concrete wall through OSMP were reviewed to determine the cost effectiveness and impacts to OSMP property based on the alternatives.

The proposed alignments would be similar in length and positioning to the US-36 Detention Berm Maximizing use of CDOT Phase I ROW. The alignments would, however, be shifted to the south so that the toe of the berm or wall would be aligned with CDOT's Phase I ROW or Ultimate configuration ROW. The length of the berm is not dramatically changed through each alternative alignment, however, depending on the CDOT ROW analyzed the impacts to open space vary with less impacts based on the Phase I ROW and greater land requirements for the ultimate CDOT ROW configuration

In addition to alignment, in an effort to minimize impacts to OSMP land, three berm/ wall configurations were developed to understand both the impacts to OSMP property and to minimize impacts to OSMP property. The three berm / wall configurations developed are described below and can be found in Figure 9-1.

1. Traditional zoned earthen berm with a bentonite slurry cutoff wall
2. Concrete wall with a moment slab, piles and bentonite slurry cutoff wall
3. Concrete structural wall tied into structural concrete cutoff wall

Ultimately, the concrete wall with the moment slab was eliminated from further consideration. The moment slab alternative was a 15-foot wide concrete moment slab supported on structural concrete piles. Due to the large cost of construction due to the structural concrete components, this alternative was eliminated. The traditional zoned berm and the concrete wall with structural concrete cutoff wall were carried forward for analysis resulting in four configurations being analyzed as described below. Figure I-3 through I-7 in Appendix I; represent each of the four alternative configurations described below including typical sections. These figures include cross sections representing the configurations of the berms and the walls.

- **US-36 Phase I Design With Berm** –This alternative utilized the US-36 Phase I CDOT Right-of-Way as the northern boundary of the project and a berm on City of Boulder OSMP property.
- **US-36 Ultimate Configuration Design With Berm** - This alternative utilized the "Ultimate Configuration" CDOT Right-of-Way as the northern boundary of the project and a berm on City of Boulder OSMP property.
- **US-36 Phase I Design With Wall** – This alternative utilized the US-36 Phase I CDOT Right-of-Way as the northern boundary of the project and a reinforced concrete wall on City of Boulder OSMP property.
- **US-36 Ultimate Configuration Design With Wall** – This alternative utilized the "Ultimate Configuration" CDOT Right-of-Way as the northern boundary of the project and a reinforced concrete wall on City of Boulder OSMP property.

Table 9-1 presents the required property for the construction and maintenance of the different design alternatives. Each alternative assumes a 15' wide access easement on the upstream face of the dam to provide maintenance and construction access for the berm facility. The three different types of property impacts are as follows:

- **CU South Campus**: Impacts to property owned by the University of Colorado. This includes only the area within the limits of grading and proposed access easement.
- **City of Boulder OSMP – Area within Limits of Grading and Access Easement**: Impacts to land owned by City of Boulder OSMP caused directly by the construction of the berm/wall and access easement.
- **City of Boulder OSMP – Areas between the Proposed Berm and US-36 Phase I ROW**: This category only influences the alternatives proposed for the US-36 "Ultimate Condition". Construction of these flood control facilities based on the US-36 "Ultimate Conditions" will cause a portion of OSMP land to be orphaned between the berm and the US-36 Phase I ROW. This land will eventually be used for the future construction of the Foothills Parkway interchange and would no longer be connected to the broader OSMP property.

All four of these alternatives were carried forward to understand impacts to OSMP and environmental resources as well as the impacts of each alternative on the cost benefit analysis to select the final preferred alignment of the US-36 flood control berm.

TABLE 9-1
Required property acquisition for the Construction of the Proposed US-36 Flood Control Facilities Analyzed in 2014

	Required Property Acquisition (Acres)			
Alternative	**CU South Campus**	**City of Boulder OSMP – Area within Limits of Grading and Access Easement**	**City of Boulder OSMP – Areas between the Proposed Berm and US-36 Phase I ROW**	**Total**
US-36 Phase I Design With Berm	12.7	5.1	0.0	**17.8**
Ultimate Configuration Design With Berm	12.6	4.9	2.5	**20.0**
US-36 Phase I Design With Wall	12.7	1.0	0.0	**13.7**
Ultimate Configuration Design With Wall	12.5	0.9	2.4	**15.8**

2015 US-36 Flood Control Facility Refinement Analysis

Goals

As mentioned previously the refinements to the US-36 Berm were requested by boards, City Council, and the public to continue to develop alternatives that minimized the environmental impacts and land takes from OSMP. To accomplish the goals, six options for berm configurations were considered, all focused on increasing detention on the CU South Campus. To accomplish these goals, two methodologies were used in differing configurations to obtain the required detention:

1. A dual berm configuration on the CU south campus coupled with the breaching of the CU South Campus levee on the south end of the property to increase the detention volume stored on the CU South Campus and,
2. Excavation on the CU South Campus to increase detention volume and decrease berm heights.

These two methodologies were combined in seven alternatives that are described below:

A. Alternative presented to WRAB in November of 2014.

B. Single Berm Alternative along the CDOT Ultimate ROW that included excavation on the CU South Campus

C. Single Berm Alternative along the CDOT Ultimate ROW that included excavation on the CU South Campus and fill on the CU South Campus

D. Single Berm Alternative along the CDOT Phase I ROW that included excavation on the CU South Campus and fill on the CU South Campus

E. Dual Berm Alternative on the CU South Campus with No Excavation. This includes breaching the CU South Campus Levee on the south end of the property to allow additional flow into the CU South Campus, a berm that closed the levee and the high ground on the west side of the property and a secondary berm along US-36 to capture and detain overflows that still were occurring at the US-36 Bridge of South Boulder Creek

F. Dual Berm Alternative on the CU South Campus with No Excavation. This included breaching the CU South Campus Levee on the south end of the property to allow additional flow into the CU South Campus, a berm that closed the levee and the high ground on the west side including excavation to minimize the berm height and area of detention, and a secondary berm along US-36 with excavation to capture and detain overflows that still were occurring at the US-36 Bridge of South Boulder Creek

G. Dual Berm Alternative on the CU South Campus with No Excavation. This included breaching the CU South Campus Levee on the south end of the property to allow additional flow into the CU South Campus, a berm that closed the levee and the high ground on the west side including excavation and fill to minimize the berm height and area of detention, and a secondary berm along US-36 with excavation to capture and detain overflows that still were occurring at the US-36 Bridge of South Boulder Creek

Figure I-8 through Figure I-14 can be found in Appendix I. All of the alternatives analyzed used a zoned earthen embankment due to the reduced cost of constructing the embankment compared to a concrete wall. It should be noted that Alternative D does contain a retaining wall along OPSM property to prevent the embankment from entering OSMP property.

Each alternative reviewed would create some unavoidable impacts to either OSMP or CDOT ROW. In addition, additional unavoidable impacts to areas defined by the city as environmentally sensitive may also occur depending on the alternative. This includes city regulated wetlands and some areas that may include critical habitat. As noted previously, a draft environmental mitigation plan was developed to address potential environmental issues and is described below. Alternative D described above would reside on the CDOT Phase I ROW, would not permanently disturb OSMP property or sensitive environmental areas, and is not anticipated to require environmental mitigation.

Design Assumptions

To complete the refined design requested at the November 2014 WRAB meeting, MIKE FLOOD models were developed for both the single berm alternative and the dual berm alternative to better reflect the real 100-year WSEL required to mitigate overflows from the South Boulder Creek floodplain. This modeling analysis allowed the project team to design the berms to match the projected 100-year WSEL that allowed the team to vary the berm height for each alternative based on the volume detained and differing inflow and outflow conditions.

- The top of berm elevation was set at 5’ above the 100-year WSEL to provide freeboard. The freeboard requirements will be further evaluated as design progresses based on an incremental damage assessment with the Probable Maximum flood as required by the Colorado State Engineer’s Office (SEO). Freeboard requirements may need to be increased to safely pass the Probable Maximum Flood (PMF) as the South Boulder Creek flood control facility will be classified as a High Hazard Dam.
- The spillway is 1350 feet long and will be set at the 100-year WSEL
- The top of the berm is a 15 feet wide.
- A 2’ thick layer of Type M soil riprap will be placed on the upstream face of the dam.
- A 1’ thick layer of seeded topsoil, except near the spillway where a 2’ thick layer of Type M riprap will be placed, will cover the downstream face of the dam.
- A 30’ tall slurry cutoff wall designed to intersect bedrock and minimize seepage will be required under the berm.
- For alternatives in which a concrete wall is used, the concrete wall is 2’ wide and extends as a structural concrete cutoff wall 30’ to bedrock.
- Geotechnical assumptions remain the same as previous analysis.

Alternative Alignment Refinement

The refinement of the recommended alternative focused on increased detention on the CU South Campus property through excavation and use of multiple embankments to prevent flooding and further reduce impact to OSMP. In addition, both the CDOT Ultimate ROW and the Phase I ROW were investigate for potential berm alignments. The detention pond still combines excavation and fill to produce a configuration that minimizes the impacts to OSMP land. In addition, multiple stakeholders including CU South Campus, CDOT, and OSMP were consulted to provide input and to help identify potential opportunities and issues with the refined detention alternatives. The six new alternatives are described below.

Alternative A: Alternative Presented to WRAB in 2014

Alternative A reflects the alternative presented to WRAB in 2014. The recommended alternative presented to WRAB in 2014 is included as Figure 9-2.

Alternative B: Single Berm Alternative along the Proposed Ultimate CDOT ROW that includes excavation

This concept mimics the alternative that was presented to WRAB in November 2014. The alignment of the embankment would follow the US-36 proposed ultimate ROW, but unlike the alternative presented to WRAB, would include additional excavation on the CU South Campus to reduce the height of the proposed embankment.

The proposed embankment for Alternative B has a maximum embankment elevation of 5363 feet and a maximum 100-year WSEL of 5358. The embankment extends from approximately 600 feet west of the US-36 South Boulder Creek bridge, following the ultimate conditions US-36 ROW, and terminating on the west side of the CU South Campus Property. Excavation included in this alternative excavates the CU South Campus property to an elevation of 5349 near the Viele Channel and extending at a 0.5% grade to the south. This alternative would end up utilizing the north end of the CU South Campus Property for storage leaving the southern two-thirds of the property for development. This alternative would also and would cause impacts to OSMP properties due to the location of the southern berm parallel to the CDOT Ultimate ROW. Figure 9-3 shows Option B.

Alternative C: Single Berm Alternative along the Proposed Ultimate CDOT ROW that includes excavation on the east side of the CU South Campus

This concept mimics the alternative that was presented to WRAB in November 2014 and Alternative B previously described. This alternative however moves the excavated storage on the CU South Campus east to follow the CU South Campus Levee leaving the western portion of the property free for development purposes. The alignment of the embankment would follow the US-36 proposed ultimate ROW.

The proposed embankment for Alternative C has a maximum embankment elevation of 5366 feet and a maximum 100-year WSEL of 5361 feet. The embankment extends from approximately 400 feet west of the US-36 South Boulder Creek bridge, following the ultimate conditions US-36 ROW, and terminating on the west side of the CU South Campus Property. Excavation included in this alternative excavates the CU South Campus property to an elevation of 5349 near the Viele Channel and extending at a 0.5% grade to the south. This alternative would end up utilizing the northeastern side of the CU South Campus Property for storage leaving the southern and western portions of the property for development if the site is filled to a minimum elevation of 5366. This alternative would also and would cause impacts to OSMP properties due to the location of the southern berm parallel to the CDOT Ultimate ROW. Figure 9-4 shows Option C.

Alternative D: Single Berm Alternative along the Phase I US-36 Row with Excavation on the eastern side of the CU South Campus

This concept mimics Alternative D previously described. This alternative however relocates the embankment from the Ultimate CDOT ROW to the Interim CDOT ROW. Moving the embankment to the Phase I US-36 ROW eliminates takes from OSMP properties and impacts to sensitive environmental resources. However, this alternative would require the relocation of the US-36 regional trail to the top of the embankment, as well as the construction of a short 4' – 9' retaining wall on the southern side of the embankment to eliminate impacts to the OSMP properties.

The proposed embankment for Alternative C has a maximum embankment elevation of 5365 feet and a maximum 100-year WSEL of 5360 feet. The embankment extends from approximately 450 feet west of the US-36 South Boulder Creek bridge, following the Phase I US-36 ROW currently under construction, and terminating on the west side of the CU South Campus Property. Excavation included in this alternative excavates the CU South Campus property to an elevation of 5349 near the Viele Channel and extending at a 0.5% grade to the south. This alternative would end up utilizing the northeastern side of the CU South Campus Property for storage leaving the southern and western portions of the property for development if the site is filled to a minimum elevation of 5365. This alternative would also and would cause impacts to OSMP properties due to the location of the southern berm parallel to the CDOT Ultimate ROW. Figure 9-5 shows Option D.

Alternative E: Dual Berm Alternative along the Proposed Ultimate CDOT ROW with no Excavation and Fill

This concept is the first of the dual berm alternatives. For Alternative E, two berms are proposed to be constructed. The first is a berm constructed approximately 500 south of the east bound Foothills Parkway to US-36 ramp closing the area between the high ground on the west side of the CU South Campus and the Levee on the east. This alternative would also require and additional embankment along US-36 to contain the remaining overflows from South Boulder Creek that are not intercepted by the upper embankment. The CU South Campus Levee would be breached on the south side to allow water from South Boulder Creek to flow into the upper detention facility. A 170' top width channel would be required to contain the flows along the remaining levee on the east side of the CU south campus levee connecting the over flow to the south and the detention facility on the north.

The proposed upper embankment for Alternative D has a maximum embankment elevation of 5378 feet and a maximum 100-year WSEL of 5373 feet. The embankment along US-36 extends from approximately 600 feet west of the US-36 South Boulder Creek bridge, following the Ultimate US-36 ROW, and terminating on the west side of the CU South Campus Property. The maximum elevation for this berm would be 5362 feet with a maximum 100-year WSEL of 5367 feet. Excavation and fill is not proposed for this alternative. The alternative would leave the southern half of the CU south Campus property available for development and would cause impacts to OSMP properties due to the location of the southern berm parallel to the CDOT Ultimate ROW. Figure 9-6 shows Option E.

Alternative F: Dual Berm Alternative along the Proposed Ultimate CDOT ROW with Excavation and Fill

This concept is similar to Alternative E; two berms are proposed to be constructed. The first is a berm constructed approximately 500 south of the east bound Foothills Parkway to US-36 ramp closing the area between the high ground on the west side of the CU South Campus and the Levee on the east. This alternative would also require and additional embankment along US-36 to contain the remaining overflows from South Boulder Creek that are not intercepted by the upper embankment. The CU South Campus Levee would be breached on the south side to allow water from South Boulder Creek to flow into the upper detention facility. A 170' top width channel would be required to contain the flows along the remaining levee on the east side of the CU south campus levee connecting the over flow to the south and the detention facility on the north.

The proposed upper embankment for Alternative D has a maximum embankment elevation of 5370 feet and a maximum 100-year WSEL of 5365 feet. The pool behind the embankment would be excavated from an elevation of 5347 at the upstream toe of the berm and sloping up to the south at a 0.5% grade. Excavation reduces the area impact to the CU property by 30%.

The embankment along US-36 extends from approximately 550 feet west of the US-36 South Boulder Creek bridge, following the Ultimate US-36 ROW, and terminating on the west side of the CU South Campus Property. The maximum elevation for this berm would be 5363 feet with a maximum 100-year WSEL of 5358 feet. Excavation in the US-36 detention facility would occur on CU South Campus property to an elevation of 5349 near the Viele Channel and extending at a 0.5% grade to the south. This alternative would leave the southern half of the CU South Campus available for detention and would cause impacts to OSMP properties due to the location of the southern berm parallel to the CDOT Ultimate ROW. Figure 9-7 shows Option F.

Alternative G: Dual Berm Alternative along the Proposed Ultimate CDOT ROW with Excavation and Fill on east side of CU South Campus

This concept is similar to Alternative F. Two berms are proposed to be constructed. The first is a berm constructed approximately 500 south of the eastbound Foothills Parkway to US-36 ramp. Excavation along the east side of the CU South Campus Property would form the flood pool while fill on the west side of the CU South Campus Property would form the embankment on the west. The north portion of the Embankment would close the area between the levee on the east and the proposed fill on the west.

This alternative would also require and additional embankment along US-36 to contain the remaining overflows from South Boulder Creek that are not intercepted by the upper embankment. The CU South Campus Levee would be breached on the south side to allow water from South Boulder Creek to flow into the upper detention facility. A 170' top width channel would be required to contain the flows along the remaining levee on the east side of the CU south campus levee connecting the over flow to the south and the detention facility on the north.

The proposed upper embankment for Alternative D has a maximum embankment elevation of 5374 feet and a maximum 100-year WSEL of 5369 feet. The pool behind the embankment would be excavated from an elevation of 5347 at the upstream toe of the berm and sloping up to the south at a 0.5% grade. Excavation reduces the area impact to the CU property by 30%.

The embankment along US-36 extends from approximately 550 feet west of the US-36 South Boulder Creek bridge, following the Ultimate US-36 ROW, and terminating on the west side of the CU South Campus Property. The maximum elevation for this berm would be 5364 feet with a maximum 100-year WSEL of 5359 feet. Excavation in the US-36 detention facility would occur on CU South Campus property to an elevation of 5349 near the Viele Channel and extending at a 0.5% grade to the south. This alternative would leave the southern half of the CU South Campus available for detention and would cause impacts to OSMP properties due to the location of the southern berm parallel to the CDOT Ultimate ROW. Figure 9-8 shows Option G.

Table 9-2 presents the impacts to the CU South Campus and OSMP for the seven alternatives reviewed in 2015.

TABLE 9-2

Proposed US-36 Flood Control Facilities Analyzed in 2015 Summary of Impacts to CU and OSMP

	Required Property Acquisition (Acres)	
Alternative	**CU South Campus**	**City of Boulder OSMP – Area within Limits of Grading and Access Easement**
Alternative A	11.2	8.1
Alternative B	11.2	7.4
Alternative C	26.1	7.6
Alternative D	26.1	0.
Alternative E	24.3	7.1
Alternative F	24.3	7.4
Alternative G	26.9	7.6

Environmental Impact Analysis

ERO Resources Corporation (ERO) was retained to assist with identifying environmental resources that occur within the U.S. 36 Flood Control Facility Property (project area). See Figure 9-9 for Environmental Impact Analysis Area. Four alternatives have been identified to create floodwater detention for US-36 as part of the entire South Boulder Creek Flood Mitigation Plan. The proposed project would consist of a berm south of U.S. 36 and west of South Boulder Creek. The alternatives would involve construction of either an earthen berm or concrete wall within the Colorado Department of Transportation (CDOT) Phase 1 Right-of Way or "Ultimate Configuration" proposed Right-of-Way.

Each alternative would result in construction of the facility on City Open Space and Mountain Parks (OSMP) property and the University of Colorado (CU) South Campus. The Ultimate Configuration Design with Earthen Berm would result in the largest amount of land disturbance (20 acres).

This memorandum outlines potential environmental resources that are known to occur or are likely to occur in the project area, potential regulatory requirements, and preliminary mitigation options. The current level of master planning and design are such that specific acreages of each resource, levels of regulatory requirements, and mitigation cannot be finalized. As design progresses further, closer coordination with agencies including the City Planning and Development Division, City of Boulder Open Space and Mountain Parks Department, U.S. Army Corps of Engineers (Corps), and U.S. Fish and Wildlife Service (Service) would occur.

Regulated Natural Resources Occurring within the Project Area

Waters of the U.S. (Including Wetlands)

Regulatory Framework

The Clean Water Act (CWA) protects the physical, biological, and chemical quality of waters of the U.S. The U.S. Army Corps of Engineers (Corps) Regulatory Program administers and enforces Section 404 of the CWA. Under Section 404, a Corps permit is required for the discharge of dredge or fill material into wetlands and waters of the U.S. The Corps defines waters of the U.S. as all navigable waters and their tributaries, all interstate waters and their tributaries, all wetlands adjacent to these waters, and all impoundments of these waters. A number of rulings have modified what constitutes a wetland or water and the level of regulatory jurisdiction.

Section 404 permits consist of three types of permits: Nationwide (NWP), General, and Individual (IP). Generally projects that result in impacts on less than 0.5 acre of waters of the U.S. and wetlands can be authorized under one or more NWPs, whereas impacts greater than 0.5 acre requires a general permit or IP. Generally, projects that impact 0.1 or more acre of waters of the U.S. and wetlands require compensatory mitigation.

The City's Streams, Wetlands, and Water Body Protection ordinance was amended and formally adopted in 2009. Streams, wetlands, and various water bodies are protected under the ordinance. Boundaries of streams include the bankfull width of the channel and the boundaries of water bodies are defined by the presence of a bed and bank or ordinary high water mark. The City defines wetlands based on procedures specified in the Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory 1987). The manual defines wetlands as an area containing three wetland indicators (i.e., hydrophytic vegetation, supportive hydrology, and hydric soils). Additionally, the City has established a 25- or 50-foot protected wetland buffer on either side of City-regulated streams, wetlands, and water bodies depending on the location and functional rating of the wetlands. The City regulates wetlands and wetland buffers on lands within the City limits and on City-owned land outside the City limits.

Streams, Ditches, Open Water, and Wetlands in the Project Area

South Boulder Creek is a known water of the U.S. because of its surface connection to other navigable waters (e.g., Boulder Creek and the South Platte River) and is under the jurisdiction of the Corps. The creek flows from south to north through the project area. Impacts on South Boulder Creek would likely require some type of Section 404 permit.

South Boulder Creek is considered a regulated stream throughout the project area under the City's Streams, Wetlands, and Water Body Protection ordinance. Impacts on the stream channel or associated 50-foot wetland buffer would likely require a City wetland permit. The scale of the impacts would also likely require authorization under a Standard Wetland Permit. Most City wetland permits require compensatory mitigation.

Several ponds occur on the CU South Campus. Four ponds are located near the project area. It is likely the ponds on the project area are isolated from any jurisdictional streams and are not under the Corps' jurisdiction. A jurisdictional determination request would need to be completed by the Corps to confirm whether the ponds are jurisdictional.

The Dry Creek No. 2 Ditch occurs along the boundary between the CU South Campus property and OSMP property. The Dry Creek No. 2 Ditch has an eventual surface connection to South Boulder Creek, downstream of the project area, and would likely be considered a jurisdictional stream. Portions of the Dry Creek No. 2 Ditch that occur on OSMP land would also be regulated under the City's Streams, Wetlands, and Water Body Protection ordinance.

Wetlands occur on the CU South Campus, along South Boulder Creek, and throughout the City OSMP lands. The extent of the wetlands is not fully known. For the purposes of this memorandum, ERO assumes that up to 20 acres of wetlands could occur within the project area, including up to 7.4 acres of wetlands on OSMP property (see Potential Impacts section below). Knowledge of the area and review of aerial imagery suggest that less than 20 acres of wetlands occur in the project area; however, a wetland delineation would need to be performed to confirm this acreage.

Threatened and Endangered Species

Regulatory Framework

Federally threatened and endangered species are protected under the Endangered Species Act (ESA) of 1973, as amended (16 U.S.C. 1531 et seq.). The ESA defines an endangered species as "a species in danger of becoming extinct throughout all or a large portion of its range" and a threatened species as "a species likely to become endangered in the foreseeable future" (50 CFR 17.3). Section 4 of the ESA prohibits "take" of any federally listed species. Take is defined as "to harm, harass, pursue, hunt, shoot, wound, kill, trap, capture, or collect wildlife." Potential effects on a federally listed species or its habitat resulting from a project with a federal action require consultation with the Service under Section 7 of the ESA.

Habitat within the Project Area

The project area is located in occupied habitat for two federally listed threatened or endangered species that potentially occur in Boulder County – the Ute ladies'-tresses orchid (ULTO) and Preble's meadow jumping mouse (Preble's).

Trapping surveys for Preble's conducted in 1998, 1999, and 2000 at South Boulder Creek north and south of U.S. 36 resulted in positive captures (Figure 9-10). Trapping surveys conducted along Dry Creek Ditch No. 2 on the CU South Campus in 2000 yielded no captures. Additionally, critical habitat for Preble's exists along South Boulder Creek from the

mouth of Eldorado Canyon to Baseline Road (Figure 9-10). Similarly, populations of ULTO have been identified on OSMP lands north and south of U.S. 36.

Migratory Birds and Raptors

Regulatory Framework

Migratory birds, including raptors, and any active nests are protected under the federal Migratory Bird Treaty Act (MBTA). The regulatory definition of a take under the MBTA means to pursue, hunt, shoot, wound, kill, trap, capture, or collect; or attempt to pursue, hunt, shoot, wound, kill, trap, capture, or collect. In Colorado, most birds except for European starling, house sparrow, and rock dove (pigeon), are protected under the MBTA (703-712). Additionally, Executive Order 13186 directs federal agencies to take certain actions to implement the MBTA (66 Fed. Reg. 3853, January 17, 2001).

Habitat within the Project Area

The project area (up to 20 acres) contains habitat for several species of migratory birds and raptors. Migratory birds may inhabit wetlands, riparian areas, grasslands, and disturbed areas. Depending on the timing of construction, a migratory bird and raptor nest survey may be necessary.

Likely Permitting Requirements and Mitigation

Waters of the U.S. (Including Wetlands)

The selected flood mitigation measures may require securing wetland permits. City of Boulder Wetland permitting is described in more detail below. For Section 404 permitting as required by the Corps, if more than 0.5 acre of waters of the U.S. and wetlands would be impacted by the project, an IP would be required. If the proposed project would impact less than 0.5 acre of wetlands and waters of the U.S., the project may be permitted under one or more NWPs.

Generally, impacts on wetlands that are greater than 0.1 acre would require compensatory mitigation by the Corps. The fundamental objective of compensatory mitigation is to offset environmental losses resulting from unavoidable impacts on waters of the U.S. authorized by Corps permits. The Corps' district engineer must determine the compensatory mitigation to be required in a Corps permit, based on what is practicable and capable of compensating for aquatic resource functions that would be lost because of the permitted activity.

The city would require compensatory mitigation for impacts on wetlands or streams in the project area. The City allows three mitigation types: enhancement, restoration, and creation. For stream and water body impacts, the City generally requires a 1:1 mitigation ratio. For wetlands, the City requires a 1:1 ratio for enhancement of wetlands, a 1:5:1 ratio for restoration of wetlands, and a 2:1 ratio for wetland creation. The City requires higher mitigation ratios for rare or hard- to-create wetlands. The ratio for rare or hard-to-create wetlands is 1.5:1 for enhancement, 2:1 for restoration, and 2.5:1 for creation. Mitigation required by the City could be completed in conjunction and within the same location as mitigation that could be required by the Corps. City-required wetland mitigation is not additive to mitigation required by the Corps.

Threatened and Endangered Species

Impacts on potential threatened or endangered species, their habitat, and critical habitat in the project area would likely require Section 7 consultation between the Corps and Service. Since Preble's are known to occur within the project area, a biological assessment (BA) summarizing impacts, conservation measures, and appropriate mitigation of Preble's habitat should be prepared and submitted to the lead federal agency (in this case, the Corps). The Corps would forward the BA to the Service to initiate consultation. The Service would respond with a biological opinion (BO) that would authorize "take" of Preble's and habitat from the project.

Craig Hansen (Service) and Clint Henke (ERO) spoke about mitigation for impacts on Preble's and ULTO on March 6, 2014 (Hansen, pers. comm. 2014b). Craig stated that he relies on the project team to come up with appropriate mitigation for impacts. The Service has no ratio standards that they use, but Craig stated that a minimum 3:1 replacement ratio would be safe. Mitigation of critical habitat must occur within the same critical habitat unit that is being impacted by a project. The Service would allow enhancement of areas along South Boulder Creek that contain low-quality Preble's habitat. As the project, design phases progress, further consultation with the Service would be necessary if any of the selected flood mitigation features would impact Preble's habitat.

The Service does not issue take permits for ULTO; they would recommend that ULTO populations be avoided. If ULTO populations cannot be avoided, the Service would work with the project team on identifying appropriate mitigation.**Migratory Birds and Raptors**

Compliance with the MBTA requires the following:

- While destruction of a nest by itself is not prohibited under the MBTA, nest destruction that results in the unpermitted take of migratory birds or their eggs is illegal and fully prosecutable under the MBTA (Migratory Bird Permit Memorandum: Steve Williams, Director of the Service, April 15, 2003). Thus, the nest or nest trees cannot be removed or destroyed during the breeding season (generally March through July).
- Take of an active nest site requires obtaining a nest depredation permit from the Migratory Bird Office of the Service.
- Nests or nest trees can be removed during the nonbreeding season to preclude nesting.

Clearing of vegetation outside of the active breeding season does not require consultation with the Service. If vegetation-clearing activities were to occur during the migratory bird-breeding season, a migratory bird nest survey is recommended so that active nests are avoided.

Invasive Species

Construction of an earthen berm would likely provide good habitat for invasive species. The City would need to conduct long-term weed management in disturbed areas to ensure that non-native species and weeds listed on the state noxious weed list do not spread to adjacent areas.

Cost Benefit Analysis of Berm Alternatives

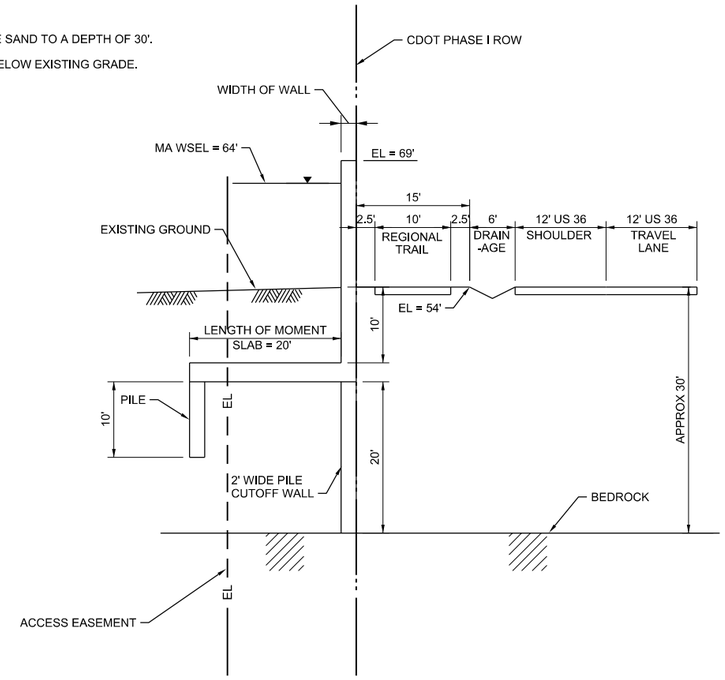
A benefit cost analysis was completed on each of the berm alignments and configurations developed and reviewed in both 2014 and 2015. The construction costs were developed utilizing the design assumptions developed during the 2014 analysis is described on page IX-1, Design Assumptions. The benefit for the US-36 Flood Control Facility is taken from Chapter 8 of the South Boulder Creek Major Drainageway Plan. Mobilization and Stormwater/Erosion Control costs are both assumed 5% of the Construction Cost. It was assumed that both the berm footprint on OSMP property and the environmental mitigation site on OSMP properties would need to be purchased. Easement costs were assumed to be $0.83/SF on OSMP properties in order to be consistent with previous analysis Engineering costs, Legal/Administrative Costs, Contract Admin/Construction Management Costs, and Contingencies are 15%, 5%, 10%, and 35% of the Subtotal Cost, respectively. This cost benefit analysis looks at the refinements to the US-36 Flood Control Facility in order to understand the cost benefit ratio and to use as a final screening and selection tool to help identify a preferred alternative. Table 9-3, Alternative Cost Benefit Summary Tables, provides the cost benefit analysis.

TABLE 9-3
Alternative Cost-Benefit Summary Table

Alternative	Construction Cost ($Millions)	Mobilization ($Millions)	Stormwater/Erosion Control ($Millions)	Utility Relocation ($Millions)	Environmental Mitigation ($Millions)	Subtotal ($Millions)	Easement/Right of Way ($Millions)	Environmental Mitigation Land Acquisition ($Millions)	Engineering ($Millions)	Legal/Administrative ($Millions)	Contract Admin/Construction Management ($Millions)	Contingency ($Millions)	Total Capital Cost ($Millions)	Present Worth of O&M Cost ($Millions)	Total Implementation Cost ($Millions)	Benefit ($Millions)	Cost to Benefit Ratio
US-36 Phase I Design With Berm	$9.46	$0.47	$0.47	$0.03	$2.79	$13.22	$0.65	$0.80	$1.98	$0.66	$1.32	$4.63	$23.26	$0.77	$24.03	$26.30	1.09
Ultimate Configuration Design With Berm	$9.25	$0.46	$0.46	$0.03	$2.79	$12.99	$0.72	$0.80	$1.95	$0.65	$1.30	$4.55	$22.95	$0.77	$23.72	$26.30	1.11
US-36 Phase I Design With Wall	$12.00	$0.60	$0.60	$0.03	$2.79	$16.02	$0.49	$0.80	$2.40	$0.80	$1.60	$5.61	$27.72	$0.77	$28.49	$26.30	0.92
Ultimate Configuration Design With Wall	$11.97	$0.60	$0.60	$0.03	$2.79	$15.99	$0.57	$0.80	$2.40	$0.80	$1.60	$5.60	$27.75	$0.77	$28.52	$26.30	0.92
Alternative A	$9.46	$0.47	$0.47	$0.03	$2.79	$13.22	$0.65	$0.80	$1.98	$0.66	$1.32	$4.63	$23.26	$0.77	$24.03	$26.30	1.09
Alternative B	$8.11	$0.41	$0.41	$0.03	$2.79	$11.75	$0.67	$0.80	$1.76	$0.59	$1.18	$4.11	$20.86	$0.77	$21.63	$26.30	1.22
Alternative C	$8.31	$0.42	$0.42	$0.03	$2.79	$11.97	$1.22	$0.80	$1.80	$0.60	$1.20	$4.19	$21.77	$0.77	$22.54	$26.30	1.17
Alternative D	$11.30	$0.57	$0.57	$0.03	$0.00	$12.47	$0.95	$0.00	$1.87	$0.62	$1.25	$4.36	$21.53	$0.77	$22.30	$26.30	1.18
Alternative E	$10.15	$0.51	$0.51	$0.03	$2.79	$13.99	$1.14	$0.80	$2.10	$0.70	$1.40	$4.90	$25.02	$0.77	$25.79	$26.90	1.04
Alternative F	$13.02	$0.65	$0.65	$0.03	$2.79	$17.14	$1.14	$0.80	$2.57	$0.86	$1.71	$6.00	$30.22	$0.77	$30.99	$26.90	0.87
Alternative G	$14.81	$0.74	$0.74	$0.03	$2.79	$19.11	$1.25	$0.80	$2.87	$0.96	$1.91	$6.69	$33.58	$0.77	$34.35	$26.90	0.78

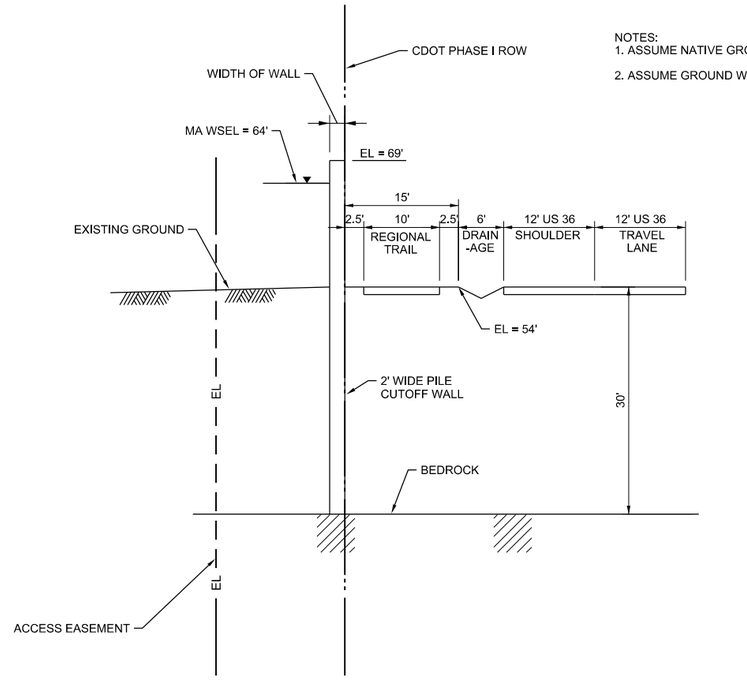
NOTES:
1. ASSUME NATIVE GROUND IS FINE SAND TO A DEPTH OF 30'.

2. ASSUME GROUND WATER IS 6" BELOW EXISTING GRADE.



WALL ALTERNATIVE 1 (CONCRETE WALL WITH MOMENT SLAB)

1 1"=10'-0"

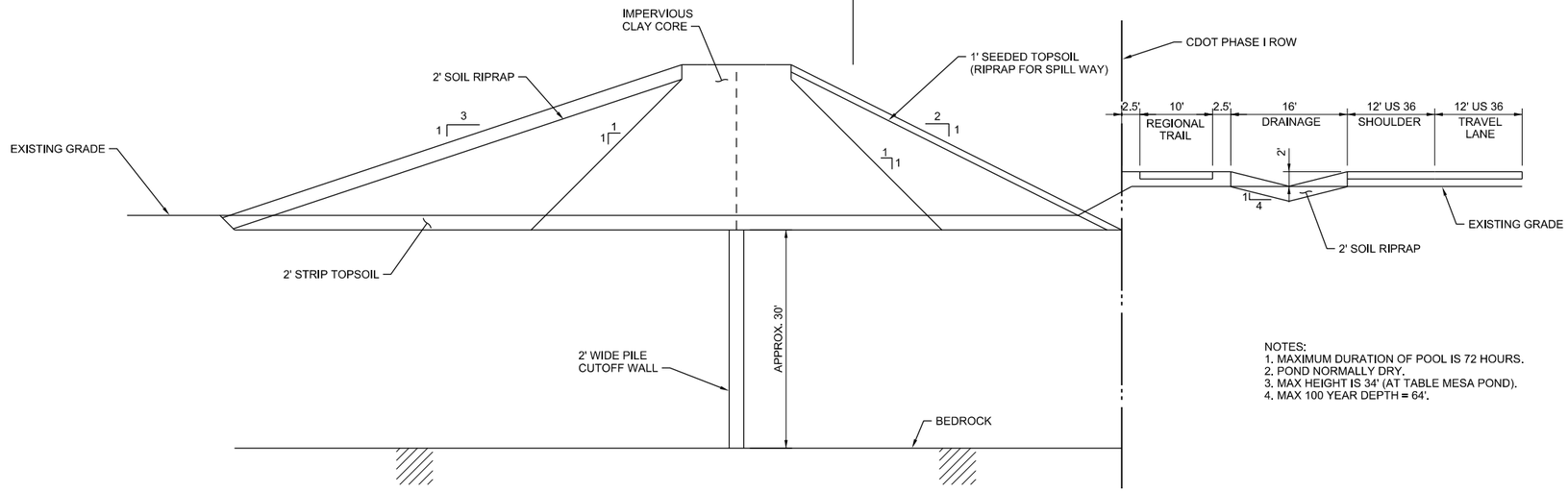


NOTES:
1. ASSUME NATIVE GROUND IS FINE SAND TO A DEPTH OF 30'.

2. ASSUME GROUND WATER IS 6" BELOW EXISTING GRADE.

WALL ALTERNATIVE 2 (CONCRETE CUT-OFF WALL)

2 1"=10'-0"



NOTES:
1. MAXIMUM DURATION OF POOL IS 72 HOURS.
2. POND NORMALLY DRY.
3. MAX HEIGHT IS 34' (AT TABLE MESA POND).
4. MAX 100 YEAR DEPTH = 64'.

EARTHEN BERM ALTERNATIVE

3 1"=10'-0"

NO.	DATE	DR	REVISION	CHK	BY	APVD
DSGN	A TURNER		SMILLER		A TURNER	

CH2MHILL®

US 36 FLOOD MITIGATION PROJECT
BOULDER, CO
CITY OF BOULDER

US 36 FLOOD CONTROL FACILITY
Figure 9-1
BERM ALTERNATIVES
BERM AT PHASE I ROW

VERIFY SCALE
BAR IS ONE INCH ON ORIGINAL DRAWING.
0 1"

DATE
PROJ
DWG
SHEET of

Stormwater Detention Upstream of US36

South Boulder Creek Flood Mitigation Project

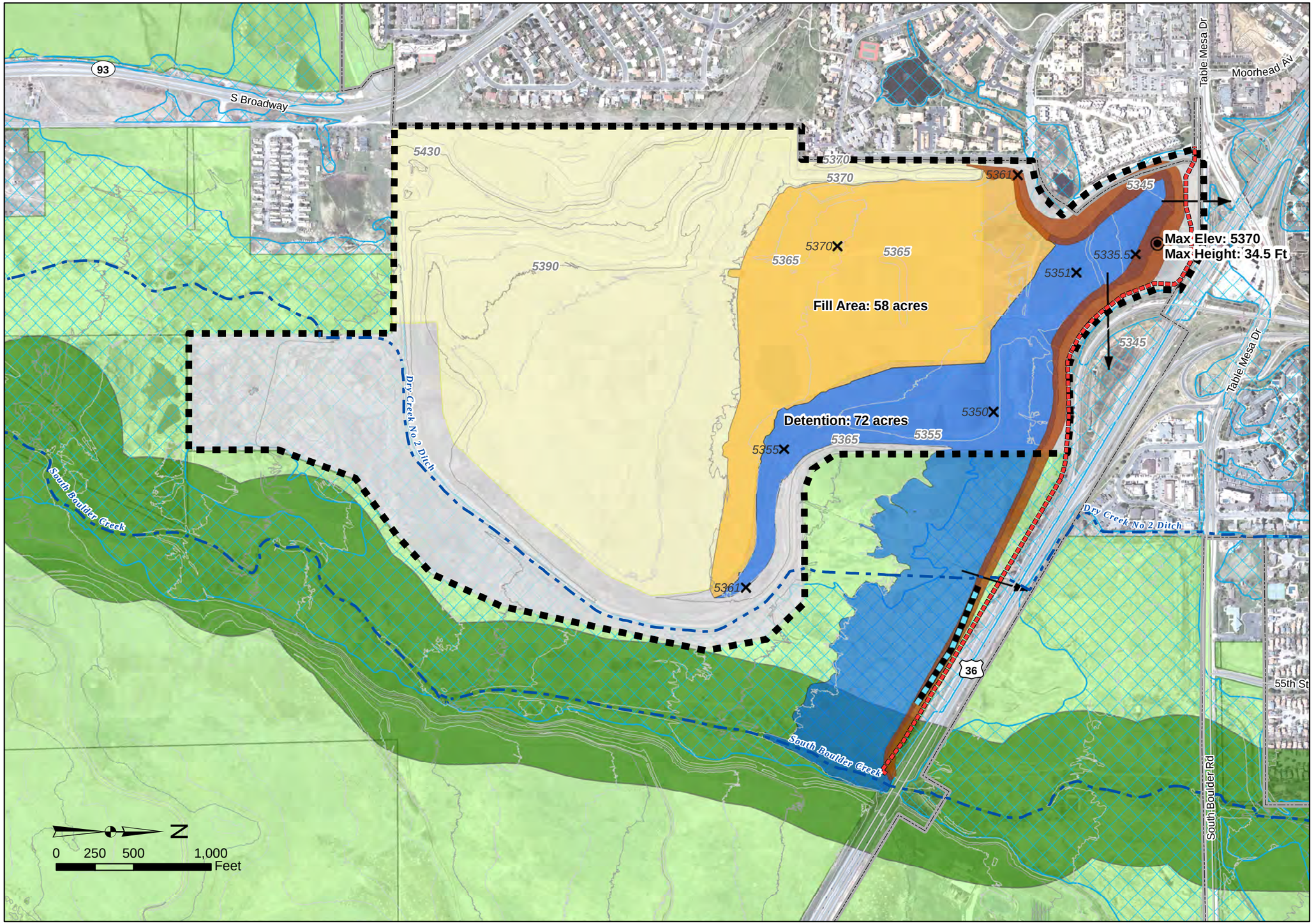


Figure 9-2
Option A

Alternative presented to WRAB in 2014

Single Berm
No excavation
With fill
On CU and OSMP property
Max Berm Height 34.5ft

Description	Acres
Total CU Property	302
CU Property Impacted	56
CU Building Potential Impacted	6
OSMP Property Impacted	40

Proposed Conditions

- New Berm
- Pool Contained By Fill or Cut Slope
- Limits of Excavation
- Detention Pond Area
- Fill Area
- Out of 100yr Inundation
- Spot Elevation
- Max Berm Elevation
- Discharge Location
- Spillway

Existing Conditions

- Boulder City Limits
- CDOT Existing ROW
- CU Site Boundary
- OSMP Property
- Prebles Critical Habitat Area
- Effective 100 Year Floodplain
- 5 Foot Contours
- 10 Foot Contours

Stormwater Detention Upstream of US36

South Boulder Creek Flood Mitigation Project

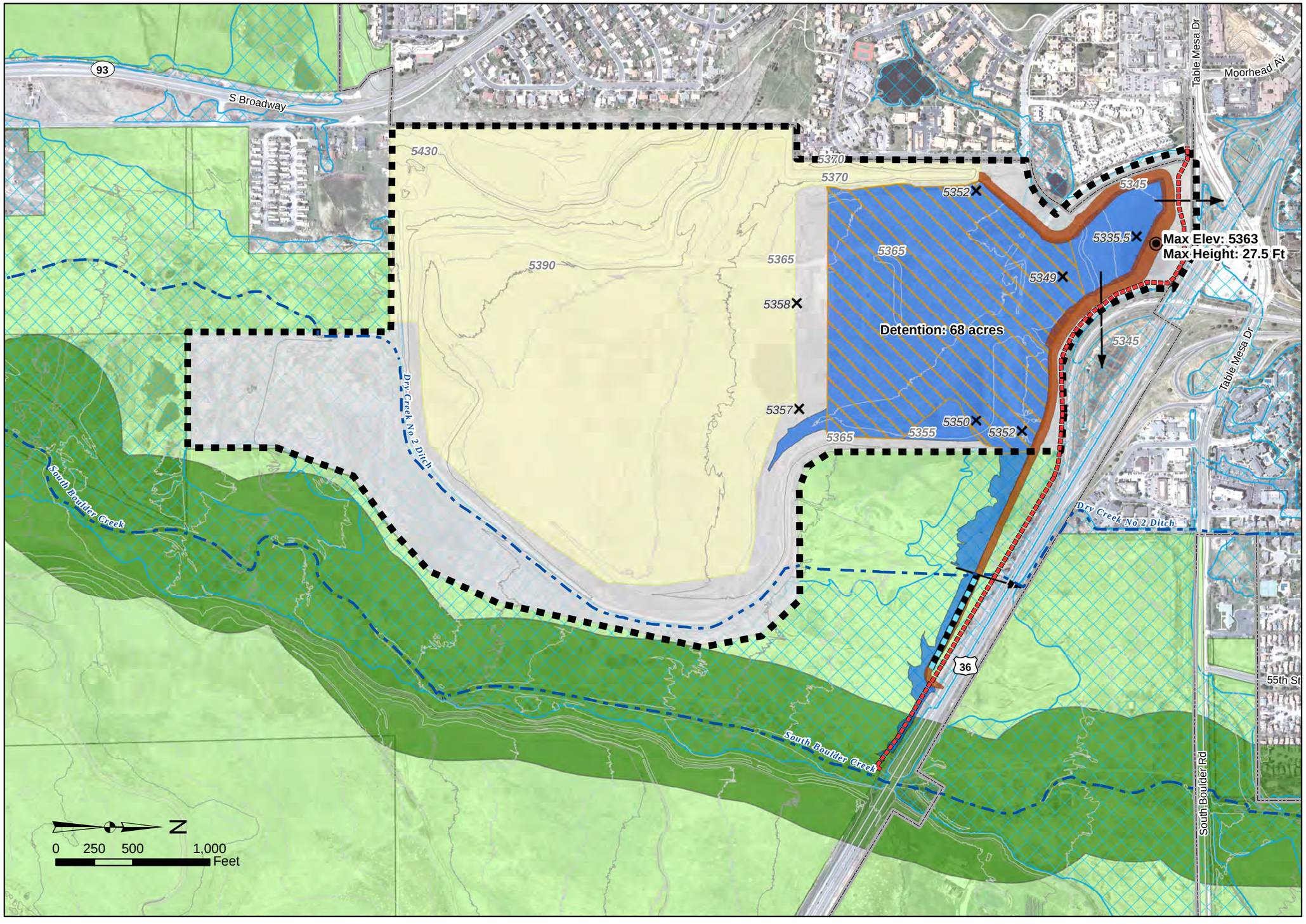


Figure 9-3
Option B

Single Berm
With excavation
No Fill
On CU and OSMP property
Max Berm Height 27.5ft
Berm length shortened to avoid critical habitat

Description	Acres
Total CU Property	302
CU Property Impacted	90
CU Building Potential Impacted	36
OSMP Property Impacted	7

Proposed Conditions

- New Berm
- Pool Contained By Fill or Cut Slope
- Limits of Excavation
- Detention Pond Area
- Fill Area
- Out of 100yr Inundation
- Spot Elevation
- Max Berm Elevation
- Discharge Location
- Spillway

Existing Conditions

- Boulder City Limits
- CDOT Existing ROW
- CU Site Boundary
- OSMP Property
- Prebles Critical Habitat Area
- Effective 100 Year Floodplain
- 5 Foot Contours
- 10 Foot Contours

Stormwater Detention Upstream of US36

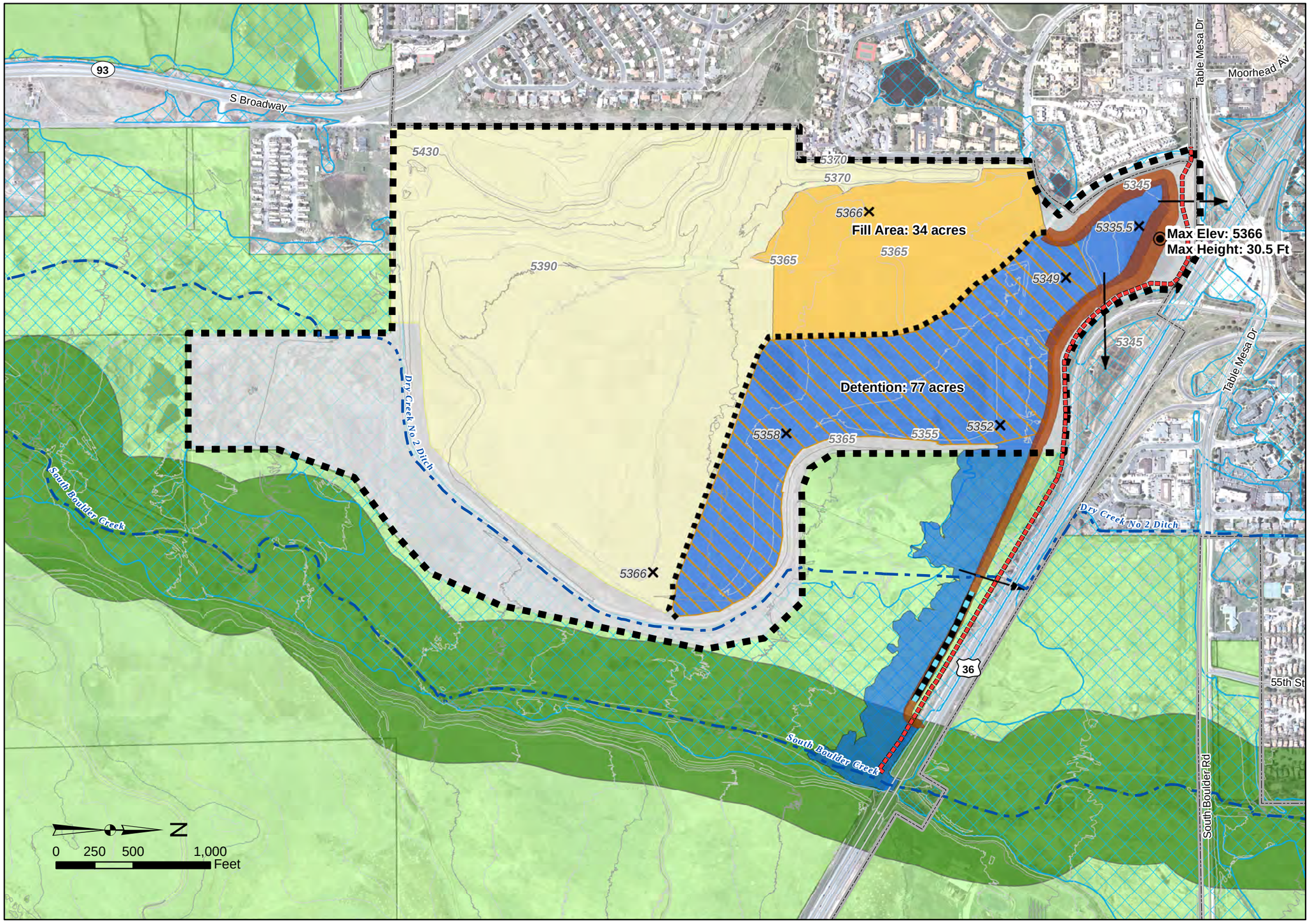
South Boulder Creek Flood Mitigation Project

Figure 9-4

Option C

Single Berm
With excavation
With fill
On CU and OSMP property
Max Berm Height 30.5ft

Description	Acres
Total CU Property	302
CU Property Impacted	80
CU Building Potential Impacted	30
OSMP Property Impacted	20



Proposed Conditions

- New Berm
- Pool Contained By Fill or Cut Slope
- Limits of Excavation
- Detention Pond Area
- Fill Area
- Out of 100yr Inundation
- Spot Elevation
- Max Berm Elevation
- Discharge Location
- Spillway

Existing Conditions

- Boulder City Limits
- CDOT Existing ROW
- CU Site Boundary
- OSMP Property
- Prebles Critical Habitat Area
- Effective 100 Year Floodplain
- 5 Foot Contours
- 10 Foot Contours

Stormwater Detention Upstream of US36

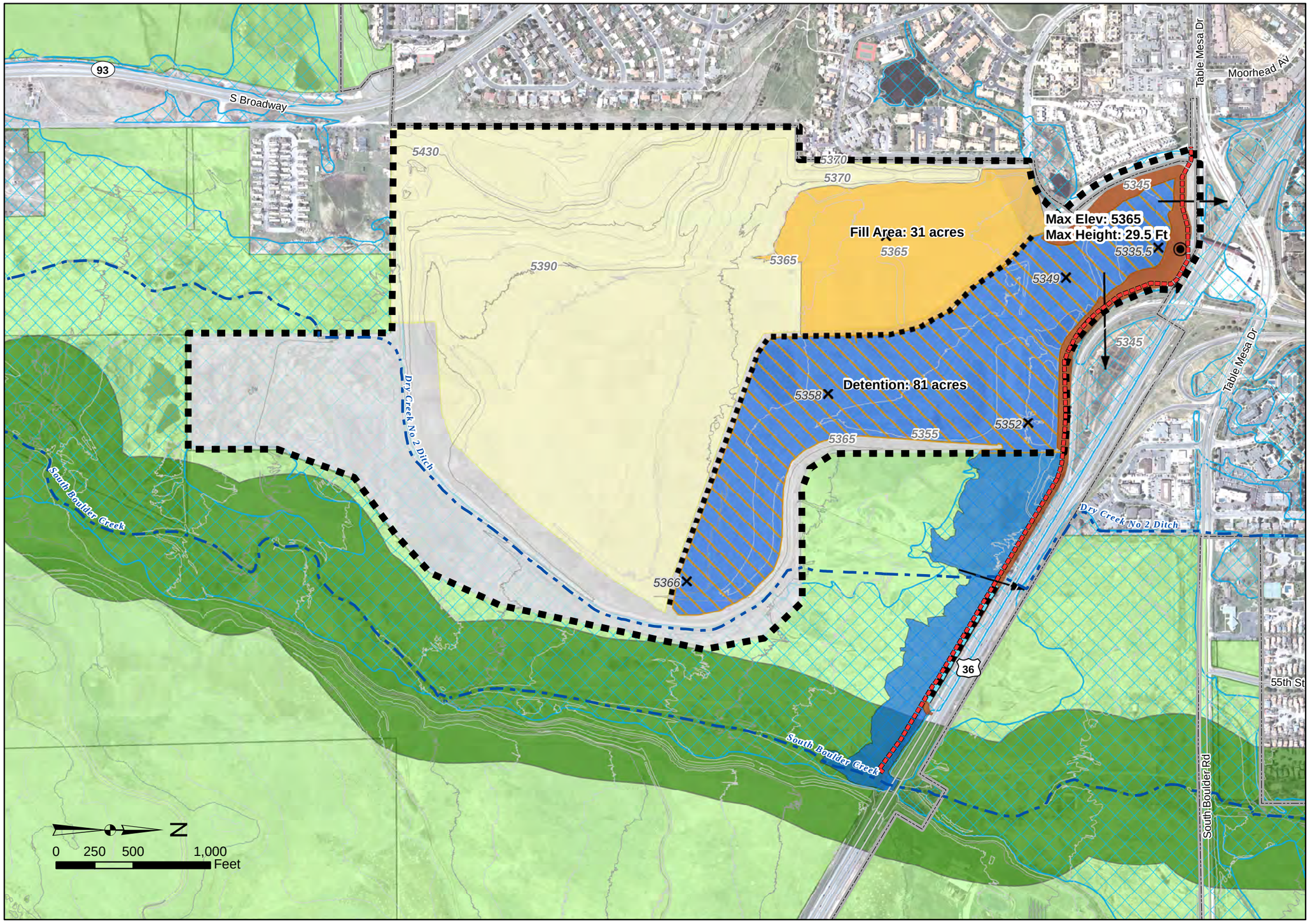
South Boulder Creek Flood Mitigation Project

Figure 9-5

Option D

Single Berm
With excavation
With fill
On CU and OSMP property
In CDOT Existing ROW
Max Berm Height 29.5ft

Description	Acres
Total CU Property	302
CU Property Impacted	78
CU Building Potential Impacted	30
OSMP Property Impacted	19



Proposed Conditions

- New Berm
- Pool Contained By Fill or Cut Slope
- Limits of Excavation
- Detention Pond Area
- Fill Area
- Out of 100yr Inundation
- Spot Elevation
- Max Berm Elevation
- Discharge Location
- Spillway

Existing Conditions

- Boulder City Limits
- CDOT Existing ROW
- CU Site Boundary
- OSMP Property
- Prebles Critical Habitat Area
- Effective 100 Year Floodplain
- 5 Foot Contours
- 10 Foot Contours

Stormwater Detention Upstream of US36

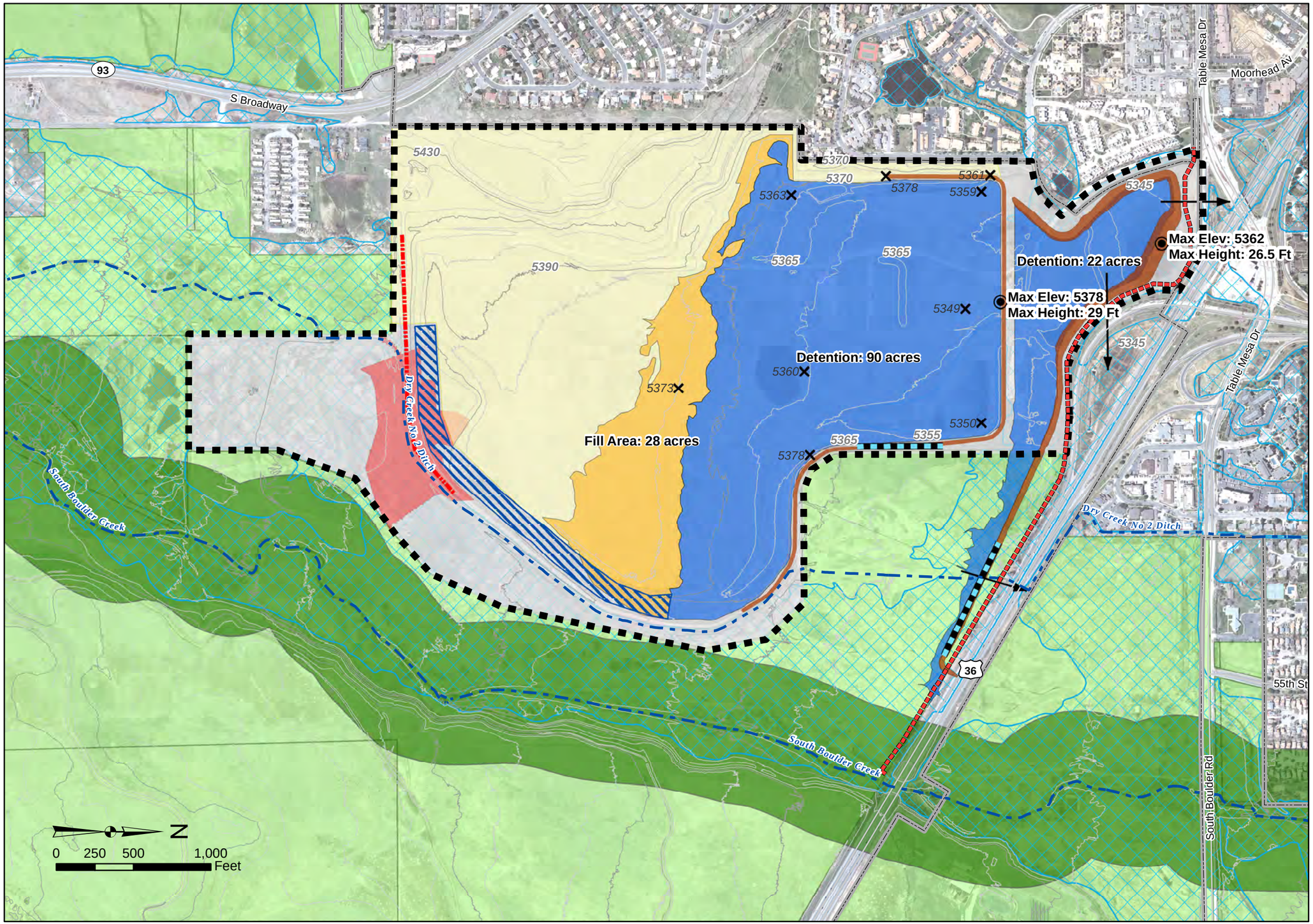
South Boulder Creek Flood Mitigation Project

Figure 9-6

Option E

Dual Berm
No Excavation
No Fill
On CU and OSMP property
Max Berm Height 29ft and 26.5ft

Description	Acres
Total CU Property	302
CU Property Impacted	142
CU Building Potential Impacted	73
OSMP Property Impacted	5



Proposed Conditions

- New Berm
- Limits of Excavation
- Detention Pond Area
- Fill Area
- New Channel
- Remove Existing Berm
- Lower Grade (Allows Flow to Pond)
- Out of 100yr Inundation
- Spot Elevation
- Max Berm Elevation
- Discharge Location
- Spillway

Existing Conditions

- Boulder City Limits
- CDOT Existing ROW
- CU Site Boundary
- OSMP Property
- Prebles Critical Habitat Area
- Effective 100 Year Floodplain
- 5 Foot Contours
- 10 Foot Contours

Stormwater Detention Upstream of US36

South Boulder Creek Flood Mitigation Project

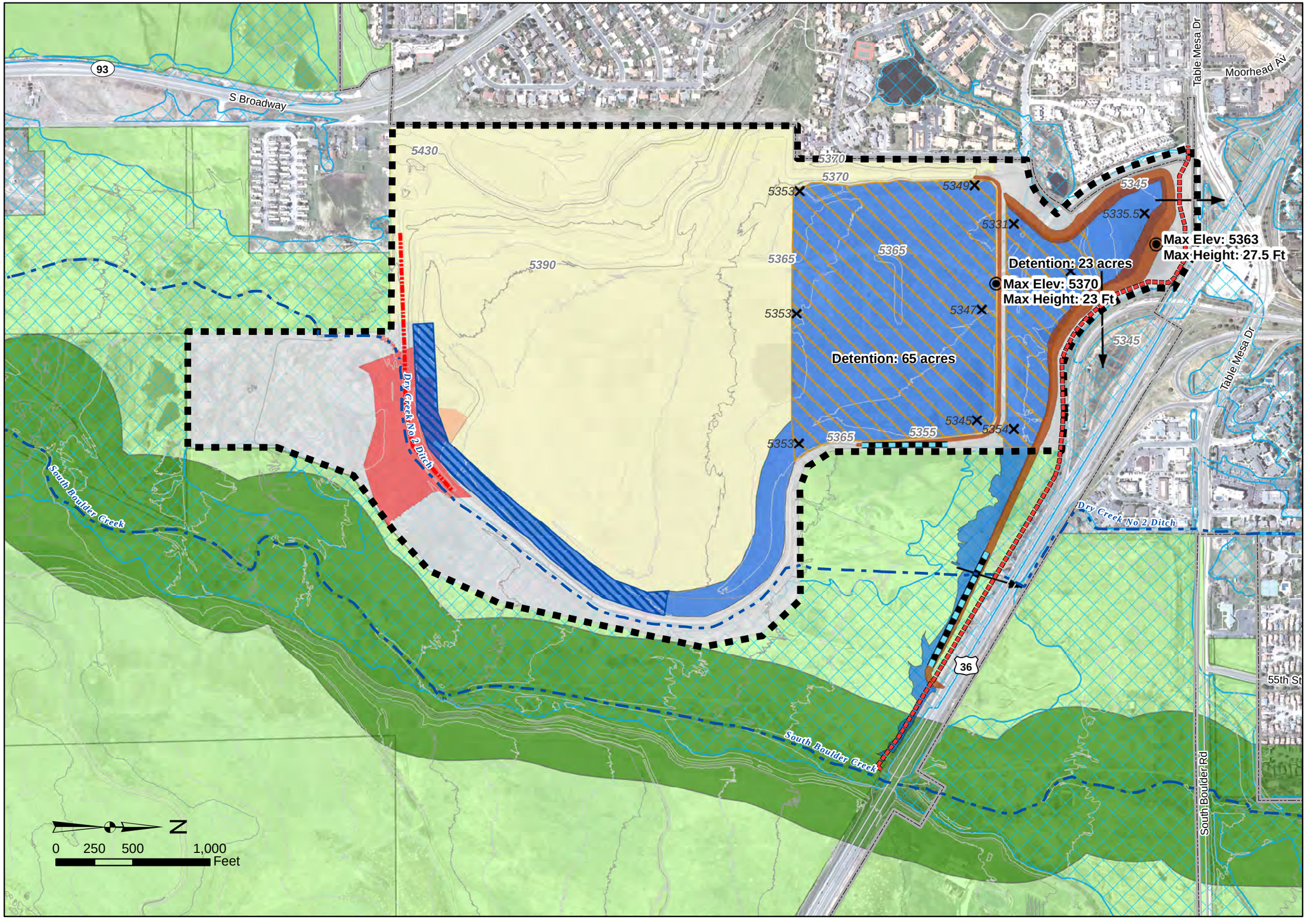


Figure 9-7

Option F

Dual Berm
With Excavation
No Fill
On CU and OSMP property
Max Berm Height 23ft and 27.5ft

Description	Acres
Total CU Property	302
CU Property Impacted	100
CU Building Potential Impacted	41
OSMP Property Impacted	7

Proposed Conditions

- New Berm
- Limits of Excavation
- Detention Pond Area
- Fill Area
- New Channel
- Remove Existing Berm
- Lower Grade (Allows Flow to Pond)
- Out of 100yr Inundation
- Spot Elevation
- Max Berm Elevation
- Discharge Location
- Spillway

Existing Conditions

- Boulder City Limits
- CDOT Existing ROW
- CU Site Boundary
- OSMP Property
- Prebles Critical Habitat Area
- Effective 100 Year Floodplain
- 5 Foot Contours
- 10 Foot Contours

Stormwater Detention Upstream of US36

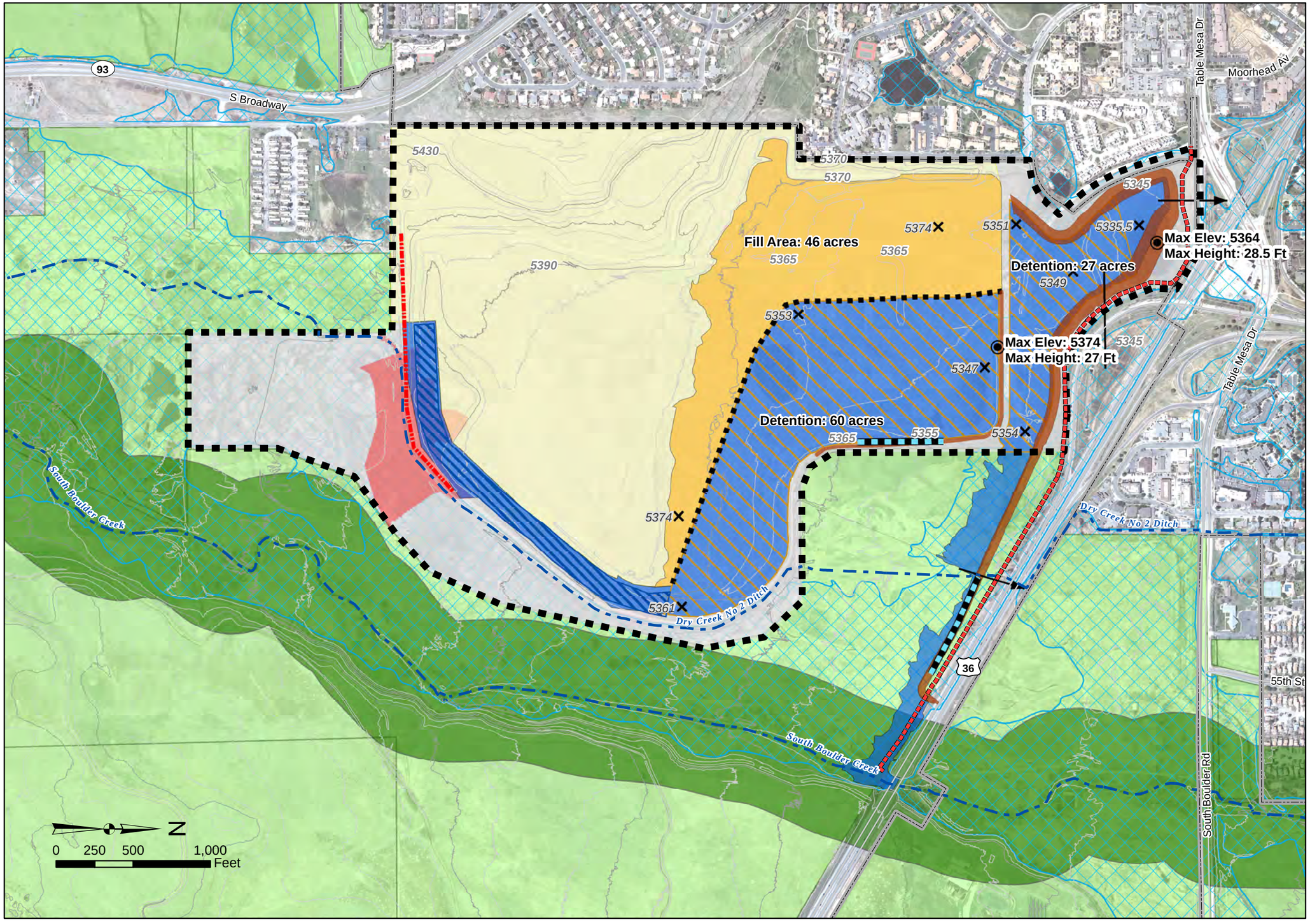
South Boulder Creek Flood Mitigation Project

Figure 9-8

Option G

Dual Berm
With Excavation
With fill
On CU and OSMP property
Max Berm Height 27ft and 28.5ft

Description	Acres
Total CU Property	302
CU Property Impacted	99
CU Building Potential Impacted	43
OSMP Property Impacted	11



Proposed Conditions

- New Berm
- Pool Contained By Fill or Cut Slope
- Limits of Excavation
- Detention Pond Area
- Fill Area
- New Channel
- Remove Existing Berm
- Lower Grade (Allows Flow to Pond)
- Out of 100yr Inundation
- Spot Elevation
- Max Berm Elevation
- Discharge Location
- Spillway

Existing Conditions

- Boulder City Limits
- CDOT Existing ROW
- CU Site Boundary
- OSMP Property
- Prebles Critical Habitat Area
- Effective 100 Year Floodplain
- 5 Foot Contours
- 10 Foot Contours

South Boulder Creek Flood Mitigation Project

Sections 9 and 10, T1S, R70W; 6th PM
UTM NAD 83: Zone 13N; 480388mE, 4425631mN
Latitude, Longitude: 39.980614°N, 105.229687°W
USGS Louisville, CO Quadrangle
Boulder County, Colorado

Figure 9-9
Environmental Assement Area

Prepared for: City of Boulder
File: 5761 Figure 1.mxd (GS)
March 7, 2014

ERO Resources Corp.

South Boulder Creek Flood Mitigation Project

Preble's Positive Capture Location
Preble's Critical Habitat
Project Area Boundary

Image Source: Microsoft©, March 2012

Figure 9-10
Preble's Meadow Jumping Mouse Critical Habitat

Prepared for: City of Boulder
File: 5761 Figure 2 Critical Habitat.mxd (GS)
March 7, 2014

ERO Resources Corp.

X. Engineers Recommended Plan

Introduction

The Engineer's Recommended Plan to address the identified flooding issues within the South Boulder Creek study area is the Regional Detention at US-36 Plan (Recommended Plan) located on CDOT right of way (Alternative D from the alternatives analysis) along with downstream improvements including Arapahoe Avenue stormwater detention and improvements in the West Valley. A review of a conceptual version of the Engineers Recommended Plan with the City of Boulder Staff, coordination with stakeholders the Water Resources Advisory Board and the Open Space Board of Trustees indicated that Option D for the US-36 flood control facility represents the recommended alignment for the stormwater detention facility. City Council will be presented with the engineers recommended plan in August 2015.

Engineers Refined Recommended Plan Description

The refined recommended plan presented here has three major components: 1) Stormwater detention at US-36, 2) Stormwater detention at Arapahoe Road and 3) Improvements through the West Valley. Each of these components is described below. Figure 10-1 graphically presents the recommended improvements. Table 10-1 presents the plan elements and associated estimated costs in tabular format.

US-36 Stormwater Detention Facility

The refined plan would prevent the overtopping of US-36 during a 100-year storm event and provide corresponding protection from the overtopping flows of South Boulder Creek to downstream properties in the West Valley. The selected US-36 detention pond alignment and configuration is Option D and the bermis located entirely within CDOT right of way (ROW) and the Cu South Campus Parcel. This configuration eliminates permanent impacts to OSMP lands along with the need for additional environmental mitigation (further engineering analysis will be required to determine whether the proposed stormwater detention facility would result in temporary construction or maintenance impacts). The alternative includes a combination of excavation and fill on the CU South Campus property, the removal and relocation of a portion of the regional bike trail currently under construction by CDOT to the top of the proposed detention facility and construction of retaining walls along the CDOT phase 1 ROW. Figure 10-2 depicts Alternative D.

Arapahoe Avenue Detention

The improvements at Arapahoe Avenue take advantage of the Flatirons Golf Club golf course to provide 58 acre-feet (AF) of storage that reduces the impact to downstream industrial and commercial properties. Two outlet channels below Arapahoe Avenue are proposed to convey attenuated flows downstream to outfalls of adequate capacity. There may be some unavoidable impacts to city-regulated wetlands at the outfall to the eastern discharge channel. However, careful design will likely minimize impacts and corresponding environmental mitigation. In addition, the alternative requires the acquisition of some private property. Figure 10-3, Arapahoe Avenue Detention, shows the details of this element.

Improvements in the West Valley

The facilities in the West Valley associated with this alternative are intended to capture and convey locally generated inflows. The proposed 25 AF detention at Manhattan Middle School (or an alternate location if feasible) is a key element of the plan capturing locally generated flows that can be controlled and discharged to the existing downstream infrastructure to help minimize or eliminate additional downstream system improvements. A conceptual layout of the proposed Manhattan Middle School detention facility can be found in Figure 10-4.

Similarly, the existing detention at the intersection of Baseline Road and Foothills Parkway will be required to be enlarged to 9 AF to take full advantage of the capacity of the downstream system. Other West Valley Improvements are defined below.

- Channel improvements including an increase in height to the concrete retaining wall along Baseline Road east of Foothills Parkway are included in the plan to move water from the proposed Foothills Parkway detention facilities to Dry Creek Ditch No. 2.
- Improvements are identified to the New Anderson Ditch to accommodate the additional flow that results from the increased hydraulic head generated by the storage upstream of US-36.
- A turnout structure for the Wellman Canal, east of Foothills Parkway, will be required to discharge flood flows from Bear Canyon Creek back into the Bear Canyon Creek historic channel. This improvement is required to help eliminate flood flows exceeding the capacity of the Wellman Canal from causing additional flood hazards through the West Valley.
- Improvements along Dry Creek No. 2 include a 72-inch diameter pipe (or larger open channel) to convey the 420 cfs that flows down the Dry Creek No. 2 Ditch corridor.

Alignments of all the facilities take full advantage of existing publically owned lands and minimize the number of individual property owners impacted and impacts to known utility lines. Figure 10-5, West Valley Improvements, summarizes the layout of the improvements proposed in the West Valley.

Basis for Selection

The primary objective defined at the outset of the study was to reduce the impact on properties within the West Valley that were within the designated 100-year floodplain. The Refined Recommended Plan does that effectively, with approximately 411 structures (1,721 dwelling units) within the city limits would no longer be located in the 100-year floodplain. Moreover, the Refined Recommended Plan addresses important life safety concerns by eliminating the high hazard zone from many areas of the West Valley and reducing the threat of overtopping of many major city and state arterials, including US-36, South Boulder Road, Baseline Road and Arapahoe Avenue eliminating the risk of roadway overtopping and improving emergency vehicle access during major flood events.

The Refined Recommended Plan has one of the highest benefit-cost ratios, while minimizing impacts to environmental resources and OSMP property among the plans evaluated. This means that the city's investment in infrastructure to address flooding generates a favorable return by reducing the average annual flood damages by a factor of 1.7 over the investment cost.

Although the Refined Recommended Plan has been designed to eliminate to the extent possible impacts to areas designated by the city as having important environmental value, future design refinements may identify unavoidable temporary or even permanent impacts to these sensitive areas. If impacts are identified during future design phases, a plan for environmental mitigation would need to be developed. Similarly, the Recommended Plan requires the acquisition of some property so that the identified facilities can be constructed. The implementation estimate includes costs for the purchase of the necessary right-of-way and easements at estimated fair market prices.

TABLE 10-1

Engineers Recommended Plan Regional Detention at US-36

Element	Construction Cost (Including Environmental Mitigation) ($Millions)	Mobilization ($Millions)	Stormwater Management / Erosion Control ($Millions)	Utility Relocation ($Millions)	Subtotal ($Millions)	Easement / Right of Way (Including Environmental Land Purchase) ($Millions)	Engineering ($Millions)	Legal / Administration ($Millions)	Contract Admin / Construction Management ($Millions)	Contingency ($Millions)	Total Capital Cost ($Millions)	Present Worth of O & M Cost ($Millions)	Total Implementation Cost ($Millions)
Alternative D: Single Berm within CDOT ROW	$11.30	$0.57	$0.57	$0.03	$12.47	$0.95	$0.95	$0.62	$1.25	$4.36	$21.53	$0.77	$22.54
Improvements to the New Anderson Ditch	$0.66	$0.03	$0.03	$0.12	$0.85	$0.00	$0.13	$0.04	$0.09	$0.30	$1.40	$0.01	$1.41
Dry Creek Ditch No. 2 Pipeline Improvements	$1.25	$0.06	$0.06	$0.37	$1.75	$1.06	$0.26	$0.09	$0.18	$0.98	$4.32	$0.00	$4.32
Local Detention at Manhattan Middle School	$1.21	$0.06	$0.06	$0.01	$1.34	$0.31	$0.20	$0.07	$0.13	$0.58	$2.63	$0.03	$2.67
Local Detention at Baseline Road/Foothills Parkway	$1.10	$0.06	$0.06	$0.02	$1.23	$0.00	$0.19	$0.06	$0.12	$0.43	$2.04	$0.01	$2.05
Wall Enhancements at Baseline Road	$0.04	$0.002	$0.002	$0.00	$0.04	$0.22	$0.01	$0.002	$0.004	$0.09	$0.37	$0.00	$0.37
Improvements to Wellman Canal	$0.04	$0.002	$0.002	$0.00	$0.05	$0.00	$0.01	$0.002	$0.005	$0.02	$0.08	$0.08	$0.16
Arapahoe Avenue Detention Pond	$3.87	$0.19	$0.19	$0.14	$4.39	$3.37	$0.66	$0.22	$0.44	$2.72	$11.80	$0.10	$11.90
Total	**$19.47**	**$0.97**	**$0.97**	**$0.69**	**$22.12**	**$5.91**	**$2.41**	**$1.10**	**$2.22**	**$9.48**	**$44.17**	**$1.00**	**$45.42**

Implementation Strategies

Implementation of the Refined Recommended Plan will require the resolution of some issues that were outside the scope of the current Mitigation Planning Study. The study team believes these issues are not insurmountable and did not impose any fatal flaws on the Recommended Plan. Continued coordination with CU, CDOT and OSMP and the Colorado State Engineers Office (SEO) on the layout of the facilities associated with the US-36 Detention would be required. The proposed layout reflects discussions with these entities but further refinement and design to optimize the use of the area while minimizing impacts from the berm but additional feedback and input from affected stakeholders would be required. In addition, the Colorado State Engineers Office will need to be consulted as a stakeholder moving forward to ensure the proposed detention facility meets State Standards for detention.

Phasing of the elements of the Refined Recommended Plan provides an opportunity to distribute the cost of implementation over a longer time and allows the community to reap benefits from the individual aspects of the improvements without full plan implementation. The elements of the Recommended Plan do allow for a phased implementation. The discussion below summarizes the recommended phasing of the proposed project.

Priority 1 – US-36 detention:

The US-36 Detention with the earthen berm within CDOT's Phase 1 ROW (Option D) is the recommended first element to be constructed. This project element fulfils on of the project's main goals, eliminating the overtopping of US-36 during a major storm event. In doing so, the flood insurance burden associated with the South Boulder Creek 100-year flood for those properties in the West Valley would be eliminated and the flood threat reduced to locally generated runoff flooding. A total of 411 structures (1,721 dwelling units) would no longer be located within the 100-year floodplain if this phase were implemented. The proposed US-36 Detention facility has an element benefit-cost ratio of approximately 1.18 and an approximate capital cost of $22.5 million.

Priority 2 – Local West Valley Improvements

The proposed improvements in the West Valley address a number of different flood related issues and are comprised of several smaller elements including:

- Local detention at Manhattan Middle School (or an adjacent feasible location),
- Dry Creek No. 2 Ditch improvements,
- Local detention at Baseline Road and Foothills Parkway,
- Floodwall improvements along Baseline Road,
- Improvements to the New Anderson Ditch, and
- Improvements to the Wellman Canal.

Implementation of these elements should generally follow broad drainage facility implementation guidance. That is, detention should be implemented early in the process to fully exploit the flow reduction realized through these facilities. Then the flood control measures such as the pipeline improvements along Dry Creek No. 2 Ditch and along Baseline Road should be implemented to provide adequate conveyance of the remaining flows. The improvements to the other irrigation ditches are intended to prevent overflows and contain those flows in the original system. These can often be done independently of any other improvements and can be implemented as need or opportunities arise. In aggregate, these improvements are expected to cost $11.0 million to implement and result in a benefit-cost ratio of 3.2. A total of 134 structures (386 dwelling units) would no longer be located within the 100-year floodplain if this phase were implemented.

Priority 3 – Arapahoe Avenue Detention

The Arapahoe Avenue detention pond and associated downstream improvements provide considerable flood relief to those properties below Arapahoe Avenue however; the floodplain reduction associated with these improvements is

relatively localized (42 structures and 6 dwelling units) making this the last of the suggested implementation priorities. The improvements are estimated to cost $11.9 million and will result in a benefit-cost ratio of 1.3.

It should be noted, however, that the proposed priority phasing for II and III elements may be revised based on the Community Results from the Community Environmental Assessment Process that would need to be completed prior to preliminary design. Figures 10.6 – 10.8 present the recommended phasing and associated residual floodplain limits.

Water Quality Impacts

In general terms, detention pond storage will have beneficial water quality impacts by providing an opportunity for pollutant carrying sediments to drop out of suspension. These improvements are likely to be realized by the inclusion of stormwater quality outlet facilities in the design of the ponds. While not explicitly addressed during this planning level, these improvements are part of local community regulations and are implicit in any proposed plans.

Any other improvements that capture and collect stormwater before they reach areas of potential contamination are also likely to have a beneficial water quality impact. Such is the case for improvements that reduce the floodplain that in turn reduces the potential for deposition of sediment and debris and exposure of hazardous materials to flood flows.

The mitigation of impacts to wetlands and other environmentally sensitive areas at a ratio in excess of one to one will have a beneficial impact on water quality. These mitigation areas will promote infiltration and filtration of floodwaters and will store and attenuate flood flows while helping to expand and reestablish wetlands throughout the corridor. All these functions tend to reduce the generation and transport of contaminants.

The Recommended Plan incorporates by reference all of the existing city programs that support the enhancement of stormwater quality. These include the various elements required by the city's NPDES Stormwater Discharge Permit. These measures assure control of erosion from construction sites, provide public education, outreach programs, and address other sources of pollution that may enter stormwater.

Operations and Maintenance

All of the facilities proposed in the Recommended Plan are intended to be passive and will not require manual operation during flood events. All control structures, spillways, inlets and outlets function without any external user control. Operations during a flood will be limited to observations and inspections to monitor system performance. In general, the facilities presented in the recommended alternative have been laid out so that permanent access is included to facilitate operations and maintenance. These access paths are typically located above the level of frequent flooding but may not be useable during periods of extreme flooding. This is not the case with the detention pond embankments, each of which has some access, generally from an adjacent roadway or bike trail that can be used for access during extreme events. In the case of the US-36 flood control facility, access can be provided via the trail and top of berm. However, as design progresses forward, access to the toe of the berm will need to be negotiated with OSMP and CU South Campus.

All of the facilities will require routine maintenance to assure correct performance and longevity. For earthen embankments and open channels, this means periodic inspections, routine mowing of grasses, weed control, removal of trees and shrubs, and debris pickup. By performing this maintenance, conformance with design assumptions can be expected. It is expected that a majority of the facilities will be re-vegetated with native grasses not requiring supplemental irrigation.

Underground facilities like pipelines and culverts are generally designed with an expected service life in excess of 50-years. However, periodic inspections are necessary to confirm that there is no damage to the facilities and that debris or sediment has not been deposited that might affect hydraulic capacity.

Surface facilities such as curb opening inlets require more frequent cleaning and debris clearing so that their full capacity remains consistent with the design assumptions. Some debris clogging has been incorporated into the hydraulic assumptions in accordance with the city's drainage guidelines. A schedule of routine maintenance should be developed and enforced to assure correct function of these important hydraulic features.

An operations and maintenance plan would likely be required for areas designated as compensatory environmental mitigation. Newly constructed wetlands for compensatory mitigation requires monitoring to assure that facilities actually establish and are sustainable.

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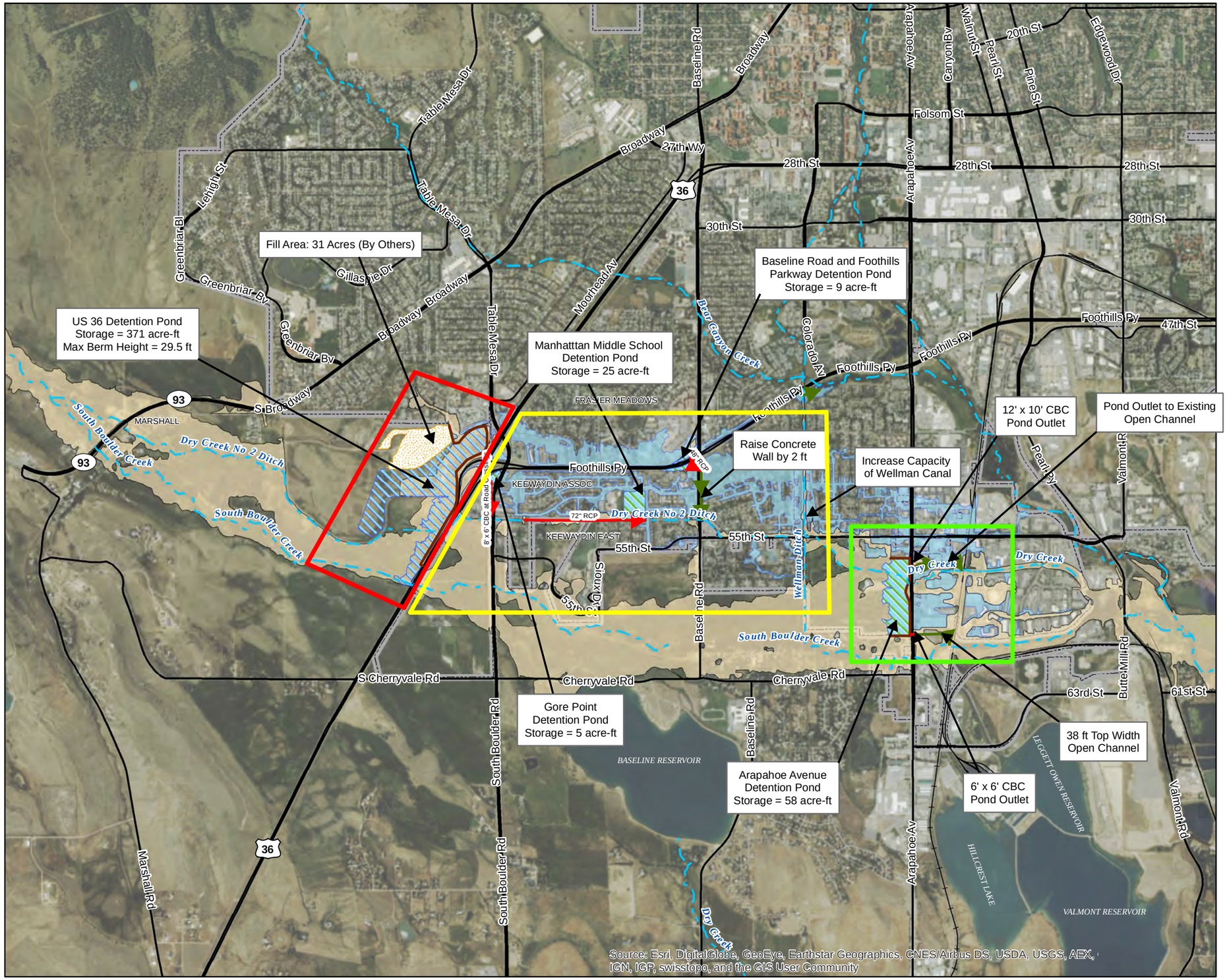
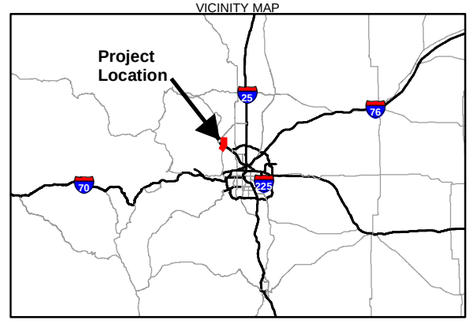


VICINITY MAP



LEGEND

Conveyance Alignment

Category

- Open Channel Improvement
- Pipeline/Culvert Improvement
- US-36_Embankment
- Area of Fill (By Others)
- Streams, Creeks and Ditches
- Detention at US-36
- Local Detention
- Post Project Floodplain
- Existing Floodplain

Notes:

1. Phase 1 Improvements
   US-36 Detention
   B/C Ratio = 1.2
2. Phase 2 Improvements
   West Valley Improvements
   B/C Ratio = 3.2
3. Phase 3 Improvements
   Arapahoe Avenue Detention
   B/C Ratio = 1.3

N

0 1,000 2,000 3,000 4,000
Feet

FIGURE 10-1
Regional Detention at US-36
Recommended Alternative
South Boulder Creek Flood Mitigation Report

Stormwater Detention Upstream of US36

South Boulder Creek Flood Mitigation Project

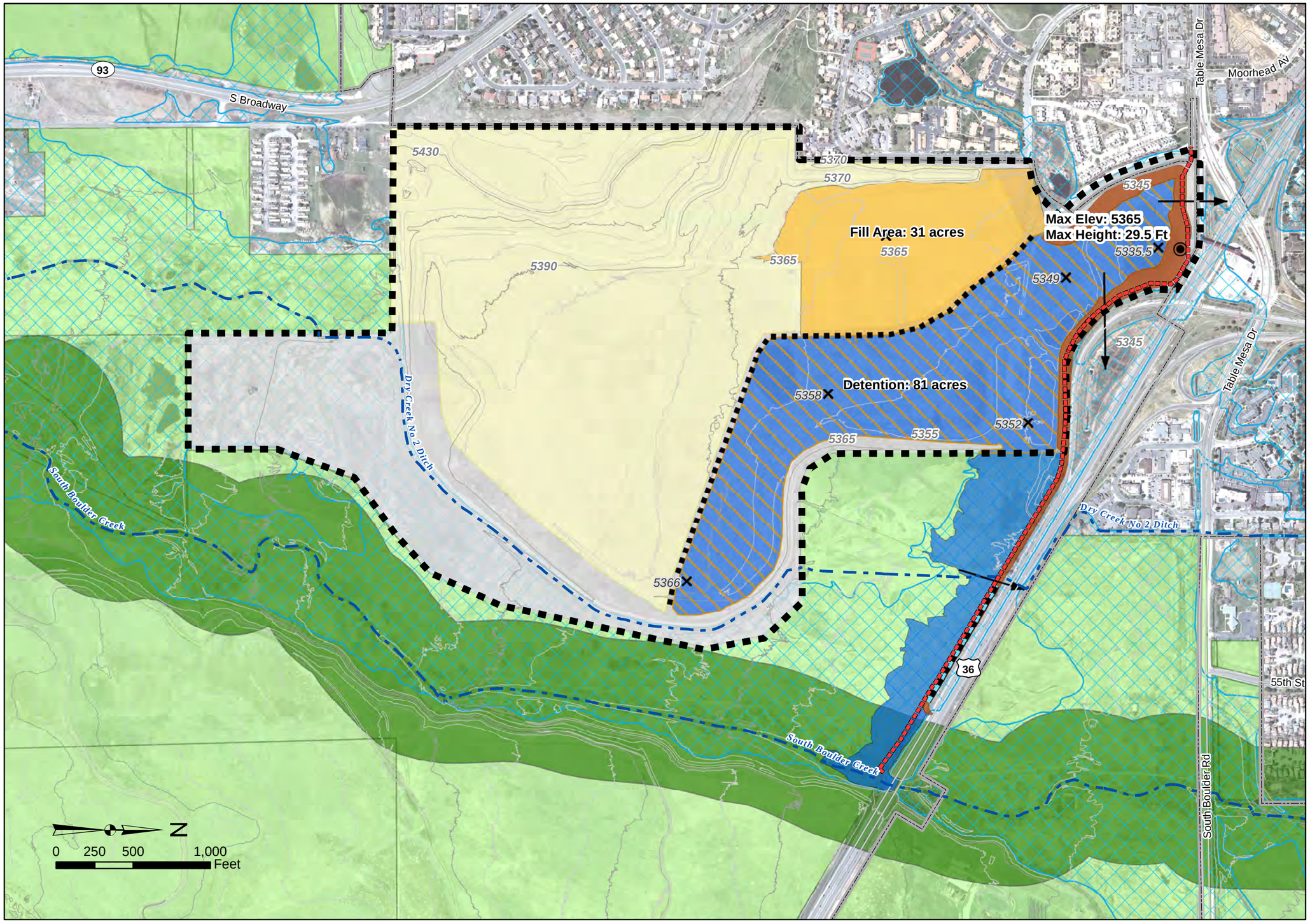


Figure 10-2

Option D

Single Berm
With excavation
With fill
On CU and OSMP property
In CDOT Existing ROW
Max Berm Height 29.5ft

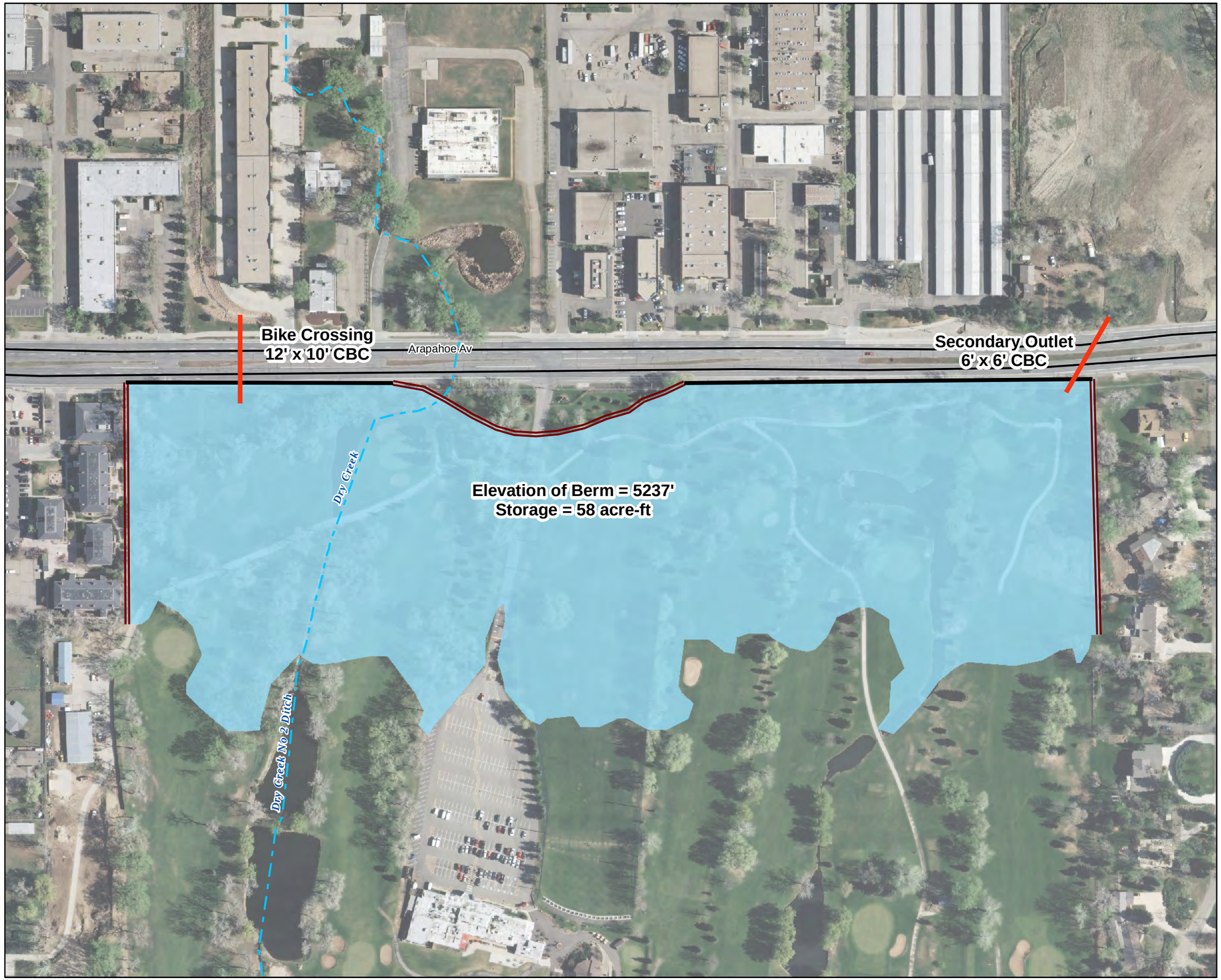
Description	Acres
Total CU Property	302
CU Property Impacted	78
CU Building Potential Impacted	30
OSMP Property Impacted	19

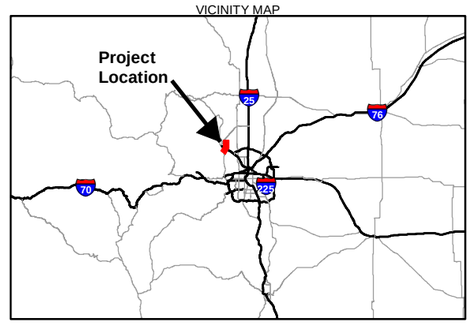
Proposed Conditions

- New Berm
- Pool Contained By Fill or Cut Slope
- Limits of Excavation
- Detention Pond Area
- Fill Area
- Out of 100yr Inundation
- Spot Elevation
- Max Berm Elevation
- Discharge Location
- Spillway

Existing Conditions

- Boulder City Limits
- CDOT Existing ROW
- CU Site Boundary
- OSMP Property
- Prebles Critical Habitat Area
- Effective 100 Year Floodplain
- 5 Foot Contours
- 10 Foot Contours





LEGEND

- Detention Pond Limits
- Culvert Outlet
- Berm
- Wall
- Streams, Creeks and Ditches

N

0 100 200 400 Feet

FIGURE 10-3
Arapahoe Avenue Detention
South Boulder Creek Flood Mitigation Report

\\gecko\wbg\400168_South_Boulder_Creek_Phase_A\08_GIS\MapFiles\Report\Chapter 9\Figure 9-3 Arapahoe Avenue Detention.mxd

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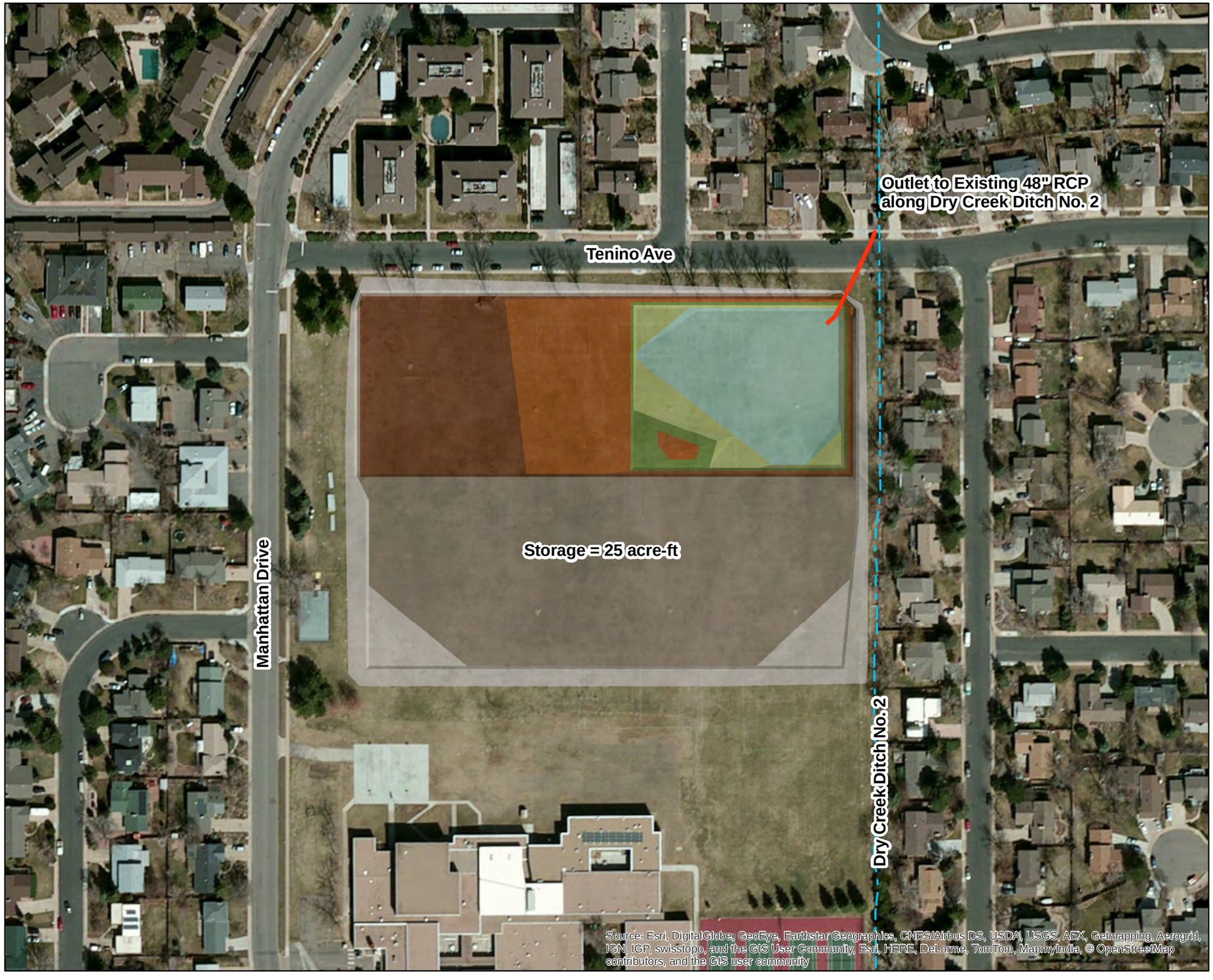
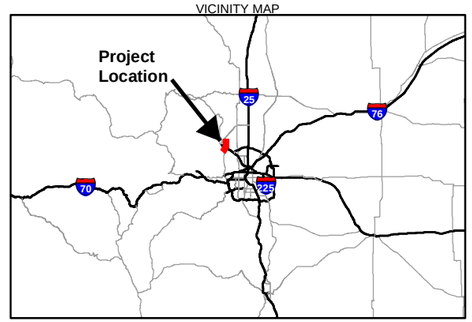




LEGEND

Depth (ft)

- 6 - 7
- 5 - 6
- 4 - 5
- 3 - 4
- 2 - 3
- 1 - 2
- 0 - 1

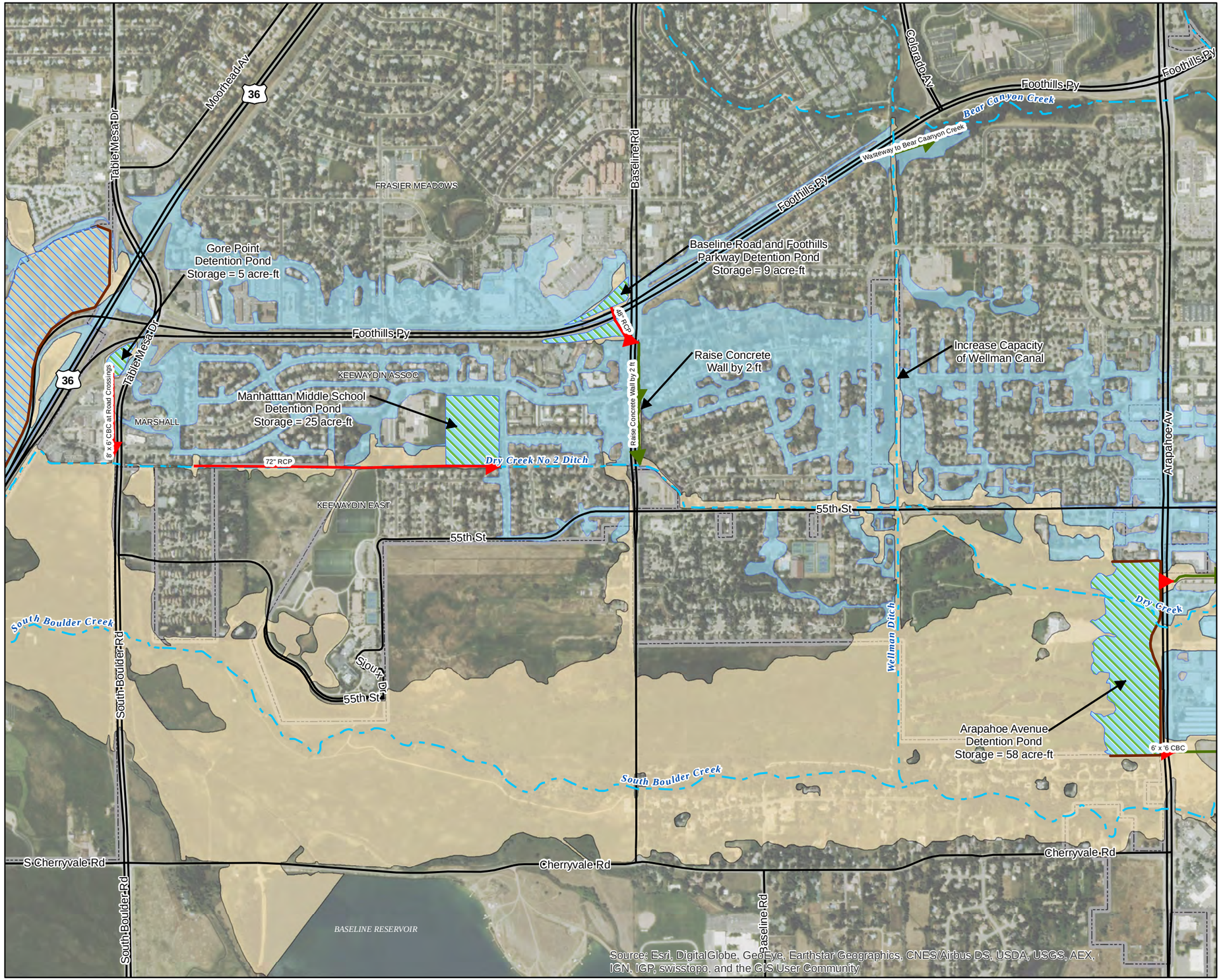
Pond Outlet

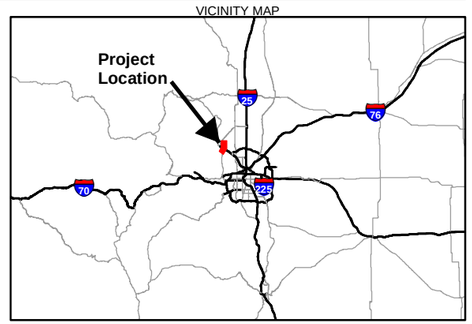
Streams, Creeks and Ditches

N

0 50 100 200 300 Feet

FIGURE 10-4
Manhattan Middle School Detention
South Boulder Creek Flood Mitigation Report





LEGEND

Conveyance Alignment

Category

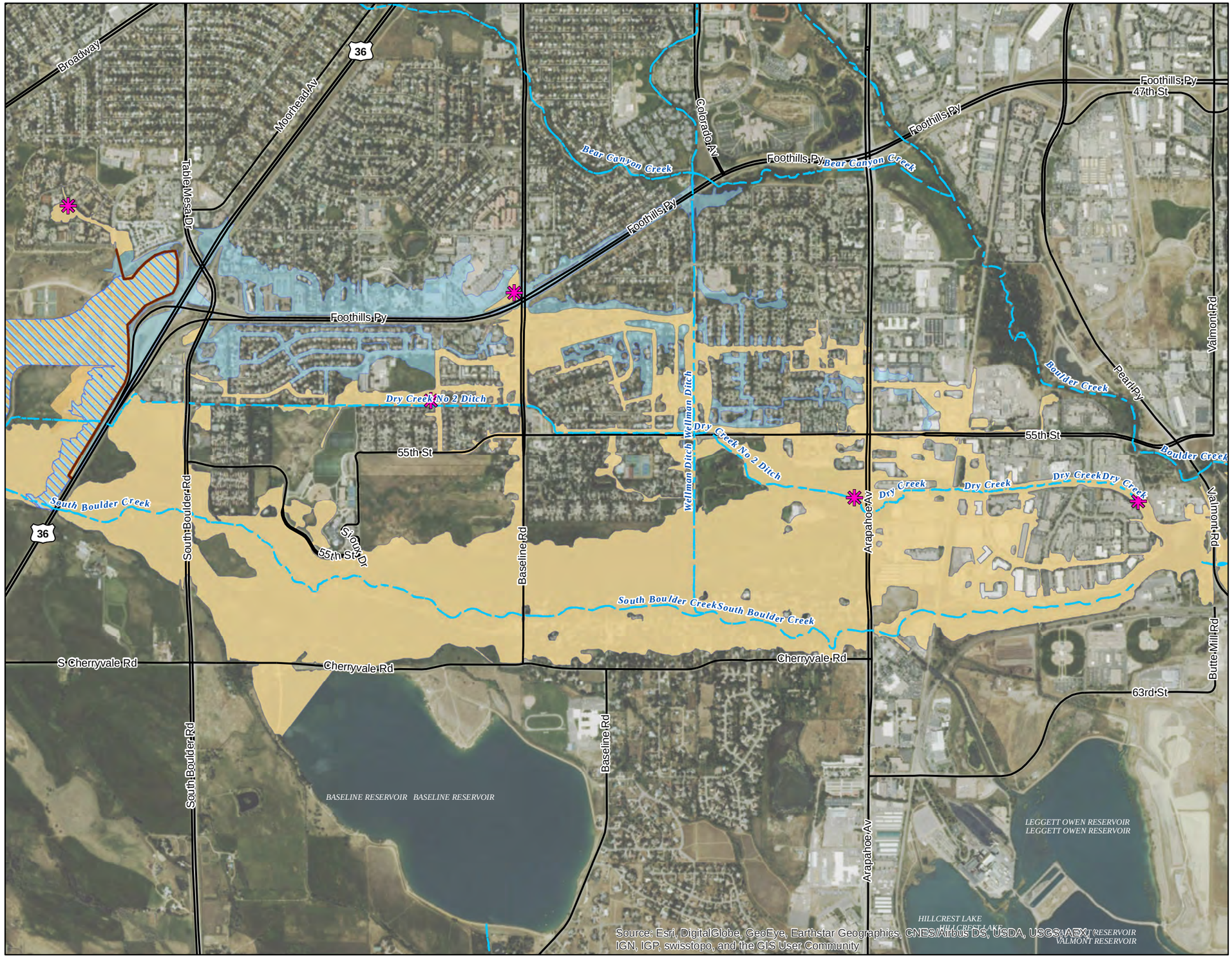
- Open Channel Improvement
- Pipeline/Culvert Improvement
- Embankment
- Streams, Creeks and Ditches
- Detention at US 36
- Local Detention
- Post Project Floodplain
- Existing Floodplain

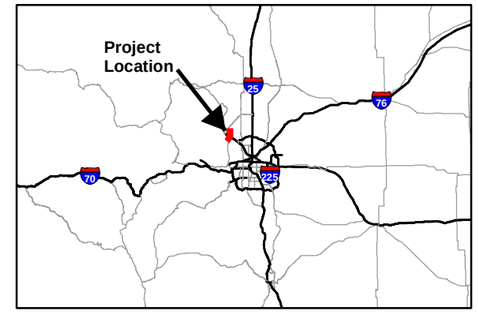
N

0 500 1,000 1,500 2,000

Feet

FIGURE 10-5
West Valley Improvements
South Boulder Creek Flood Mitigation Report





LEGEND

- C2 Basin Hydrologic Loading Points
- Streams, Creeks and Ditches
- Main Road
- Area of Fill (By Others)
- Streams, Creeks and Ditches
- LAKES
- US-36_Embankment
- Detention at US-36
- Post Project Condtions Floodplain
- Existing Floodplain (Regulatory Zone AE)

N

0 380 760 1,520 2,280 3,040 Feet

Figure 10-6
Priority 1 Improvments, US-36 Alternative D Stormwater Detention Facility With Residual Floodplain
South Boulder Creek Flood Mitigation Project

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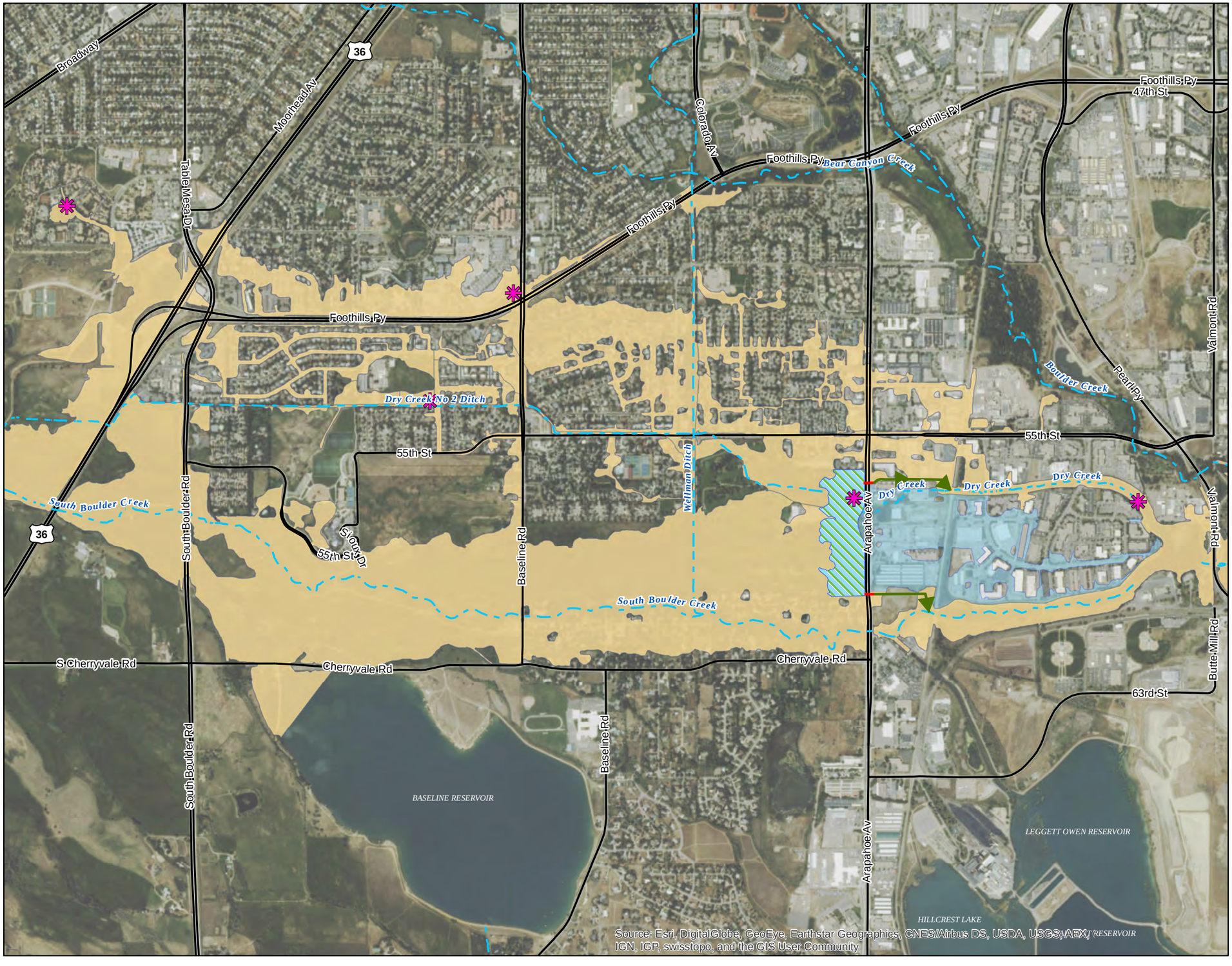
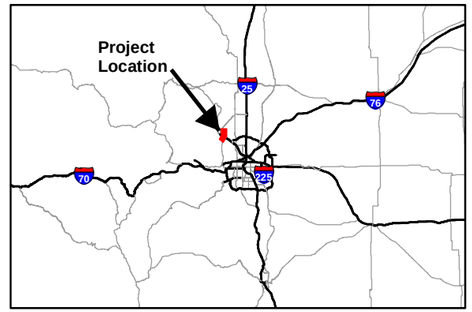




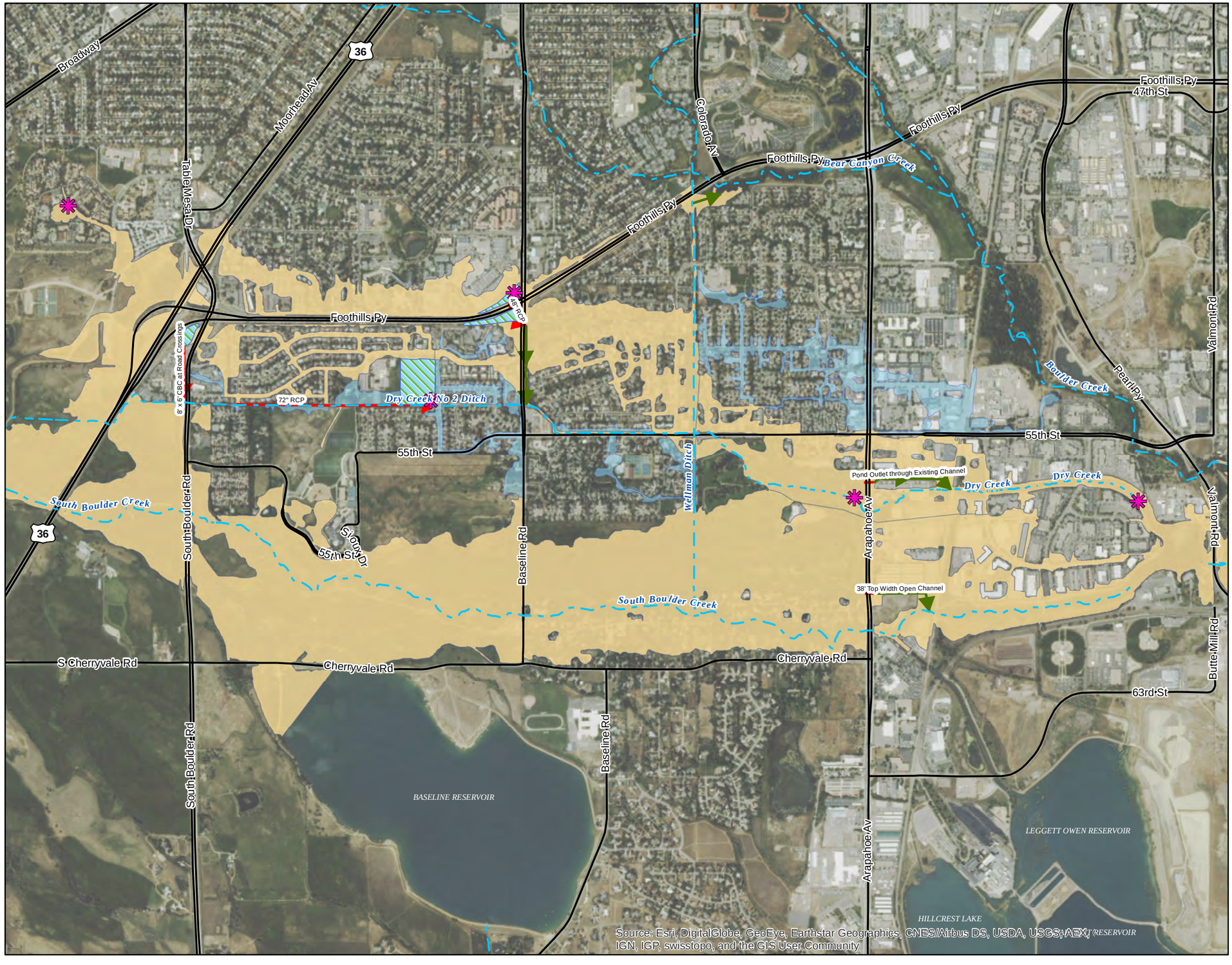
LEGEND

- C2 Basin Hydrologic Loading Points
- Open Channel Improvement
- Pipeline/Culvert Improvement
- Arapahoe Avenue Detention Facility
- Streams, Creeks and Ditches
- Main Road
- Post Project Condtions Floodplain
- Existing Floodplain (Regulatory Zone AE)

N

0 380 760 1,520 2,280 3,040 Feet

Figure 10-7
Priority 2 Improvements, Arapahoe Avenue Detention Facility with Residual Floodplain
South Boulder Creek Flood Mitigation Report



LEGEND

- C2 Basin Hydrologic Loading Points
- Streams, Creeks and Ditches
- Main Road
- Engineers Recommended Phase 2 Detention

Engineers Recommended Conveyance Improvements

- Open Channel Improvement
- Pipeline/Culvert Improvement
- Post Project Condtions Floodplain
- Existing Floodplain (Regulatory Zone AE)

N

0 380 760 1,520 2,280 3,040 Feet

Figure 10-8
Priority 3 Improvments, West Valley Imrpovments with Residual Floodplain
South Boulder Creek Flood Mitigation Report

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