GEOTECHNICAL AND
WATER RESOURCES ENGINEERING

CONCEPT DESIGN REPORT

SOUTH BOULDER CREEK REGIONAL DETENTION PROJECT

BOULDER COUNTY, COLORADO

Submitted to

City of Boulder
1777 Broadway
Boulder, Colorado 80301

Submitted by

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Project 16134

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Graphs

Appendices

List of Abbreviations

Abbreviation	**Term**
Ac-Ft	Acre-Feet
BCS	Base Construction Subtotal
BVCP	Boulder Valley Comprehensive Plan
CDOT	Colorado Department of Transportation
City	City of Boulder
CLOMR	Conditional Letter of Map Revision
CORVUS	CORVUS Environmental Consulting, LLC
CU	University of Colorado
CWA	Clean Water Act
DCS	Direct Construction Subtotal
DHI	DHI Water and Environment, Inc.

Abbreviation	Term
El.	Elevation
EM100	100-Year Effective Model
EM500	500-Year Effective Model
ESA	Endangered Species Act
EPA	Environmental Protection Agency
ERO	ERO Resources
FEMA	Federal Emergency Management Agency
Flatirons	Flatirons, Inc.
HDR	HDR, Inc.
HMR	Hydrometeorological Report
H:V	Horizontal to Vertical
IDF	Inflow Design Flood
LEDPA	Least Environmentally Damaging Practicable Alternative
LOMR	Letter of Map Revision
MHFD	Mile High Flood District
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OPPC	Opinion of Probable Project Cost
OSBT	Open Space Board of Trustees
OSMP	Open Space and Mountain Parks
OS-O	Open Space – Other
PK-U/O	Park, Urban, and Other
PMJM	Preble's meadow jumping mouse
PMP	Probable Maximum Precipitation
Project	South Boulder Creek Regional Detention
PUB	Public
PVC	Polyvinyl chloride
RCBC	Reinforced Concrete Box Culverts
RCP	Reinforced Concrete Pipes
Report	Concept Design Report
RJH	RJH Consultants, Inc.
ROW	Right-of-Way
Rules and Regulations	Rules and Regulations for Dam Safety and Dam Construction
SBC	South Boulder Creek
SEO	Colorado Office of the State Engineer
T&E	Threatened and Endangered
ULTO	Ute-ladies'-tresses orchid

Abbreviation	Term
US36	U.S. Highway 36
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
V1-500	Variant 1, 500-Year
WOTUS	Waters of the United States
WRAB	Water Resources Advisory Board
WSE	Water Surface Elevation

SECTION 1 – INTRODUCTION

1.1 Purpose and Objectives

RJH Consultants, Inc. (RJH) was retained by the City of Boulder (City) and Mile High Flood District (MHFD) to provide engineering services for the South Boulder Creek (SBC) Regional Detention (Project). The initial phase of work for the Project consists of developing concept-level alternatives to facilitate the City's selection of a preferred alternative to advance into preliminary design.

The primary objectives of the concept design include:

- Develop approximate sizes and general layouts for possible alternatives.
- Identify potential environmental permitting issues that could impact selection of a preferred alternative.
- Identify concept selection criteria.
- Populate concept selection criteria for each alternative.
- Develop a cost opinion suitable to compare alternative costs.

The purpose of this Concept Design Report (Report) is to present the methodology, results, and conclusions of the concept design. The concept design presented in this Report is based on engineering judgment, our previous experience on similar projects, hydrologic and hydraulic modeling, our current understanding of subsurface and groundwater conditions based on initial site investigations, and limited engineering analyses of Project components. The information in this Report is expected to be refined and modified during the preliminary design phase.

1.2 Background

Over the past 80 years, SBC has flooded significantly six times. SBC has limited channel capacity upstream of U.S. Highway 36 (US36), and US36 overtops during large storm events. Overtopping stormwater flows north and west to a low point on the University of Colorado's (CU) Boulder South campus parcel near US36 and Table Mesa Drive. In sufficiently large flood events, stormwater overtops US36 and floods extensively through a portion of the City known as the West Valley that includes portions of the Frasier Meadows, Keewaydin Meadows, and East Boulder neighborhoods. SBC flooded in 1938, 1950, 1969, and 2013.

The City initiated a floodplain remapping study in 2003 that formally recognized flood risks from the overtopping of US36. This study was adopted by the City in 2008 and accepted by the Federal Emergency Management Agency (FEMA) in 2010. Following the floodplain remapping study, the City partnered with MHFD in 2009 to initiate a flood mitigation master plan to identify options to mitigate flooding from SBC. The plan recommended improvements in three phases:

1. Regional stormwater detention at US36.
2. Improvements in the West Valley.
3. Stormwater detention at Flatirons Golf Course.

Six planning-level layouts were developed for the regional stormwater detention facility at US36. The preferred layout (Option D) included an earthen embankment along the north portion of the CU Boulder South campus, a floodwall in the Colorado Department of Transportation (CDOT) right-of-way (ROW), and fill and excavation on the CU Boulder South campus. The SBC Flood Mitigation Master Plan was accepted by City Council in 2015.

Following the 2015 Master Plan and acceptance of the Option D concept, the CU Boulder South campus' potential future was extensively and publicly discussed as part of the 2015 Boulder Valley Comprehensive Plan (BVCP) update (City of Boulder and Boulder County, 2017). Acceptance of the BVCP update in July 2017 changed the land use designations for approximately 80 acres of the CU Boulder South campus to facilitate construction of the regional stormwater detention facility at US36. The BVCP CU Boulder South Guiding Principles also provided direction to consider mitigating flood risk to the highest practicable standard while balancing environmental, social, and financial impacts.

The City and MHFD retained RJH to provide engineering services for conceptual and preliminary design of the regional stormwater detention facility at US36 (Phase I). The City requested that RJH refine the preferred Master Plan alternative (Option D) to accommodate considerations from the BVCP update and evaluate additional concepts that could reasonably be implemented in the vicinity of the US36 regional detention facility site to reduce the risk for overtopping of US36 during a major flood event while also addressing other parameters established during the master planning process.

1.3 Scope of Services

RJH performed the following services for the concept design phase of the Project:

1. Managed and coordinated the work performed by RJH and our subconsultants.
2. Prepared invoices and a monthly written progress report.
3. Collected, reviewed, and evaluated previous reports developed by others.
4. Performed topographic surveying, and identified property boundaries and easement limits.
5. Developed a base map for use in design.
6. Performed subsurface investigations to begin collecting baseline groundwater data and improve our understanding of general subsurface conditions.
7. Performed hydrologic analyses to develop the Inflow Design Flood (IDF) hydrograph in accordance with Colorado Office of the State Engineer (SEO) *Rules and Regulations for Dam Safety and Dam Construction* (SEO, 2007) (Rules and Regulations).
8. Modified the effective FEMA regulatory model using the MIKE FLOOD program to incorporate the detention facility at US36 and performed flood routing to support sizing of Project facilities.
9. Developed and evaluated concept-level layouts for Project configurations for the proposed detention facility.
10. Performed wetlands mapping and concept-level evaluations on impacts to open water and threatened and endangered (T&E) species habitat.
11. Developed quantity estimates for primary materials required to construct the Project components.
12. Prepared an ASTM E 2516-11 Class 4 (i.e., high-level, non-budgetary) opinion of probable project cost (OPPC) for each alternative.
13. Prepared concept-level figures to illustrate the Project configurations.
14. Conducted Phase I geotechnical investigations.
15. Supported and participated in City public meetings related to the Project.

1.4 Project Personnel

The work described in this Report was completed by RJH as the prime consultant with assistance from the following subconsultants (collectively referred to as the RJH Team):

Hydraulic Modeling:	DHI Water and Environment, Inc. (DHI)
Environmental Permitting:	CORVUS Environmental Consulting, LLC (CORVUS)

Surveying:	Flatirons, Inc. (Flatirons)

The following RJH team personnel are responsible for the work contained in this Report:

Project Manager:	Robert Huzjak, P.E. (RJH)
Project Engineer:	Eric Hahn, P.E. (RJH)
Lead Geotechnical Engineer:	Adam Prochaska, Ph.D., P.E., P.G.(1) (RJH)
Lead Hydraulic Modeler:	Ian Dubinski, Ph.D. (DHI)
Lead Environmental Scientist:	Timothy DeMasters (CORVUS)
Staff Engineers:	Jacquelyn Hagbery, P.G.(1), E.I. (RJH)
	Samantha Guillies, E.I. (RJH)
Technical Advisor:	Stephen Blake, P.E. (DHI)

Note 1: Licensed in states other than Colorado.

The work described in this Report was overseen and coordinated by the City and MHFD. The City and MHFD team include the following personnel:

City Project Manager:	Brandon Coleman, P.E.
Project Advisor:	Douglas Sullivan, P.E.
Dam Safety Advisor:	Kevin Clark, P.E.
MHFD Advisor:	James Watt, P.E.
Director of Public Works	Joseph Taddeucci, P.E.

SECTION 2 – EXISTING CONDITIONS

2.1 General

The RJH Team reviewed existing data and performed site reconnaissance to better understand and define the existing site conditions. Existing land uses, constraints, and site conditions are expected to have a significant impact on development of the Project.

The Project site is located in southeast Boulder County, Colorado, adjacent to City limits. The Project site is generally located south of US36, west of SBC, and east of several residential communities. Property owners include CU, Open Space and Mountain Parks (OSMP), and CDOT. A site vicinity map is presented on Figure 2.1 and a site plan is presented on Figure 2.2.

2.2 University of Colorado Boulder South Campus

The CU Boulder South campus is a 308-acre property located south of US36, east of several residential communities, and west of OSMP property. The CU Boulder South campus currently includes a tennis complex, a maintenance building with an asphalt parking lot, and a series of pedestrian trails. The pedestrian trails experience significant use from the public throughout the year. The tennis complex is used seasonally by the CU athletic department.

A plan of CU Boulder South campus and BVCP land use designations is presented on Figure 2.3.

Gravel mining operations were performed on the CU Boulder South campus property before it was acquired by CU. The gravel mining created a large excavation that is about 10 to 15 feet below the original ground surface. Gravel mining operations also created a series of below-grade ponds that fill with groundwater. Water levels in these ponds fluctuate with groundwater levels.

An earthen levee extends along the south and east boundaries of the CU Boulder South campus. The levee is approximately 7,500 feet long and varies in height with a maximum height of about 14 feet. The levee was constructed in 1980 and consists primarily of clayey sand materials. The levee was raised in 1998 and certified by FEMA in 2000. The levee was raised again in 2009 based on updated hydraulic modeling and subsequently recertified by FEMA (Leonard Rice, 2009). A pedestrian trail extends along the crest of the levee. The dry-side slope is covered with grasses and other vegetation. The wet-side slope is covered by riprap slope protection. Dry Creek Ditch No. 2 extends along the upstream toe of the levee. A drainage channel extends along the dry-side of the levee. This channel was constructed to collect surface water runoff from behind the levee and convey the runoff to an outfall at Viele Channel.

Viele Channel extends through the northwest portion of the CU Boulder South campus. Viele Channel is tributary to SBC and has a basin area of approximately 1 square mile upstream of the CU Boulder South campus. A majority of the Viele Channel watershed consists of residential land use. Flow in Viele Channel is conveyed beneath the US36 east-bound on-ramp through three 72-inch diameter culverts and subsequently beneath US36 through three 60-inch diameter culverts.

South Loop Drive is the primary means of vehicle access to the CU Boulder South campus. South Loop Drive is a 24-foot-wide, paved road that extends from Table Mesa Drive to the existing CU maintenance building and gravel parking lot. South Loop Drive is owned and maintained by CU.

As part of the 2017 update to the BVCP, the land use designations for the CU Boulder South campus were amended to provide the following designations:

- **Open Space – Other (OS-O):** This area generally corresponds with the regulatory 500-year floodplain on the east portion of the CU Boulder South campus (approximately 119 acres). The intent of this land is that it would be maintained primarily as open space for floodplain functionality, recreation, and ecological benefits.
- **Public (PUB):** This area is located on the west portion of the CU Boulder South campus (approximately 129 acres). This land will be developed in the future as part of development of the CU Boulder South campus.
- **Park, Urban, and Other (PK-U/O):** This area is located on the north portion of the CU Boulder South campus (approximately 65 acres) and generally corresponds with Option D presented in the 2015 Master Plan. This land has been designated for flood mitigation facilities and allows for active and passive recreational uses.

2.3 Open Space and Mountain Parks Property

OSMP property is located on both sides of US36, west of SBC, and east of the CU Boulder South campus. The OSMP property contains extensive wetlands and federally listed T&E species habitat for the Preble's meadow jumping mouse (PMJM) and Ute-ladies'-tresses orchid (ULTO).

Viele Channel extends through the west edge of OSMP property, north of US36. In this reach, Viele Channel consists of a trapezoidal channel with thick vegetation. Numerous other ditches and small drainage channels extend through the OSMP property, including Dry Creek Ditch No. 2. A gravel pedestrian trail extends north-south through the property and experiences significant use from the public. The property is also used for cattle grazing seasonally and portions are irrigated for hay production.

2.4 Colorado Department of Transportation Right-of-Way

The CDOT Right-of-Way (ROW) extends parallel to and on both sides of US36. Along the south ROW, a small drainage ditch is located in the ROW along the shoulder of the road. The drainage ditch collects surface water runoff from east-bound lanes on US36. A concrete multi-use trail is also located in the south ROW. The multi-use trail experiences significant use from the public. Additionally, multiple buried utilities are located throughout the ROW.

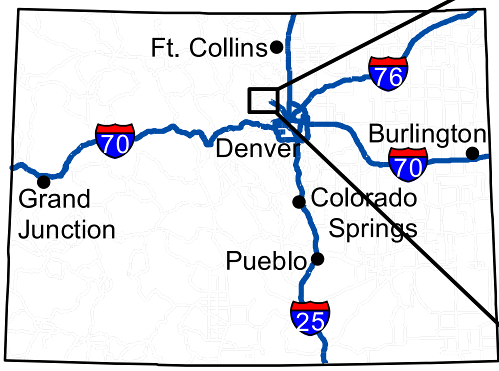
A series of culverts extend from the CDOT ROW beneath US36. These include dual 4-foot by 10-foot reinforced concrete box culverts (RCBC) that function as a wildlife crossing, a 4-foot by 6-foot RCBC to convey Dry Creek Ditch No. 2 flows, three 60-inch-diameter reinforced concrete pipes (RCP) to convey Viele Channel flows, and multiple smaller RCPs for site drainage.

SBC extends beneath US36 through a multi-span bridge. The bridge was widened in 2014 as part of the US36 widening project. The bridge has three spans that total approximately 115 feet with a row of concrete bridge piers on each creek bank about 47 feet apart. The concrete multi-use trail extends below the bridge to the west of SBC. A plan of facilities along the US36 ROW is presented on Figure 2.4.

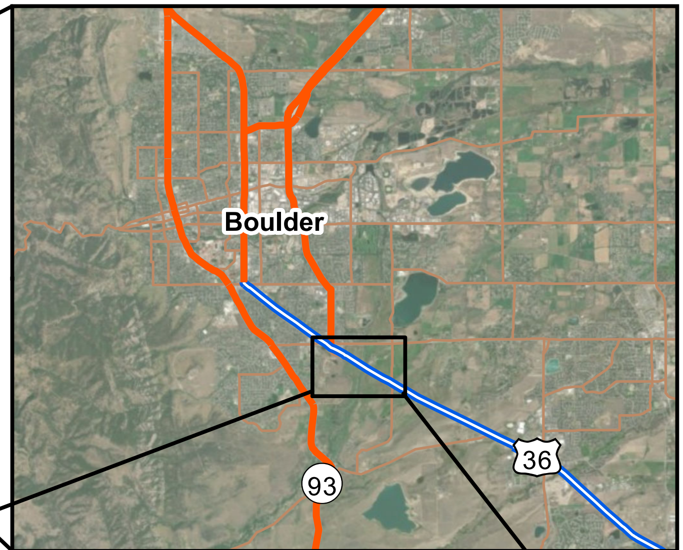
2.5 South Boulder Creek

SBC is a major drainageway that extends from its headwaters in the mountains through Eldorado Canyon and subsequently southeast of the City before discharging to Boulder Creek. The SBC watershed encompasses approximately 136 square miles. Gross Reservoir is located on SBC upstream of Eldorado Canyon and is a water supply reservoir owned and operated by Denver Water. No reservoir volume is allocated for flood control in Gross Reservoir, but the reservoir provides significant temporary flood storage above the spillway crest. Approximately 90 square miles of the SBC watershed is located upstream of Gross Reservoir.

SBC has limited channel capacity through the Project site and overflows the main channel during large storm events. The US36 embankment directs overflowing flood waters north and west to a low point located at the northwest corner of the CU Boulder South campus near US36 and Table Mesa Drive. Flood waters pond in this area before overtopping US36 and flooding extensively through a portion of the City known as the West Valley. The West Valley generally follows the alignment of Foothills Parkway and consists of a mixture of residential and commercial structures. Flooding of the West Valley occurred in 1969 and 2013. The 2013 flood event on SBC was estimated to be between about a 75- to 100-year event (Wright Water Engineers, 2014).



PROJECT VICINITY MAP
(NOT TO SCALE)



PROJECT LOCATION MAP
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SITE LOCATION MAP
(NOT TO SCALE)

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	SITE VICINITY MAP	
	PROJECT NO. 16134	February 2020	**Figure 2.1**

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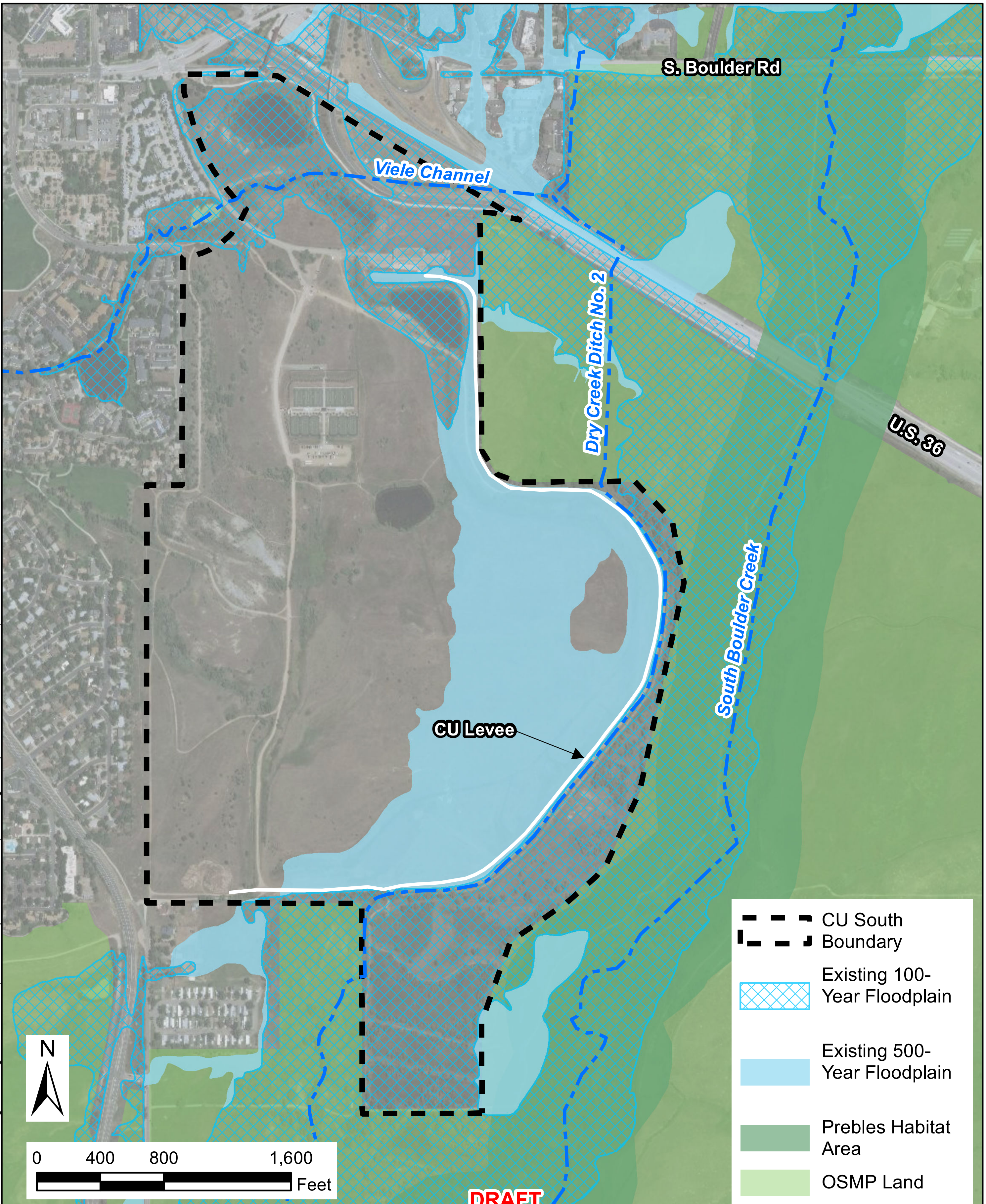

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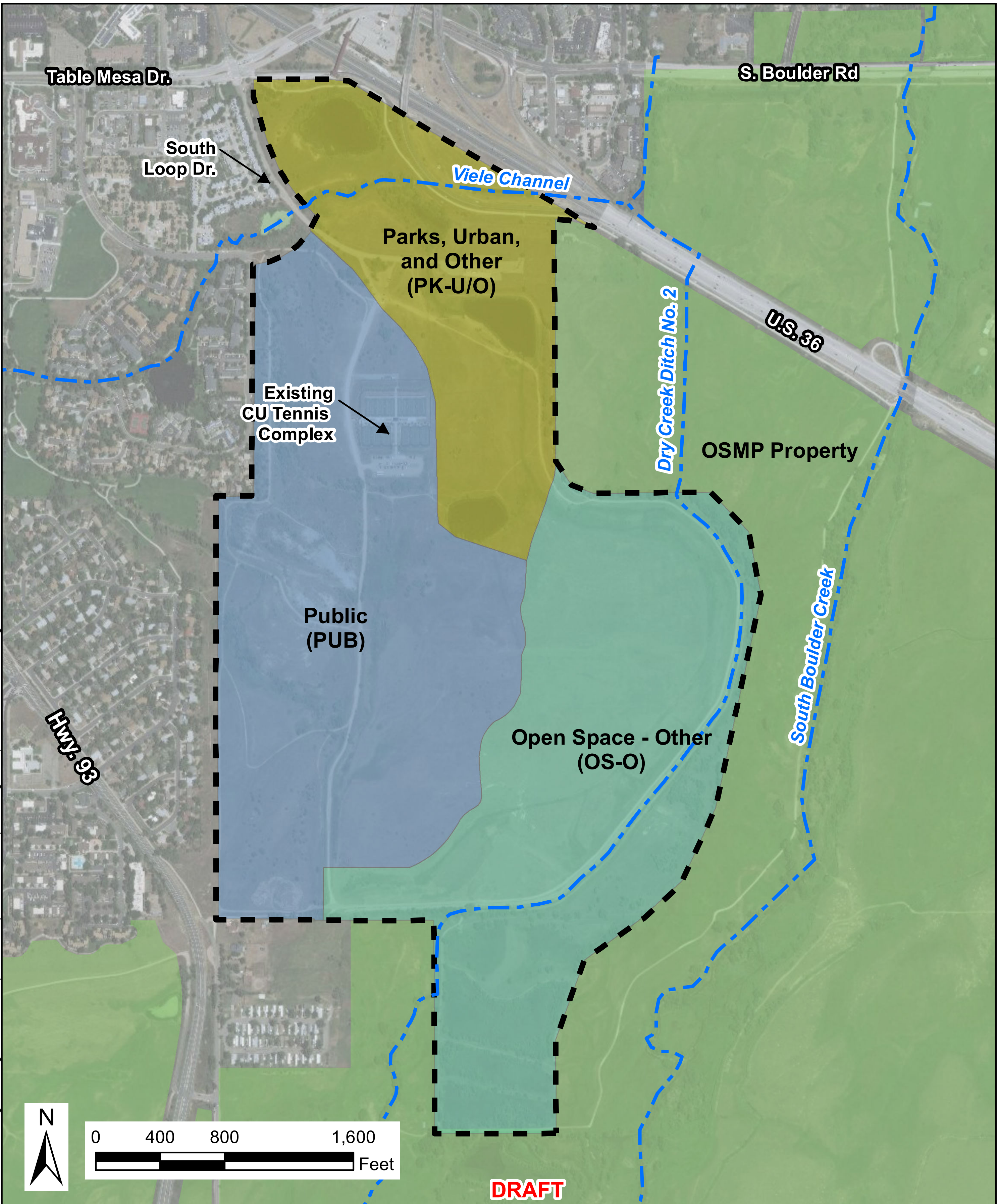
REPRODUCE IN COLOR	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	EXISTING CONDITIONS SITE PLAN
		PROJECT NO. 16134	February 2020 **Figure 2.2**



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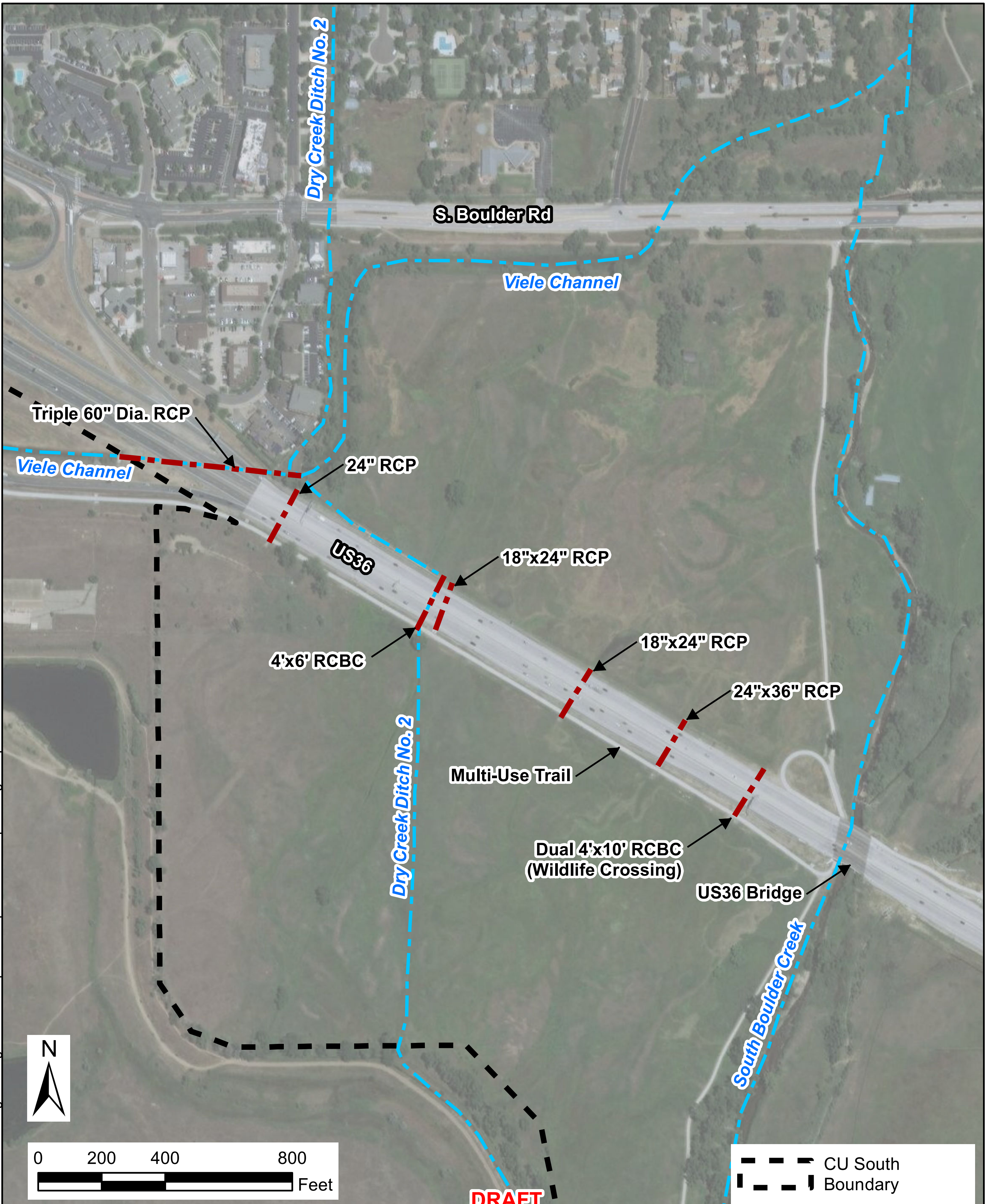
REPRODUCE IN COLOR	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	CU SOUTH CAMPUS AND LAND USE DESIGNATIONS
		PROJECT NO. 16134	February 2020 **Figure 2.3**



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REPRODUCE IN COLOR	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	PLAN OF FACILITIES ALONG US36 ROW
		PROJECT NO. 16134	February 2020 Figure 2.4

SECTION 3 – PREVIOUS STUDIES AND REPORTS

3.1 General

Numerous planning and engineering studies of SBC and surrounding areas have been performed over the last several decades for the City, MHFD, and others. The RJH Team collected and reviewed previous studies including flood mapping studies, hydrology reports, and major drainageway master plans. A summary of relevant previous studies is provided below.

3.2 Flood Mapping Study

HDR, Inc. (HDR) completed a comprehensive flood mapping study that serves as the basis for the FEMA regulatory floodplain. The HDR study consisted of three reports:

- *South Boulder Creek Climatology/Hydrology Report* (HDR, 2007).
- *South Boulder Creek Hydraulic Modeling Report* (HDR, 2008).
- *South Boulder Creek Risk Assessment Report* (HDR, 2009).

The *South Boulder Creek Climatology/Hydrology Report* evaluated basin-specific design storms for both the general storm (i.e., long-duration) and thunderstorm (i.e., high-intensity, short-duration) precipitation events for return frequencies ranging from 2 to 500 years. Various combinations of spatial orientations were evaluated to identify critical precipitation events. In general, storms containing the created main stem peak flows were determined to occur in the lower watershed (i.e., downstream of Gross Reservoir).

Rainfall-runoff analyses were performed using a MIKE 11 model, which is part of DHI's MIKE FLOOD proprietary software program. MIKE 11 is a dynamic, one-dimensional hydrologic model. The watershed was divided into 27 sub-basins and hydrologic characteristics were developed for each sub-basin.

Hydraulic modeling was performed using a combination of MIKE 11 and MIKE 21 models. MIKE 11 was used to model the channel and hydraulic structures along the mainstem of SBC and major tributaries. MIKE 21 was used to model overbank and floodplain areas. The following blockages were used in the FEMA regulatory model at relevant structures:

- US36 bridge at SBC: 10-foot-wide obstructions at both bridge piers (approximately 20 percent blocked).

- Dry Creek Ditch No. 2 culvert at US36: 35 percent blocked.
- Viele Channel culvert at US36: 0 percent blocked.

Topographic information was developed from photogrammetry obtained by the City in 2003. A 4-meter grid was used to develop the FEMA regulatory model.

3.3 Master Plans

Several comprehensive master plans have been developed to identify and evaluate flood mitigation concepts along SBC. These include:

- Taggart Engineering Associates, *South Boulder Creek Major Drainageway Planning Phase A Report* (Taggart, 2001).
- CH2M, *Final South Boulder Creek Major Drainageway Plan – Alternative Analysis Report* (CH2M, 2015).

The 2015 Master Plan superseded the 2001 Master Plan. The primary purpose of the 2015 Master Plan was to identify alternatives to address flood issues in the West Valley. Flood studies prior to 1996 did not identify a flood threat in the West Valley from SBC, and the West Valley was subsequently developed without consideration for a large flood event. As part of the 2015 Master Plan, 15 initial alternatives were developed to mitigate downstream flooding and meet other Project criteria including preserving OSMP property, reducing environmental impacts and disruptions to the public, etc. The alternatives were conservatively sized using peak flow rates from the regulatory MIKE FLOOD model and a simplified hydraulic modeling approach using the Environmental Protection Agency's (EPA) Storm Water Management Model.

Nine of the 15 alternatives were identified as "Best Alternative Plans." Hydraulic modeling was performed to develop sizes and configurations for each alternative using a modified version of the regulatory MIKE FLOOD model. The model was modified to accommodate shorter model run durations. The modified model was developed by reducing the topographic grid resolution from 4 meters to 8 meters and truncating modeling extents as practicable. Based on recommendations from WRAB and OSMP staff, the nine "Best Alternative Plans" were subsequently reduced to five. The five preferred alternate plans from the Master Plan included:

- Status Quo.
- High-Hazard Zone Mitigation.
- Regional Detention Facility at US36.

- Distributed Regional Detention.
- Bear Canyon Creek Pipeline.

These five alternate plans were evaluated for multiple considerations including benefit-cost, water quality, environmental impacts, T&E species impacts, OSMP impacts, and social impacts. The Regional Detention Facility at US36 with downstream improvements was selected as the recommended alternative. The recommendation included implementing the project in the following phases:

- Phase I – Regional Detention Facility at US36.
- Phase II – West Valley Improvements.
- Phase III – Stormwater Detention Facility at Flatirons Golf Course.

Six planning-level layouts were then developed for the regional detention facility at US36 to reduce impacts to OSMP property and ensure compatibility with the US36 widening project (CH2M, 2015). The preferred layout (Option D) included an earthen embankment along the north portion of the CU Boulder South campus, a floodwall in the CDOT ROW, and fill and excavation on the CU Boulder South campus. The combination of excavation and fill on the CU Boulder South campus was selected to reduce impacts to OSMP and CU Boulder South campus property. The floodwall in the CDOT ROW was required because space constraints in the ROW would prohibit the construction of an earthen embankment.

3.4 Boulder Valley Comprehensive Plan Update

Following the 2015 Master Plan and acceptance of the Option D concept, the CU Boulder South campus' potential future was extensively and publicly discussed as part of the 2015 BVCP update. This input ultimately led to the creation of CU Boulder South Guiding Principles approved by the City Planning Board, City Council, Boulder County Planning Commission, Boulder County Board of County Commissioners, and CU.

Acceptance of the BVCP update in July 2017 changed the land use designations for approximately 80 acres of the CU Boulder South campus to facilitate construction of the regional stormwater detention facility at US36. The BVCP CU Boulder South Guiding Principles also provided direction to consider mitigating flood risk to the highest practicable standard while balancing associated environmental, social, and financial impacts. These guiding principles included:

- Developing and evaluating detention storage alternatives that consider removal of the existing CU levee.
- Developing and evaluating detention storage alternatives based on a long-duration storm event and a 500-year FEMA storm event, in addition to the 100-year FEMA storm event.
- Conducting groundwater assessments to collect information necessary to verify feasibility and for design of any necessary conveyance systems.
- Seeking opportunities for ecological restoration and improvement.

3.5 Conditional Letter of Map Revision and Letter of Map Revision

A Conditional Letter of Map Revision (CLOMR) was prepared by Plenary Roads and Michael Baker Jr., Inc. to document changes in the SBC floodplain resulting from the US36 widening project. Typically, a CLOMR is performed using the same modeling approach and software as the effective regulatory study. However, modeling for this CLOMR was performed using a one-dimensional HEC-RAS model instead of the MIKE FLOOD model, which is the effective regulatory model. The change in modeling approach and software was discussed and approved by the City, Boulder County, MHFD, and FEMA. Manning's n values and blockage percentages of key structures were generally unchanged from the effective model. A series of lateral structures were used in the HEC-RAS model to account for the transfer of flow between reaches to replicate two-dimensional effects. The CLOMR did not evaluate any impacts associated with the Project.

The proposed conditions model included the following changes:

- Widening US36 and reconstructing it to have a center crown.
- Widening the US36 bridge over the main channel of SBC.
- Adding an elevated bikeway parallel to US36.
- Adding two wildlife crossing culverts under US36. These culverts were modeled as 35 percent blocked.

Based on CLOMR modeling, base flood elevations would increase in some areas and decrease in other areas. Most increases would occur upstream of US36 along the portion of flow that overtops the SBC main channel and flows west along the US36 embankment. The maximum increase in this area is 0.21 feet, which would occur to the east of the Dry Creek Ditch No. 2 culvert. The model was subsequently updated following construction and a Letter of Map Revision (LOMR) was issued by FEMA in 2017.

SECTION 4 – DATA COLLECTION

4.1 General

Various types of data collection will be required throughout the Project to advance the design. During the concept design, the RJH Team performed topographic surveying, a preliminary geotechnical investigation program, and an environmental survey. A description of data collection performed is provided below.

4.2 Topographic Survey

Flatirons performed topographic surveying in winter 2018 to develop a base map. Topographic surveying was performed using a combination of aerial survey equipment and conventional (i.e., field) survey equipment to develop a base map of the Project site. The limits of the survey are presented on Figure 4.1. Topography used for the base map for areas outside the limits of survey was obtained from City LiDAR data developed in 2013 prior to the 2013 flooding.

4.3 Geotechnical Investigation

An initial geotechnical investigation (i.e., Phase I) was performed concurrently with the concept design. The objectives of the initial geotechnical investigation included:

- Advancing the generalized understanding of geologic, geotechnical, and hydrogeological conditions at and around the site.
- Evaluating foundation conditions along the floodwall alignment.
- Evaluating available on-site borrow materials.
- Obtaining data to develop and calibrate a preliminary baseline groundwater model of the SBC alluvial valley.

The initial geotechnical investigation included advancing geotechnical borings at 26 locations throughout the SBC valley and performing geotechnical laboratory tests on collected subsurface materials. Monitoring wells were installed in 24 of the borings to provide long-term monitoring of groundwater levels. A plan of boring locations is presented on Figure 4.2.

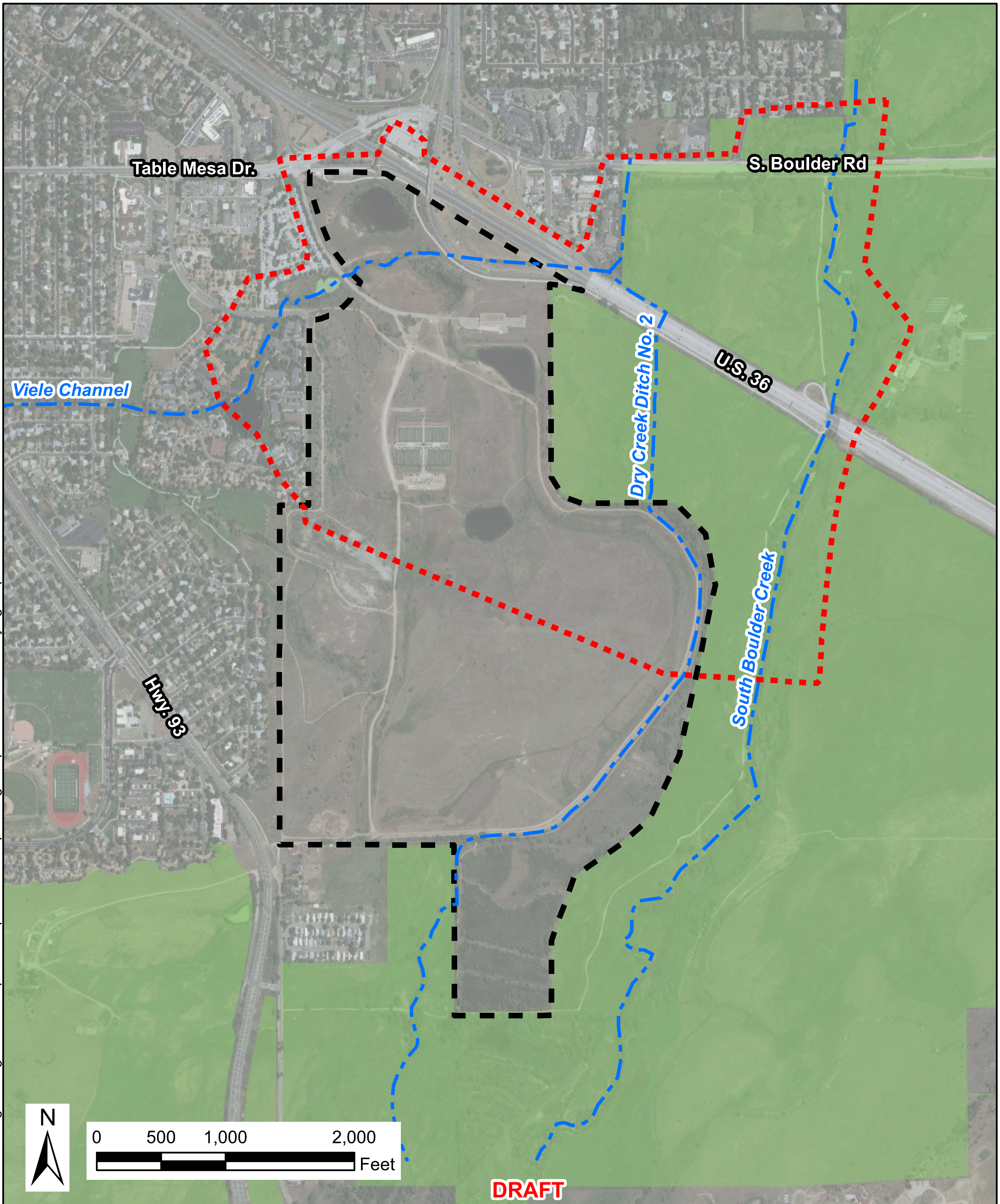
A summary of data collected and laboratory test results is presented in the *Phase I Geotechnical Data Report – South Boulder Creek Regional Detention* (RJH, 2019). Additional geotechnical investigations will be performed in subsequent stages of Project development as appropriate to advance the design.

4.4 Environmental Survey

CORVUS performed an environmental survey between September 11 and October 14, 2019 that included delineating Waters of the United States (WOTUS) and assessing potential habitat for T&E species listed under the Endangered Species Act (ESA). The WOTUS delineation included identifying channels, ditches, open water, and wetlands abutting or adjacent to such features. The wetland determination followed methods described in the U.S. Army Corps of Engineers (USACE) *Wetlands Delineation Manual* (USACE 1987) and, where applicable, in accordance with the methods identified in the Regional Supplement to the USACE Wetland Delineation Manual: Great Plains Region (Supplement) (USACE 2010). As part of preparation for this field work, CORVUS reviewed readily available information, including U.S. Fish and Wildlife Service (USFWS) National Wetland Inventory, U.S. Geological Survey National Hydrography Dataset, Natural Resources Conservation Service (NRCS) soil mapping, previous wetland mapping on the CU Boulder South campus performed by ERO Resources (ERO), and Google Earth aerial imagery.

Using methods described in the Supplement, CORVUS collected data on vegetation, soil, and hydrology characteristics that are used as the basis for wetland boundary determinations. CORVUS identified plant species observed in the study area using Flora of Colorado (Ackerfield 2015), with nomenclature following the National Wetland Plant List (Lichvar et al. 2016). Wetland indicator status of each species was determined based upon the National Wetland Plant List. If a species is not listed in the National Wetland Plant List, then nomenclature follows PLANTS Database (USDA, NRCS 2019).

Data on wetland boundaries and the ordinary high-water mark were gathered in the field with a global positioning system unit and were digitized into ArcGIS shapefiles using high-resolution aerial photography. All wetland and waters boundaries are considered preliminary until approved by the USACE.



Limit of Survey CU Site Boundary OSMP Land	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	PLAN OF LIMIT OF SURVEY
		PROJECT NO. 16134	February 2020 **Figure 4.1**

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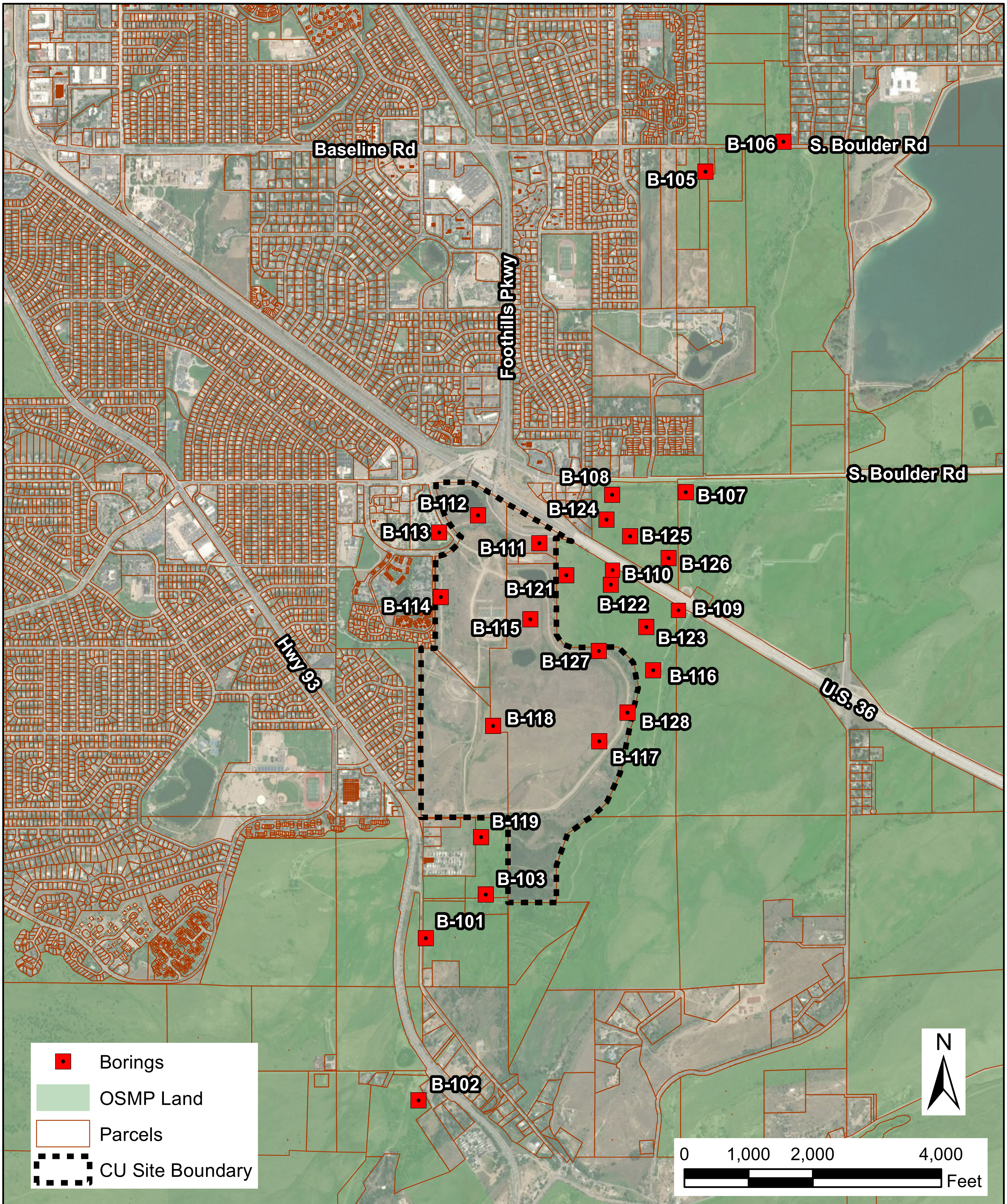

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RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	PLAN OF GEOTECHNICAL BORINGS
PROJECT NO. 16134	February 2020 **Figure 4.2**

SECTION 5 – ALTERNATIVES

5.1 Background

The RJH Team, the City, and MHFD (collectively referred to as the Project Team) identified a series of key issues that would impact development of the Project based on our collective understanding of Project objectives, constraints, site conditions, public input, and City staff input. Based on these key issues, the Project Team initially identified and evaluated three general concept-level alternatives for the detention facility at US36. The initial concept-level alternatives included:

- **Master Plan:** This alternative built upon Option D presented in the 2015 Master Plan and included an earthen embankment along the northwest portion of the CU Boulder South campus, a structural floodwall in the CDOT ROW, a 60-inch-diameter outlet tunnel below US36, and detention excavation on the PK-U/O land use area.
- **Variant 1:** This alternative was similar to the Master Plan; however, the alignment of the earthen embankment was shifted to the south of Viele Channel. This alignment would allow Viele Channel to flow unobstructed in its existing configuration.
- **Variant 2:** This alternative consisted of constructing a flow control structure across SBC at the US36 bridge, an earthen embankment near the existing CU levee, and a structural floodwall in the CDOT ROW. The reservoir footprint would be primarily located on OSMP property instead of the CU Boulder South campus.

These three alternatives were evaluated for both the 100-year and 500-year flood events. The evaluation included developing concept-level layouts and cost opinions.

On August 7, 2018, the Project Team presented the results of the initial evaluation to City Council. On August 21, 2018, City Council directed the Project Team to proceed with preliminary design for the Variant 1, 500-year (V1-500) configuration and to concurrently evaluate ways to reduce flood detention on the PUB land use area because approximately 36 acres of the PUB land use would be inundated in this configuration. City Council requested that the Project Team return on September 20, 2018 to present high-level (i.e., feasibility-level) concepts of modifications to the V1-500 configuration to meet direction provided by City Council.

On September 20, 2018, the Project Team presented three high-level concepts to modify the V1-500 configuration to reduce the flood detention on the PUB land use area. Concept-level layouts and cost opinions were not developed. These high-level concepts included:

- Enlarging the detention excavation on the PK-U/O land use area.
- Adding fill on the OS-O land use area and changing the land use designation to PUB.
- Constructing a supplemental upstream storage reservoir on the CU Boulder South Campus property.

On September 20, 2018, City Council directed the Project Team to perform a concept-level evaluation of enlarging the detention excavation on the PK-U/O land use area. This included developing concept-level layouts and cost opinions. The results of this evaluation were presented to City Council on February 5, 2019. At this meeting, City Council directed the Project Team to abandon the enlarged excavation concept and continue to advance preliminary design of the initial V1-500 configuration.

Subsequent to the February 5, 2019 City Council meeting, CU provided a letter to the City stating that inundating 36 acres of the PUB land use area would be unacceptable. In addition, CDOT stated that above-ground portions of the Project must be built generally outside of the existing US36 ROW. This would require shifting the floodwall to OSMP property. Also, CDOT stated that the Project could not impact the existing US36 bridge at SBC. This would generally prohibit a) physical modifications to the bridge and b) increases in hydraulic conditions (i.e., flow rates and velocities) through the bridge.

On July 16, 2019, City Council provided the following direction to the Project Team:

- Evaluate changes in the design storm in conjunction with proposed changes to the existing land use designations on the CU Boulder South Campus to maintain 129 acres of buildable area for CU.
- Continue to advance preliminary design of the initial V1-500 configuration.

Based on direction provided by City Council and clarification from CDOT, the Project Team identified the following potential modifications to the initial V1-500 configuration:

- Decreasing the magnitude of the design event to less than the 500-year event.
- Placing fill on other portions of the CU Boulder South campus site to provide buildable area above the 500-year floodplain for CU.

- Increasing the capacity of the outlet tunnel. Increases in capacity would be limited by Viele Channel capacity, downstream flooding impacts, and pipe cover requirements.

The Project Team identified additional concept-level alternatives to evaluate based on combinations of these potential modifications. The alternatives are modifications of the initial V1-500 configuration and are described below.

- **Option 1:** This option would be designed for the 100-year event and would include an earthen embankment along the northwest portion of the CU Boulder South campus, a structural floodwall on OSMP property along the US36 ROW, an outlet tunnel below US36, and detention excavation on the PK-U/O land use area. Earthfill would be placed on the northern PUB land use area so that it would not be inundated during the design event. A plan of Option 1 is presented on Figure 5.1.
- **Option 2:** This option would be designed for the 500-year event and would include an earthen embankment along the northwest portion of the CU Boulder South campus, a structural floodwall on OSMP property along the US36 ROW, an outlet tunnel below US36, and detention excavation on the PK-U/O land use area. Earthfill would be placed on the OS-O land use to mitigate the portion of the northern PUB land use that would be inundated during a 500-year event. This fill could not be placed on the northern PUB land use area like Option 1 because it would reduce the detention storage to an unacceptable level for the design event. A plan of Option 2 is presented on Figure 5.2.
- **Option 3:** This option would be designed for an event between the 100-year and 500-year events and would include an earthen embankment along the northwest portion of the CU Boulder South campus, a structural floodwall on OSMP property along the US36 ROW, an outlet tunnel below US36, and detention excavation on the PK-U/O land use area. Earthfill would be placed on a combination of the northern PUB land use and OS-O land use. The entirety of this fill could not be placed on the northern PUB land use area like Option 1 because it would reduce the detention storage to an unacceptable level for the design event. A plan of Option 3 is presented on Figure 5.3.

A discussion of key issues, primary Project components, and evaluations is provided in the following sections.

5.2 Key Considerations Impacting Alternative Development

Key considerations that influenced the development and evaluation of the alternatives include:

- The Project should prevent overtopping of US36 from the design flood event. Both the short-duration, high-intensity, and long-duration design events should be considered.
- The Project cannot negatively impact existing floodplains at any upstream or downstream locations for the selected design event.
- Future impacts to regional hydrology and flooding along SBC from changes in the basin, climate change, etc. are unknown at this time. The ability to modify Project facilities in the future to accommodate a larger flood event may be desirable.
- Project facilities will temporarily detain flood water. The City does not own water rights to the flood water and detained flood water will need to be released back to SBC within 120 hours for flood events greater than the 5-year event in accordance with Colorado Revised Statute 37-92-602(8).
- Above-ground Project facilities must be built outside of the existing CDOT ROW along US36, but at- or below-ground portions of Project facilities (i.e., foundations, drains, etc.) could be installed within the existing CDOT ROW.
- Impacts to the existing US36 bridge at SBC are not acceptable to CDOT. This presently prohibits a) physical modifications to the bridge and b) increases in hydraulic conditions (i.e., flow rates and velocities) through the bridge.
- The BVCP update changed the land use designations for the CU Boulder South campus to facilitate a flood mitigation project. The selected Project configuration should be consistent with revised BVCP land use designations. Variations in land use from the BVCP update would likely require approval from the City Planning Board, City Council, Boulder County Planning Commission, Boulder County Board of County Commissioners, and CU.
- The BVCP update prohibits the construction of habitable structures on the CU Boulder South campus in the area protected by the existing levee. As a result, the existing levee does not provide flood mitigation benefits to CU. It may be desirable to remove the existing levee to potentially a) provide increased riparian connectivity between SBC and existing wetlands on the west side of the levee, and b) accommodate ecological restoration or enhancement.

- The BVCP land use update provided approximately 129 acres of buildable area for CU (i.e., PUB land use area). The Project needs to maintain this amount of buildable area for CU, but CU has stated that it may be acceptable to modify the configuration of buildable area. South Loop Drive is a public road and the primary access route to the CU Boulder South campus. Project alignments that cross South Loop Drive would require modifications to the road.
- Construction will require a detour of the multi-use trail, possibly impact the US36 east-bound shoulder, and create visual and noise disruptions to nearby residences and OSMP users. Reducing the duration of construction to the extent reasonably practicable without negatively impacting Project operations or design criteria is desirable.
- Project facilities will likely include a jurisdictional, high-hazard and extreme hydrologic hazard dam as defined by the SEO. The Project should be designed in accordance with SEO design criteria, and the design will be reviewed and approved by the SEO.
- The SEO requires that extreme hydrologic hazard dams have a spillway capable of conveying the IDF, which is based on the Probable Maximum Flood event.
- Viele Channel and other local off-site drainages flow through the site. Project facilities should allow off-site flows to be conveyed through or around the site without causing additional upstream or downstream flood impacts along these drainages.
- Several irrigation ditches including Dry Creek Ditch No. 2 flow through the Project site and are used to irrigate OSMP property. Maintaining irrigation flows on OSMP property is required.
- Jurisdictional wetlands are located throughout the site. Impacts to jurisdictional habitat would require environmental permitting and mitigation. Reducing impacts to wetlands is desirable.
- Habitat for two federally T&E species (i.e., PMJM and ULTO) is located throughout the site. Impacts to T&E species habitat would require environmental permitting and mitigation. Reducing impacts to T&E species habitat is desirable.
- Groundwater at the site is thought to sustain wetlands on both sides of US36. Groundwater will need to be conveyed through Project facilities in a manner that substantially replicates existing flow patterns to prevent upstream groundwater mounding, potential adverse impacts (i.e., flooding of basements), and drying up downstream wetlands.

- The Project will be funded by the City and MHFD. Reducing costs to extent reasonably practicable without negatively impacting Project operations or design criteria is desirable.
- Project facilities will be visible from US36, CU Boulder South campus, OSMP trails, and nearby residences. Project facilities should be aesthetically pleasing and integrate into the surrounding infrastructure and landscape.

5.3 Primary Project Components

Primary components required to develop the Project were identified for each alternative. Project components vary from heavy civil features (i.e., dams, excavation, fill, etc.) to hydraulic structures (i.e., spillway, pipelines, outlet works, etc.) to site modifications. A description of primary Project components is provided below.

5.3.1 Earthen Embankment on CU Boulder South Campus

The earthen embankment would generally be located in the northern portion of the CU Boulder South campus. Based on its proximity to US36 and nearby residences, the earthen embankment would most likely be classified by the SEO as a high-hazard and extreme hydrologic hazard dam. The crest elevation of the earthen embankment for each alternative configuration was established to provide 1-foot of freeboard above the routed IDF water surface elevation (WSE).

The earthen embankment would consist of a homogeneous earthfill embankment with internal filters and drains. The earthfill would have sufficiently low permeability to prevent excessive seepage during transient reservoir loading. Earthen materials required to construct the dam could be obtained from a) on-site detention excavation, b) on-site borrow from designated areas on the CU Boulder South campus, c) excavated levee materials, and d) materials imported from an off-site location. Based on preliminary data collection, the on-site soils at the CU Boulder South Campus and the levee fill appear to predominantly consist of clayey sand and gravel with about 20 to 30 percent fines. In our opinion, borrow material obtained from these on-site sources is expected to perform suitably as embankment fill. Internal filter and drain zones would be included within the embankment to safely manage seepage through the embankment fill. The filter and drain zones are anticipated to consist of specially graded sand and gravel. It might be possible to process filter and drain material from native alluvial soils present on-site, otherwise these materials will need to be imported from off-site commercial sources.

The upstream and downstream dam slopes would ideally be constructed at a 4 horizontal (H) to 1 vertical (V) slope to reduce long-term maintenance and provide improved aesthetics. The embankment crest would be 18 feet wide in accordance with SEO Rules and Regulations. This should provide sufficient width for vehicle access.

Additional analyses will be required as the design progresses to identify if a barrier wall would be required below the earthen embankments to manage seepage. If a barrier wall is required to manage seepage when the reservoir is storing water, it would likely consist of a soil-bentonite barrier wall below the centerline of the earthen embankment alignment. To construct the barrier wall, a narrow trench would first be excavated and filled with bentonite slurry to provide temporary support during construction. The excavated material would then be mixed on-site with dry bentonite powder and additional bentonite slurry to produce backfill material with the desired engineering properties. This material would then be placed back into the trench excavation to displace the bentonite slurry and provide the permanent seepage barrier. The barrier wall would connect to the earthen embankment fill at the ground surface and the underlying Pierre Shale bedrock to provide a continuous low-permeable seepage barrier along the dam alignment.

A typical section of the earthen embankment is presented on Figure 5.4.

5.3.2 Structural Floodwall along US36

A structural floodwall would be required instead of an earthen embankment along the US36 corridor to limit impacts to OSMP property and the CDOT ROW. The floodwall would extend from near the west side of the US36 bridge to the east side of the CU Boulder South campus where it would connect to the earthen embankment. The earthen embankment and floodwall would collectively comprise the high-hazard, jurisdictional dam.

The top elevation of the floodwall for each option was established at the reservoir WSE for a selected design event.

The floodwall would consist of a reinforced concrete wall with below-ground seepage control. Seepage control would be required to prevent excessive seepage through the floodwall foundation when the reservoir is full or partially full. Foundation soils along the floodwall are anticipated to contain cobbles and boulders, which would likely preclude installation of driven seepage control (e.g., sheet piles). The seepage control system would likely consist of a continuous secant pile wall, which consists of a row of concrete-filled drilled shafts (i.e., caissons) that slightly overlap each other. The secant pile wall would extend to bedrock and provide structural support for the wall and a low-permeable barrier to foundation seepage beneath the wall.

The floodwall would also function as a spillway to convey the IDF and storm events that exceed the design event. A reinforced concrete apron would be required on the downstream side of the floodwall to dissipate energy and control erosion from overtopping flows. Spillway flows would be discharged from the concrete apron to US36 and flow north through both the SBC floodplain and West Valley. Flood inundation limits for the IDF would be similar with and without the project. A typical section of the floodwall is presented on Figure 5.5.

The above-ground portions of the floodwall (i.e., concrete wall) would be located on OSMP property directly adjacent to the CDOT ROW. At- and below-grade portions of the floodwall (i.e., spillway apron, foundation, seepage control) would be located on both OSMP property and the CDOT ROW.

The multi-use trail extends parallel to US36 through the CDOT ROW and will need to be demolished to accommodate construction of the floodwall and then reconstructed. The multi-use trail could potentially be reconstructed on either side of the floodwall. Locating the multi-use trail upstream of the floodwall may provide a more desirable experience for trail users by screening visual and acoustics impacts from US36, but would impact additional OSMP property. However, if the multi-use trail is located downstream of the floodwall, it could potentially be incorporated into the spillway apron to provide cost savings.

Various architectural treatments could be considered to the floodwall for improved aesthetics in future stages of design. Some options include concrete staining or stamping, architectural trellises to facilitate plant growth, curvilinear alignment, etc.

5.3.3 Groundwater Conveyance System

A groundwater conveyance system would be required to allow groundwater to pass through the floodwall foundation during routine operating conditions when the reservoir is empty. Conveyance of normal groundwater flows is critical to maintain the existing hydrogeologic regime, and prevent upstream groundwater mounding and lower downstream groundwater, which could impact wetlands.

The intent of the groundwater conveyance system is to convey natural aquifer flows past the floodwall without causing a hydraulic restriction. Two general categories of groundwater conveyance systems could be used: passive and active. A passive system uses gravity to convey groundwater through the system while an active system uses mechanical pumps in addition to gravity. Passive systems are easier to operate and maintain, and we intend to use a passive system.

The passive groundwater conveyance system would consist of a collection trench upstream of the secant pile wall, a distribution trench downstream of the secant wall, and piping and valves within and between the two trenches. These trenches would be filled with permeable material and similar applications are commonly used to convey groundwater.

The upstream trench would be used to collect groundwater. The collected groundwater would be conveyed through a series of conveyance pipes spaced at regular intervals through the wall to the downstream trench for distribution. Manholes would be located at the upstream and downstream ends of the conveyance pipes for access and maintenance.

The system would be designed to have a flow capacity that exceeds that of the alluvial aquifer intercepted by the floodwall seepage barrier. During operation of the system, the regulating valves would be operated as needed to generally match the natural groundwater levels between the upstream and downstream monitoring wells. A detail of the groundwater conveyance system concept is presented on Figure 5.5.

5.3.4 Modifications to Existing Culverts below US36

The existing culverts below US36 will need to connect to the floodwall to facilitate flow conveyance. The Project will likely increase the potential maximum hydraulic head on each culvert. Modifications would likely be required to accommodate the increased hydraulic head, which at minimum could likely include installing energy dissipation facilities at the downstream end of the culverts. Based on simplified culvert hydraulics performed by RJH for the increased hydraulic head, we estimate that velocities through the culverts would be less than 25 feet per second, which should be acceptable for RCP that has been properly installed.

5.3.5 Detention Excavation on CU Boulder South Campus

To ensure that the Project does not cause additional flooding on the main stem of SBC downstream of US36, the Project must be configured to maintain or reduce flows downstream of South Boulder Road for the selected design event. To accomplish this, detention storage is required below the existing ground. The detention storage would be achieved by excavation on the PK-U/O land use area. The largest reasonable excavation that can be achieved without steep side slopes and retaining walls is approximately 45 acre-feet (ac-ft). Excavated materials would likely be used in construction of the earthen embankment. The bottom of the excavation was set at Elevation (El.) 5343 to facilitate drainage to Viele Channel on the north side of US36.

Since the excavation would be below existing groundwater elevations, a barrier wall is needed to keep the excavation from filling with groundwater, which would render it ineffective for detention storage. The barrier wall would be similar to the barrier wall described above for the earthen embankment.

A grouted boulder rundown would be required along the northeast side of the excavation to convey overtopping flood flows from SBC into the excavation.

5.3.6 Outlet Works below US36

The lower portion of the reservoir pool would not freely drain back to SBC. An outlet works pipe would be required to meet SEO dam safety requirements and to allow the entire reservoir to be drained to meet water rights requirements. The outlet works pipe would extend from the detention excavation on the CU Boulder South campus to Viele Channel north of US36. This would require approximately 600 feet of tunneling below US36. A profile of the outlet works is presented on Figure 5.6.

Tunneling is anticipated to consist of a micro-tunneling operation where a cutterhead advances through the ground, and the outlet works pipe would be installed immediately behind the cutterhead to case the excavation. The invert of the outlet works will vary from El. 5343 to El. 5340 and is expected to be located within alluvial soils. Difficulties that would need to be considered when designing the tunneling operation include: a) high groundwater levels and high-permeable soils, b) likely cobbles and boulders within the soil, c) elevation of bedrock, and d) the presence of US36 above the tunnel alignment, which restricts allowable ground movement and would complicate access to the cutterhead if difficulties arise during tunneling.

Appropriate sizing of the outlet works pipe is crucial. The outlet works would need to be large enough to drain the reservoir in 120 hours and prevent the detention area from filling at the beginning of the flood while not increasing downstream flooding.

5.3.7 Reconstruction of South Loop Drive

The alignment of the earthen embankment would obstruct South Loop Drive. South Loop Drive would need to be reconstructed to extend above the earthen embankment. This would involve constructing an earthen ramp on both sides of the earthen embankment.

5.3.8 Fill on CU Boulder South Campus

Placing earthfill on a portion of the CU Boulder South campus would be required for all of the options to provide CU with 129 acres of buildable area. Similar to the embankment, earthen materials required to construct the earthfill could be obtained from a) on-site detention excavation, b) on-site borrow from designated areas on the CU Boulder South campus, c) excavated levee materials, and d) materials imported from an off-site location. The location and configuration of the earthfill would vary for each option. The top of the earthfill would be placed at the 500-year WSE in accordance with the BVCP update, which requires all buildings on the CU Boulder South Campus to be located outside of the 500-year floodplain.

5.3.9 Removal of CU Levee

As previously discussed, the existing CU levee does not provide flood mitigation benefits outside of the CU Boulder South property. Removing the levee would likely provide increased riparian connectivity between SBC and existing wetlands on the west side of the levee, and accommodate ecological restoration or enhancement. Excavated levee materials would likely be used in construction of the earthen embankment. Portions or the entirety of the existing levee could be removed.

5.3.10 Environmental Mitigation

Impacts to resources regulated under the Clean Water Act (CWA), City Wetland Permit Process, and the ESA must be mitigated as part of implementing any alternative. For this reason, compensatory mitigation will be necessary for permanent impacts to wetlands and habitat of PMJM and ULTO. The USACE typically requires wetland mitigation on a per-acre basis at a one-to-one (1:1) ratio. Additional mitigation acreage above that needed for the CWA Section 404 Permit will be needed to comply with the City's Stream, Wetland, and Water Body Regulations, which requires mitigation at a ratio between 2:1 and 2.5:1 for permanent wetland impacts, depending on the quality of the wetland. PMJM habitat is also mitigated on a per-acre basis and is typically mitigated at least at a 1.5:1 ratio. Additionally, impacts to critical habitat must be mitigated within the critical habitat unit within which impacts occur. Critical Habitat Unit 5 is along SBC from just downstream of Eldorado Springs to about Baseline Road. Impacts to ULTO would consist of creating or enhancing orchid habitat at a ratio determined by the USFWS.

Compensatory mitigation for wetland and PMJM and ULTO habitat impacts is a challenging undertaking because of the many ecological parameters such as soils, hydrology, and plant communities that must be correctly established to provide successful mitigation. On-site and off-site mitigation opportunities would be evaluated in consultation with regulators.

5.4 Alternatives

5.4.1 General

Various combinations of the primary Project components described above comprise each alternative. Additional descriptions for each alternative are provided below.

5.4.2 Option 1 (100-Year)

Option 1 includes the following primary Project components:

- Earthen embankment along the northern portion of the CU Boulder South campus. The embankment concept and location would generally be the same as the original V1-500 configuration, but the embankment would be shorter/smaller based on the reduced design event and increased outlet capacity.
- Floodwall in OSMP property along the edge of the existing CDOT ROW along US36. The floodwall concept is the same as the original V1-500 concept but could be shorter in height based on the reduced design event and increased outlet capacity, and would be moved to the OSMP property.
- Groundwater conveyance system. This would remain unchanged from the original V1-500 configuration.
- Modifications to existing culverts below US36. This would remain unchanged from the original V1-500 configuration.
- Detention excavation on the CU Boulder South campus with a perimeter soil-bentonite barrier wall. This would remain unchanged from the original V1-500 configuration.

- Dual 60-inch-diameter outlet tunnels below US36. The outlet tunnel concept would generally remain unchanged from the original V1-500 configuration but the capacity would be increased from a single 60-inch-diameter pipe to dual 60-inch-diameter pipes.
- Earthfill on 34 acres of the CU Boulder South northern PUB land use area to raise the ground above the 500-year floodplain. Fill on the northern PUB land use area was not included in the original V1-500 configuration. The top of fill on the PUB land use area would be set at the 500-year WSE in SBC and transition to existing ground at a 3H:1V slope along the northern and eastern edges of the fill.
- Environmental mitigation. The environmental mitigation concept would remain unchanged from the original V1-500 configuration. However, the amount of environmental mitigation would increase because the floodwall is on OSMP property.
- Reconstruction of South Loop Drive. This would generally remain unchanged from the original V1-500 configuration.

Key elevations for Option 1 (100-Year) are based on preliminary hydraulic modeling performed by DHI and are presented in Table 5.1.

TABLE 5.1
OPTION 1 KEY ELEVATIONS (100-YEAR)

Maximum Normal WSE (ft)	IDF WSE (ft)	Top of Floodwall (ft)	Dam Crest El. (ft)
5363.8	5370.8	5363.8	5371.8

A plan of the Option 1 (100-Year) configuration is presented on Figure 5.7

5.4.3 Option 2 (500-Year)

Option 2 includes the following primary Project components:

- Earthen embankment along the northern portion of the CU Boulder South campus. The embankment concept and location would generally be the same as the original V1-500 configuration, but the embankment would be shorter/smaller based on the increased outlet capacity.

- Floodwall in OSMP property along the edge of the existing CDOT ROW along US36. The floodwall concept is the same as the original V1-500 concept but could be shorter based on the increased outlet capacity and would be moved to the OSMP property.
- Groundwater conveyance system. This would remain unchanged from the original V1-500 configuration.
- Modifications to existing culverts below US36. This would remain unchanged from the original V1-500 configuration.
- Detention excavation on the CU Boulder South campus with perimeter soil-bentonite barrier wall. This would remain unchanged from the original V1-500 configuration.
- Triple 60-inch-diameter outlet tunnels below US36. The outlet tunnel concept would generally remain unchanged from the original V1-500 configuration but the capacity would be increased from a single 60-inch-diameter pipe to triple 60-inch-diameter pipes.
- Earthfill on 34 acres of the OS-O land use area to mitigate the portion of the northern PUB land use that would be inundated by the 500-year event. The fill would be placed so that the top of the fill at the southern end is at the 500-year WSE in SBC. The fill would then slope northeast at a 2-percent slope. This quantity of fill is required to avoid the fill operating as a levee, which is prohibited by the BVCP. Placing this fill on the OS-O land use area would also require placing fill on 42 acres of adjacent southern PUB land use area. The fill on the southern PUB land use area is required so that this area is also not protected by a levee.
- Environmental mitigation. The environmental mitigation concept would remain unchanged from the original V1-500 configuration, but additional area of environmental mitigation is required based on relocating the floodwall to OSMP property and placing fill on the OS-O land use area.
- Reconstruction of South Loop Drive. This would remain unchanged from the original V1-500 configuration.

Key elevations for Option 2 (500-Year) are based on preliminary hydraulic modeling performed by DHI and are presented in Table 5.2.

TABLE 5.2
OPTION 2 KEY ELEVATIONS (500-YEAR)

Maximum Normal WSE (ft)	IDF WSE (ft)	Top of Floodwall (ft)	Dam Crest El. (ft)
5365.6	5372.6	5365.6	5373.6

A plan of the Option 2 (500-Year) configuration is presented on Figures 5.8 and 5.9. Option 2 (500-Year) sections through the CU Boulder South earthfill are presented on Figure 5.10.

5.4.4 Option 3 (Approx. 200-Year)

Option 3 (Approx. 200-Year) includes the following primary Project components:

- Earthen embankment along the northern portion of the CU Boulder South campus. The embankment concept and location would generally be the same as the original V1-500 configuration, but the embankment would be shorter/smaller based on the reduced design event and increased outlet capacity.
- Floodwall in OSMP property along the edge of the existing CDOT ROW along US36. The floodwall concept is the same as the original V1-500 concept but could be shorter in height based on the reduced design event and increased outlet capacity, and would be moved to the OSMP property.
- Groundwater conveyance system. This would remain unchanged from the original V1-500 configuration.
- Modifications to existing culverts below US36. This would remain unchanged from the original V1-500 configuration.
- Detention excavation on the CU Boulder South campus with perimeter soil-bentonite barrier wall. This would remain unchanged from the original V1-500 configuration.
- Triple 60-inch-diameter outlet tunnels below US36. The outlet tunnel concept would generally remain unchanged from the original V1-500 configuration, but two additional 60-inch-diameter pipes would be added.
- Fill placed on 17 acres of the CU Boulder South campus northern PUB land use area. Fill on the PUB land use area was not included in the original V1-500 configuration.

- Fill placed on 17 acres of the CU Boulder South campus OS-O land use area. Similar to Option 2, the fill would be placed so that the top of the fill at the southern end is at the 500-year WSE in SBC. The fill would then slope northeast at a 2-percent slope. This quantity of fill is required to avoid the fill operating as a levee, which is prohibited by the BVCP. Placing this fill on the OS-O land use area would also require placing fill on 42 acres of adjacent southern PUB land use area. The fill on the southern PUB land use area is required so that this area is also not protected by a levee. Fill on the OS-O land use area was not included in the original V1-500 configuration.
- Environmental mitigation. The environmental mitigation concept would remain unchanged from the original V1-500 configuration, but additional area of environmental mitigation is required based on relocating the floodwall to OSMP property and placing fill on the OS-O land use area.
- Reconstruction of South Loop Drive. This would remain unchanged from the original V1-500 configuration.

Key elevations for Option 3 (Approx. 200-Year) are based on preliminary hydraulic modeling performed by DHI and are presented in Table 5.3.

TABLE 5.3
OPTION 3 KEY ELEVATIONS (APPROX. 200-YEAR)

Maximum Normal WSE (ft)	IDF WSE (ft)	Top of Floodwall (ft)	Dam Crest El. (ft)
5364.5	5371.5	5364.5	5372.5

A plan of the Option 3 (Approx. 200-Year) configuration is presented on Figures 5.11 to 5.12. Option 3 (Approx. 200-Year) sections through the CU Boulder South earthfill are presented on Figure 5.13.

5.5 Evaluations

5.5.1 General

Development of the alternatives included performing the following evaluations:

- Simplified hydrologic modeling to develop an estimate of the IDF.
- Hydraulic modeling to develop sizes and configurations for each alternative.

- Concept-level evaluations of environmental impacts.

Information on the evaluations is presented below.

5.5.2 IDF Modeling

RJH performed simplified hydrologic modeling to develop an estimate of the IDF for initial spillway sizing. The simplified hydrologic modeling was performed using the 2007 SEO Rules and Regulations and will need to be updated in preliminary design using the 2020 SEO Rules and Regulations. Using the 2007 SEO Rules and Regulations for a high-hazard dam, the IDF is based on 90-percent of the Probable Maximum Precipitation (PMP). PMP depths were obtained using the National Oceanic and Atmospheric Administration (NOAA) Hydrometeorologic Report (HMR) No. 51 (NOAA, 1978). For future updates to the hydrologic analysis, we will utilize the SEO's new Regional Extreme Precipitation Study tool, which has now superseded HMR No. 51.

To provide consistency with previous hydrologic modeling, we obtained sub-basins from the *South Boulder Creek Climatology/Hydrology Report* (HDR, 2007). Hydrologic parameters (i.e., precipitation losses, lag times, etc.) for each sub-basin were estimated in accordance with the *Hydrologic Basin Parameter Response Estimation Guidelines* (SEO, 2009). A USACE HEC-HMS model was developed to identify IDF hydrographs. RJH evaluated both the general storm and local storm (i.e., thunderstorm) for two spatial distributions: an event occurring over the entire SBC watershed and an event occurring over the lower portion of the watershed (i.e., downstream of Gross Reservoir). Results of the simplified IDF evaluation are presented in Table 5.4.

TABLE 5.4
IDF RESULTS

Storm	Entire Basin		Lower Basin	
	Flow (cfs)(1)	Volume (ac-ft)	Flow (cfs)(1)	Volume (ac-ft)
General	65,800	68,500	61,100	39,600
Local	63,300	25,700	85,700	14,100

Note:
1. cfs = cubic feet per second

Runoff volumes for each event significantly exceed detention volumes for the flood mitigation facility. Therefore, peak flow rate will control spillway sizing. Spillway routing was performed using the local storm for an event on the lower portion of the basin (i.e., 85,000 cfs event).

5.5.3 Hydraulic Modeling

5.5.3.1 General

DHI performed hydraulic modeling to evaluate impacts of the proposed Project configurations on downstream flood depths and extents. The current FEMA 100-year Effective Model (EM100) and 500-year Effective Model (EM500) covering the Project site are the SBC Effective Model series built using the MIKE FLOOD program. Digital copies of EM100 and EM500 models were obtained by DHI from the MHFD in October 2017.

The EM100 and EM500 models obtained from the MHFD are in the Version 2009 SP1 of the MIKE FLOOD software modeling package. DHI upgraded the EM100 and EM500 models from Version 2009 SP1 to Version 2017 SP1 to incorporate software updates that include computational speed increases that allow for running multiple scenarios much more efficiently.

The computed maximum water depths for each software version and the differences between them for EM100 are shown in Figure 5.14. The mean difference in maximum flow depth between Version 2009 SP1 and Version 2017 SP1 for EM100 is 0.01 foot with a standard deviation of 0.09 foot. Less than 0.1-percent of the inundated areas have a difference greater than 1 foot and less than 3.5 percent have a difference greater than 0.1 foot. These differences are considered sufficiently small and the RJH Team concluded that modeling to support the concept design phase should be performed with the MIKE FLOOD Version 2017 SP1. Additional work would be required in future stages of design to convert this model to a full corrective effective model using the current software version.

The current 100-year and 500-year design flood events for SBC through the City are from the Flood Mapping Study as documented in the *South Boulder Creek Climatology/Hydrology Report* (HDR 2007). Both the 100-year and 500-year design flood events are generated by a short-duration, high-intensity thunderstorm (i.e., the 100-year Thunderstorm and 500-year Thunderstorm). The simulated peak flows for each of these design flood events when a) approaching the Project site and b) passing under the US36 bridge for EM100 and EM500 updated to version 2017 SP1 are presented in Table 5.5. Initial simulations using the 100-year General Storm showed lower flood inundation extents and depths than the 100-year Thunderstorm, indicating that the Thunderstorm is the governing design storm for flood extents and depth relative to these events. Therefore, the General Storm was not included in this concept design evaluation.

TABLE 5.5
PEAK FLOWS AT US36

Design Flood Event	Simulated Peak Flow Approaching US36 (cfs)(1)	Simulated Peak Flow Passing Under US36 Bridge (cfs)(2)
100-Year General Storm	2,936	--
100-Year Thunderstorm (EM100)	6,901	3,997
500-Year Thunderstorm (EM500)	11,203	5,419

Notes:
1. This is the combined flow in the SBC channel and floodplain including nearby Dry Creek Ditch No. 2.
2. Flow split upstream at the US36 bridge diverts a portion of approaching flow to west where it overtops US36.

Hydraulic modeling was performed for each of the three options. The embankment was modeled in MIKE FLOOD using a series of "no-flow" cells. The floodwall was modeled by setting cells along the floodwall alignment to an elevation representing the top of the floodwall. These cells can convey flow in the model and were used to model the overtopping component of the floodwall. Topography of the detention excavation was inserted into the MIKE FLOOD model replacing the existing topography in that footprint. The outlet works pipe was represented as a culvert structure in the MIKE FLOOD model connecting the interior of the detention facility to an outlet in Viele Channel downstream of US36.

The linked cells for the section of the Dry Creek Ditch No. 2 MIKE 11 channel reach were modified into single linked reach to represent the floodwall bisection of Dry Creek Ditch No. 2 along US36. This will still allow flow exchange across Dry Creek Ditch No. 2 across the floodplain but also allow flow to leave Dry Creek Ditch No. 2 through the culvert underneath US36.

5.5.3.2 Option 1 (100-Year)

Hydraulic modeling was performed for the 100-year Thunderstorm Event for Option 1 for three outlet capacities. The outlet capacity would likely be provided by using multiple 60-inch-diameter pipes because of cover limitations. However, the modeling was performed for single 60-inch, 84-inch, and 108-inch-diameter pipes to simplify modeling input. The 84-inch-diameter pipe would provide an effective flow area similar to dual 60-inch-diameter pipes, and the 108-inch-diameter pipe would provide a similar flow area to triple 60-inch-diameter pipes. The modeling also includes approximately 34 acres of new fill on the northern PUB land use in the CU Boulder South campus. Key hydraulic modeling results are presented in Table 5.6. Hydrographs through the US36 bridge and at South Boulder Road are presented on Figures 5.15 and 5.16, respectively. A plan of differences in maximum WSEs compared to EM100 is presented on Figure 5.17.

TABLE 5.6
OPTION 1 HYDRAULIC MODELING RESULTS (100-YEAR)

Configuration	Max WSE at US36 Bridge (ft)	Max WSE in Pond (ft)	Peak Flow US36 Bridge (cfs)(2)	Peak Flow S. Boulder Rd. (cfs)	Peak Outlet Flow (cfs)	Increase Downstream Flooding (Yes/No)(1)
Existing Conditions	5362.0	N/A	4,000	5,550	N/A	N/A
60-Inch-Diameter	5362.6	5364.4	4,330	4,930	360	No
84-Inch-Diameter (~2 – 60” Diameter)	5362.2	5363.8	4,120	5,100	760	No
108-Inch-Diameter (~3 – 60” Diameter)	5361.9	5363.0	3,780	5,270	1,280	Yes

Note:
1. Increases attributed to minor modeling fluctuations were not considered. Minor modeling fluctuations was generally considered to consist of rises less than 0.1 feet in areas where rises could not be reasonably explained.

The 108-inch-diameter outlet would reduce peak flows through the US36 bridge by about 5 percent compared to existing conditions. However, the 108-inch-diameter outlet may increase flooding in the Keewaydin neighborhood (i.e., between Foothills Parkway and SBC). Since one of the Project goals is to prevent increases in downstream flooding during the design event, we dismissed the 108-inch-diameter outlet for this concept evaluation.

The 60- and 84-inch-diameter outlets would increase peak flows through the US36 bridge by 8 and 3 percent, respectively. Neither outlet size would cause additional flooding downstream of South Boulder Road or in the Keewaydin neighborhood. Based on the hydraulic modeling results and engineering judgment, RJH selected dual 60-inch-diameter outlet pipes for Option 1 to maintain existing peak flows through the US36 bridge. The selection of dual 60-inch-diameter outlet pipes will be confirmed with hydraulic modeling in future stages of design if this alternative is advanced.

5.5.3.3 Option 2 (500-Year)

Hydraulic modeling was performed for the 500-year Thunderstorm Event for Option 2 for two outlet sizes: 60- and 108-inch-diameter pipes. As previously discussed, the 108-inch-diameter pipe would provide a similar flow area to triple 60-inch-diameter pipes. The modeling also includes new fill on the southern PUB and OS-O land uses on the CU Boulder South campus. The 34 acres of fill on the northern PUB land use from Option 1 has been removed. Key hydraulic modeling results are presented in Table 5.7. Hydrographs below the US36 bridge and at South Boulder Road are presented on Figures 5.18 and 5.19, respectively. A plan of differences in maximum WSEs compared to EM500 is presented on Figure 5.20.

TABLE 5.7
OPTION 2 HYDRAULIC MODELING RESULTS (500-YEAR)

Configuration	Max WSE at US36 Bridge (ft)	Max WSE in Pond (ft)	Peak Flow US36 Bridge (cfs)	Peak Flow S. Boulder Rd. (cfs)	Peak Outlet Flow (cfs)	Increase Downstream Flooding (Yes/No)(1)
Existing Conditions	5363.6	N/A	5,420	9,320	N/A	N/A
60-Inch-Diameter	5364.2	5366.7	6,500	7,010	380	No
108-Inch-Diameter (~3 – 60” Diameter)	5363.8	5365.6	5,740	8,070	1,380	No

Note:
1. Increases attributed to minor modeling fluctuations were not considered. Minor modeling fluctuations was generally considered to consist of rises less than 0.1 feet in areas where rises could not be reasonably explained.

The 60-inch-diameter outlet would result in increases in flow through the US36 bridge (i.e., 20 percent) and would likely not be acceptable to CDOT. For this reason, the 60-inch-diameter outlet was dismissed.

The 108-inch-diameter outlet would increase peak flows through the US36 bridge by about 6 percent but would not cause additional flooding downstream of South Boulder Road. It is possible that the increases in flow through the bridge may not cause negative impacts (i.e., scour) or that negative impacts could be mitigated by installing scour protection through the bridge. Additional analyses would be required to identify if mitigation is needed. It is also possible that a small increase in outlet capacity could maintain peak flows through the bridge without causing incremental increases in downstream flooding. This will be further evaluated with hydraulic modeling in future stages of design if this alternative is advanced.

Based on the results of the 108-inch diameter outlet modeling, we did not evaluate an 84-inch diameter outlet because it is apparent that flow through the US36 bridge would be significantly increased above EM500. RJH selected triple 60-inch-diameter outlet pipes for Option 2 (500-Year) for this concept-level evaluation.

The fill placed on the OS-O land use area resulted in minor rises (i.e., < 0.01 foot) in WSEs in upstream areas. In the RJH Team's experience, these rises are typically model "fluctuations" associated with complex, two-dimensional hydraulic models, and we anticipate these issues could be resolved in the next stage of design through refinements in the modeling.

Additional analyses would be required to evaluate the performance of Option 2 (500-Year) for a 100-year flood event.

5.5.3.4 Option 3 (Approx. 200-Year)

5.5.3.4.1: Hydrology

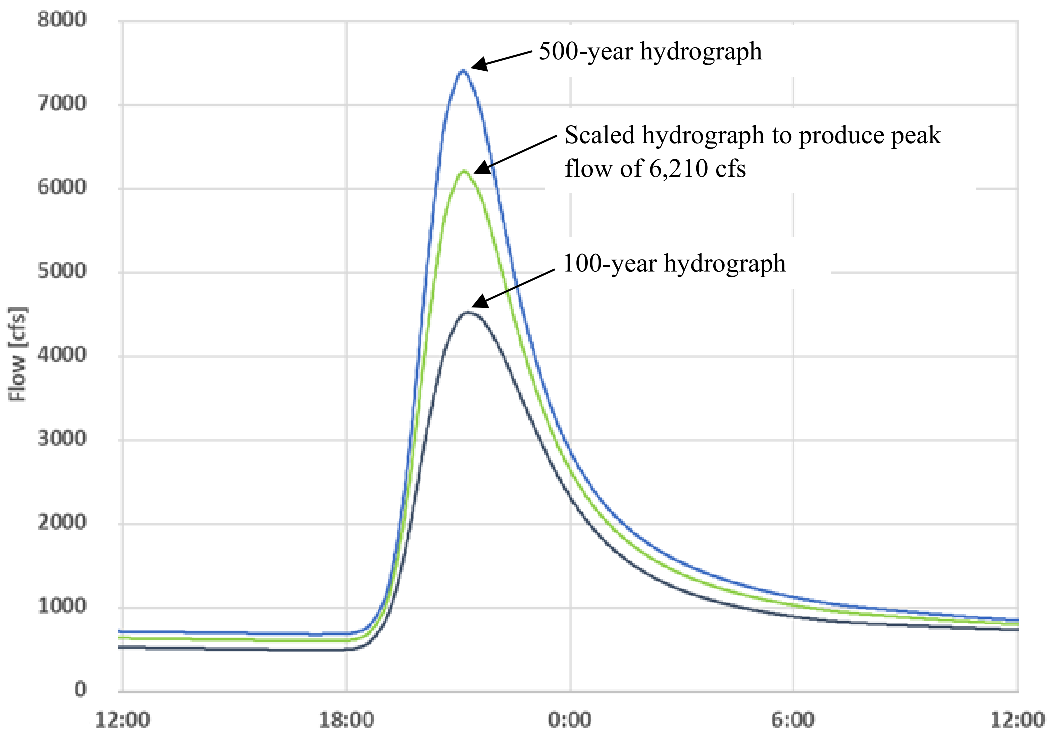
A primary objective of Option 3 (Approx. 200-Year) is to reduce the design event from the 500-year event to an event between the 100-year and 500-year events. The existing MIKE FLOOD model that was used as the basis for performing the hydraulic modeling is a combination hydrologic/hydraulic model but only includes the 100-year and 500-year events. A previous hydrology study was performed (HDR, 2007) that includes hydrologic modeling for the 200-year event completed in the MIKE 11 hydrologic model. However, it would require a significant amount of effort to incorporate the 200-year hydrology results from the MIKE 11 model into the existing MIKE FLOOD model. Therefore, a simplified approach was used to approximate the 200-year inflow for this alternative evaluation.

To simplify this process for the purposes of advancing this concept option, the 500-year hydrograph along the main stem of SBC at Eldorado Canyon in the existing MIKE FLOOD model was scaled down to match peak flow results generated from the MIKE 11 hydrology model for SBC at Eldorado Canyon. MIKE 11 peak flow results at Eldorado Canyon are presented in Table 5.8. MIKE FLOOD hydrographs at Eldorado Canyon are presented in Graph 5.1 below. Other hydrographs along the main stem of SBC in the MIKE FLOOD model were scaled down similarly to the Eldorado Canyon hydrographs. Hydrographs for local basins (i.e., basins not on the main stem of SBC) were based on hydrographs used in the 2015 Master Plan, and range from more frequent events (i.e., 5-

to 10-year events) up to the 100-year event. The hydrographs for the local basins were not changed to be consistent with previous studies.

TABLE 5.8
PEAK FLOWS IN SOUTH BOULDER CREEK AT ELDORADO CANYON

Event	Peak Flow (cfs)
100-year	4,520
200-year	6,210
500-year	7,400



Graph 5.1 – Hydrographs at Eldorado Canyon

While the scaled hydrographs are based in part on 200-year hydrologic modeling results, they do not represent the 200-year event as reliably as hydrographs developed using rainfall-runoff modeling for the 100-year and 500-year events. For this reason, the Project Team decided to use the term “approximate 200-year event” herein to describe this event.

5.5.3.4.2: Baseline (Approx. 200-Year)

Hydraulic modeling was initially performed for the intermediate-year event for a 60-inch-diameter outlet and with fill on approximately 34 acres on the northern PUB land use in the CU Boulder South campus similar to Option 1. Key hydraulic modeling results are presented in Table 5.9. Hydrographs below the US36 bridge and at South Boulder Road are presented on Figures 5.21 and 5.22, respectively. A plan of differences in maximum WSEs compared to the effective model is presented on Figure 5.23.

TABLE 5.9
BASELINE HYDRAULIC MODELING RESULTS (APPROX. 200-YEAR)

Configuration	Max WSE in Pond (ft)	Peak Flow US36 Bridge (cfs)	Peak Flow S. Boulder Rd. (cfs)	Peak Outlet Flow (cfs)	Increase Downstream Flooding (Yes/No)(1)
Existing Conditions	N/A	4,580	6,710	N/A	N/A
60-Inch-Diameter	5366.0	6,360	7,300	375	Yes

Notes:
1. Increases attributed to minor modeling fluctuations were not considered. Minor modeling fluctuations was generally considered to consist of rises less than 0.1 feet in areas where rises could not be reasonably explained.

This configuration would result in increases in flows through the US36 bridge (i.e., 40 percent), at South Boulder Road (i.e., 9 percent), and at other downstream locations compared to existing conditions. These increases in flows are primarily caused by the loss of flood detention storage resulting from placing fill on 34 acres on the northern PUB land use area. A portion of this area would be required for flood storage during the intermediate event. In our opinion, increasing the outlet capacity for this configuration would not be sufficient to prevent incremental increases in downstream flooding compared to the existing conditions. For this reason, we dismissed the Baseline configuration for the approximate 200-year.

5.5.3.4.3: Option 3 (Approx. 200-Year)

Based on the Baseline hydraulic modeling results, the Project Team decided to reduce the area of fill on the northern PUB land use area and add fill to the OS-O land use area to maintain 129 acres of buildable area for CU. Placing fill on the northern PUB land use is more desirable because placing fill on the OS-O land use area would restrict future environmental restoration/mitigation activities on this land use.

RJH performed a simplified analysis to identify an approximate preferred fill distribution. Placing fill on the northern PUB land use area will provide additional buildable area for CU but would also reduce the amount of flood storage in this area. These are competing considerations – as one of these considerations is improved, the other is worsened. The preferred fill distribution will provide the best combination of providing buildable area for CU while limiting reductions in flood storage.

RJH evaluated three fill distributions. A plan of the fill distributions on the northern PUB land use area is shown on Figure 5.24. For each distribution, we calculated a) the percent of full buildable area that would be retained and b) the percent of full flood storage that would be retained. We defined the preferred fill distribution as the distribution where the sum of these two percentages is the highest. Results of this evaluation are presented in Table 5.10. Based on this evaluation, the preferred fill distribution would be approximately 50 percent on the northern PUB land use and 50 percent on the OS-O land use. This configuration was used for the hydraulic modeling.

TABLE 5.10
FILL DISTRIBUTION RESULTS

Fill Configuration	Buildable Area on PUB (ac)	(A) Percent of Full Buildable Area on PUB	Flood Storage (ac-ft)	(B) Percent of Full Flood Storage	(C) = (A) + (B) Percent Buildable Area + Percent Flood Storage
Zero Fill on northern PUB	0	0	210	100	100
25 Percent of Fill on northern PUB	9	25	199	95	120
50 Percent of Fill on northern PUB	17	50	165	78	128
70 Percent of Fill on northern PUB	24	70	113	54	124

Hydraulic modeling was performed for the intermediate event for three outlet sizes: 60-, 84-, and 108-inch-diameter pipes with the fill distribution described above. Key hydraulic modeling results are presented in Table 5.11. Hydrographs below the US36 bridge and at South Boulder Road are presented on Figures 5.25 and 5.26, respectively. A plan of differences in maximum WSEs compared to the effective model is presented on Figure 5.27.

TABLE 5.11
OPTION 3 HYDRAULIC MODELING RESULTS (APPROX. 200-YEAR)

Configuration	Max WSE at US38 Bridge (ft)	Max WSE in Pond (ft)	Peak Flow US36 Bridge (cfs)	Peak Flow S. Boulder Rd. (cfs)	Peak Outlet Flow (cfs)	Increase Downstream Flooding (Yes/No)(1)
Existing Conditions	5362.8	N/A	4,580	6,710	N/A	N/A
60-inch-diameter	5363.7	5365.5	5,650	6,950	370	Yes
84-inch-diameter (~2 – 60" Diameter)	5363.4	5365.0	5,230	6,100	790	Yes
108-inch-diameter (~3 – 60" Diameter)	5363.0	5364.5	4,730	6,350	1,340	No

Notes:
1. Increases attributed to minor modeling fluctuations were not considered. Minor modeling fluctuations was generally considered to consist of rises less than 0.1 feet in areas where rises could not be reasonably explained.

All of the outlet sizes would increase peak flows through the US36 bridge compared to existing conditions. The 108-inch-diameter outlet would increase peak flows the least (i.e., 3 percent), and it is possible that this level of increase may not result in negative impacts to the bridge or could be mitigated with scour protection at the bridge. The 60-inch-diameter outlet would increase peak flows at South Boulder Road compared to existing conditions and is not acceptable. The 84-inch-diameter outlet would reduce the peak flow at South Boulder Road but would result in incremental rises in downstream WSEs up to about 0.1 foot along the main stem of SBC because of timing issues with downstream tributary hydrographs. For this reason, the 84-inch-diameter outlet is not acceptable. RJH selected three 60-inch-diameter outlet pipes for Option 3 (Approx. 200-Year).

Additional analyses would be required to evaluate the performance of Option 3 (Approx. 200-Year) for a 100-year flood event.

5.5.4 Environmental Impacts

5.5.4.1: Evaluation

Potential impacts were identified based on a) the CORVUS 2019 environmental survey for areas within the environmental survey limits and b) a combination of a 2014 environmental survey by ERO and high-resolution aerial photography for areas outside of the CORVUS 2019 survey limits.

A summary of potential permanent environmental impacts is provided in Table 5.12. A summary of potential temporary environmental impacts is provided in Table 5.13. The temporary impacts would result from construction activities on OSMP property for construction of the floodwall and would likely need to be mitigated. We considered that an approximate 90-foot-wide strip of land south of the floodwall would be disturbed during construction.

TABLE 5.12
POTENTIAL PERMANENT ENVIRONMENTAL IMPACTS

Configuration	Wetlands (ac)	Open Water (ac)	Total Open Water and Wetlands(1) (ac)	Total T&E Habitat(1) (ac)
Option 1	4.80	2.58	7.38	0.88
Option 2	7.11	2.57	9.68	5.01
Option 3	8.92	2.58	11.50	5.00

Notes:
1. Some areas of wetlands and T&E habitat may overlap.

TABLE 5.13
POTENTIAL TEMPORARY ENVIRONMENTAL IMPACTS

Configuration	Wetlands (ac)	Open Water (ac)	Total Open Water and Wetlands(1) (ac)	Total T&E Habitat(1) (ac)
Option 1	2.56	0.02	2.96	5.52
Option 2	2.56	0.02	2.96	5.52
Option 3	2.56	0.02	2.96	5.52

Notes:
1. Some areas of wetlands and T&E habitat may overlap.

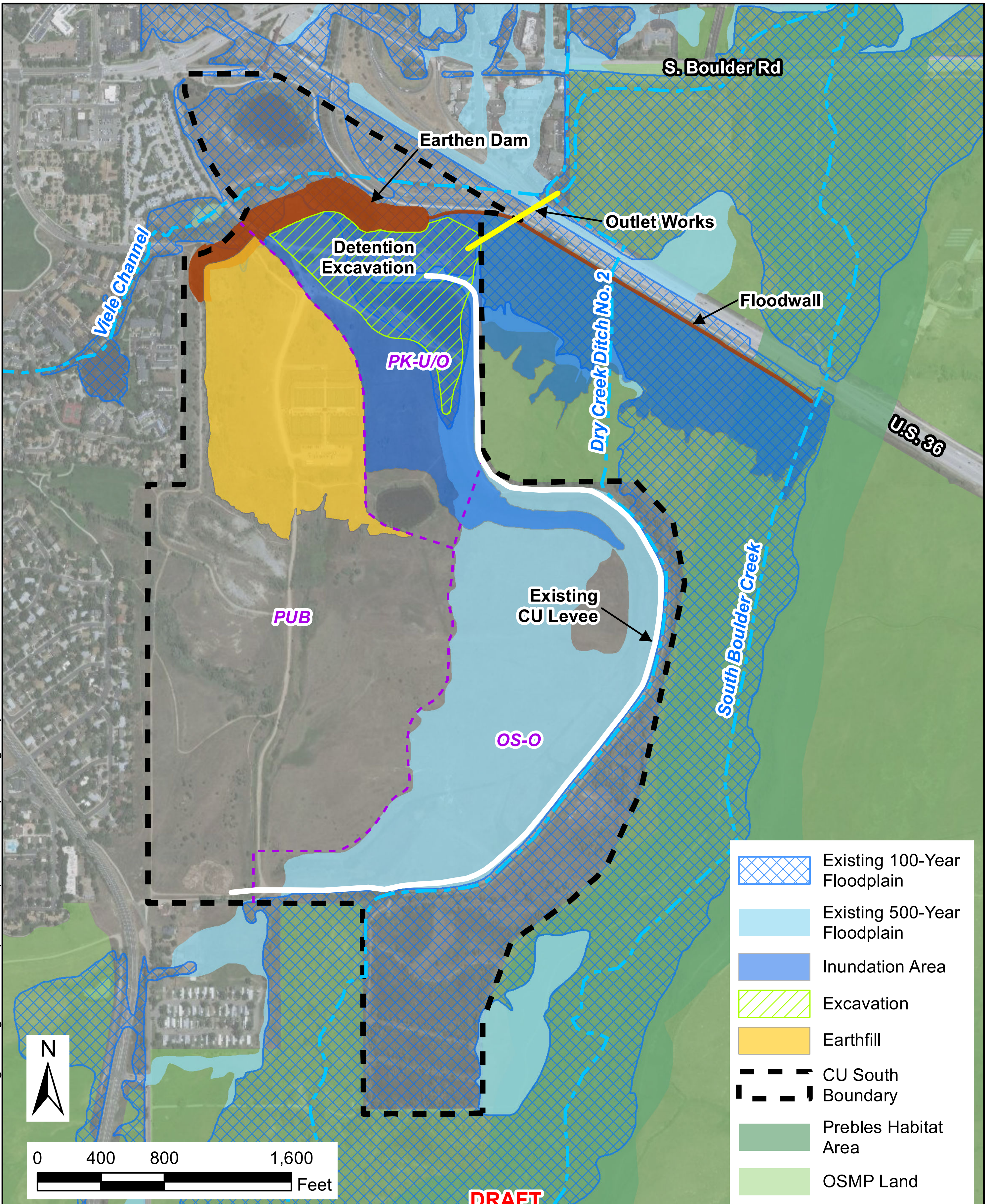
Environmental impacts shown in Table 5.12 do not include impacts associated with removal of the CU levee. The current concept is to remove the functionality of the levee and provide riparian connectivity to SBC by selectively removing portions of the levee without impacting wetlands, open water, or T&E species habitat. Therefore, levee removal has been assumed to not contribute to environmental impacts for any of the alternatives and is not a differentiating consideration for the concept design phase.

Potential permanent impacts to open water and wetlands vary from about 7.4 to 11.5 acres with Option 3 having the most impacts. Potential permanent impacts to T&E species habitat vary from about 0.9 to 5.0 acres with Options 2 and 3 having the most impacts. Impacts to potential ULTO habitat would occur in herbaceous wetlands in the

CU Boulder South property. Impacts to PMJM habitat would only occur along the main stem of SBC and are not anticipated.

5.5.4.2: Permitting Feasibility

Prior to impacting wetlands and open water, the City will need to obtain CWA Section 404 authorization from the USACE. As part of its review of the Section 404 permit, the USACE is required to evaluate alternatives to the proposed project that will achieve the project's purpose. The USACE will not issue a permit if a practicable alternative exists that would have less adverse impact on the aquatic ecosystem (i.e., the Least Environmentally Damaging Practicable Alternative (LEDPA)). Typically, the project alternative with the least impacts to wetlands and open water is designated by the USACE as the LEDPA. Based on the environmental impacts evaluation, Option 1 has the fewest environmental impacts, but a direct comparison is not be appropriate because the options are based on different design events and therefore have a different Project purpose. Additional alternatives may need to be evaluated after the City has selected a preferred design event to identify the LEDPA.



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REPRODUCE IN COLOR

RJH CONSULTANTS, INC.

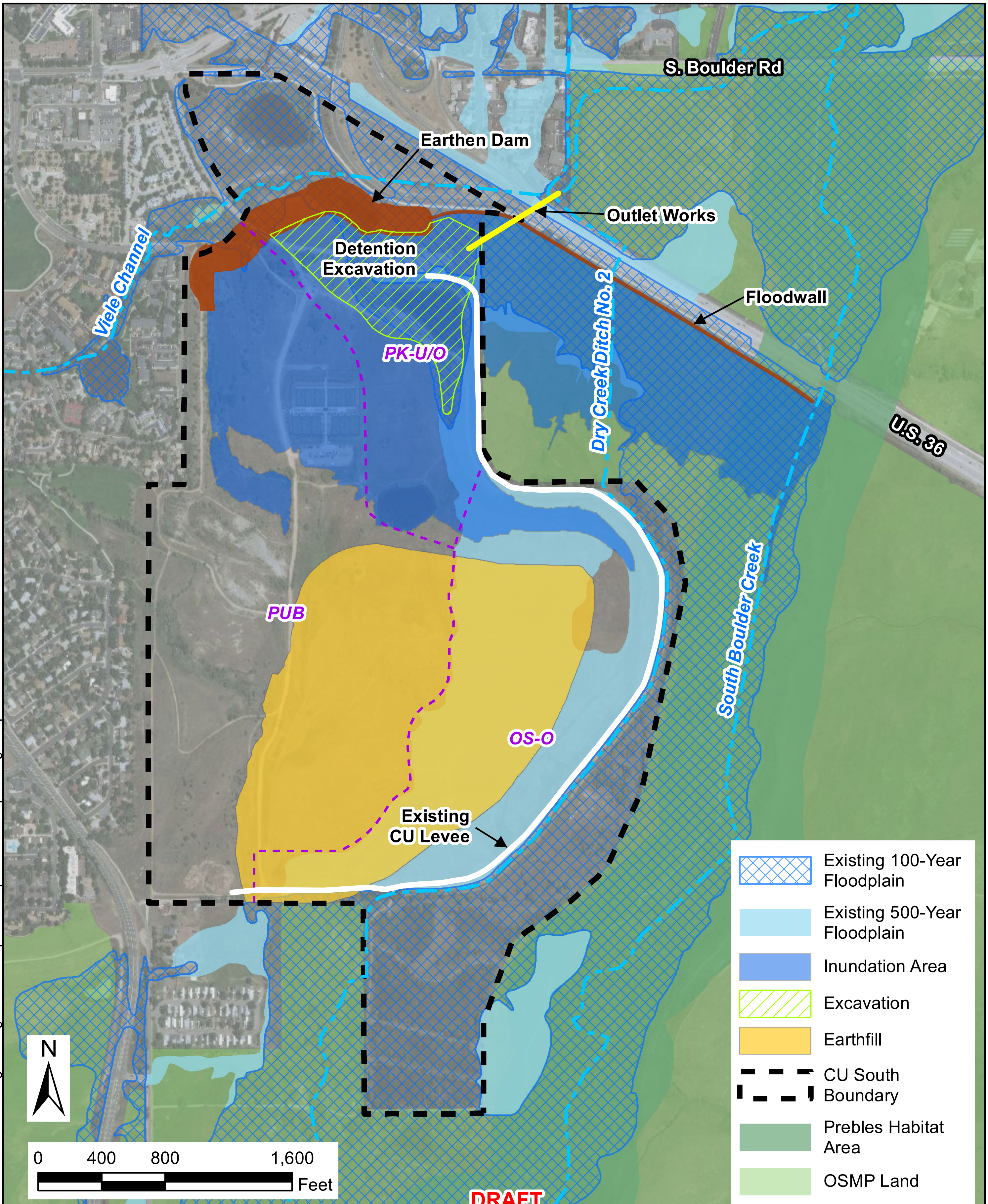
SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN

PROJECT NO. 16134

PLAN OF OPTION 1

February 2020

Figure 5.1



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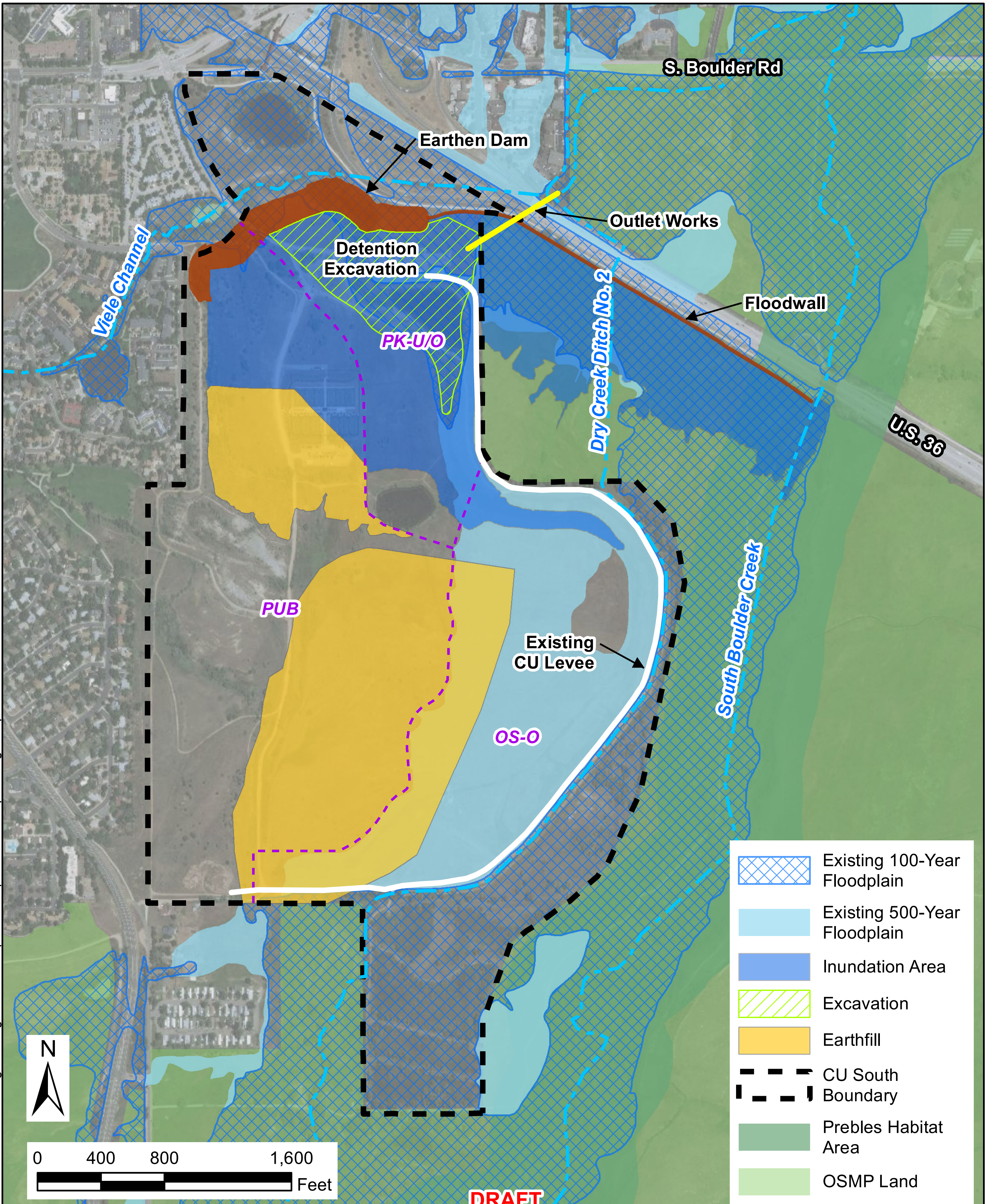
REPRODUCE IN COLOR	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	PLAN OF OPTION 2
		PROJECT NO. 16134	February 2020 **Figure 5.2**



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REPRODUCE IN COLOR

RJH CONSULTANTS, INC.

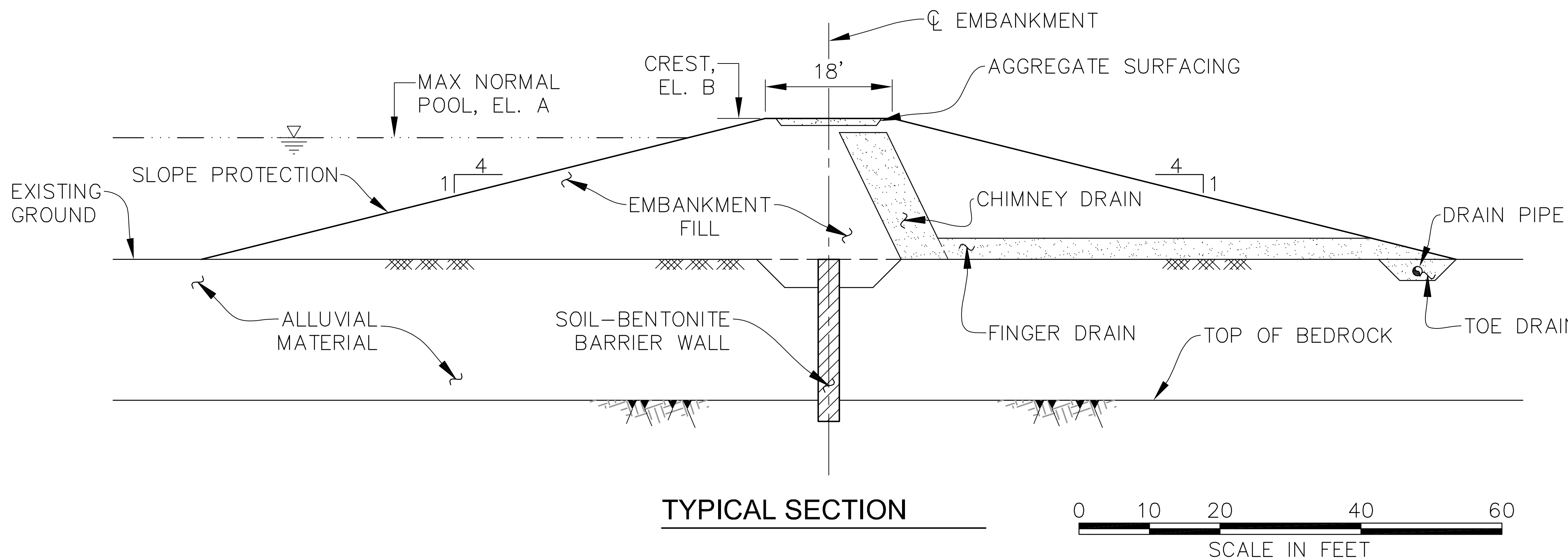
SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN

PLAN OF OPTION 3

PROJECT NO. 16134

February 2020

Figure 5.3



TYPICAL SECTION

CONFIGURATION	ELEV. A	ELEV. B
OPTION 1	5363.8	5371.8
OPTION 2	5365.6	5373.6
OPTION 3	5364.5	5372.5

NOT FOR CONSTRUCTION

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN

PROJECT NO. 16134

TYPICAL SECTIONS - EARTHEN EMABANKMENT

February 2020

Figure 5.4

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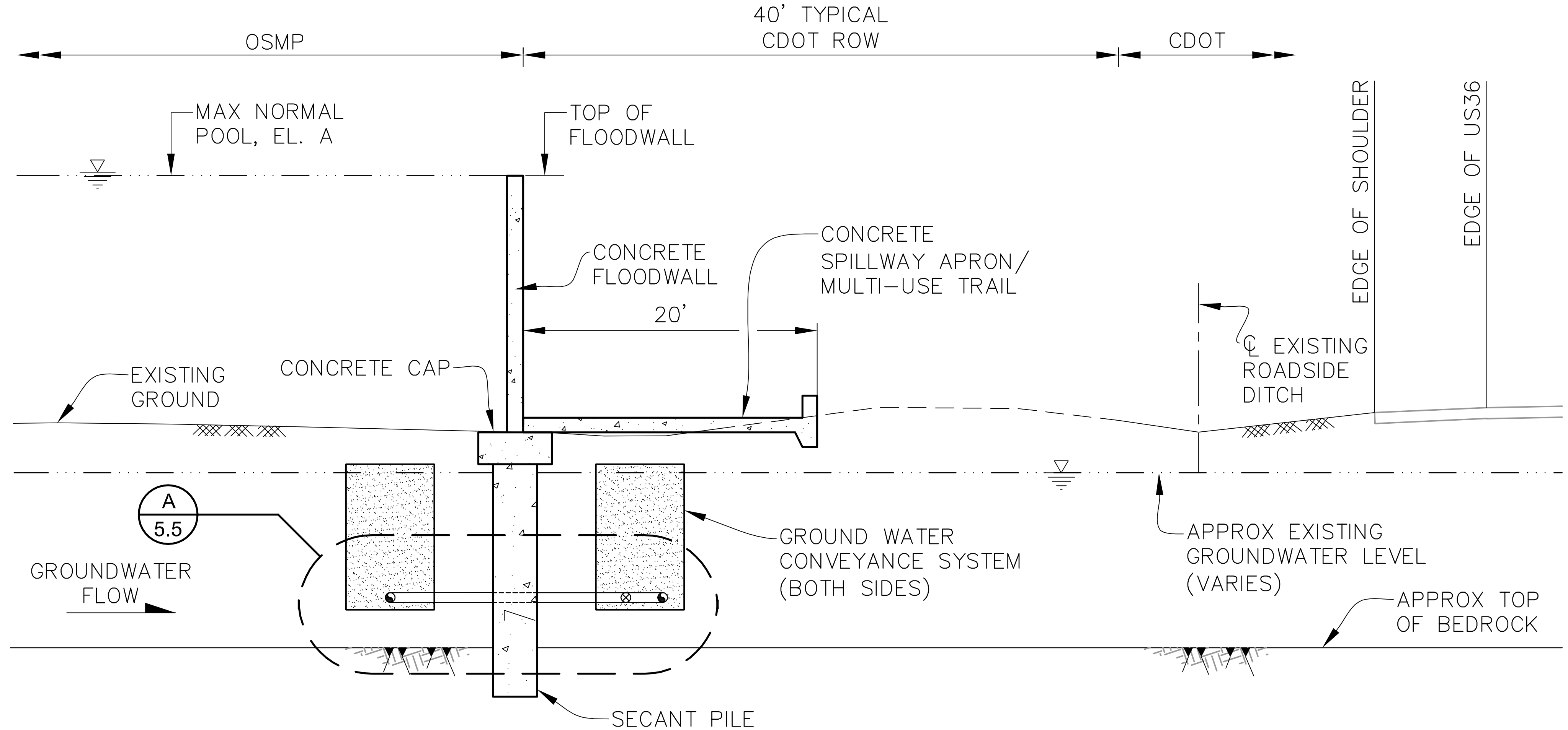
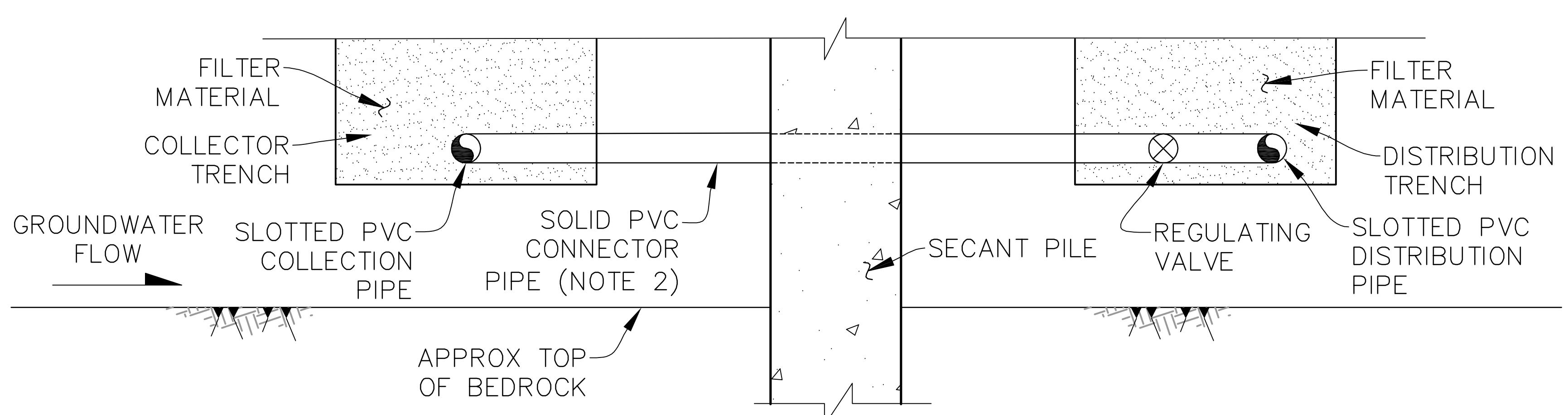


TYPICAL SECTION



DETAIL A 5.5

GROUND WATER CONVEYANCE SYSTEM

NOT FOR CONSTRUCTION

NOTES:

1. REINFORCEMENT NOT SHOWN FOR CONCRETE STRUCTURES.
2. SIZE AND SPACING TO BE IDENTIFIED DURING PRELIMINARY DESIGN.

CITY OF BOULDER

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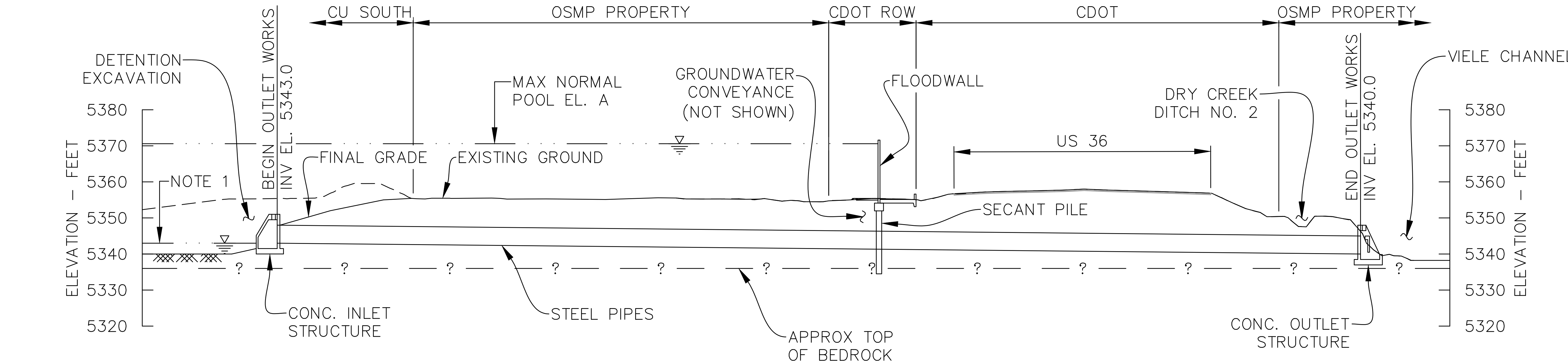
SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN

PROJECT NO. 16134

FLOODWALL AND GROUNDWATER CONVEYANCE SYSTEM

February 2020

Figure 5.5



NOTES:

1. MIN. NORMAL POOL ELEVATION 5343.0.

PROFILE
OUTLET WORKS

NOT FOR CONSTRUCTION

0 30 60 120 180
HORIZONTAL SCALE IN FEET

0 1 2 4 6
VERTICAL SCALE IN FEET

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN
		PROJECT NO. 16134
OUTLET WORKS PROFILE		
February 2020		**Figure 5.6**

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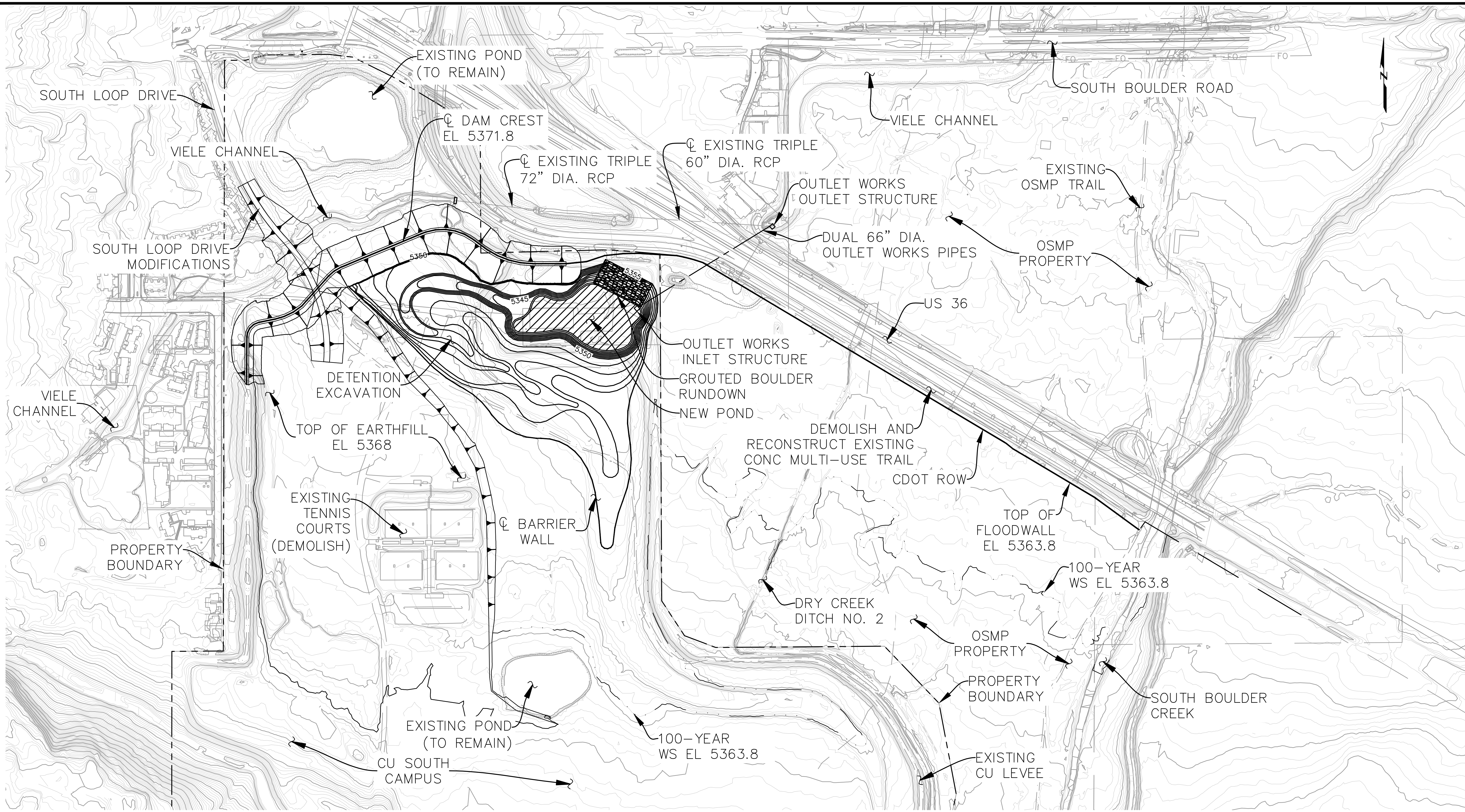

0 200 400 800
SCALE IN FEET

NOT FOR CONSTRUCTION

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SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	PLAN OF OPTION 1	
PROJECT NO. 16134	February 2020	**Figure 5.7**

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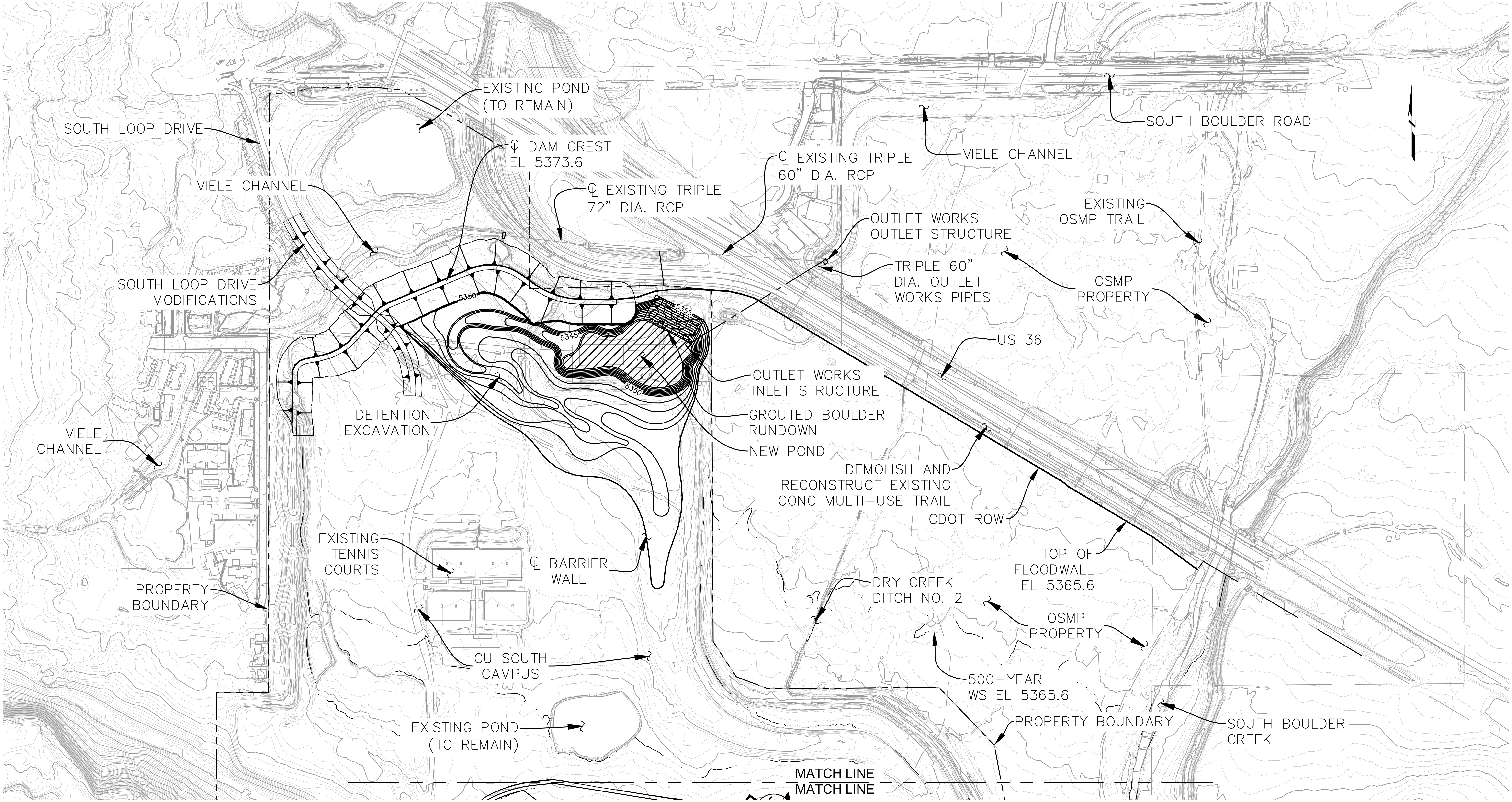

NOT FOR CONSTRUCTION

0 200 400 800
SCALE IN FEET

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK
REGIONAL DETENTION
CONCEPT DESIGN

PLAN OF OPTION 2
SHEET 1 OF 2

PROJECT NO. 16134

February 2020

Figure 5.8

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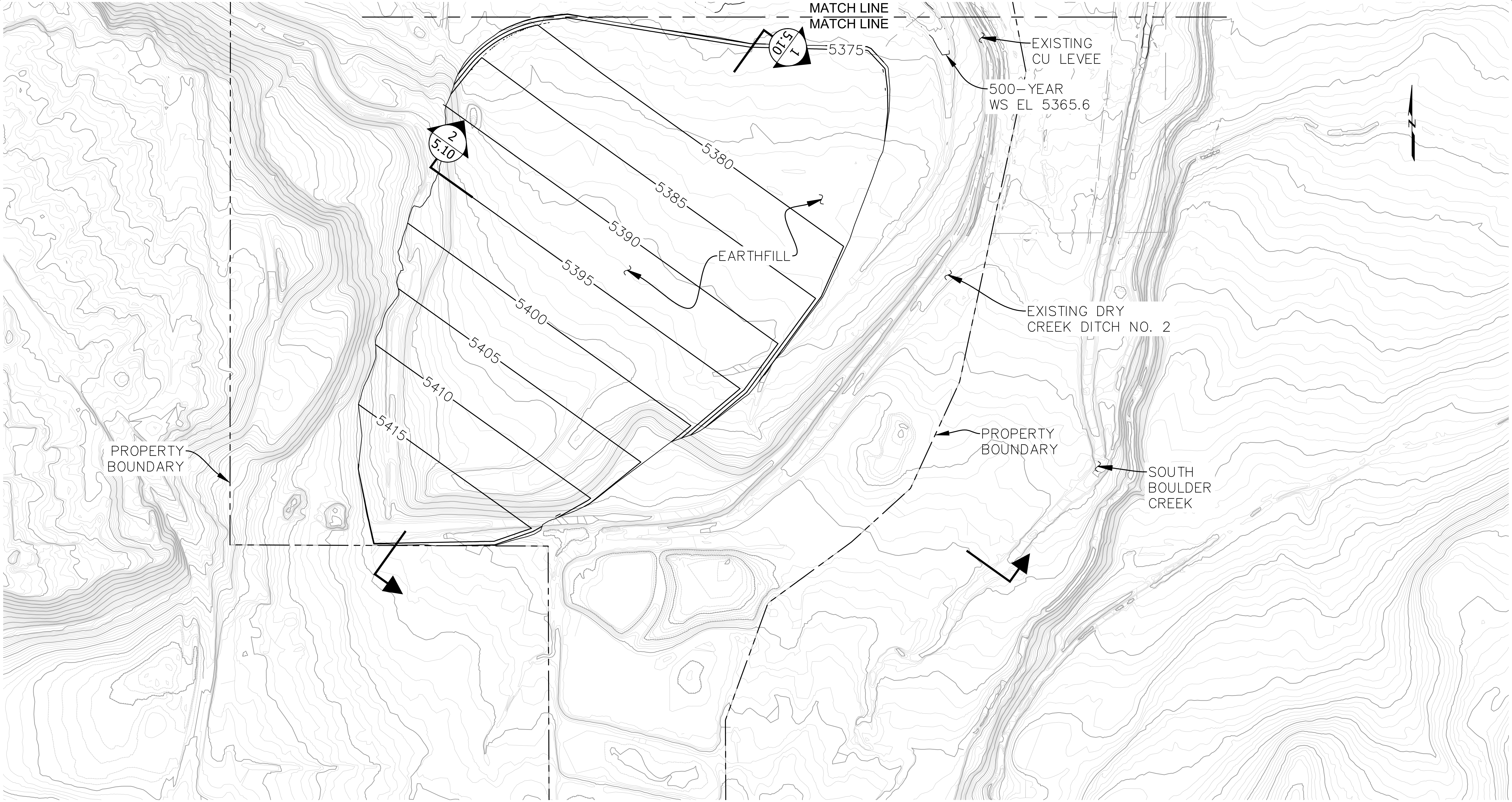

NOT FOR CONSTRUCTION

0 200 400 800
SCALE IN FEET

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK
REGIONAL DETENTION
CONCEPT DESIGN

PLAN OF OPTION 2
SHEET 2 OF 2

PROJECT NO. 16134

February 2020

Figure 5.9

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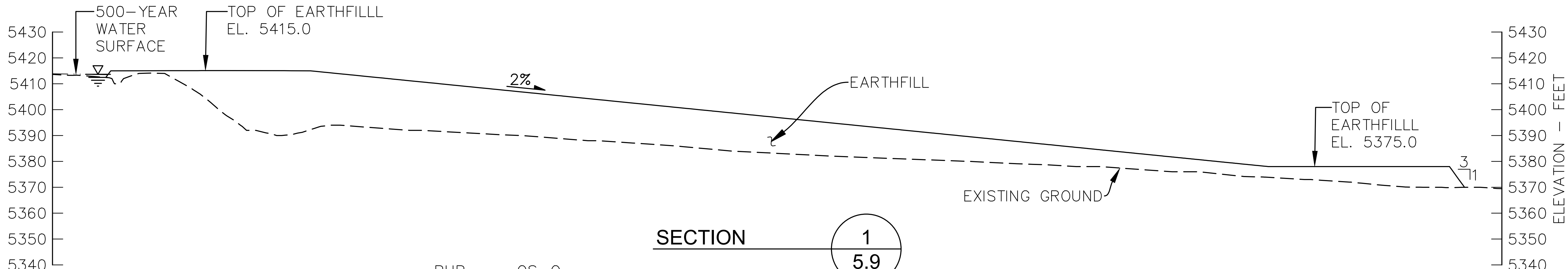
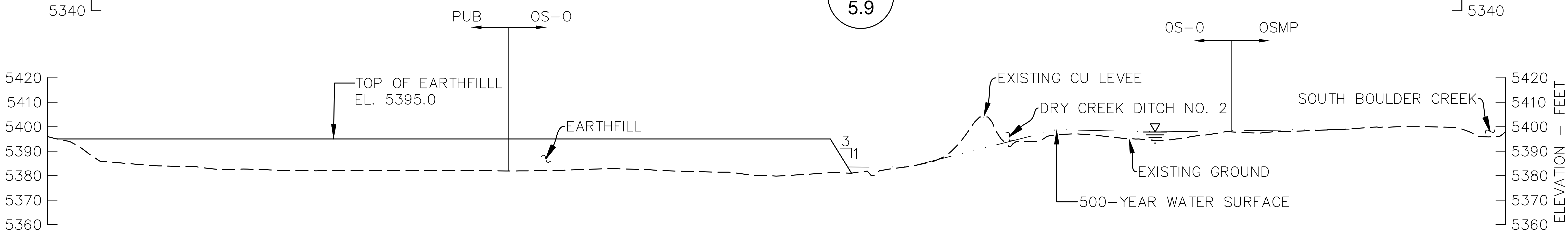
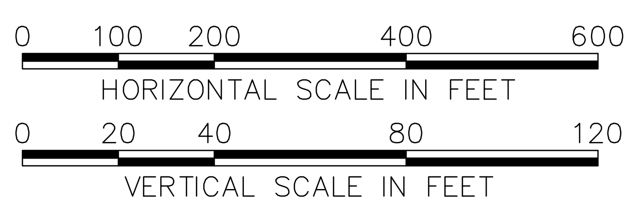


SECTION 1/5.9



SECTION 2/5.9



NOT FOR CONSTRUCTION

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	OPTION 2 SECTIONS
		PROJECT NO. 16134	February 2020 **Figure 5.10**

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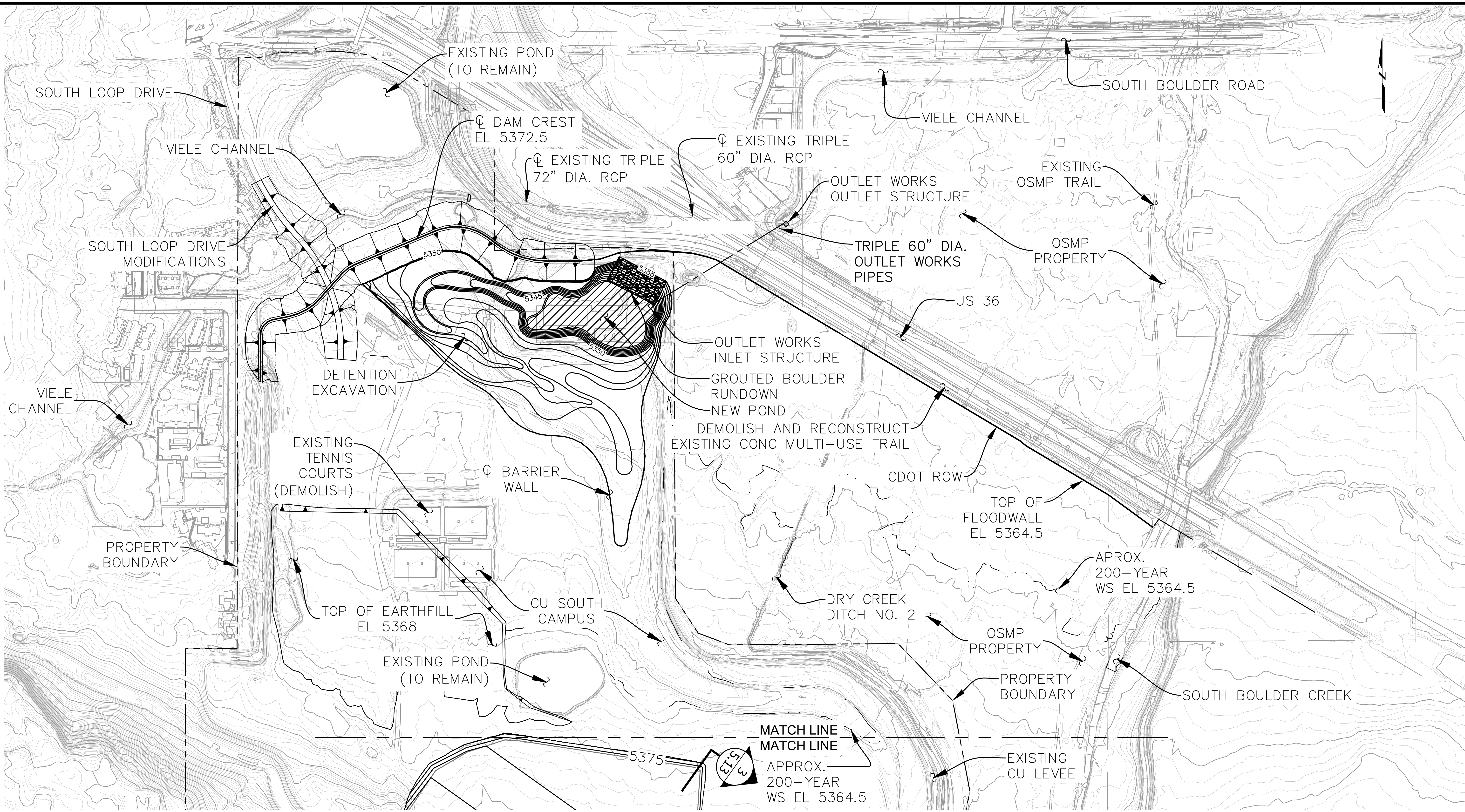
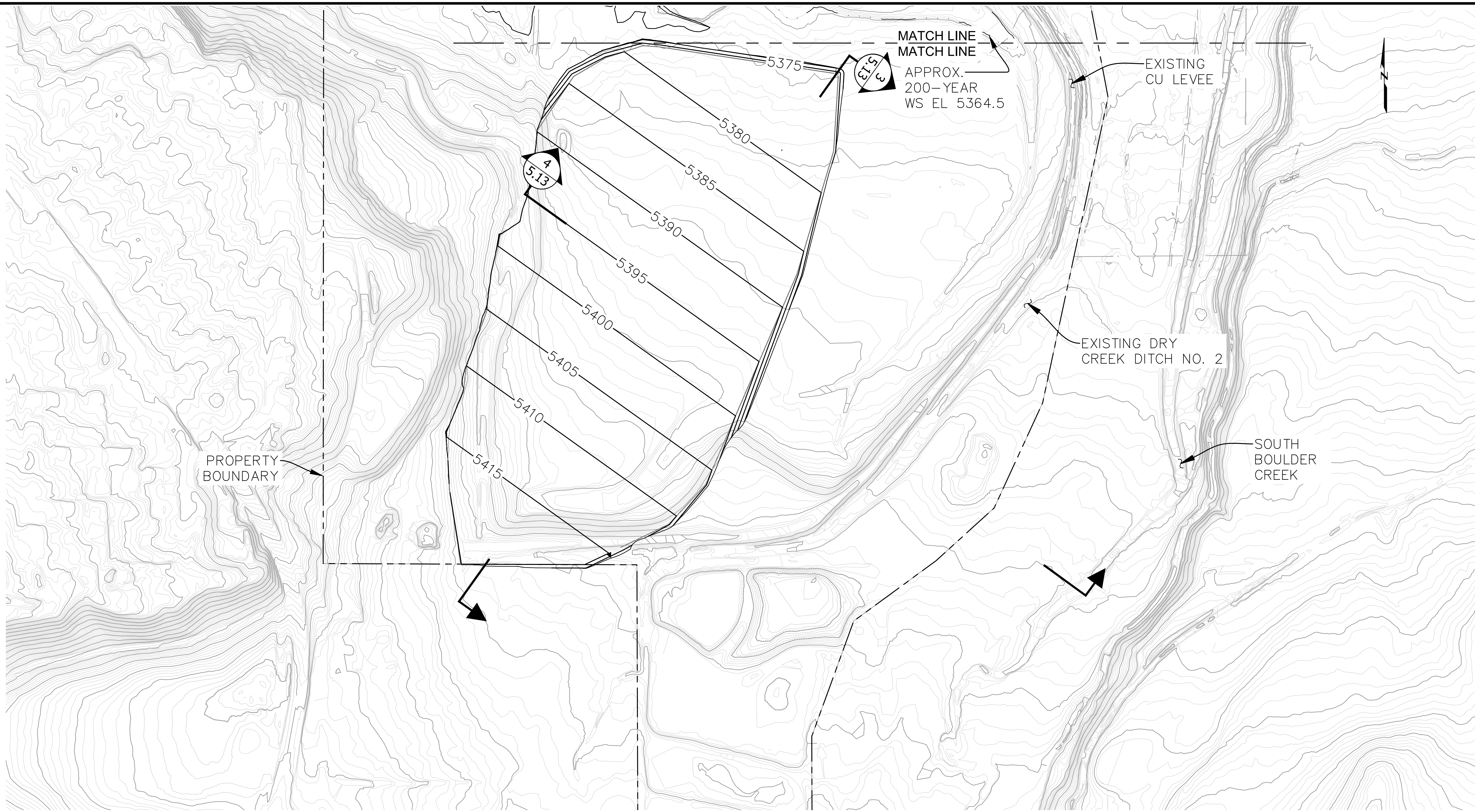


NOT FOR CONSTRUCTION

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	PLAN OF OPTION 3 SHEET 1 OF 2
		PROJECT NO. 16134	February 2020 **Figure 5.11**

P:\16134 - SOUTH BOULDER CREEK\CAD\FIGURES\OPTION 3.DWG 1/30/2020 2:22 PM



NOT FOR CONSTRUCTION

SOUTH BOULDER CREEK
REGIONAL DETENTION
CONCEPT DESIGN

PROJECT NO. 16134

PLAN OF OPTION 3
SHEET 2 OF 2

February 2020

Figure 5.12

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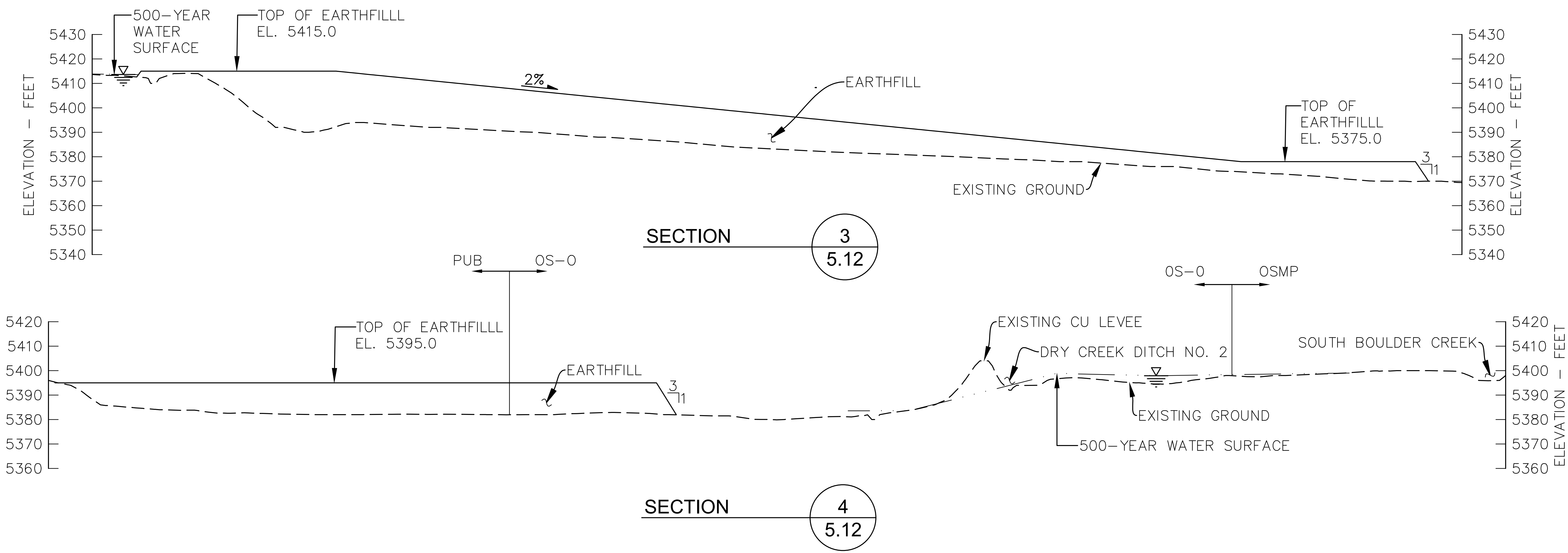

0 100 200 400

HORIZONTAL SCALE IN FEET

0 20 40 80

VERTICAL SCALE IN FEET

NOT FOR CONSTRUCTION

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK
REGIONAL DETENTION
CONCEPT DESIGN

PROJECT NO. 16134

OPTION 3 SECTIONS

February 2020

Figure 5.13

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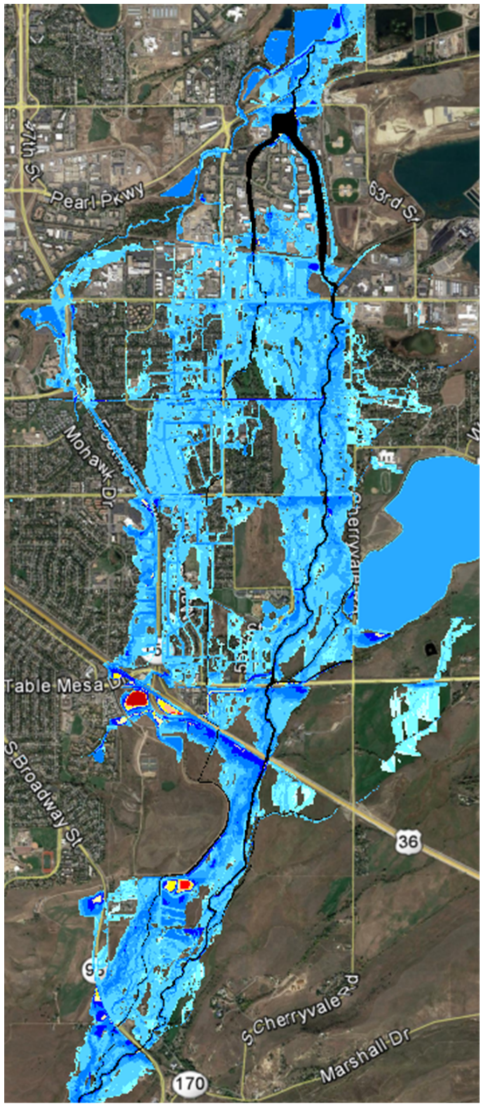
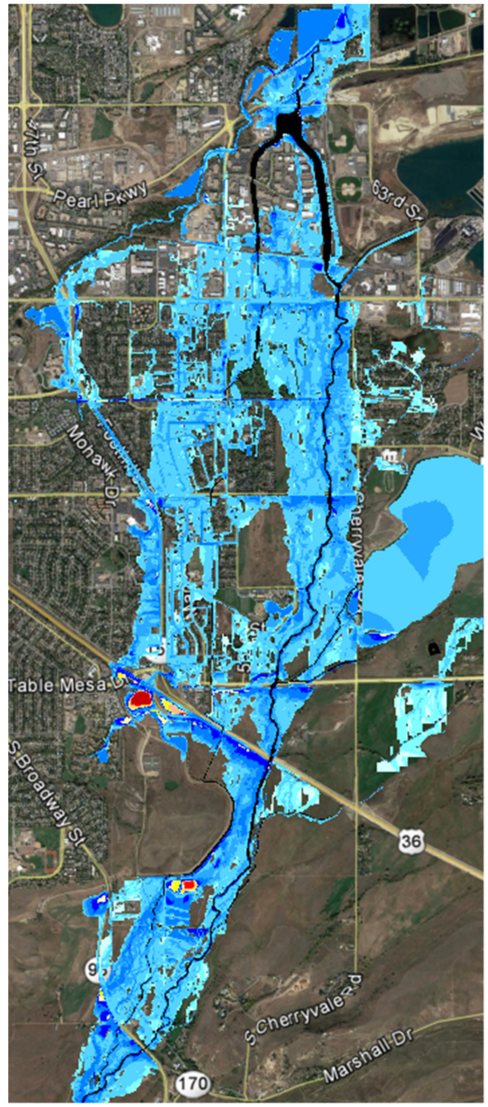
Max. Flow Depth [ft]

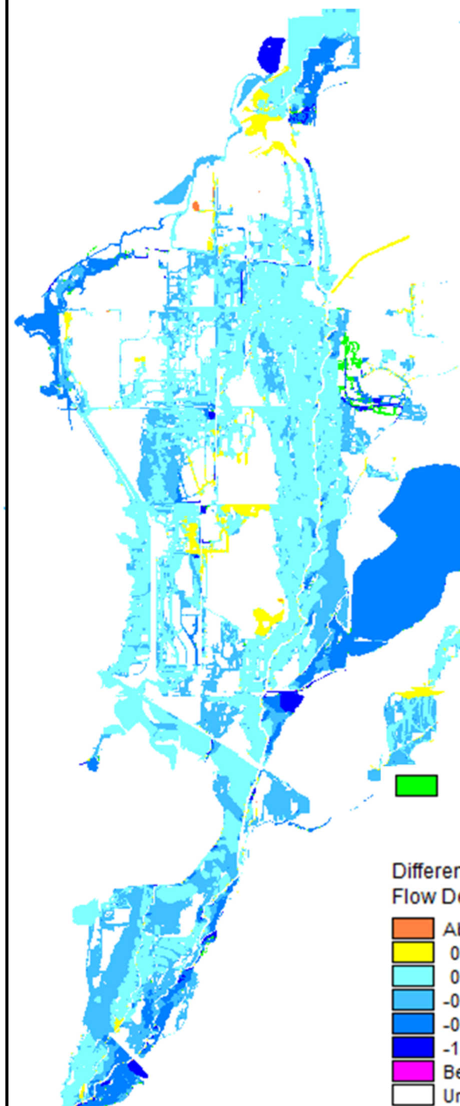
- Above 14.00
- 12.00 - 14.00
- 10.00 - 12.00
- 8.00 - 10.00
- 6.00 - 8.00
- 4.00 - 6.00
- 2.00 - 4.00
- 1.00 - 2.00
- 0.10 - 1.00
- 0.01 - 0.10
- Below 0.01
- Undefined Value



EM100 Version 2009 SP1



EM100 Version 2017 SP1



Ver. 2009 SP1 Inundated Area Not in Ver. 2017 SP1

Difference in Max. Flow Depth [ft]

- Above 1.00
- 0.10 - 1.00
- 0.01 - 0.10
- -0.01 - 0.01
- -0.10 - -0.01
- -1.00 - -0.10
- Below -1.00
- Undefined Value

Differences in Water Surface Elevations

REPRODUCE IN COLOR

DHI / RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	EFFECTIVE MODEL CONVERSION RESULTS
	PROJECT NO. 16134	February 2020 Figure 5.14

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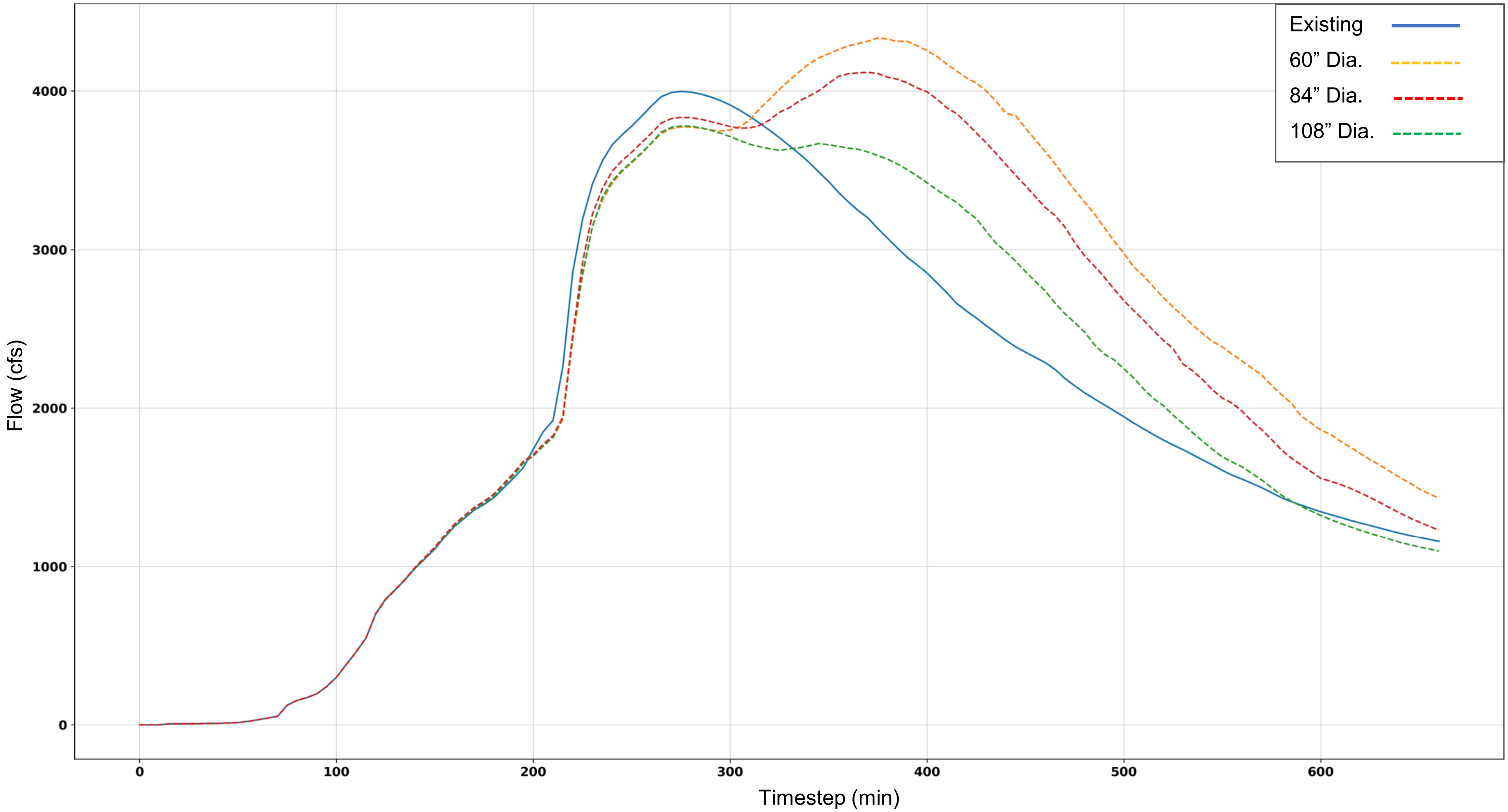

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REPRODUCE
IN COLOR

DHI

RJH CONSULTANTS, INC.

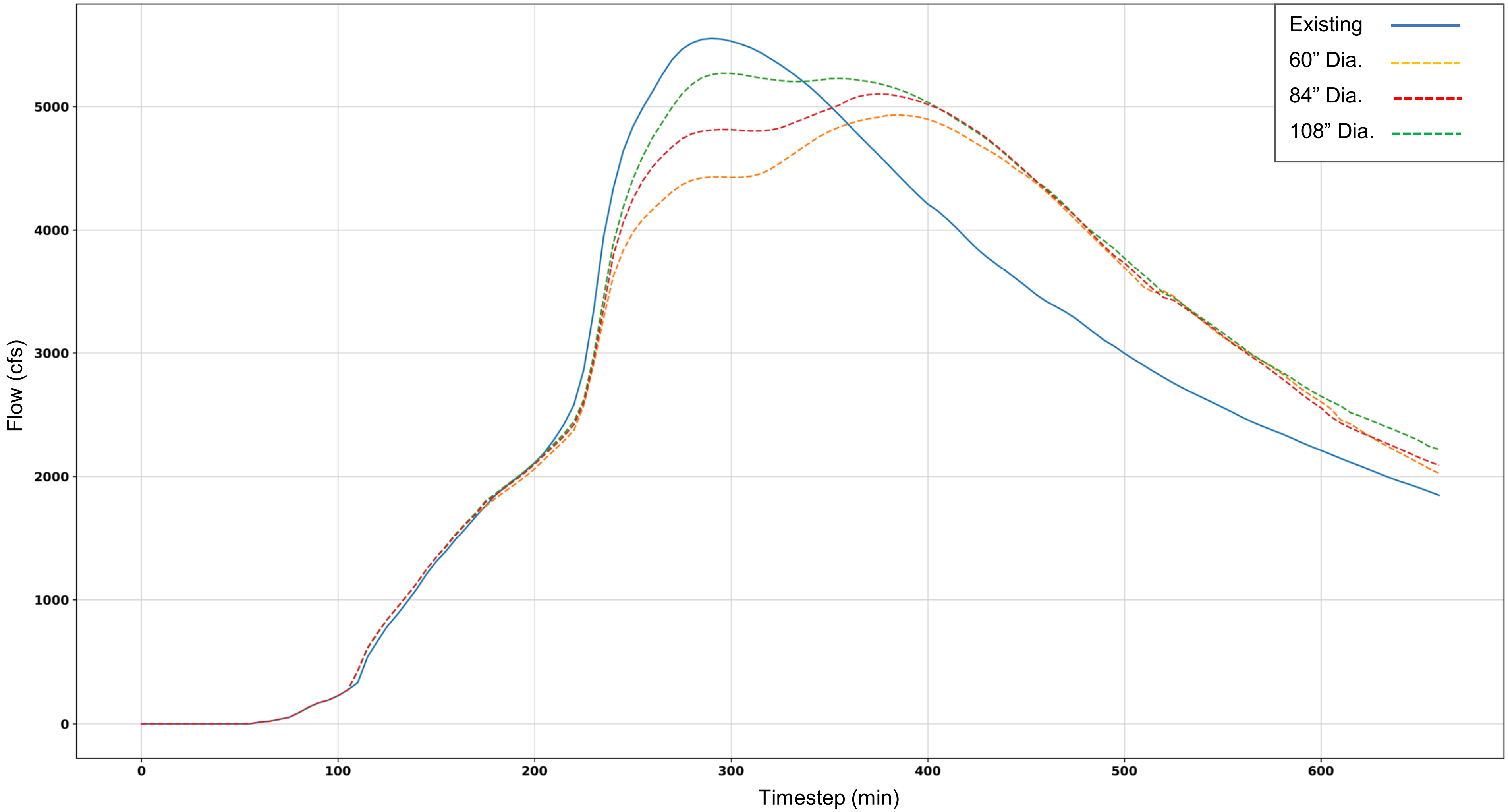
SOUTH BOULDER CREEK
REGIONAL DETENTION
CONCEPT DESIGN

OPTION 1 – HYDROGRAPHS
THROUGH US36 BRIDGE
(100-YEAR)

PROJECT NO. 16134

February 2020

Figure 5.15



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REPRODUCE IN COLOR

DHI

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN

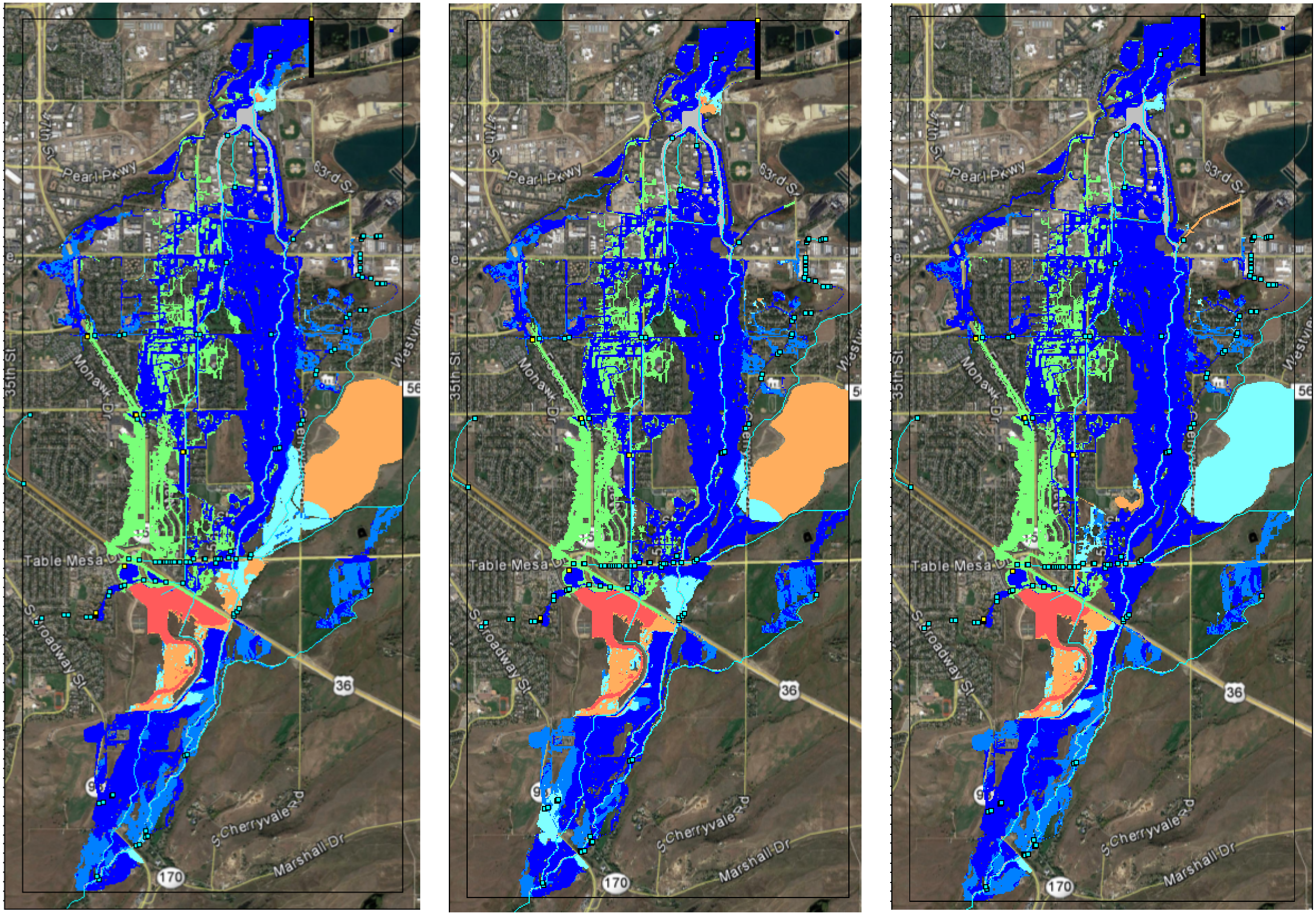
PROJECT NO. 16134

OPTION 1 – HYDROGRAPHS AT SOUTH BOULDER ROAD (100-YEAR)

February 2020

Figure 5.16

COMPARED TO EFFECTIVE MODEL



60” Dia.

84” Dia.

108” Dia.

Difference in max H [ft]

- Above 1.000
- 0.100 - 1.000
- 0.010 - 0.100
- 0.000 - 0.010
- Below 0.000
- Undefined Value
- Dry

REPRODUCE IN COLOR

DHI

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN

OPTION 1 – DIFFERENCES IN MAXIMUM WATER SURFACE ELEVATION (100-YEAR)

PROJECT NO. 16134

February 2020

Figure 5.17

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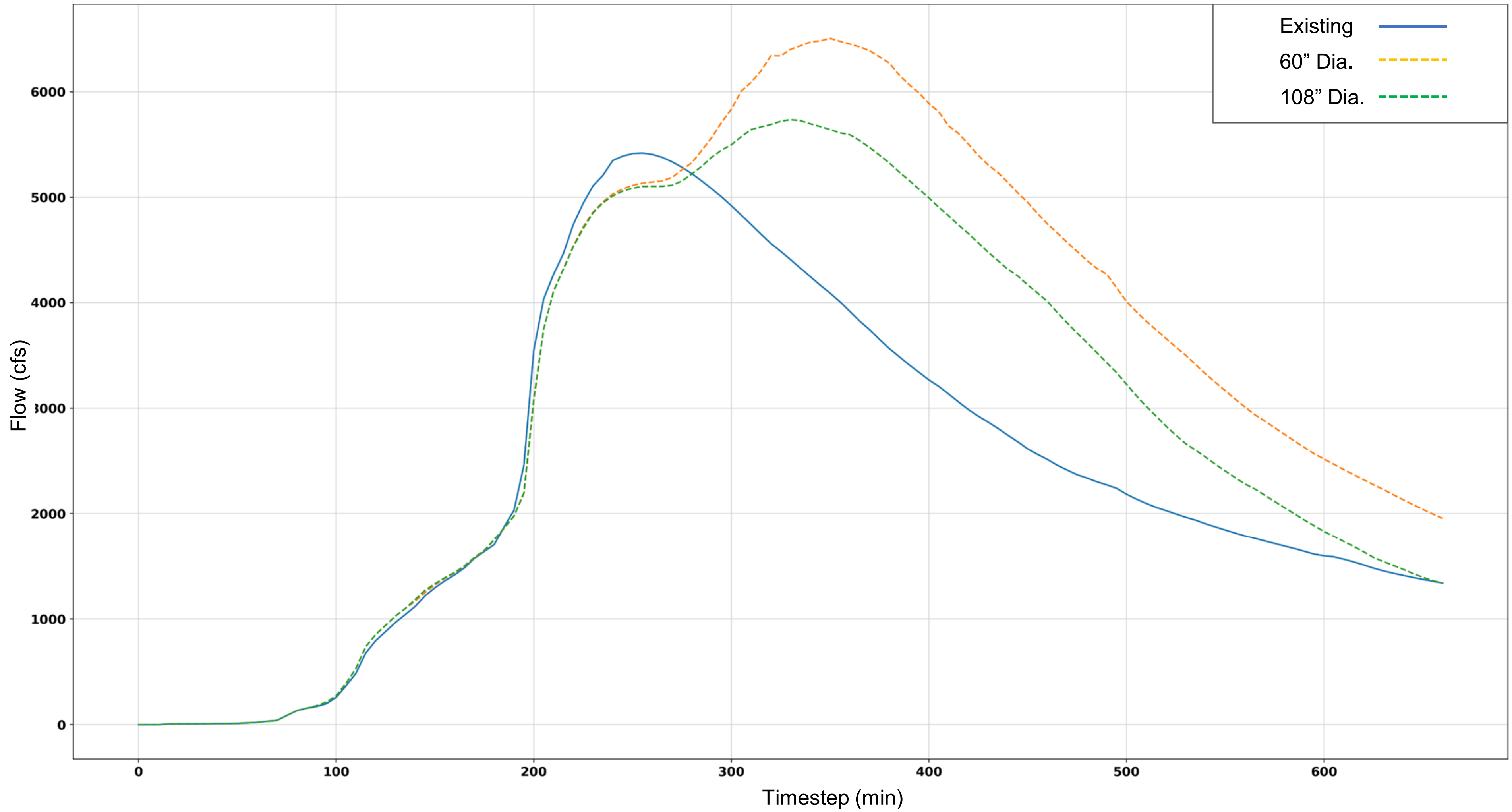

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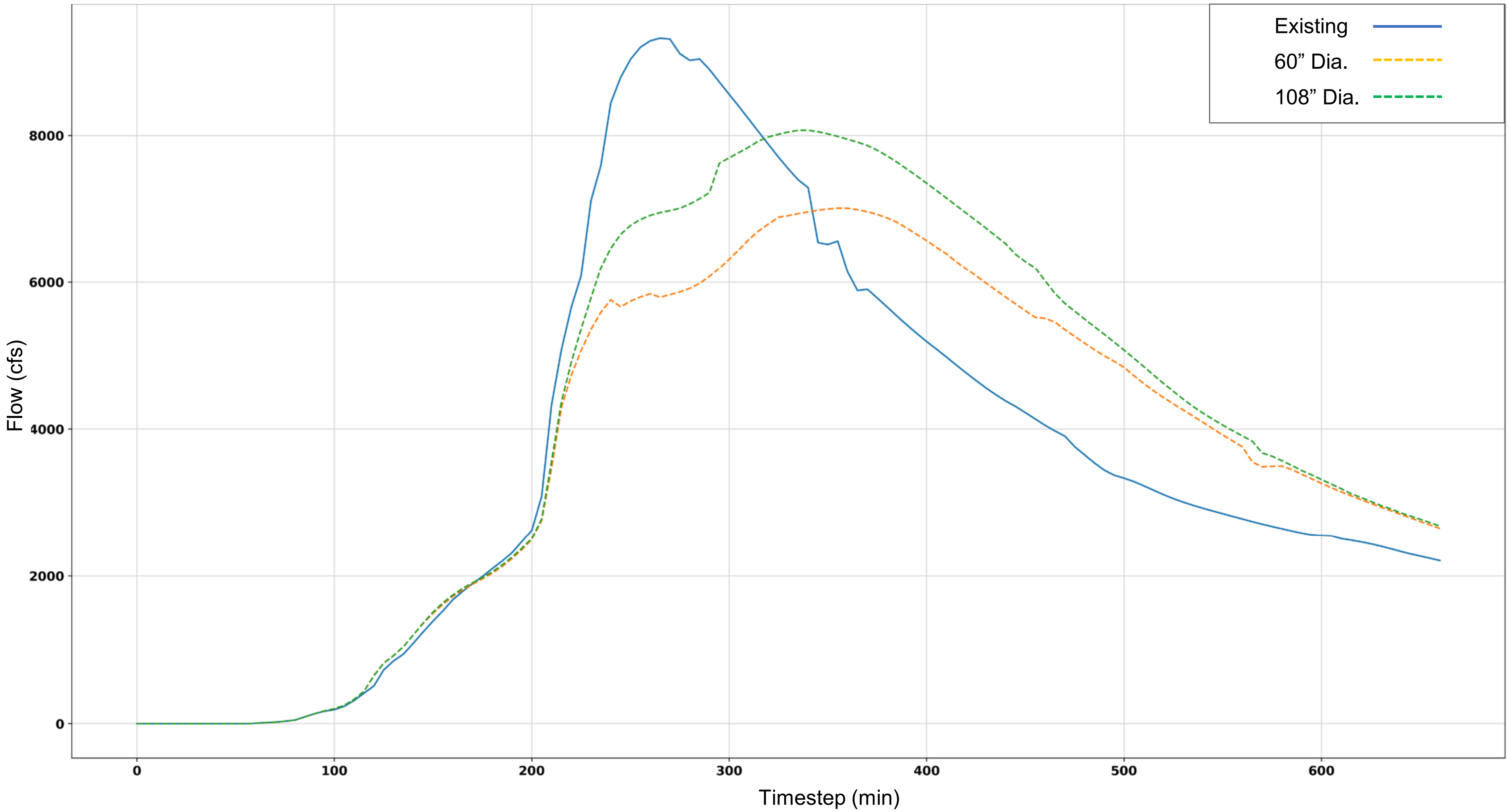
REPRODUCE IN COLOR

DHI	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	OPTION 2 – HYDROGRAPHS THROUGH US36 BRIDGE (500-YEAR)
		PROJECT NO. 16134	February 2020 Figure 5.18



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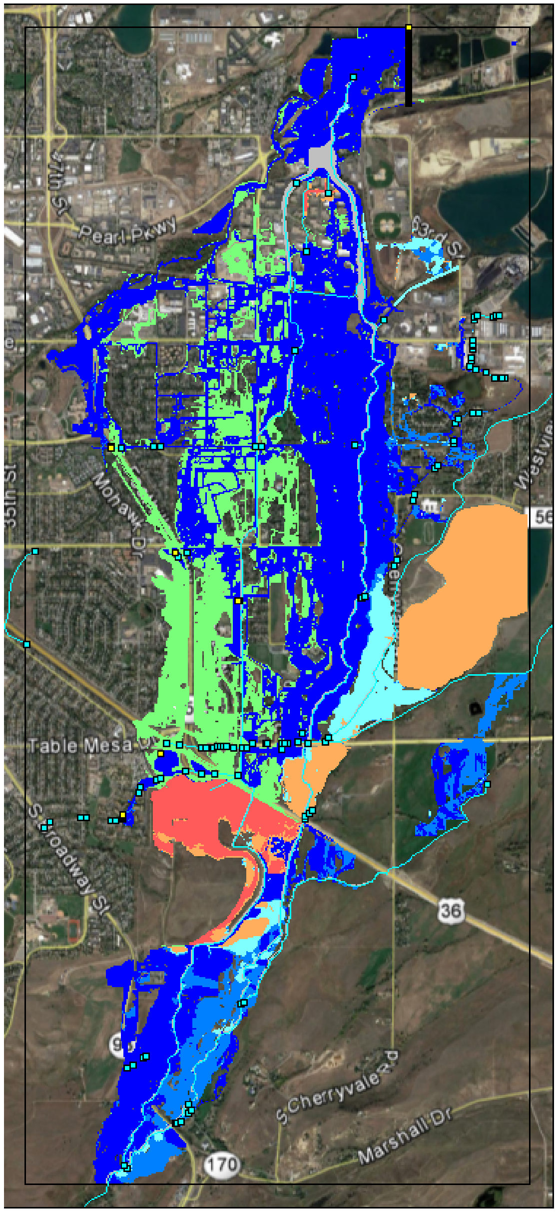
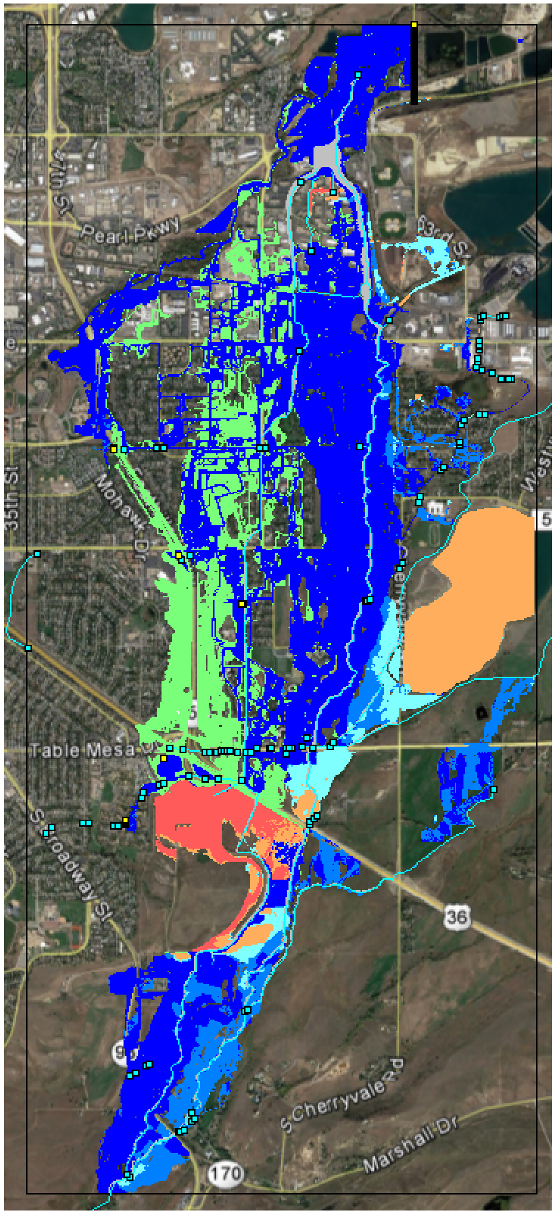
REPRODUCE
IN COLOR

DHI	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	OPTION 2 – HYDROGRAPHS AT SOUTH BOULDER ROAD (500-YEAR)
		PROJECT NO. 16134	February 2020 Figure 5.19

COMPARED TO EFFECTIVE MODEL



60” Dia.



108” Dia.

Difference in max H [ft]

- Above 1.000
- 0.100 - 1.000
- 0.010 - 0.100
- 0.000 - 0.010
- Below 0.000
- Undefined Value
- Dry

REPRODUCE IN COLOR

DHI

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	OPTION 2 – DIFFERENCES IN MAXIMUM WATER SURFACE ELEVATION (500-YEAR)	
PROJECT NO. 16134	February 2020	Figure 5.20

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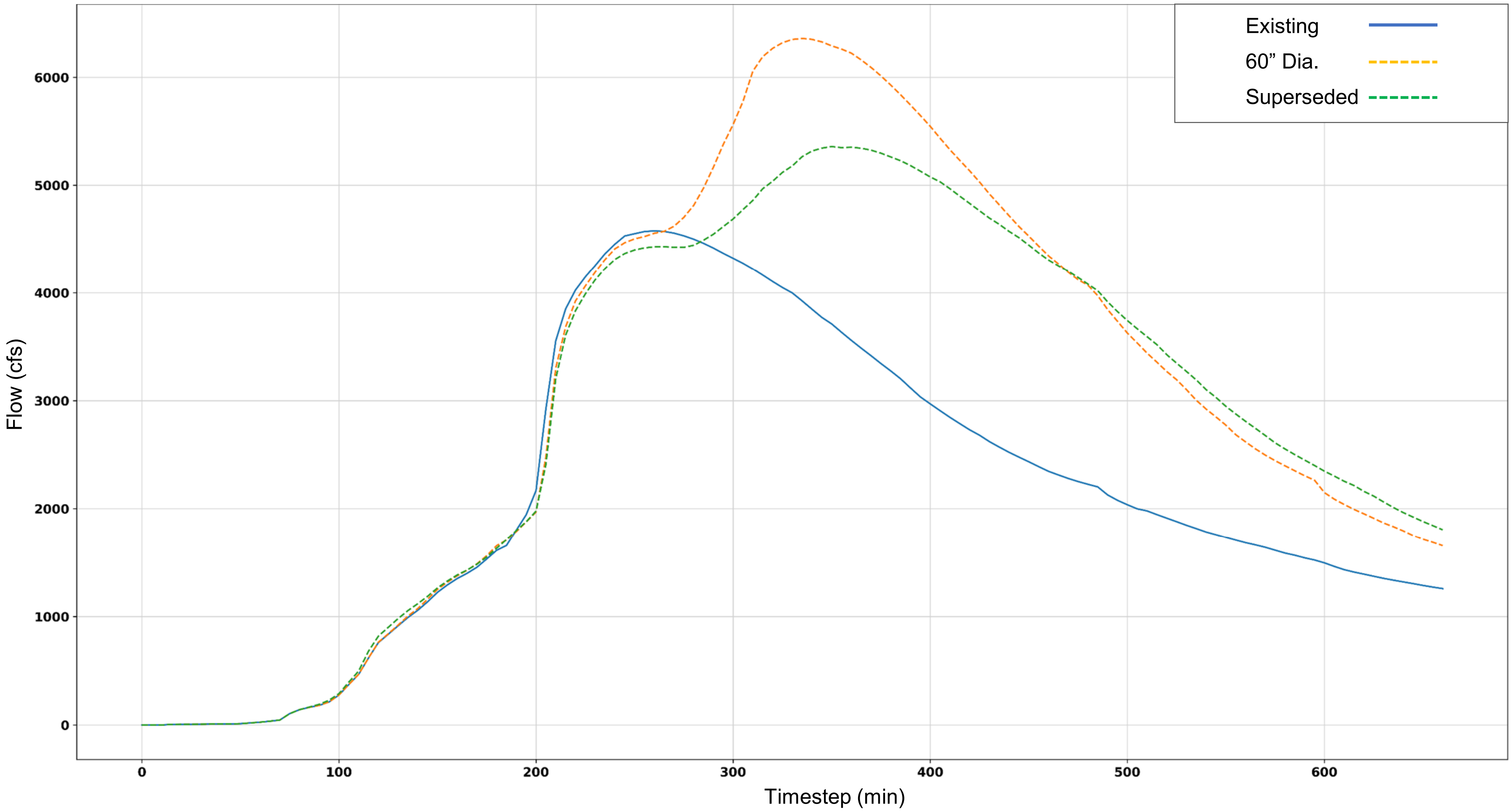

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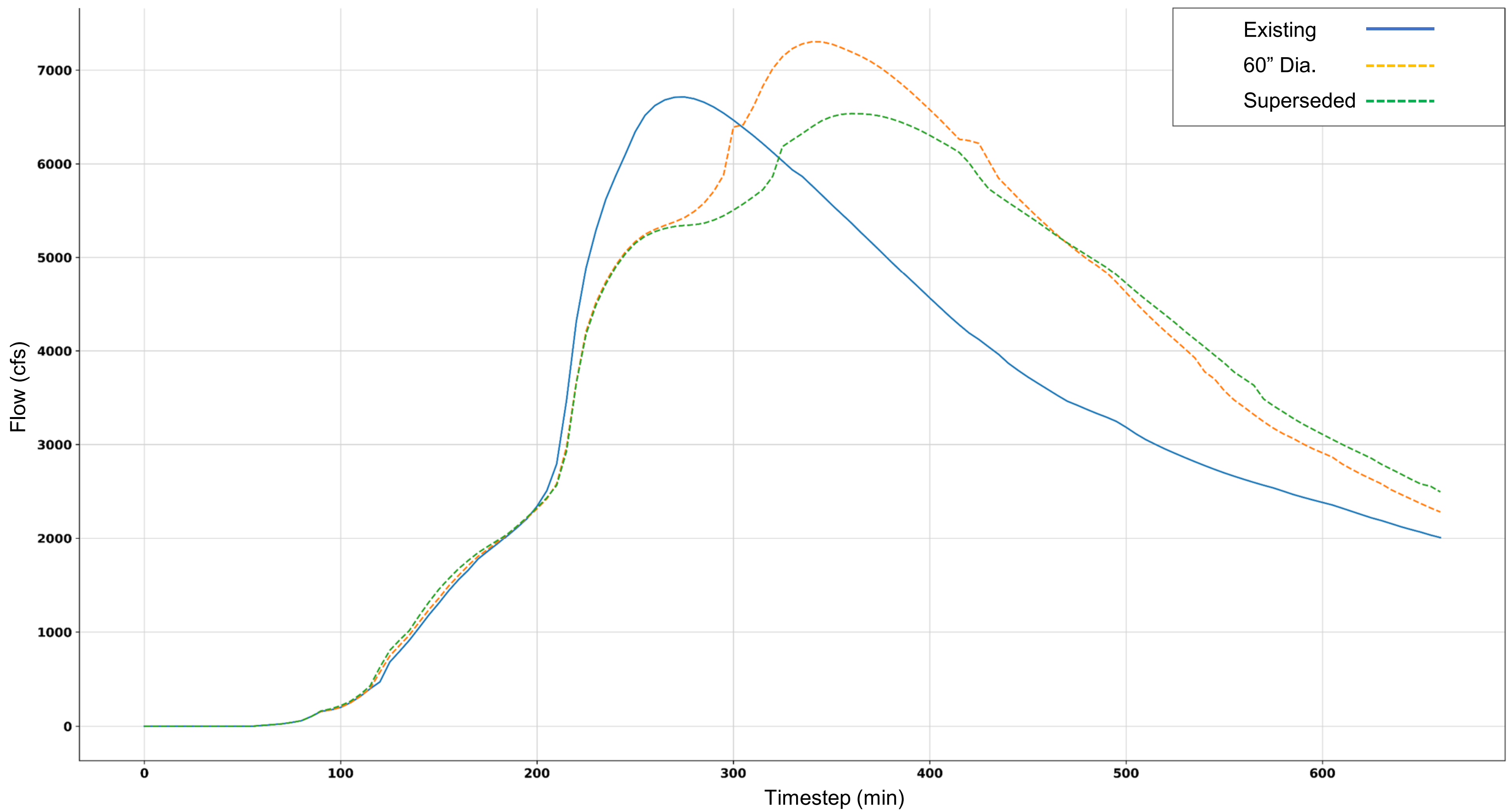
REPRODUCE IN COLOR

DHI / RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	BASELINE – HYDROGRAPHS THROUGH US36 BRIDGE (APPROX. 200-YEAR)
	PROJECT NO. 16134	February 2020 Figure 5.21



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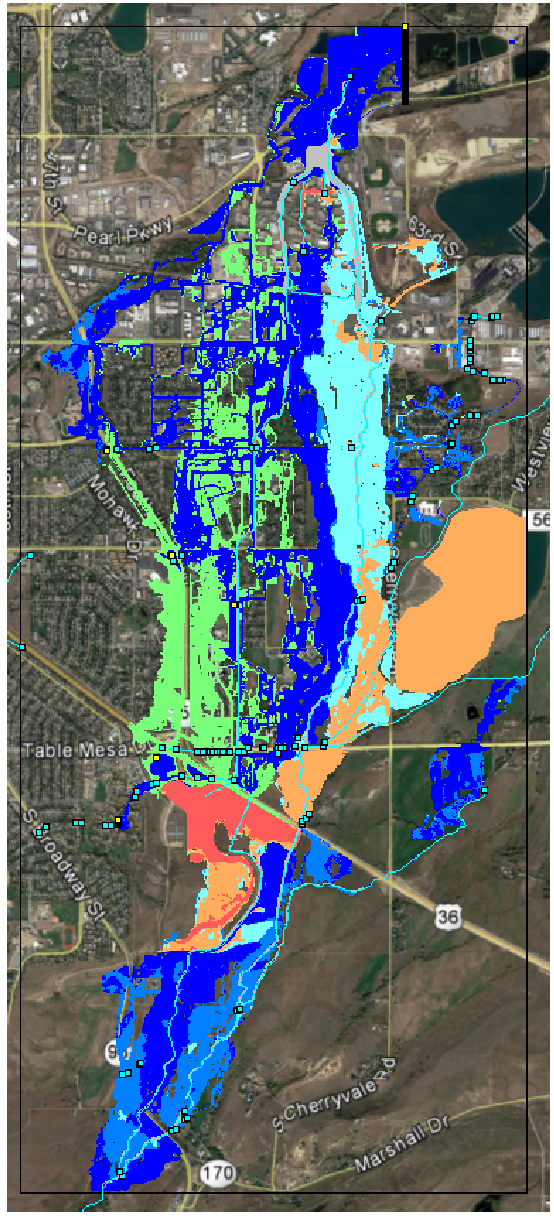
REPRODUCE IN COLOR

DHI	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	BASELINE– HYDROGRAPHS AT SOUTH BOULDER ROAD (APPROX 200-YEAR)
		PROJECT NO. 16134	February 2020 Figure 5.22

COMPARED TO EFFECTIVE MODEL



60” Dia.

Difference in max H [ft]

- Above 1.000
- 0.100 - 1.000
- 0.010 - 0.100
- 0.000 - 0.010
- Below 0.000
- Undefined Value
- Dry

REPRODUCE IN COLOR

DHI / RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	BASELINE– DIFFERENCES IN MAXIMUM WATER SURFACE ELEVATION (APPROX. 200-YEAR)
	PROJECT NO. 16134	February 2020 Figure 5.23

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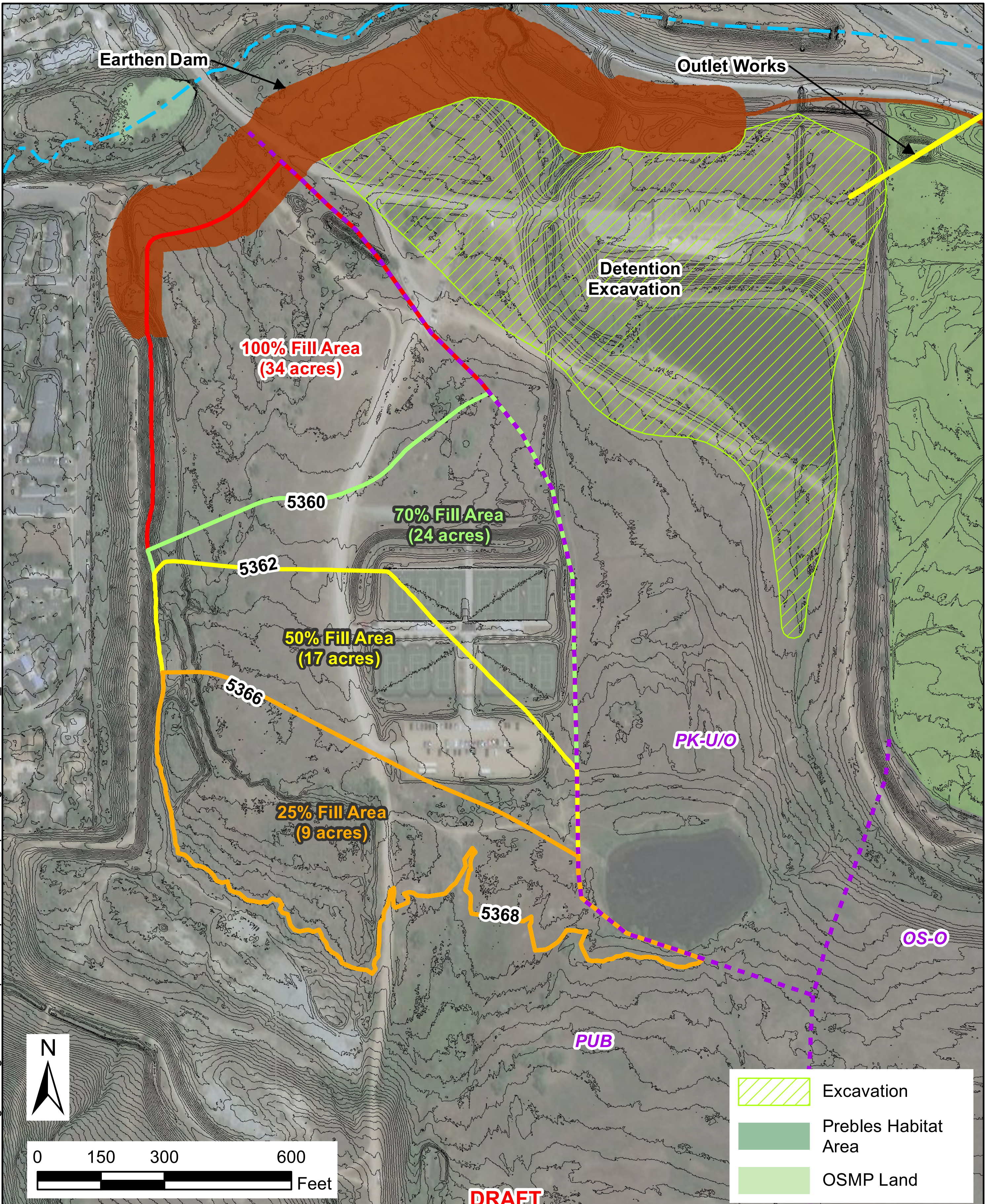

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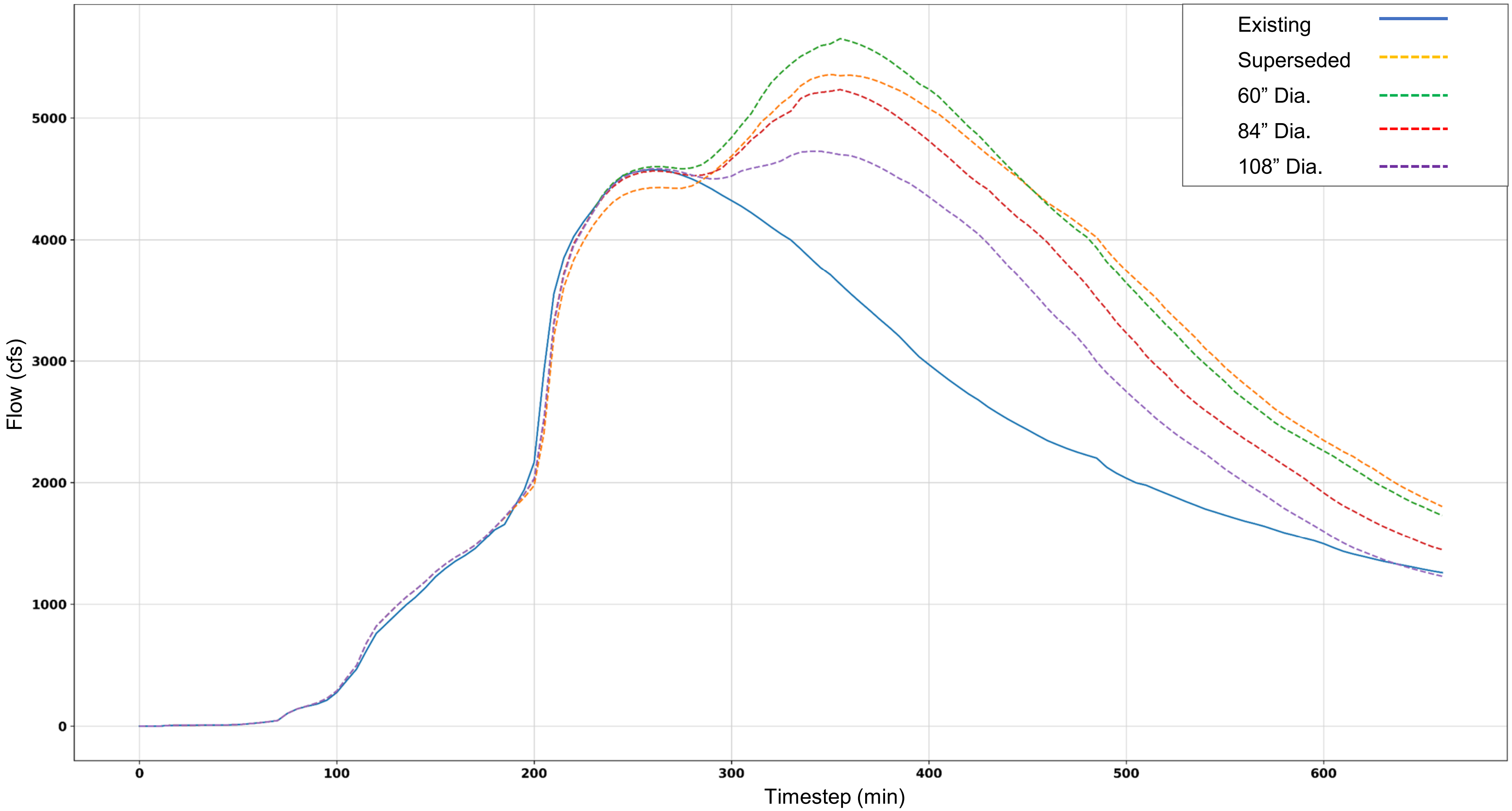
REPRODUCE IN COLOR	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	PLAN OF OPTION 3 NORTHERN PUB FILL CONFIGURATIONS
		PROJECT NO. 16134	February 2020 **Figure 5.24**



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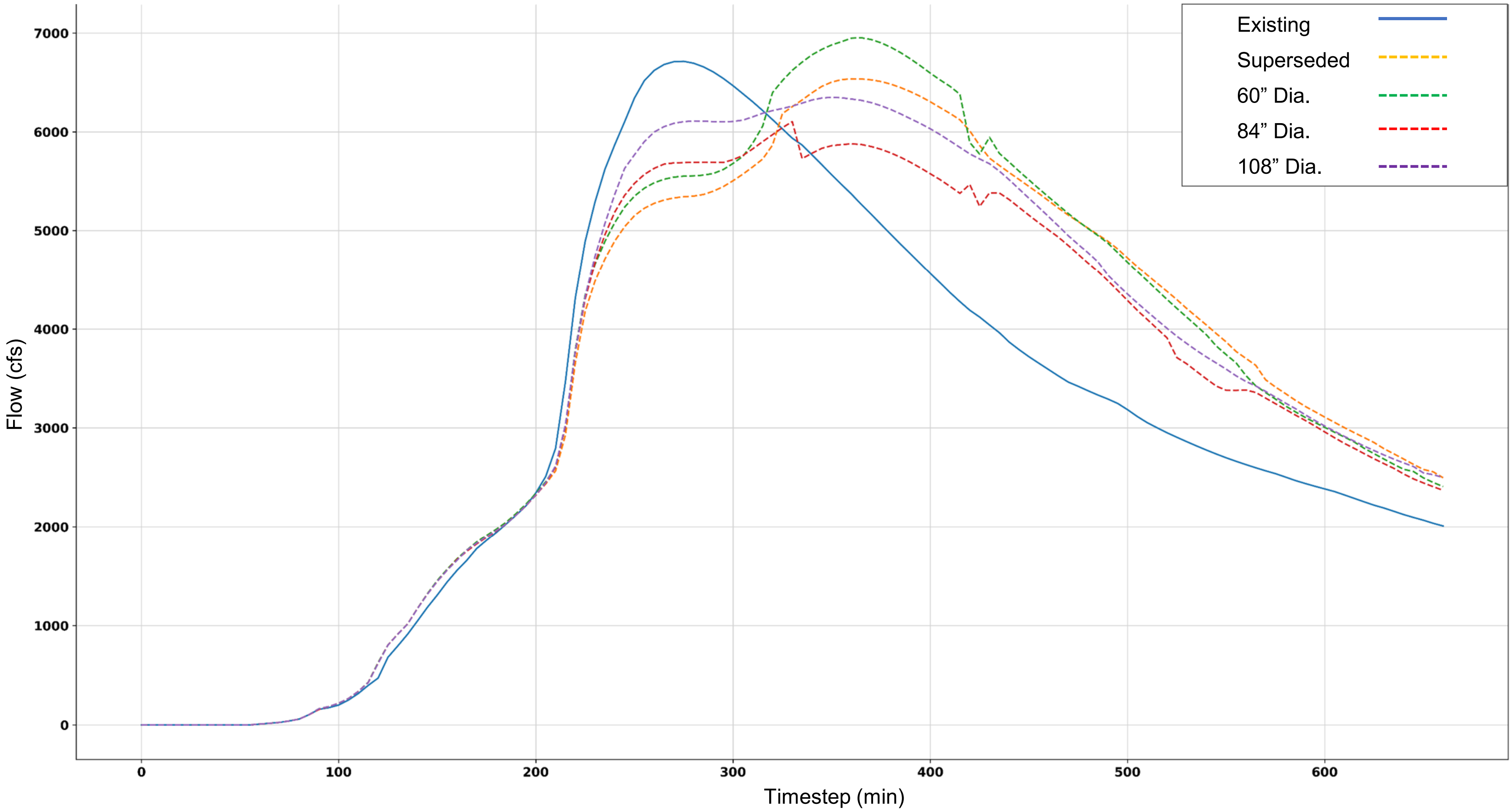
REPRODUCE IN COLOR

DHI	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	OPTION 3 – HYDROGRAPHS AT US36 BRIDGE (APPROX. 200-YEAR)
		PROJECT NO. 16134	February 2020 Figure 5.25



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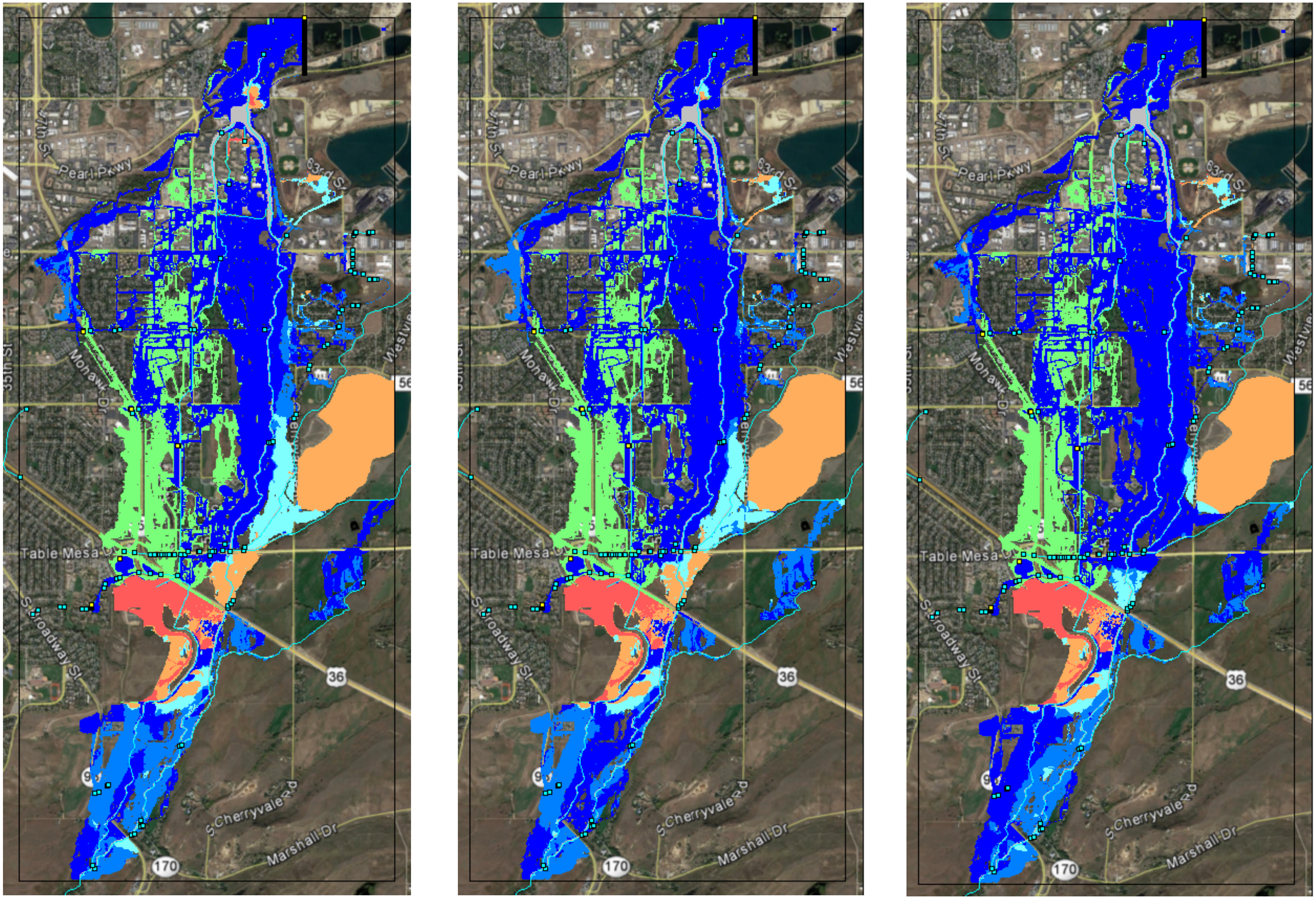
REPRODUCE IN COLOR

DHI	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	OPTION 3 – HYDROGRAPHS AT SOUTH BOULDER ROAD (APPROX. 200-YEAR)
		PROJECT NO. 16134	February 2020 Figure 5.26

COMPARED TO EFFECTIVE MODEL



60” Dia. 84” Dia. 108” Dia.

Difference in max H [ft]

- Above 1.000
- 0.100 - 1.000
- 0.010 - 0.100
- 0.000 - 0.010
- Below 0.000
- Undefined Value
- Dry

REPRODUCE IN COLOR

DHI

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION CONCEPT DESIGN	OPTION 3 – DIFFERENCES IN MAXIMUM WATER SURFACE ELEVATION (APPROX. 200-YEAR)
PROJECT NO. 16134	February 2020 Figure 5.27

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SECTION 6 – OPINION OF PROBABLE PROJECT COSTS

6.1 General

The RJH Team developed an OPPC for each option. The OPPCs presented in this Report are considered Class 4 estimates as defined by the Association for the Advancement of Cost Estimating and ASTM E2516-11: Standard Classification for Cost Estimate Classification Systems. This class designation is used when the design is less than 15 percent complete. Class 4 estimates are appropriate to use for comparing alternatives, but do not typically provide reliable budgetary estimates.

Cost opinions were developed by estimating quantities of primary elements of the work based on concept-level design and unit costs developed from the following sources:

- Published and non-published bid price data for similar work.
- R.S. Means Heavy Construction Cost Data for 2018.
- Manufacturer's budgetary price quotes.
- Our previous experience and judgment.

Costs in this Report are presented in 2018 dollars to be consistent with previous cost opinions presented to City Council and the public. We subdivided the OPPC into two parts (i.e., regional flood detention facility and earthfill for CU development) because the earthfill for the CU development a) is not required for the regional flood detention facility to function, and b) should have different cost allowances and contingencies because it should be simpler to design and construct, and has fewer unknowns than the regional flood detention facility at this stage of design. Cost allowances for bonds, insurance, construction contingencies, design engineering, construction engineering, environmental permitting, etc. used to develop the OPPCs are presented in Table 6.1.

TABLE 6.1
OPINION OF PROBABLE PROJECT COSTS

Item	Regional Flood Detention Facility	Fill for CU Development
Mobilization/Demobilization	10 Percent of BCS	3 Percent of BCS
Bonds/Insurance	1.5 Percent of BCS	1.5 Percent of BCS
Construction Contingencies	40 Percent of DCS	15 Percent of DCS
Investigations, Surveys, Preliminary and Final Design	12 Percent of DCS	3 Percent of DCS
Construction Engineering	10 Percent of DCS	10 Percent of DCS
Legal Fees	2 Percent of DCS	2 Percent of DCS
CLOMR/LOMR Engineering and Fees	$600,000	$0
Environmental Permitting	2 Percent of DCS	2 Percent of DCS

Notes:
1. Base Construction Subtotal (BCS) for each alternative is the sum of construction costs for primary work elements.
2. Direct Construction Subtotal (DCS) is the sum of the BCS, mobilization, demobilization, bonds, and insurance.

A summary of OPPCs for each alternative is presented in Table 6.2. Additional information regarding the cost opinions are provided in Appendix A.

TABLE 6.2
OPINION OF PROBABLE PROJECT COSTS

Configuration	Regional Flood Detention ($M)	Fill for CU Development ($M)	Total ($M)
Option 1 (100-Year)	41.0	9.4	50.4
Option 2 (500-Year)	47.3	34.1	81.4
Option 3 (Approx. 200-Year)	46.9	31.5	78.4

The OPPCs are based on professional opinions and may change as more design details are developed. Actual costs would be affected by a number of factors beyond current control, such as supply and demand for the types of construction required at the time of bidding, the Project vicinity, changes in material supplier costs, changes in labor rates, competitiveness of contractors and suppliers, availability of qualified bidding contractors, changes in applicable regulatory requirements, and changes in design standards. Conditions and factors arising as the Project proceeds from development through bidding and construction may result in construction costs that differ significantly from the estimate provided in this Report.

6.2 Basis of Cost Opinion

Primary considerations used to develop the OPPC are:

- Clearing would consist of removing existing vegetation within the limits of disturbance. Stockpiling would consist of stockpiling topsoil materials on-site for use in site reclamation.
- Demolition of existing CU Boulder South facilities would include the existing maintenance building, asphalt parking lot, and tennis complex. Demolished materials would be disposed at the Front Range Landfill, which is about 25 miles northeast of the site.
- Erosion and sediment control measures would consist of installing silt fence along the perimeter of the anticipated limits of disturbance.
- Dewatering for construction would consist of dewatering the various excavations as needed to construct the work, and would likely include installing wellpoints and other pumping systems. Dewatering costs were identified for general site work, a groundwater conveyance system, and outlet works tunnel.
- The outlet works intake structure would consist of an ungated, low-level reinforced concrete structure.
- The outlet works pipe would consist of a welded steel pipe tunneled through alluvial materials below US36.
- The outlet works outlet structure would consist of a reinforced concrete, U.S. Bureau of Reclamation-type baffle structure.
- The earthen embankment would be constructed using a combination of excavated materials from the detention storage excavation and imported earthfill materials. We have assumed a 50-mile haul cycle for imported earthfill. The upstream and downstream slopes will be 4H:1V.
- The earthfill on the CU Boulder South campus would be constructed using imported earthfill materials.
- The gravel surfacing along the earthen embankment crest would consist of imported aggregate materials.
- The barrier walls along the alignment of the earthen embankment and along the perimeter of the detention excavation would consist of soil-bentonite barrier walls extending from the ground surface into bedrock.

- The earthen embankment filter and drain would be constructed using imported materials.
- The upstream embankment slope protection would consist of grass with an underlying erosion control mat.
- Monitoring instrumentation would include surface monuments, piezometers, and inclinometers.
- Costs associated with excavation for detention are included in fill costs for the earthen embankment.
- The grouted boulder inlet rundown for the detention storage would consist of 24-inch-diameter grouted boulders.
- The spillway energy dissipation apron would consist of a 20-foot-wide, reinforced concrete apron that extends the entire length of the floodwall.
- The floodwall would consist of a reinforced concrete wall with the following wall thicknesses:

Wall Height (ft)	Wall Thickness (inches)
> 15	26
13 – 15	22
11 – 13	18
9 – 11	14
< 9	12

- The floodwall foundation would consist of secant (i.e., fixed end caisson) piles with 25-percent overlap. The piles would extend two feet into bedrock. The piles would be 36-inch-diameter for floodwall heights less than 13 feet and 48-inch-diameter for floodwall heights greater than 13 feet.
- The reinforced secant piles would include a reinforced concrete cap.
- The groundwater conveyance system would consist of two rows of 6-inch-diameter polyvinyl chloride (PVC) slotted pipes parallel to the floodwall with one pipe on each side of the floodwall foundation secant piles. The slotted pipes would be encapsulated with bedding material. Solid 6-inch-diameter PVC pipes would penetrate through the floodwall foundation at about 500-foot intervals to connect the upstream pipe with the downstream pipe. The collection and distribution trenches would consist of imported aggregate materials.
- The temporary detour of the multi-use trail would extend from near the intersection of South Cherryvale Road and US36 north along South Cherryvale

Road approximately 3,400 feet and west along South Boulder Road approximately 7,000 feet to the Regional Transportation District bus stop near South Loop Drive. Costs associated with the temporary detour would include initial setup of signs, daily inspection and maintenance of signs over an 18-month duration, and removal of signs.

- Multi-use trail demolition and reconstruction would include:
    - Demolishing the existing concrete trail.
    - Hauling demolished concrete to Front Range Landfill, which is about 25 miles northeast of the site.
    - Constructing a new 6-inch-thick, 12-foot-wide reinforced concrete trail.
- Environmental mitigation would consist of installing wetland plugs and cottonwood poles, and performing wetland seeding to mitigate wetland areas that are impacted by construction.
- The quantity and extent of levee removal is unknown at this stage of design. Excavated levee materials could be used in the construction of the earthen embankment, which would reduce the amount of imported earthfill and lower overall Project costs. Cost savings associated with levee removal were not considered for the alternative configurations that include levee removal.
- Traffic control on US36 would consist of installing approximately 2,300 linear feet of jersey barriers along the US36 shoulder adjacent to the floodwall work, and maintaining the barriers and signage for an 18-month duration.
- Modifications to South Loop Drive would consist of constructing an earthfill ramp to convey traffic over the earthen embankment and installing asphalt pavement to replace the existing road in-kind.
- Modifications to the existing culverts would consist of installing reinforced concrete baffled outlet structures at the downstream end of the culverts on the north side of US36.
- Site restoration would consist of placing stockpiled topsoil, finish grading, and seeding all disturbed areas.
- Cost associated with the following items or considerations were not included in the OPPC:
    - Land acquisition.
    - Environmental enhancements.

- Grading and other site features for athletic fields for CU Boulder South.
- Reconstruction of the CU Boulder South maintenance building and asphalt parking lot.
- Reconstruction of the CU Boulder South tennis complex.
- Utility relocates in the US36 ROW.
- Landscape architecture features.
- Restricted work hours (potentially limited to 7:30 am to 5:00 pm Monday through Friday).

SECTION 7 – CONCEPT SELECTION CRITERIA

7.1 General

An overall objective of the concept design is to identify one of the concept options to advance into preliminary design. To fulfill this objective, selection criteria were developed to facilitate a comparison of the options for a variety of considerations including technical, operational, environmental, economic, etc. The evaluation included two general categories of criteria:

- Baseline criteria: The baseline criteria are minimum Project criteria that each concept option is required to meet. If a concept alternative does not meet all of the baseline criteria, it is not considered a viable alternative.
- Project evaluation criteria: Evaluation criteria include technical, operational, environmental, economic, and land owner considerations. Evaluation criteria will vary between the different alternatives and will be used to distinguish the options.

7.2 Baseline Criteria

The baseline criteria are as follows:

- Overtopping of US36 during the selected flood design event must be prevented.
- Is likely permittable by regulatory agencies (FEMA, EPA, USACE and USFWS).
- Must be acceptable to the SEO.
- Landowners (CU, CDOT and OSMP) must be willing to allow construction of the Project.
- Groundwater impacts from the Project must be mitigated to maintain current groundwater conditions.
- Existing regulatory floodplains upstream and downstream of the Project cannot be negatively impacted.

7.3 Project Evaluation Criteria

The Project evaluation criteria were developed collaboratively by the Project Team, and were informed by public input from a community open house on April 23, 2018 and an associated questionnaire. A qualitative explanation was developed for each evaluation criterion for each configuration describing its ability to meet the criterion relative to the other configurations. Qualitative descriptions were developed collaboratively by the Project Team based on the concept evaluations and layouts. The Project evaluation criteria and descriptions are as follows:

- **Downstream flood benefits.** Option 2 will inherently provide the most downstream flood benefits because it would provide protection for a 500-year event. Option 1 would inherently provide the least downstream flood protection because it would only provide protection up to the 100-year event.
- **Adaptability for climate change.** The ability to modify Project facilities in the future to accommodate potential increases in flood flows associated with climate change is desirable. Future modifications to provide additional flood storage would likely include raising the embankment and floodwall, construction of a flow control structure on South Boulder Creek, and raising the earthfill or constructing a levee to protect CU buildings on the northern PUB land use area. Option 1 is the least adaptable because it would require raising or protecting the most area on the northern PUB land use. Option 2 is the most adaptable because the earthfill on the southern PUB and OS-O land use areas would likely be outside of the raised reservoir pool and may not need to be modified.
- **Total Project cost.** Lower Project costs are desirable and scoring was developed based on the cost opinions presented in Section 6.
- **Design, permitting, and construction schedule.** A short design, permitting, and construction schedule is desirable so that flood protection is provided to downstream residents as soon as reasonably possible. We anticipate that the time to design, permit, and construct all of the configurations would be similar.
- **Long-term operations and maintenance requirements.** Simple long-term operations and maintenance requirements are preferred over more complex requirements. We anticipate that long-term operations and maintenance would be similar for all of the options.
- **Groundwater mitigation complexity.** Construction of any of the concepts would require groundwater flows to move below the dam and floodwall in a similar manner as existing conditions. We anticipate that groundwater conveyance system would be similar for all of the options.
- **Riparian connectivity and habitat enhancement opportunities.** The presence of encroachments into the SBC riparian corridor, including the levee on CU Boulder South, adversely affect the ecological and open space values by constricting flood flows, which results in higher water velocities, and by presenting a barrier or impediment to animal movement in the floodplain.

Increased riparian connectivity and habitat enhancement opportunities are desirable along the SBC riparian corridor. Options that require placing fill on the OS-O land use area would limit riparian connectivity and habitat enhancement opportunities in this area. Option 2 would fill 34 acres on the OS-O land use area, and Option 3 would fill 17 acres on the OS-O land use area. Option 2 was scored as "least opportunities" and Option 3 was scored as "less opportunities."

- **Length, height, and size of dam.** Smaller dam heights and footprints are preferred to larger dam heights and footprints from an aesthetic and operations maintenance perspective. Option 1 has the smallest footprint and was scored as "smallest," and Option 2 has the largest footprint and was scored as "largest."
- **Wetlands and open water impacts.** Direct wetlands and open water impacts are not desirable because they may increase the risk of Project delays or ability to obtain a federal environmental permit. Impacts were measured quantitatively for each configuration based on acres that would be impacted. Option 1 would impact the fewest acres of open water and wetlands and was scored as "least impacts." Option 2 and Option 3 were scored as "moderate impacts" and "most impacts," respectively.
- **T&E habitat impacts.** Direct T&E habitat impacts are not desirable because they may increase the risk of Project delays or ability to obtain a federal environmental permit. Impacts were measured quantitatively for each configuration based on acres that would be impacted. Option 1 would impact the fewest acres of T&E habitat and was scored as "least impacts." Option 2 and Option 3 were scored "most impacts."

A summary matrix of the evaluation criteria is presented in Table 7.1.

TABLE 7.1
EVALUATION CRITERIA MATRIX

Criteria	Option 1 (100-Year)	Option 2 (500-Year)	Option 3 (Approx. 200-Year)
Downstream Flood Benefits	Least flood protection	Most flood protection	More flood protection
Adaptability for Climate Change	Less adaptable	Most adaptable	More adaptable
Total Project Cost	Least expensive	Most expensive	Most expensive
Design, Permitting, and Construction Schedule	Similar for all of the options		
Long-Term Operations and Maintenance Requirements	Similar for all of the options		
Groundwater Mitigation Complexity	Similar for all of the options		
Riparian Connectivity and Habitat Enhancement Opportunities	Most opportunities	Least opportunities	Less opportunities
Length, Height and Size of Dam	Smallest	Largest	Middle
Direct Wetlands and Open Water Impacts	Least impacts	Moderate impacts	Most Impacts
Direct T&E Habitat Impacts	Least impacts	Most Impacts	Most Impacts

Note:
1. The same rating was assigned for scoring that was effectively similar.

SECTION 8 – NEXT STEPS

Based on direction from City Council and discussions with City staff and MHFD, we have identified the following next steps for the Project.

- Winter/Spring 2020: The Project Team will present the concept-level alternatives presented in this Report to City Council, WRAB, and OSBT. At the end of this process, ideally City Council will assist in selecting a preferred alternative to advance into preliminary design.
- Summer/Fall 2020: Community Engagement around future annexation of CU Boulder South. Staff will proceed with community engagement in accordance with the feedback from the September 20, 2018 City Council meeting.
- Fall 2020/Winter 2021: Updates on the Flood Mitigation Preliminary Design. Staff will provide regular updates to boards and the community regarding Project progress. During the preliminary design phase of the Project, the Project Team will:
    - Continue to collect and evaluate groundwater and geotechnical data.
    - Develop baseline and proposed conditions groundwater models.
    - Design specific elements of the selected concept variation.
    - Revise concept cost estimates.
    - Secure necessary permits and approvals.
    - Secure agreements with property owners.
    - Develop design documents for construction.
- Summer/Fall 2020: Planning Board and City Council meetings regarding CU Boulder South annexation. Planning Board and City Council will consider a draft annexation agreement between the City and CU.
- Following completion of preliminary design and agreements with the property owners, the Project Team will proceed with final design, permitting, and construction of the Project, which combined is anticipated to take approximately 3 to 4 years.

SECTION 9 – REFERENCES

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APPENDIX A

COST OPINION INFORMATION

16134 South Boulder Creek
Project No. 16134

REGIONAL DETENTION FACILITY

Item No.	Item	Unit	Unit Cost ($)	OPTION 1 (100-YEAR) Quantity	OPTION 1 (100-YEAR) Cost ($)	OPTION 2 (500-YEAR) Quantity	OPTION 2 (500-YEAR) Cost ($)	OPTION 3 (APPROX 200-YEAR) Quantity	OPTION 3 (APPROX 200-YEAR) Cost ($)
1	Clearing and Topsoil Stockpiling	acre	$ 3,800	160	$ 608,000	220	$ 836,000	220	$ 836,000
2	Demolition of CU Maintenance Building	LS	$ 140,000	1	$ 140,000	1	$ 140,000	1	$ 140,000
3	Demolition of CU Tennis Court	LS	$ 500,000	1	$ 500,000	1	$ 500,000	1	$ 500,000
4	Erosion and Sediment Control	LS	$ 75,000	1	$ 75,000	1	$ 75,000	1	$ 75,000
5	Temporary Dewatering for Construction	--	--	--	--	--	--	--	--
6	General Site	LS	$ 120,000	1	$ 120,000	1	$ 120,000	1	$ 120,000
7	Groundwater Conveyance System	LS	$ 525,000	1	$ 525,000	1	$ 525,000	1	$ 525,000
8	Tunnel	LS	$ 100,000	1	$ 100,000	1	$ 100,000	1	$ 100,000
9	Outlet Works Intake Structure	LS	$ 100,000	1	$ 100,000	1	$ 100,000	1	$ 100,000
10	Outlet Works Pipe - Dual 60" Dia.	LF	$ 9,000	650	$ 5,850,000	0	$ -	0	$ -
11	Outlet Works Pipe - Triple 60" Dia.	LF	$ 12,000	0	$ -	650	$ 7,800,000	650	$ 7,800,000
12	Outlet Works Outlet Structure	LS	varies	1	$ 150,000	1	$ 225,000	1	$ 225,000
13	Dam Embankment using on-site excavation (1)	CY	$ 4.00	69,000	$ 276,000	69,000	$ 276,000	69,000	$ 276,000
14	Dam Embankment using imported earthfill	CY	$ 19.00	46,000	$ 874,000	66,000	$ 1,254,000	51,000	$ 969,000
15	Gravel Surfacing - Dam Crest	CY	$ 50	760	$ 38,000	760	$ 38,000	760	$ 38,000
16	Subsurface Barrier Wall - Dam	SF	$ 8.50	26,300	$ 223,550	26,300	$ 223,550	26,300	$ 223,550
17	Subsurface Barrier Wall - Pond Liner	SF	$ 8.50	37,000	$ 314,500	37,000	$ 314,500	37,000	$ 314,500
18	Dam Embankment Filter and Drain	CY	$ 50	7,100	$ 355,000	8,100	$ 405,000	7,500	$ 375,000
19	Upstream Embankment Erosion Control Mat	SY	$ 4.20	15,000	$ 63,000	18,000	$ 75,600	16,000	$ 67,200
20	Dam Embankment Monitoring Instrumentation	LS	$ 250,000	1	$ 250,000	1	$ 250,000	1	$ 250,000
21	Excavation for Detention (2)	CY	$ -	69,000	$ -	69,000	$ -	69,000	$ -
22	Grouted Boulder Inlet Rundown for Detention	SY	$ 300	2,000	$ 600,000	2,000	$ 600,000	2,000	$ 600,000
23	Spillway Energy Dissipation Apron	CY	$ 575	1,800	$ 1,035,000	1,800	$ 1,035,000	1,800	$ 1,035,000
24	Floodwall	CY	$ 575	675	$ 388,125	1,000	$ 575,000	750	$ 431,250
25	Floodwall Foundation (Secant Piles - 36 in dia.)	VLF	$ 160	25,600	$ 4,096,000	25,600	$ 4,096,000	25,600	$ 4,096,000
26	Floodwall Foundation Wall Cap	CY	$ 350	750	$ 262,500	750	$ 262,500	750	$ 262,500
27	Groundwater Conveyance System	LS	$ 1,600,000	1	$ 1,600,000	1	$ 1,600,000	1	$ 1,600,000
28	Multi-Use Trail Temporary Construction Detour	LS	$ 110,000	1	$ 110,000	1	$ 110,000	1	$ 110,000
29	Multi-Use Trail Demolition and Reconstruction	LS	$ 320,000	1	$ 320,000	1	$ 320,000	1	$ 320,000
30	Environmental Mitigation	acre	$ 130,000	10.3	$ 1,339,000	12.6	$ 1,638,000	14.5	$ 1,885,000
31	CU Levee Removal (3)	CY	$ -	0	$ -	0	$ -	0	$ -
32	US 36 Traffic Control	LS	$ 220,000	1	$ 220,000	1	$ 220,000	1	$ 220,000
33	South Loop Drive Reconstruction	LS	$ 500,000	1	$ 500,000	1	$ 500,000	1	$ 500,000
34	Modifications to Existing Culverts	LS	$ 175,000	1	$ 175,000	1	$ 175,000	1	$ 175,000
35	Site Restoration	acre	$ 4,000	160	$ 640,000	220	$ 880,000	220	$ 880,000
	Base Construction Subtotal (BCS)				**$ 21,847,675**		**$ 25,269,150**		**$ 25,049,000**
	Mob/Demob (10% of BCS)				$ 2,184,768		$ 2,526,915		$ 2,504,900
	Bonds/Insurance (1.5% of BCS)				$ 327,715.13		$ 379,037.25		$ 375,735
	Direct Construction Subtotal (DCS)				**$ 24,360,158**		**$ 28,175,102**		**$ 27,929,635**
	Construction Contingencies (40% of DCS)				$ 9,744,063		$ 11,270,041		$ 11,171,854
	Investigations, Surveys, Preliminary - Final Design (12% of DCS)				$ 2,923,219		$ 3,381,012		$ 3,351,556
	Construction Engineering (10% of DCS)				$ 2,436,016		$ 2,817,510		$ 2,792,964
	Legal Fees (2% of DCS)				$ 487,203		$ 563,502		$ 558,593
	CLOMR/LOMR Engineering and Fees				$ 600,000		$ 600,000		$ 600,000
	Environmental Permitting (2% of DCS)				$ 487,203		$ 563,502		$ 558,593
	Opinion of Probable Project Cost, Class 4 (2018)				**$ 41,037,862**		**$ 47,370,670**		**$ 46,963,194**

FILL FOR CU DEVELOPMENT

Item No.	Item	Unit	Unit Cost ($)	OPTION 1 (100-YEAR) Quantity	OPTION 1 (100-YEAR) Cost ($)	OPTION 2 (500-YEAR) Quantity	OPTION 2 (500-YEAR) Cost ($)	OPTION 3 (APPROX 200-YEAR) Quantity	OPTION 3 (APPROX 200-YEAR) Cost ($)
1	CU Fill using imported earthfill	CY	$ 19.00	360,000	$ 6,840,000	1,300,000	$ 24,700,000	1,200,000	$ 22,800,000
	Base Construction Subtotal (BCS)				**$ 6,840,000**		**$ 24,700,000**		**$ 22,800,000**
	Mob/Demob (3% of BCS)				$ 205,200		$ 741,000		$ 684,000
	Bonds/Insurance (1.5% of BCS)				$ 102,600		$ 370,500		$ 342,000
	Direct Construction Subtotal (DCS)				**$ 7,147,800**		**$ 25,811,500**		**$ 23,826,000**
	Construction Contingencies (15% of DCS)				$ 1,072,170		$ 3,871,725		$ 3,573,900
	Investigations, Surveys, Preliminary - Final Design (3% of DCS)				$ 214,434		$ 774,345		$ 714,780
	Construction Engineering (10% of DCS)				$ 714,780		$ 2,581,150		$ 2,382,600
	Legal Fees (2% of DCS)				$ 142,956		$ 516,230		$ 476,520.00
	Environmental Permitting (2% of DCS)				$ 142,956		$ 516,230		$ 476,520.00
	Opinion of Probable Project Cost, Class 4 (2018)				**$ 9,435,096**		**$ 34,071,180**		**$ 31,450,320**

Total Opinion of Probable Project Cost, Class 4 (2018)		**$ 50,472,958**		**$ 81,441,850**		**$ 78,413,514**

Items Not Included:
Land Acquisition
Environmental Enhancements
Rebuild CU Building
Rebuild CU tennis courts
Utility Relocates in US36 ROW
Landscape Architecture Features
Restricted Work Hours

Notes:
1. Upstream and downstream slopes are 4H:1V.
2. Cost for excavation for detention pond included in costs for dam embankment fill.
3. Excavation for levee could vary from 0 to 63,000 cy. We assumed no levee excavation.
4. Class 4 estimates are used when the design is less than 15-percent complete.