



# Flood Hazard Area Delineation

## Cherry Creek Minor Tributaries in Arapahoe County

October 2021

Project Sponsors:



ARAPAHOE COUNTY  
COLORADO'S FIRST



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October 29, 2021

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Subject: Cherry Creek Minor Tributaries  
In Arapahoe County  
Major Drainageway Plan Flood Hazard Area Delineation  
MHFD Agreement No. 18-08.13

Dewberry Engineers is pleased to submit the Digital Flood Hazard Area Delineation Report for Cherry Creek Minor Tributaries in Arapahoe County to the Mile High Flood District, the Southeast Metro Stormwater Authority, and the City of Aurora.

This report provides a description of the watersheds, updated hydrologic modeling for eleven major basins upstream of Cherry Creek Reservoir, new detailed hydraulic modeling for five of the eleven major basins, and an assessment of damage that would occur under existing conditions in major flood events.

Included within the study area are more than twenty (20) miles of drainageways, which convey stormwater runoff from approximately 4,320 acres. Drivers for this project include providing additional data for unstudied areas, updating data from previously studied areas, quantifying potential impacts caused by limited regional detention, and providing guidance for development that is anticipated with the King's Point Development near 17 Mile Farm House.

Approximately 8.6 miles of detailed HEC-RAS hydraulic modeling was completed for five major basins: Little Raven Creek, Joplin Tributary, South Arapahoe Tributary, Chenango Tributary, and Kragelund Tributary.

The report format and submittal are intended to follow the requirements of the Mile High Flood District DFHAD Guidelines. This report provides the following information:

- A summary of the hydrologic and hydraulic analyses,
- HEC-RAS water surface profiles for the 10-, 25-, 50-, 100-, and 500-year storm events, and
- Delineation of the 100- and 500-year floodplains, and a 0.5-foot rise floodway.

This floodplain and floodway information provide Arapahoe County, City of Aurora, Southeast Metro Stormwater Authority, and Mile High Flood District updated or new analyses and mapping for better floodplain management, depending on each basin.

The project team at Dewberry acknowledges and thanks the Mile High Flood District, the Southeast Metro Stormwater Authority, the City of Aurora, and Arapahoe County for their assistance and cooperation in the preparation of this study. Thank you for the opportunity to complete this portion of the project.

Sincerely,



Danny Elsner, P.E., CFM  
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# 1.0 INTRODUCTION

## 1.1 Authorization

The Mile High Flood District (MHFD) contracted with Dewberry Engineers Inc. (previously Dewberry | J3) for engineering services to complete a Major Drainageway Plan (MDP) and Flood Hazard Area Delineation (FHAD) for the Cherry Creek Minor Tributaries in Arapahoe County. This report was authorized by the following project sponsors: MHFD, the Southeast Metro Stormwater Authority (SEMSWA), and the City of Aurora (COA). Arapahoe County (AC) is also involved in this project as a stakeholder. The specific tasks completed during this project were performed in accordance with the Agreement: Contract No. 18-08.13 executed on August 30, 2018.

## 1.2 Purpose and Scope

The purpose of this project is to create an MDP for 11 major basins and a FHAD for 5 of those major basins that are tributary to Cherry Creek. This project provides new and updated hydrology, flood hazard area mapping, alternatives analysis, and conceptual design for specific improvements that correct any deficiencies that are identified.

Several of the studied tributaries were previously unnamed and are subsequently named herein: Little Raven Creek (previously North Unnamed Tributary), Suhaka Creek (previously Tributary to Cottonwood Creek), and Kragelund Tributary (previously South Unnamed Tributary).

The tributaries included in this study are as follows: Little Raven Creek (LR), Suhaka Creek (S), Joplin Tributary (J), Grove Ranch Tributary (GR), Valley Club Acres Tributary (VCA), North Arapahoe Tributary (NA), South Arapahoe Tributary (SA), Chenango Tributary (C), Tagawa Tributary (T), Kragelund Tributary (K), 17 Mile Tributary (17).

Several of the tributaries in this study are comprised of little to no open channel or were excluded from the FHAD by the project sponsors. The tributaries included in the FHAD are as follows: Little Raven Creek (LR), Joplin Tributary (J), South Arapahoe Tributary (SA), Chenango Tributary (C), Kragelund Tributary (K).

The project stakeholders' primary goals are to confirm watershed hydrology, define the floodplain and flood risks, and evaluate alternatives to reduce or eliminate those risks, as necessary. This Major Drainageway Plan makes it possible to evaluate necessary improvements to reduce peak flows and stabilize tributary reaches by implementing detention (if possible), grade control, and water quality facilities.

A summary of the objectives of the study is as follows:

- Quantify project hydrology,

- Quantify magnitude of runoff and associated flood risks,
- Identify alternatives to address flood hazards and/or conveyance deficiencies, and
- Provide conceptual design for recommended improvements.

## 1.3 Planning Process

Portions of the project area have been studied in an Outfall Systems Plan that was completed in 1999 (WRC Engineering, Inc., 1999). Seven tributaries and 4 DFAs were previously studied in the 1999 Cherry Creek Corridor Reservoir to County Line Outfall Systems Plan by WRC (WRC Engineering, Inc., 1999). However, a detailed hydraulic analysis to define the distinct floodplains has not been completed. This data was approximately 20 years old at the time of this study and does not reflect all revisions to land use. Four notable areas of interest not captured by the 1999 study are the undeveloped areas within the watershed of Kragelund Tributary; drainage across the 17 Mile Farm property; the Grove Ranch area and active erosion at the Pioneer Hills Development. Additionally, 2 existing detention ponds, 1 on Joplin Tributary and 1 on North Arapahoe Tributary, are included in this analysis.

A kickoff meeting and several progress meetings were held to discuss the project goals, project status, hydrologic analysis, areas of concern, potential alternatives, and comments with MHFD and the project sponsors. The meetings were held on September 10, 2018, October 23, 2018, January 14, 2019, April 10, 2019, August 5, 2019, October 24, 2019 and February 2, 2021. Minutes from the meetings are included in Appendix A.

The baseline hydrology developed for this study represents an updated analysis using CUHP 2016 version 2.0.0 and EPA SWMM version 5.1. Further explanation of the hydrologic modeling process is included in **Section 3.0**.

MHFD and the project sponsors reviewed the draft baseline hydrology and returned comments on January 14, 2019. Comments were received on the flood hazard area delineation at each step of the review process. The comments were incorporated into the final report. Summaries of the review comments and responses are included in Appendix A.

A project website was created to provide updated information on the project and can be found at [www.cherrycreektributaries.com](http://www.cherrycreektributaries.com).

\*Following completion of the baseline hydrology in January 2018, additional storm sewer infrastructure data was obtained from CDOT As-Builts for the Arapahoe/Parker interchange project (Federal Aid Project No. STU 0831-107 dated May 9, 2012). These plans depict existing storm sewer lines that were not included in the municipal GIS shapefiles used to inform the original baseline hydrology modeling. In an effort to better characterize urban flooding on Arapahoe Road and within Valley Club Acres, the baseline hydrology SWMM model was revised to reflect the 2012 CDOT plans. The outputs documented in the text and appendices of this report have been updated to reflect these revisions. See **Section 3.7** for additional information.

### 1.4 Mapping and Surveys

One-foot contours from 2014 USGS LiDAR data were provided by MHFD for the Project Area, as well as a structure survey for detailed information at each crossing. Other information such as jurisdictional boundaries, stormwater infrastructure, and roadways were obtained from the COA, SEMSWA, and Arapahoe County. All data is spatially referenced using the *NAD 1983 Colorado State Plane, Central Zone* projected coordinate system and vertical elevations for the contours are referenced using the *NAVD 1988* vertical datum.

### 1.5 Data Collection

Background research and data collection were required to conduct the analysis and to develop this Major Drainageway Plan. This included development plans, drainage reports, topographic data, land use data and miscellaneous items. Stakeholders provided much of the topographic and land use data while Dewberry located the remainder. These sources are identified in **Table 1-1**.

**Table 1-1** Collected Data

Source	Date	Description
MHFD	Sep 25, 2018	1-foot LIDAR contour shapefiles developed by the USGS in 2014.
SEMSWA	Sep 27, 2018	Impervious data for incorporated areas within the City of Centennial. Dewberry created project shape files to describe resultant Land Use.
City of Aurora	Oct 1, 2018	Digital PDF copies of development plans for the Kings Point Development.
MHFD	Nov 5, 2018	Detailed structure surveys by Wilson & Co were provided as AutoCAD electronic files.
National Land Cover Database	Nov 20, 2018	NLCD raster image with land use categories for entire area. Dewberry used this information to backcheck the Land Use layer.
City of Aurora & SEMSWA	Sep 27 & Nov 27, 2018	Detailed mapping of stormwater infrastructure was downloaded from the public domain as shapefiles.
Arapahoe County	Nov 27, 2018	Partial land use data, including the 2018 Comprehensive Plan provided as shapefiles. Dewberry created shapefiles where data was incomplete.
Arapahoe County & City of Aurora	Nov 27, 2018	Zoning data for some areas. Dewberry considered these shape files when developing a Land Use layer.
Arapahoe County	Nov 27, 2018	Natural water elements including streams and lakes.
SEMSWA & Arapahoe County	Dec 5, 2018	Development Plans for King's Point, Basin RB1-Pond 4 (RB1-4) Drainage Improvements, and Filings 7,8 & 9 of the Farm at Arapahoe County.
MHFD	Feb 6, 2019	Detailed structure survey for the North Arapahoe pond on North Arapahoe Tributary.

MHFD	July 8, 2019	Detailed structure survey for the Hinsdale Ave. crossing and the Chambers Rd. crossing on Joplin Tributary.
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### 1.6 Acknowledgments

Project sponsors include:

- Mile High Flood District
- Southeast Metro Stormwater Authority
- Arapahoe County
- City of Aurora

Dewberry wishes to acknowledge the various individuals who assisted in the preparation of this Master Plan and who provided valuable contributions. The following individuals and the agencies they represented are:

Shea Thomas, PE	MHFD – Watershed Services Manager (Retired)
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Stacey Thompson, CFM	MHFD – Floodplain Manager
Hung-Teng Ho, PE, CFM	MHFD – Hydraulic Modeler
Melanie Poole, PE	MHFD – Project Engineer
Brik Zivkovich, CFM	MHFD – Staff Engineer
Stacey Thompson, CFM	SEMSWA – Group Manager, Floodplain and Master Planning (Retired)
Angela Howard, PE, CFM, LEED® AP	SEMSWA – Master Plan Coordinator
Cathleen Valencia, PE	Arapahoe County Public Works & Development – Engineer II
Roger Harvey	Arapahoe County – Open Space Planning Administrator
Craig Perl, PE, CFM	City of Aurora – Senior Engineer, Floodplain Administrator

The following project Dewberry team members contributed to the preparation of this study:

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Dana Morris, EI, CFM	Dewberry
Katie Kerstiens, EI, CFM	Dewberry

# 2.0 STUDY AREA DESCRIPTION

## 2.1 Project Area

The project area consists of 11 tributaries upstream of Cherry Creek Reservoir within Arapahoe County (Project Reuse Watershed No. 4600). The watersheds are within the Cities of Aurora, Centennial, Greenwood Village, the Town of Foxfield, and unincorporated Arapahoe County. **Figure 2-1** shows the 11 watersheds and the FHAD reaches. **Table 2-1** and **Table 2-2** list the lengths, areas, and jurisdictions of each basin. Tributary lengths were either approximated from the MHFD stream layer or, if included in the FHAD analysis, determined during the hydraulic modeling phase.

**Table 2-1** Watershed Areas and Tributary Lengths

Tributary	Tributary Length		Watershed Area	
	(ft)	(mi)	(ac)	(mi <sup>2</sup> )
<b>Little Raven Creek (LR)</b>	<b>6,556/2,307</b>	<b>1.2/0.4</b>	<b>349</b>	<b>0.55</b>
Suhaka Creek (S)	6,100	1.2	360	0.56
<b>Joplin Tributary (J)</b>	<b>10,669/8,470</b>	<b>2.0/1.6</b>	<b>774</b>	<b>1.21</b>
Grove Ranch Tributary (GR)	4,450	0.8	81	0.13
Valley Club Acres Tributary (VCA)	5,350	1.0	207	0.32
North Arapahoe Tributary (NA)	9,874	1.9	372	0.58
<b>South Arapahoe Tributary (SA)</b>	<b>7,500/2,959</b>	<b>1.4/0.6</b>	<b>396</b>	<b>0.62</b>
<b>Chenango Tributary (C)</b>	<b>10,875/10,647</b>	<b>2.1/2.0</b>	<b>917</b>	<b>1.43</b>
Tagawa Tributary (T)	5,760	1.1	107	0.17
<b>Kragelund Tributary (K)</b>	<b>10,048/9,285</b>	<b>1.9/1.8</b>	<b>611</b>	<b>0.95</b>
17 Mile Tributary (17)	4,126	0.8	145	0.23
<b>TOTAL</b>			<b>4,319</b>	<b>6.75</b>

\***Bold** = included in the FHAD study  
 Tributary Length = Total length/Length modeled in FHAD

The overall project area is roughly bounded by Cherry Creek Reservoir to the north, S. Dayton St. to the west, S. Himalaya Way to the east, and the county line and E-470 to the south. Eight of the tributaries are bounded by Piney Creek to the north and the county line to the south, and outfall to Cherry Creek. Joplin lies north of Piney Creek, bounded by E. Smoky Hill Rd, and outfalls to Cherry Creek. Two tributaries do not outfall directly to Cherry Creek: Little Raven Creek and Suhaka Creek. Little Raven

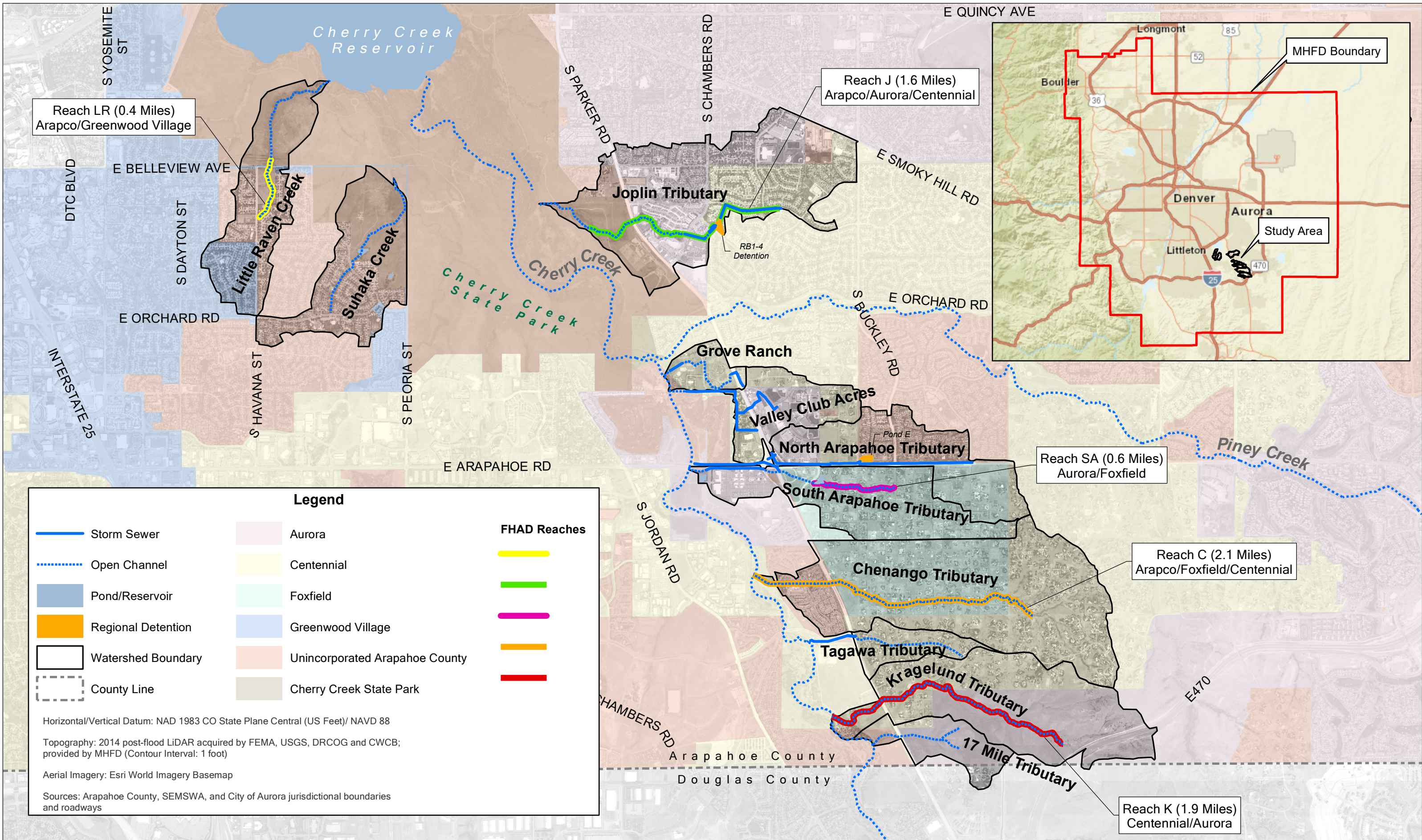
Creek outfalls directly to the reservoir and is bounded to the south by E. Orchard Rd. Suhaka Creek outfalls to Cottonwood Creek just upstream of the reservoir, and the basin is bounded to the west by S. Havana St. The total watershed area studied is 6.75 square miles or 4,319 acres.

Several of the tributaries in this study are comprised of little to no open channel or were excluded from the FHAD by the project sponsors. The tributaries included in the FHAD are as follows: Little Raven Creek (LR), Joplin Tributary (J), South Arapahoe Tributary (SA), Chenango Tributary (C), Kragelund Tributary (K). These tributaries are shown in bold in **Table 2-1** and **Table 2-2**.

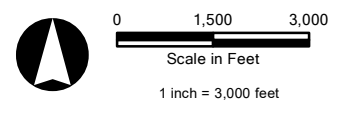
**Table 2-2** Watershed Outfalls and Jurisdictions

Tributary	Outfall	Jurisdiction
<b>Little Raven Creek (LR)</b>	<b>Cherry Creek Reservoir</b>	<b>SEMSWA, Unincorporated Arapahoe County, City of Greenwood Village, Cherry Creek State Park</b>
Suhaka Creek (S)	Cottonwood Creek	SEMSWA, Unincorporated Arapahoe County, City of Greenwood Village, Cherry Creek State Park
<b>Joplin Tributary (J)</b>	<b>Cherry Creek</b>	<b>SEMSWA, City of Aurora, Unincorporated Arapahoe County</b>
Grove Ranch Tributary (GR)	Cherry Creek	SEMSWA (City of Centennial, Unincorporated Arapahoe County)
Valley Club Acres Tributary (VCA)	Cherry Creek	SEMSWA (City of Centennial, Unincorporated Arapahoe County), City of Aurora
North Arapahoe Tributary (NA)	Cherry Creek	SEMSWA (City of Centennial, Unincorporated Arapahoe County), City of Aurora, Town of Foxfield
<b>South Arapahoe Tributary (SA)</b>	<b>Cherry Creek</b>	<b>SEMSWA, City of Aurora, Unincorporated Arapahoe County, Town of Foxfield</b>
<b>Chenango Tributary (C)</b>	<b>Cherry Creek</b>	<b>SEMSWA, City of Aurora, Unincorporated Arapahoe County, Town of Foxfield</b>
Tagawa Tributary (T)	Cherry Creek	SEMSWA (City of Centennial, Unincorporated Arapahoe County)
<b>Kragelund Tributary (K)</b>	<b>Cherry Creek</b>	<b>SEMSWA, City of Aurora (City of Centennial, Unincorporated Arapahoe County)</b>
17 Mile Tributary (17)	Cherry Creek	SEMSWA, City of Aurora (City of Centennial, Unincorporated Arapahoe County)

\***Bold** = included in the FHAD study



Designed By: HH  
 Drawn By: HH  
 Checked By: KC/DE  
 Date: 08/2021



MILE HIGH FLOOD DISTRICT,  
 SOUTHEAST METRO STORMWATER AUTHORITY,  
 CITY OF AURORA, AND ARAPAHOE COUNTY

CHERRY CREEK MINOR  
 TRIBUTARIES IN ARAPAHOE  
 COUNTY

PROJECT AREA MAP

FIGURE  
 2-1



## 2.2 Land Use

Due to the built-out nature of the studied basins, future land use hydrology is considered equal to existing for all basins except two: 17 Mile Tributary and Kragelund Tributary, where large swaths of undeveloped area still exist. As a result, existing conditions land use and hydrology in this study were developed for 17 and K only.

Most of the existing development in the Project Area consists of residential land use. Small pockets of office, commercial, and industrial developments are also present, primarily along the major local thoroughfares such as S. Parker Rd., E. Smoky Hill Rd., and E. Arapahoe Rd. Large portions of Little Raven Creek, Suhaka Creek and Joplin Tributary basins are located within the Cherry Creek State Park. The proposed King’s Point Subdivision is anticipated to build out the remaining undeveloped area within the 17 Mile Tributary and Kragelund Tributary basins east of S. Parker Rd. sometime in the near future.

Land use for existing and future conditions was evaluated based on several pieces of data, referenced in **Table 1-1**. At the start of the project, Arapahoe County and SEMSWA provided future land use GIS data for areas of unincorporated Arapahoe County from the 2018 Comprehensive Plan and PDF maps of the Centennial NEXT Plan. Other data from the County’s GIS portal were used to identify land use, including zoning, parks and open space, parcels, and lakes. Additional zoning data from the City of Aurora, the City of Centennial, and Douglas County was used to categorize land use in these areas. The spatial location of the 2 modeled regional detention ponds, Pond RB1-4 in Joplin Watershed and NA Pond (Pond E) in North Arapahoe Watershed, are from SEMSWA’s detention pond data. And finally, the extents for S. Parker Rd. and E. Arapahoe Rd. were digitized by hand to include street imperviousness for these major roads.

**Figure B-2** depicts the sources used to develop land use by location, as well as original Arapahoe County land use designations and original City of Aurora Zoning data.

To determine appropriate percent imperviousness values, the collected land use categories were converted to MHFD land use types and corresponding imperviousness values were assigned using *Table 6-3 Recommended Percentage Imperviousness Values* in the MHFD Criteria Manual Volume 1, which are included in **Table 2-3** for reference (Mile High Flood District, 2016). Composite imperviousness values calculated for each subwatershed are listed in **Table B-2** in Appendix B for the existing and future conditions hydrology and maps showing the existing and future land use are shown in **Figure B-1** as the *Existing Land Use Map* and the *Future Land Use Map* layers.

Planimetric data covering areas such as sidewalks, roofs, and roads was also made available for the City of Aurora and SEMSWA service area as a backcheck of assigned land use imperviousness values. Also, it may be noted that land use data from the National Land Coverage Database (NLCD) was used early in the study to verify the results using MHFD land use and values were similar.

Some specific areas were discussed by stakeholders to agree on some assumptions. First, S. Parker Rd. is planned to be expanded to 6 lanes in the future. This change is not considered as part of this study

since S. Parker Rd., in addition to lakes, detention basins, and E. Arapahoe Rd., has been conservatively assigned as 100% impervious. Second, further development at 17 Mile Farm House was neglected since this area is only 1.8 acres large and the parcel has been assigned a conservative existing land use of single-family 2.5 acres or larger by the municipal data, even though most of the area is undeveloped.

**Table 2-3** Land Use Categories and Imperviousness

Land Use	Imperviousness (%)
Apartments	75%
Business, Suburban	75%
Industrial, light	80%
Open Water	100%
Parks, cemeteries	10%
SF, 0.25 acres or less	45%
SF, 0.25-0.75 acres	30%
SF, 0.75-2.5 acres	20%
SF, 2.5 acres or larger	12%
Schools	55%
Streets	100%
Undeveloped Areas	2%

## 2.3 Reach Description

Descriptions of the tributaries are provided in the sections below. Major crossings are listed in **Table 2-4**.

**Little Raven Creek (LR)**, previously referred to as North Unnamed Tributary, conveys runoff from an approximately 350-acre basin and is 7,700 feet in length. Little Raven Creek was named after the Principal Chief of the Southern Arapahoe Indians and was born on the central Great Plains around 1810 perhaps along the Platte River in present day Nebraska. The tributary is largely controlled by Cherry Creek State Park and is the only tributary in this study with an immediate outfall into Cherry Creek Reservoir. Regional detention and water quality are not present. Upstream of the reservoir, the tributary crosses under W. Lakeview Rd., which is located within the park and utilizes a partially buried, corrugated metal pipe (CMP) to convey the tributary flow. This pipe is a 36” CMP and partially silted in. Upstream to E. Belleview Ave., the tributary is dominated by dense vegetation, several mono-culture cattail areas, and a pedestrian trail crossing named “Pope Trail”. The second road crossing is E. Belleview Ave. which utilizes 2 reinforced concrete pipes (RCPs), vertically offset by 5 feet, to convey the tributary flow. Upstream and south of E. Belleview Ave. is a wide storage basin with no outlet controls in place. This area is adjacent to The Hills development and is owned by Cherry Creek State Park. It inadvertently provides detention, however, does not appear to be maintained and thus is not included in evaluation. The tributary continues upstream of Cherry Creek State Park through Bear Park and across S. Havana St. via an elliptical 52” x 32” RCP.

Finally, the tributary continues upstream through a small concrete channel adjacent to the Hills West Swimming Pool and on to an open area that collects overland flow.

This tributary basin includes about 93 acres in the City of Greenwood Village and 256 acres in unincorporated Arapahoe County, 133 acres of which is served by SEMSWA. The area not served by SEMSWA is owned by Cherry Creek State Park. The area is fully built out and there are no vacant properties for future development within this basin. Site visits indicate that small reaches within the State Park may present the most significant challenge where active bank erosion is notable. There is at least 1 exposed utility present, and erosion is occurring in another location along the right bank.

**Suhaka Creek (S)** was added to the project scope of work during the Kickoff Meeting since it has not been previously studied. After the Comment Review meeting the name was changed from Tributary to Cottonwood Creek (TC) to Suhaka Creek, as described in the meeting minutes. Suhaka Tributary was named due to its proximity to the Suhaka Model Airfield named after an avid radio control airplane flyer. The tributary is a left bank tributary to Cottonwood Creek, which discharges to Cherry Creek Reservoir. The drainageway conveys runoff from approximately 360 acres of single-family development with open space at the downstream reaches. The major stormwater conveyance system is comprised of open channel flow that begins upstream near E. Orchard Rd. Further downstream, it crosses Cherry Creek Dr. with 2-48" RCPs. After this point, the tributary flows through a stock pond that is contained on the downstream end by a berm and an elevated broad-crested weir, and is subsequently conveyed as sheet flow to S. Peoria St. Runoff ponds behind a small inlet structure with an orifice plate and overflow grate and upon entering the structure, flows under S. Peoria St. via 2-12" RCP pipes. Flow then continues through a natural earthen channel to Cottonwood Creek.

Most of the watershed lies in unincorporated Arapahoe County with a small 9-acre area located in Greenwood Village near Lake Ct. Approximately 193 acres of this area is served by SEMSWA and the area not served by SEMSWA is owned by Cherry Creek State Park. Challenges include erosion upstream of the stock pond, poorly defined hydraulics from the stock pond to the outfall and lack of ponds that provide water quality or extended detention.

**Joplin Tributary (J)** is a large tributary to Cherry Creek and is approximately 9,700 feet in length. The downstream half of the tributary runs through Cherry Creek State Park where it crosses multiple park trails, and the other half upstream of S. Parker Rd. conveys runoff from dense, mixed-use developments comprised of commercial big box stores and single- and multi-family developments in the Cities of Aurora and Centennial. The drainageway conveys runoff from 775 acres with 600 acres upstream of Parker Rd. Runoff crosses S. Parker Rd. via 2-14' x 4' reinforced concrete box culverts. Construction is underway at Pioneer Hills Development from the crossing at S. Parker Rd. upstream to S. Chambers Rd. This reach is dominated by wetlands and retains a cross-section showing where the floodplain connects to the overbank areas. This section has challenges including severe right bank erosion encroaching on the adjacent multi-family development, a severe channel bend, and a complex outlet structure near S. Chambers Rd. Private

water quality and detention ponds are located along the banks for Pioneer Hills and adjacent shopping centers. Upstream of S. Chambers Rd., runoff is conveyed along connected property lines between S. Granby Way and Home Depot.

Upstream of this, a City of Aurora 72" and a parallel City of Centennial 36" storm sewer is aligned for approximately 550 feet at the rear lot lines of adjoining single-family residences. The storm sewers are contained within a 40' easement with 20' on the City of Aurora side and 20' on the City of Centennial side. Upstream of the piped section at S. Joplin Way, the tributary daylighted at Pond RB1-4 which is owned and maintained by SEMSWA. The pond is described in the as-built drawings for The Summit at Piney Creek development and appears to be in good condition, with a boulder-lined trickle channel and other appurtenances. A pre-sedimentation forebay and micro-pool are not present. The as-built drawings indicate a maintenance path was constructed; however, it was not visible during the site visit. Upstream from the pond, the tributary is contained in a 72" RCP.

The Joplin watershed combines a 360-acre area in the City of Aurora, a 218-acre area in the City of Centennial, and a 198-acre area in unincorporated Arapahoe County. SEMSWA serves the City of Centennial area and approximately 59 acres of unincorporated Arapahoe County. Subbasin J1 and parts of Subbasins J2, J3, and J4 near S. Parker Rd. are not served by SEMSWA and are located within Cherry Creek State Park. Challenges along Joplin Tributary include a lack of regional detention or water quality within the lower basin, some streambank erosion, stream maintenance, complex hydraulic conditions with possibly undersized elements, and potentially cumbersome easement issues should the parallel storm system need improvement.

**Grove Ranch Tributary (GR)** was added to the project scope of work during the Kickoff Meeting due to anticipated redevelopment and it is named in reference to the Grove Family properties within the watershed. It is the smallest watershed studied at 80 acres and less than a mile in basin length. The land use is defined by mixed-use and commercial development in the downstream basin and single-family residential development in the upstream basin. Runoff is conveyed across S. Parker Rd. by a 36" CMP and is conveyed from open channel to Cherry Creek via a 36" RCP.

The Grove Ranch watershed is served entirely by SEMSWA, with 77 acres located in the City of Centennial and 4 acres within unincorporated Arapahoe County. Challenges include poorly defined open channel hydraulics in the vicinity of the Fellowship Community Church, pooling wetlands upstream of pipe conveyance to Cherry Creek, and lack of ponds that provide water quality or extended detention.

**Valley Club Acres Tributary (VCA)** drains a tributary area of approximately 210 acres. The tributary is predominantly contained in storm sewer, with only 600 feet of open channel at the downstream confluence with Cherry Creek. The entire open channel reach is encumbered by the regulatory floodplain of Cherry Creek, as are approximately 1,500 feet of the upstream storm sewer. System capacity will need to be evaluated with this constraint in mind. This tributary is the outfall for part of the Arapahoe Crossing

Development and adjoining areas. Lower portions of the storm sewer in and around the Valley Country Club Golf Course transition from 8' x 3' RCBC to 66" RCP and then back to 8' x 3' RCBC.

The VCA area is composed of 110 acres in the City of Centennial, 91 acres in the City of Aurora, and 6 acres in unincorporated Arapahoe County. SEMSWA serves the areas in the City of Centennial and unincorporated Arapahoe County. Challenges include crowns not matching at pipe transitions mentioned in the previous paragraph and potentially undersized piping. If capacity is determined to be insufficient, alternatives will be complicated by multiple utilities including crossing and parallel sanitary lines, water lines, and golf course irrigation.

**North Arapahoe Tributary (NA)** was added to the project scope of work during the Kickoff Meeting to help address flows to Cherry Creek adjacent to E. Arapahoe Rd. Runoff from North Arapahoe watershed east of S. Buckley Rd. is conveyed in storm sewer and through a SEMSWA owned and maintained regional detention pond referred to herein as the North Arapahoe (NA) Pond. This pond is also referred to as Pond E by SEMSWA and is located in Tract A of Filing No. 9 for The Farm in Arapahoe County (P.R. Fletcher & Associates, Inc., 2000). Further downstream, runoff is conveyed under S. Parker Rd. in a 48" concrete pipe before discharging directly to Cherry Creek. The upper-most part of this watershed is located south of E. Arapahoe Rd. in the Town of Foxfield and drains to a downstream manhole that joins outflow from NA pond.

The North Arapahoe watershed combines a 372-acre area, 206 acres of which are served by SEMSWA, 114 acres by the Town of Foxfield, and 51 acres by the City of Aurora. This watershed includes 141 acres in unincorporated Arapahoe County. Challenges include NA Pond hydraulics due to discrepancies between LiDAR contours and as-built records, complex hydraulics at the S. Parker and E. Arapahoe Rd. interchange and upstream, and potentially undersized conveyance in downstream areas.

**South Arapahoe Tributary (SA)** was also added to the project scope of work during the Kickoff Meeting to help address flows to Cherry Creek along E. Arapahoe Rd. Runoff is discharged by a 12' x 6' RCBC that was designed to convey 645 cfs from the previously planned Southeast Regional Detention Basin. Research indicates that the Foxfield Outfall from the E. Arapahoe/S. Parker Interchange Water Quality Pond became MHFD maintenance eligible in January 2014. However, the downstream detention component of this pond is not publicly owned and maintained, or maintenance eligible, and so it is not included in project hydrology.

The SA watershed combines a 317-acre area in the Town of Foxfield, a 70-acre area in the City of Aurora, a 4.5-acre area in unincorporated Arapahoe County, and a 4-acre area in the City of Centennial. SEMSWA provides service to the City of Centennial area and 3 acres of unincorporated Arapahoe County. A small area along the east side of S. Parker Rd. in Subbasin SA2, an area of 1.5 acres, is located in unincorporated Arapahoe County but is not currently served by SEMSWA. Challenges include complex

hydraulics at the S. Parker and E. Arapahoe interchange, WQ detention only and no regional detention, and potential bank instability in the downstream channel to the outfall.

**Chenango Tributary (C)** is the largest watershed and conveys runoff from 920 acres to Cherry Creek through the Cherry Creek Valley Ecological Park from the Chenango Development, which is a single-family large lot rural development that is fully built out. There are direct outfalls from the Landing at Cherry Creek development with no apparent water quality or detention. Red Hawk Ridge Elementary School provides some level of stormwater management. Regional detention and water quality do not exist along Chenango Tributary. Both developments discharge along a grouted sloping boulder drop structure and moderate infrastructure is located along portions of this tributary, predominantly in the downstream reaches. A sloped/tapered throat 10' x 5' RCBC crosses Cherokee Trail, and upstream a CDOT 3-barrel 12' x 6' RCBC with baffle chute drop structure crosses S. Parker Rd. The condition of these structures is good.

Upstream from S. Parker Rd., drainage infrastructure is more rural in design. At E. Hinsdale Way, a 54" CMP has incorporated a gated section at the outlet, presumably to function as fencing for the private property through which it passes. Seven additional public road crossings and 6 private drive crossings, some of which are bridges, are located upstream to the basin headwaters.

The Chenango watershed combines a 450-acre area in the City of Centennial, a 376-acre area in the Town of Foxfield, and a 90-acre area in unincorporated Arapahoe County. SEMSWA serves the areas in the City of Centennial and unincorporated Arapahoe County. Noted challenges that are present in this basin include no regional detention or water quality, a poorly defined or potentially undersized conveyance, a multi-split flow at the intersection of S. Richfield St. and E. Hinsdale Ave.; significant head cutting at S. Yampa St. with exposed twin 30" CMP and floating inverts due to erosion; widespread wetlands; at least 1 manmade impoundment with rusted and partially buried CMP; bank instability in the upper reaches; and numerous roadside ditches with timber grade control. The main tributary measures more than 2 miles in length with multiple left and right bank tributaries that measure another 1.5 miles in length.

**Tagawa Tributary (T)** was added to the project scope of work during the Kickoff Meeting as a direct flow area (DFA) to help address flows across S. Parker Rd. near Chenango and Kragelund Tributaries and was added as the 11<sup>th</sup> Tributary after removal of the remaining DFAs. Tagawa was named as a part of this study and has an area of approximately 107 acres. The tributary outfalls directly to Cherry Creek and is located to the south of Chenango Tributary and north of Kragelund Tributary. The crossing at S. Parker Rd. is located on the south side of E. Broncos Pkwy. The SEMSWA GIS data for stormwater mains indicates that the crossing is 2-42" pipes: 1 CMP and 1 RCP and both are noted to be in good condition. These pipes are also shown in the 1999 OSP (WRC Engineering, Inc., 1999). The area modeled is the portion east of S. Parker Rd. as this area will flow through the crossing at S. Parker Rd. and downstream 48" RCP piping to the Cherry Creek outfall.

The Tagawa watershed is entirely contained in the City of Centennial, which is served by SEMSWA. Challenges for Tagawa Tributary include poorly defined hydraulics upstream of S. Parker Rd., potentially undersized piping west of S. Parker Rd., and lack of ponds that provide water quality or extended detention.

**Kragelund Tributary (K)** conveys runoff from approximately 610 acres of mostly undeveloped land and provides the best opportunity for floodplain preservation. Before the Comment Review meeting Kragelund was referred to as South Unnamed Tributary, as described in the meeting minutes. Future development is anticipated from the headwaters near E-470 and King’s Point, through privately owned property currently managed by the Vermillion Creek Metropolitan District, to the confluence with Cherry Creek within the PJCOS. There is currently no drainage easement across this property. Minimal infrastructure is present with the most prominent feature being a CDOT 22’ x 8’ RCBC crossing of S. Parker Rd. upstream of which, possibilities exist for regional detention and water quality. For approximately 2,800 feet upstream of S. Parker Rd., the floodplain is wide with no defined main channel. At this point, moderate channel definition begins, and it splits into a right stem (2,600 feet long) that drains southern portions of the existing Chenango development, and a left stem that proceeds towards the headwaters where it intersects a second right bank tributary (3,200 feet long). The majority of Kragelund Tributary is devoid of wetlands.

The Kragelund watershed combines a 343-acre area in the City of Aurora, a 259 acre-area in the City of Centennial, and 7-acre area in unincorporated Arapahoe County. SEMSWA serves the areas in the City of Centennial and unincorporated Arapahoe County. Challenges for Kragelund Tributary include upstream erosion near E-470, lack of ponds that provide water quality or extended detention, and undefined conveyance to Cherry Creek.

**17 Mile Tributary (17)** was added to the project scope of work during the Kickoff Meeting to help address flows across the 17 Mile House Farm Park. It is the most southern tributary of this study and is located just north of the Arapahoe County / Douglas County border. This poorly defined tributary drains approximately 145 acres, and is bisected by S. Parker Rd. through which, 2-48” RCP conveys runoff. This watershed is also largely undeveloped upstream of S. Parker Rd. but is expected to be fully built-out following development of King’s Point.

17 Mile watershed combines a 97-acre area in the City of Aurora, a 17 acre-area in the City of Centennial, and 15-acre area in unincorporated Arapahoe County. SEMSWA serves the areas in the City of Centennial and unincorporated Arapahoe County. Challenges include poorly defined hydraulics from S. Parker Rd. to Cherry Creek and lack of ponds that provide water quality or extended detention.

**Table 2-4** Major Crossing Structure Inventory

Tributary	Description	Road Crossing / Type
Little Raven Creek (LR)	54" RCP and 48" x 66" Box Culvert	E. Belleview Ave.

Tributary	Description	Road Crossing / Type
	Wooden pedestrian bridge	Cherry Creek State Park
	Culvert Crossings	Lakeview Rd., pedestrian trails and bike paths
Suhaka Creek (S)	2- 60" RCP	Cherry Creek Dr.
Joplin Tributary (J)	2- 14' x 4' Box Culverts	S. Parker Rd.
	Elevated Pipe Crossing	S. Parker Rd.
	RB1 Pond 4 / Powers Pond	S. Joplin Way and S. Chambers Rd.
	Drop Structures	S. Chambers Rd. near Bed Bath and Beyond
	Culvert Crossings	Dirt pedestrian trail
Grove Ranch Tributary (GR)	None	
Valley Club Acres (VCA) Tributary	Inlet Structure	S. Helena St.
North Arapahoe Tributary (NA)	None	
South Arapahoe Tributary (SA)	144" x 72" Box Culvert	Along E. Arapahoe Rd. from outfall to S. Parker Rd.
	WQ Pond and Outlet Structure	S. Lewiston St.
	Culvert Crossings	Across and/or along Richfield St., Pitkin St., Buckley Rd., S. Parker Rd., and private roads.
Chenango Tributary (C)	4' x 2' RC Box	Cherry Creek Trail
	Grouted boulder drop structures	Red Hawk Elementary School
	10' x 5' Box Culvert	Cherokee Trail
	3- 132" x 172" Box Culverts	S. Parker Rd.
	Culvert Crossings	Across and/or along Yampa St., Hinsdale Ave., Telluride Ct., Richfield St., and private drives
Kragelund Tributary (K)	22' x 8' Box Culvert	Crossing S. Parker Rd. at Kragelund Acres
17 Mile Tributary (17)	2- 48" RCP	S. Parker Rd.
	2- 48" RCP	Driveway at 17 Mile House

## **2.4 Flood History**

This Master Plan lies within the FEMA Flood Insurance Rate Maps for Arapahoe County, Map Number 08005C, map panels 0476L, 0477L, 0181K, 0481L, and 0484L revised February 17, 2017, and Map Number 08005C, map panel 0483K revised December 17, 2010. None of the project tributaries are mapped on the effective FIRM panels. SEMSWA noted that a number of homeowners in the Valley Club Acres neighborhood (located along the North Arapahoe Tributary) reported that their crawl spaces had been flooded as a result of the heavy rainfall in the area on June 17<sup>th</sup>, 2019. The heavy rainfall guidance indicated up to 2.07 inches of rain were possible that day. There was no other statistical or anecdotal flood history available during the preparation of this Master Plan.

## **2.5 Environmental Assessment**

*See complimentary Major Drainageway Plan Report for Environmental Assessment.*

# 3.0 HYDROLOGIC ANALYSIS

## 3.1 Overview

The hydrologic analysis presented herein was developed independent of the 1999 OSP and no existing model input files were recreated or available for use. Basins were delineated using 1-foot LiDAR data described in **Section 1.4**. Shapefiles for notable infrastructure such as road networks and storm conveyance systems were also used to logically subdivide major basins at points of interest. The analysis identifies drainage patterns and runoff characteristics for the following 9 storm events: the 1-, 2-, 5-, 10-, 25-, 50-, 100-, 500-year and water quality (WQ) storm events. Land use was analyzed for existing and future conditions and the resultant hydrology is the foundation for the subsequent evaluation of drainage facilities and the systemwide level of service.

The Colorado Urban Hydrograph Procedure program (CUHP) 2016 version 2.0.0 was used to develop runoff hydrographs which were then routed using the EPA Storm Water Management Model (EPA SWMM) version 5.1 to account for the effects of storm sewer, stream reaches, and detention on lag and time to peak. Input data for CUHP is subwatershed specific and includes rainfall depth, watershed area, distance to centroid, length of flow path, slope, composite imperviousness, and depression storage and soil infiltration rates. This data was obtained through GIS analysis and project research to accurately model individual sub-basin conditions. Values are in accordance with recommendations provided by the MHFD and CUHP manuals.

The baseline project hydrology for the study utilizes the future land use conditions model and the subsequent sections provide a summary of the information utilized to quantify the peak runoff values. The summary includes design rainfall, sub-watershed characteristics, hydrograph routing and the results of the analysis. Hydrologic calculations were approved by MHFD on February 4, 2019.

## 3.2 Design Rainfall

Design rainfall depths for the for the 1-, 2-, 5-, 10-, 25-, 50-, 100- and 500-year storm events were obtained from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 (Volume 8, Version 2) Point Precipitation Frequency Estimates. Specifically, the 1-hour and 6-hour recurrence interval rainfall depths were utilized as direct inputs into the CUHP rain gage data. The WQ event is pre-defined, according to the CUHP manual, to be a 0.6 in. rainfall event for the 1-hour duration recurrence interval. None of the project basins exceed ten square miles and therefore no area adjustments to rainfall were required. This study is analyzing the WQ event and the 1-year storm event as part of a MHFD effort to assess WQ and bankfull conditions in the alternatives phase. **Table 3-1** summarizes the 1-hour and 6-hour rainfall depths, and the rainfall distributions developed by CUHP are in **Table B-1**.

**Table 3-1** Point Rainfall

Recurrence Interval	Rainfall Depth (in)	
	1-Hour	6-Hour
1	0.721	1.19
2	0.868	1.39
5	1.13	1.77
10	1.37	2.13
25	1.73	2.67
50	2.03	3.13
100	2.36	3.63
500	3.21	4.96

## 3.3 Subwatershed Characteristics

### Subwatershed Delineation

The 11 tributary basins are comprised of 44 subwatersheds. Each is shown on the subwatershed layer with the Baseline Hydrology Map in **Figure B-1**. The sub-basin sizes range from 21.8 to 140.0 acres, with the average value being 99.0 acres. The major basin boundary for each tributary was verified by evaluating LiDAR data, stormwater infrastructure, roadways, and field reconnaissance. Additional review of approved Drainage Reports, Construction Drawings, and As-Built Drawings within the Project Area further informed the development of the models. Where there is overlap, the basin delineation is reasonably comparable to the 1999 OSP. However, the sub-basin naming convention is fully independent and conforms to the tributary in which they are located, as follows:

Little Raven Creek: LR1 – LR3

Suhaka Creek: S1 – S3

Joplin Tributary: J1 – J8

Grove Ranch Tributary: GR1

Valley Club Acres Tributary: VCA1 – VCA2

North Arapahoe Tributary: NA1 – NA4

South Arapahoe Tributary: SA1 – SA4

Chenango Tributary: C1 – C9

Kragelund Tributary: K1 – K7

17 Mile Tributary: 17A – 17B

Reference the *Subwatershed Boundaries Map* layer of the Baseline Hydrology Map in **Figure B-1** for the locations and delineations of the CUHP sub-basins.

Numerous physical characteristics associated with each subwatershed are used to produce a storm runoff hydrograph for each subwatershed in CUHP. The hydrograph outputs from CUHP are saved in a tabular format to a text file that is then used as the Inflow file for SWMM. These hydrographs represent the overland flow for each subwatershed which are represented as nodes in SWMM. The CUHP input parameters that define the hydrograph for each subwatershed include the following and are further detailed in **Table B-2** located in Appendix B.

Drainage area (acres)

Length and Distance to Centroid (ft)

Watershed Slope (ft/ft)

Composite Imperviousness (%)

Horton's Soil Infiltration Rates

Depression Losses/Retention Storage Values

#### Watershed Imperviousness

Watershed imperviousness was determined using land use maps, zoning data, and aerial imagery. Most of the tributary watersheds are almost fully developed; therefore, the watershed imperviousness developed for 9 of the basins is considered future conditions (i.e. existing conditions = future conditions). The weighted average future percent imperviousness for all the studied basins is 33%. Existing watershed imperviousness was evaluated for the 17 Mile Tributary and the Kragelund Tributary only, since these basins are largely undeveloped at the time of this study. The weighted average existing percent imperviousness for each basin is 8% and 14%, respectively. King's Point, a planned development in the area, is anticipated to build out these basins east of S. Parker Rd. in the near future; the associated increase in imperviousness to 36% and 35% is reflected in the future conditions hydrology. For further description regarding how land use was used to determine subwatershed imperviousness, refer to **Section 2.2**.

#### 3.3.1 NRCS Soil Information

Soil conditions for each subwatershed were used as CUHP inputs to determine the infiltration rates based on Horton's Equation. Data for soils was collected from the National Resources Conservation Service (NRCS) Web Soil Survey (USDA, 2018) and corresponding hydrology soil groups (HSG) were determined for each soil type. The 4 HSG types are A, B, C and D, with Type A having the highest infiltration rate and thus lowest runoff potential, and Type D have very low infiltration rates and high runoff potential. Soils in the overall Project Area are classified as: 11.8% Type A, 44.9% Type B, 20.6% Type C, and 22.7% Type

D. HSG types and corresponding Horton values, including initial and final infiltration rates (in/hr) and decay coefficients ( $s^{-1}$ ), were taken from *Table 6-7 Recommended Horton's equation parameters* in the MHFD Criteria Manual Volume 1. To determine composite Horton's parameters for each subcatchment for CUHP determination of infiltration rates, an area-weighted average was used. Refer to **Table B-2** in Appendix B for a summary of the resultant Horton's parameters and the Soils Map layer in **Figure B-1** for a map of the hydrologic soil groups. For Baseline Hydrographs, refer to **Figure B-4** in Appendix B.

#### 3.4 Detention

Two regional detention facilities are included in the baseline hydrology EPA SWMM model: Pond RB1-4 on Joplin Tributary and North Arapahoe (NA) Pond on the North Arapahoe Tributary. North Arapahoe Pond serves the developments from Farm Filing No. 7, 8 & 9 where it is referred to as "Pond E". Both are publicly-owned and MHFD maintenance-eligible and are herein referred to as Pond RB1-4 and NA Pond. Detention rating curves for both were sourced from engineering reports, record drawings, and survey data that are on file with the project sponsors.

Pond RB1-4, which is owned and maintained by SEMSWA, is an on-line pond located on Joplin Tributary between E. Crestline Ave. and S. Joplin Way. The detention rating curves were developed from a stage-storage-discharge table located in the as-built drawings prepared for East Cherry Creek Valley (ECCV) Water and Sanitation District on April 28, 1994 (Muller Engineering Co., Inc., 1994). The as-built data is assumed to be correct and supersedes data presented in the approved drainage report "Cherry Creek Basin RB1 Drainage Improvements" dated November 1989 (Muller Engineering Co., Inc., 1989). The as-built stage-storage curve was back-checked using 2014 LiDAR 1-foot contours; the final stage-storage curve incorporates additional data points from the 2014 LiDAR and the same total storage volume as the 1994 as-builts. Refer to **Table B-3** in Appendix B for the Pond RB1-4 stage-storage-discharge curves.

NA Pond, also owned and maintained by SEMSWA, is not located on the main stem of the NA Tributary, however, sits on-line a tributary of North Arapahoe and serves Filings No. 7, 8 & 9 of the Farm at Arapahoe County. Detention rating curves were originally obtained from as-built drawings prepared on May 4, 2000 (Aztec Consultants & P.R. Fletcher & Associates, Inc., 2000) and the Phase III Drainage Erosion & Sedimentation Control Report dated 15, 1999 (P.R. Fletcher & Associates, Inc., 1999). However, it was noted that the 2014 LiDAR indicated that the total storage volume quoted in the as-builts was larger than physically feasible. Therefore, new stage-storage-discharge curves were calculated using survey data collected by the MHFD in February 2019. The new storage volume was calculated from the survey using the average-end area method and totaled 4.9 acre-feet as compared to the 2000/1999 volume of 11.1 acre-feet, at an elevation of 5772 feet (approximate top of berm). The UD-Detention spreadsheet (Version 3.07, Released February 2017) was used to estimate a new stage-discharge curve according to the surveyed outlet configuration. See **Table B-3** in Appendix B for the NA Pond stage-storage-discharge curves and calculations.

Neither of the 2 detention facilities was designed to detain the 500-year flow; therefore, additional points were added in the EPA SWMM model to both the stage-storage and stage-discharge curves, which minimally modifies the total storage volume but allows the 500-year maximum flows to pass without flooding model nodes.

### 3.5 Hydrograph Routing

Hydrograph routing for each subwatershed through the Cherry Creek Minor Tributary basins was modeled using EPA SWMM 5.1 and the Kinematic Wave routing method. The routing scheme described in this section applies to both existing and future conditions, as no changes to hydrologic routing is anticipated. Refer to the *Baseline Hydrology SWMM Routing Map* layer in **Figure B-1** and **Figure B-3** in Appendix B for a visual representation of the routing scheme. Summarized input and output files from EPA SWMM are included in **Table B-5** and **Table B-6**.

Each subwatershed is represented in EPA SWMM by a junction node with an invert elevation reflecting the lowest point in the subwatershed. Overland flow within each basin is routed via a conduit link labeled "SUB\_OF" and contains no geometry or physical information additional to that reflected in the hydrograph output produced by CUHP. Design points are represented by junction nodes and contain the invert elevation found at that location, and these elevations dictate the slope of any attached link that represents open channel, stormwater sewer, or overflow conveyance elements. These links are labeled "SUB\_OC", "SUB\_SS", and "SUB\_OVF", respectively.

Channel characteristics and the associated SWMM routing elements were estimated using topographic contours, aerial photography, GIS and plan data, and site visits. Stormwater infrastructure shapefiles from SEMSWA and the City of Aurora were the primary source of information for conduit shape, maximum depth, length, and material. For conduit lengths that included several pipe sizes, an average size was selected for the SWMM link. Lengths were estimated using ArcGIS in the *NAD 83 Colorado State Plane, Central Zone* projected coordinate system. Most stormwater sewer conveyance elements were reinforced concrete, which corresponds to a Manning's roughness coefficient of 0.013 and translates to a value of 0.016 for CUHP-connected models.

To obtain cross-section geometry for open channels, approximate sections were drawn using GeoHECRAS version 2.1.0.17569. Using this program and 2014 LiDAR elevation data, a total of 6 different 4-point channel geometries were established based on open channels studied in subwatersheds LR2, J3, SA2, C4, K4, and 17A. Each open channel conduit modeled corresponds to one of these geometries depending on similar geometry. Manning's roughness coefficients were estimated for each subwatershed using *Equation 6-8* from the MHFD Criteria Manual Volume 1. This equation suggests that Manning's roughness coefficient for open channels is directly proportional to the slope of the channel and inversely proportional to the hydraulic radius. FlowMaster V8i was used iteratively at various flow rates (cfs) to solve for the hydraulic radius and Manning's roughness coefficient for 5 slope cases: 1%, 1.5%, 2%, 2.5%, and 3%. Key tables were developed for each channel geometry and these tables were used for

each conduit link to select a coefficient appropriate for the slope and channel shape. It should be noted that this determination was made using the original 8-point channel geometry determined for the 6 shapes; however, the geometries used for the SWMM conduits were reduced to 4 points to allow for hydrograph convergence. And finally, the open channel lengths and alignments were estimated using ArcGIS and 1-foot LiDAR-sourced contours.

To eliminate nodal flooding during larger storm events, 12 divider nodes were included at the following junctions: Lewiston\_J, Laredo\_J, Shalom\_J, Fair\_Place\_VCA, Parker\_T1, Waco\_NA, Buckley\_NA, Parker\_NA, NA\_M130, Parker\_SA, NA\_SA\_S125, and NA\_SA\_S123. These nodes were assigned cutoff flow values just before surcharging and direct overflow to a secondary dummy link created to convey the entire flow downstream.

Finally, detention ponds were modeled using storage unit nodes with downstream outlet links. Each storage node and outlet link used a tabular stage-storage curve and stage-discharge curve as described in **Section 3.4**.

### 3.6 Previous Studies

Two sources of previous hydrologic analysis are available for the Cherry Creek Minor Tributaries to-date. The first is the 1999 Cherry Creek Corridor Reservoir to County Line Outfall Systems Plan (WRC Engineering, Inc., 1999). This is a regional study that provides a limited number of common design points for reference and comparison. The second source is individual site drainage reports. Drainage reports were referenced only where necessary for the modeling of regional detention ponds, as discussed in **Section 3.4**.

### 3.7 Results of Analysis

Peak flow rates for the existing and future land use conditions models were established at design points after incorporating the rainfall data, hydrologic characteristics, and drainage conveyance parameters within EPA SWMM. The basin-wide peak flow rate and volume results at each of the design points along the stream corridor for the WQ, 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year storm events are presented in Appendix B with key points shown in **Table 3-2**.

A summarized input and output file from the EPA SWMM version 5.1 model are included in Appendix B. These files provide the detailed information regarding subwatershed hydrologic input and the resulting hydrograph routing and peak flows. As noted earlier, only Kragelund Tributary and 17 Mile Tributary have existing conditions hydrology.

Following completion of the baseline hydrology in January 2018, additional storm sewer infrastructure data was obtained from CDOT As-Builts for the Arapahoe/Parker interchange project (Federal Aid Project No. STU 0831-107 dated May 9, 2012). These plans depict existing storm sewer lines that were not included in the municipal GIS shapefiles used to inform the original baseline hydrology modeling. In an effort to better characterize urban flooding on Arapahoe Road and within Valley Club Acres, the baseline hydrology



SWMM model was revised to reflect the 2012 CDOT plans. The outputs documented in the text and appendices of this report have been updated to reflect these revisions.

As a result of the 2012 CDOT plan modeling revisions, it was determined that the majority of North Arapahoe Tributary is redirected to South Arapahoe just upstream of S. Parker Road via a 48" RCP. The capacity of the 48" RCP is exceeded by the 100-year, resulting in approximately 200 cfs of overflow which would continue as street flow under the interchange on the north side of the road. Assuming this water can re-enter the storm system, all of this overflow fits within the capacity of an existing pipe that begins on the northwest corner of the Parker interchange and continues to Cherry Creek. North Arapahoe flow contained within the 48" RCP is routed to a 54" RCP that runs parallel to a second 54" RCP that serves South Arapahoe Tributary. The 54" RCPs combine on the west side of S. Parker Road into an 8' x 6' box that transitions quickly into a larger 12' x 6' box. The parallel 54" RCP sections overflow in the 100-year by approximately 150 cfs and the 12' x 6' box overflows by approximately 56 cfs.

**Table 3-2** Peak Flows at Key Design Points

Basin	Location	Design Point	Existing (cfs)			Future (cfs)		
			Q <sub>5</sub>	Q <sub>25</sub>	Q <sub>100</sub>	Q <sub>5</sub>	Q <sub>25</sub>	Q <sub>100</sub>
Little Raven Creek (LR)	Outfall to Reservoir	LR_outfall	-	-	-	72	253	454
	E. Belleview Ave.	Belleview_LR	-	-	-	86	242	404
Suhaka Creek (S)	Cottonwood Creek Confluence	S_outfall	-	-	-	65	238	423
Joplin Tributary (J)	Outfall to Cherry Creek	J_outfall	-	-	-	173	348	613
	S. Parker Rd.	Parker_J	-	-	-	182	331	535
	RB1-4 Pond Outflow	out_RB1-4_pond	-	-	-	110	205	352
	RB1-4 Pond Inflow	RB1-4_pond	-	-	-	146	345	570
Grove Ranch Tributary (GR)	Outfall to Cherry Creek	GR_outfall	-	-	-	43	96	150
Valley Club Acres Tributary (VCA)	Outfall to Cherry Creek	VCA_outfall	-	-	-	83	211	349
North Arapahoe Tributary (NA)	Outfall to Cherry Creek	NA_outfall	-	-	-	0	0	191
	S. Buckley Rd.	Buckley_NA	-	-	-	45	150	325
South Arapahoe Tributary (SA)	Outfall to Cherry Creek	SA_outfall	-	-	-	148	455	717
	S. Parker Rd.	NA_SA_123	-	-	-	115	389	606
Chenango Tributary (C)	Outfall to Cherry Creek	C_outfall	-	-	-	112	478	942
	S. Parker Rd.	Parker_C	-	-	-	96	436	857
Tagawa Tributary (T)	Outfall to Cherry Creek	T_outfall	-	-	-	14	52	105
Kragelund Tributary (K)	Outfall to Cherry Creek	K_outfall	49	308	626	151	478	859
	S. Parker Rd.	Parker_K	50	307	615	149	472	839
	Tributary Confluence	Confluence_K	36	181	334	121	309	505
17 Mile Tributary (17)	Outfall to Cherry Creek	17_outfall	8	84	169	52	155	267
	S. Parker Rd.	Parker_17	6	70	141	47	135	229

**Table 3-4** compares the results of the 1999 OSP with the results of this Master Plan, where applicable, for future conditions hydrology. The tributaries have only a handful of comparable points and not all of the tributaries were studied in the 1999 OSP (WRC Engineering, Inc., 1999). Several variables in this Master Plan differ from the 1999 OSP. Each of these variables affected the hydrology of the tributary basins to a different degree and therefore no overall trend exists of the change in peak flows. However, a unit discharge comparison, as shown in **Table 3-4**, indicates that both studies resulted in similar volumes of runoff per acre.

Notable items that differ between the 1999 OSP and this Master Plan are summarized below.

- Little Raven Creek, Suhaka Creek, and Joplin Tributary were not studied in the 1999 OSP.
- Compared to the 1999 OSP, the rainfall depths used in the current MDP are lower, except for the 1-year storm event. The 100-year 1-hour rainfall depth used in the 1999 OSP was 2.67 inches, as opposed to 2.36 inches used in this study.

**Table 3-3** Rainfall Depths, 1999 OSP vs. MDP

Recurrence Interval	1-Hour Point Rainfall Depth (in)	
	1999 OSP	2019 MDP
1	0.4	0.721
2	0.97	0.868
5	1.38	1.13
10	1.65	1.37
50	2.32	2.03
100	2.67	2.36

- Residential land use east of S. Parker Rd. between E. Arapahoe Rd. and the southern boundary of the County was estimated as 5% and 8% vs. 20% in this Master Plan. This impacts most of the Chenango Tributary, Tagawa Tributary and South Arapahoe Tributary basins. Additionally, the 1999 OSP estimated the future King's Point development would increase existing imperviousness to 50% as opposed to the single-family land uses of 30% and 45% used in this study.
- With the benefit of a more refined data set, the variables used in this study's hydrologic analysis lead to a more detailed and comprehensive basin-wide examination. This study prepared a model with more detailed routing by identifying storm sewer drainage versus overland flow. Additionally, Manning's roughness coefficients were estimated using *Equation 6-8* from the MHFD Criteria Manual Volume 1, which resulted in overall higher values than those used in the 1999 OSP, but values that are more appropriate for hydrologic routing. Both of these factors result in differences in the timing of the storm hydrographs and, ultimately, the calculated peak flows.

**Table 3-4** 100-year Peak Flows, 1999 OSP vs. Current MDP

Basin	Design Point		Future Q <sub>100</sub> (cfs)		Basin Area (acres)		Unit Discharge (cfs/acre)		Notes
	1999 OSP	2020 MDP	1999 OSP	2020 MDP	1999 OSP	2020 MDP	1999 OSP	2020 MDP	
Valley Club Acres Tributary (VCA)	164	Fair_Place_VCA	486	349	262.2	207	1.85	1.69	
North Arapahoe Tributary (NA)	n/a	Buckley_NA1	n/a	325	n/a	272	n/a	1.19	OSP combined North and South Arapahoe basins
South Arapahoe Tributary (SA)	126	Parker_SA	599	321	603.2	326	0.99	0.98	
Chenango Tributary (C)	112	Bridle_Trail_C	533	412	308.6	321	1.73	1.28	
Kragelund Tributary (K)	102	Confluence_K	453	505*	300.2	257	1.51	1.96*	*Existing is 334 cfs @ 1.30 cfs/acre
17 Mile Tributary (17)	108	Parker_17	171	229*	125.6	124	1.36	1.85*	*Existing is 141 cfs @ 1.14 cfs/acre

The following text notes the level of compatibility for comparison between design nodes found in the 1999 OSP versus design nodes used in this study. Unit discharges have been included in **Table 3-4** as an alternate form of comparison given the many variables that vary between this Master Plan and the 1999 OSP.

- The stakeholder interests along Grove Ranch Tributary are to address redevelopment within the lower reaches of the basin, identify the conveyance path, and identify the outfall to Cherry Creek. Therefore, the Grove Ranch Tributary is delineated as a single sub-basin downstream of S. Parker Rd. with its outfall located at Cherry Creek. The 1999 OSP does not provide adequate delineation downstream of S. Parker Rd. Its most useful design point is upstream of S. Parker Rd. at DP109, where the 100-year future conditions flow is reported as 77 cfs. Therefore, no comparison is made.

- Valley Club Acres is compared at design point 164, which is slightly upstream from the confluence with Cherry Creek. The next downstream design point is within the main stem of Cherry Creek and therefore, includes other upstream basins. Due to basin transfers, basin 57 - that was previously modeled as part of North Arapahoe (NA) Tributary - is modeled with Valley Club Acres Tributary in this study. A comparison is made, but it is not a direct correlation.
- The Chenango Tributary and Kragelund Tributary have common design points at the respective basin outfalls to Cherry Creek, as identified in **Table 3-4**.
- The 17 Mile Tributary is modeled with the 1999 OSP. However, a review of Figure A-6.2 in that report indicates that it was not routed to a design point. OSP basin 8 is upstream of S. Parker Rd. and therefore, it is assumed to be comparable to the design point listed in **Table 3-4**.

# 4.0 HYDRAULIC ANALYSIS

Several of the tributaries in this study are comprised of little to no open channel or were excluded from the FHAD by the project sponsors. The tributaries included in the FHAD are as follows: Little Raven Creek (LR), Joplin Tributary (J), South Arapahoe Tributary (SA), Chenango Tributary (C), Kragelund Tributary (K). These tributaries are shown in bold in **Table 2-1** and **Table 2-2**.

Flood Hazard Area Delineation (FHAD) hydrology is typically based on existing infrastructure and future land use conditions. For the Kragelund and 17 Mile Tributaries, the 100-year peak discharge for future land use conditions is greater than 30 percent (threshold established by FEMA) higher than the 100-year peak discharge for existing land use. Therefore, existing conditions hydrology was prepared for Kragelund and 17 Mile Tributaries and Kragelund Tributary’s delineation is required to use existing land use conditions hydrology. 17 Mile Tributary is not included in the FHAD analysis. The other four FHAD tributaries were analyzed using the typical future land use conditions hydrology.

A one-dimensional (1D) hydraulic model was developed for each of the 5 tributaries included in the FHAD using the U.S. Army Corps of Engineer’s HEC-RAS, Version 5.0.7. Cross-sectional profiles were populated electronically using a DEM (provided by MHFD) developed from the 2014 post-flood USGS topographic LiDAR. Major crossings were individually surveyed in the field by Wilson & Co. The models were run using a sub-critical regime in accordance with the floodplain mapping criteria. River centerlines were determined by tracing the low flow path for each tributary. All models are included in the Technical Appendix.

Flow data in the model came from the results of the EPA SWMM 5.1 hydrograph routing, as outlined in **Section 3.5**. A steady flow analysis was used to determine the flood profiles for the 10-, 25-, 50-, 100-, and 500-year storm events. All models reflect existing infrastructure and future flows, except Kragelund which reflects existing infrastructure with existing flows. Stakeholders agreed it should be existing flows because future flows won’t be achieved due to detention requirements for future developments. Flow change locations were established at critical design points where there are significant changes in hydrology, as determined by the EPA SWMM model. The downstream boundary conditions for the Little Raven Creek and Joplin Tributary models were normal depth computations with a slope of 0.01. For the Chenango Tributary and Kragelund Tributary models, the downstream hydraulic controls were set to the 10-year flood elevation of Cherry Creek per MHFD guidelines. The South Arapahoe Tributary model was set to a known water surface elevation based on the headwater elevation of each flood profile at the Lewiston Way culvert crossing. Since the models were run in sub-critical, no upstream boundary conditions were specified in any of the models. Roughness values were chosen using USDCM Table 8-5 and Equation 9-1. Manning’s n values were estimated for existing conditions using aerial imagery and Google street view and ranged from 0.05-0.16, shown in **Table 4-1**. Photographs of typical channel sections used to determine Manning’s n values are included in Appendix C. In lieu of conveyance obstructions, areas with overland flow across residential and commercial areas use a higher Manning’s n

value to account for reduced flow around buildings. Ineffective flow areas were used to account for flow areas with little or no flow conveyance.

**Table 4-1** Roughness Values

Category	Roughness Value
Native Grasses	0.05
Willow Stands	0.16
Herbaceous Wetlands	0.12
Housing/Commercial	0.1-0.2
Turf Grass	0.04
Fences	0.1

The Kragelund Tributary model contains a lateral weir structure from cross-section 1812 to 2101. There is shallow flooding occurring at this location, so the lateral weir structure was used to contain these cross-sections. A two-dimensional (2D) hydraulic model was used to model the shallow flooding beyond the lateral weir. Flows applied to the 2D model were estimated by the lateral weir structure for the 100-year and 500-year events.

A draft model was prepared for the North Arapahoe Tributary, which consists of shallow roadway flooding due to limited storm sewer capacity and no open channel. The initial results showed the floodplain to be contained within the right-of-way and therefore it was determined that a FHAD would not be appropriate. This draft model is included in the Technical Appendix as supplemental information only.

The floodway was defined for each tributary to establish the portion of the channel that must remain free from obstruction for effective conveyance of the 100-year flood. The floodway was defined using a 0.5-foot allowable rise in the Energy Grade Line (EGL) and the Hydraulic Grade Line (HGL). The floodway was delineated so that the encroachments were evenly distributed to the fullest extent possible.

Shallow flooding areas were identified at South Arapahoe Tributary crossing Arapahoe Road and Kragelund Tributary west of Parker Road. The South Arapahoe Tributary only included 500-year shallow flooding and Kragelund Tributary included 100- and 500-year shallow flooding. Two separate 2D HEC-RAS models were created of each tributary to model these areas and determine the shallow overland flow depth. Auto-delineation of the shallow flooding for both tributaries was exported from HEC-RAS and is shown on the flood maps.

Flood maps showing the 100-year, 500-year, and Floodway delineations are shown in Appendix E and identify areas, structures, and properties which have the potential of being inundated by the 100-year flood event. Flood profiles for the 10-, 25-, 50-, 100-, and 500-year events are shown in Appendix F. Locations of cross-sections and all hydraulic structures are shown on both the flood maps and profiles. The Floodplain and Floodway Data Table is shown in **Table D-1**. This table identifies the cross-sections;

channel thalweg elevations; 10-, 25-, 50-, 100-, and 500-year discharges and water surface elevations; 100-year floodplain top widths and EGL elevations; and the floodway water surface elevation, top width, cross-sectional area and velocity. The Agreement Table is shown in **Table D-2** and serves as quality control to ensure that data from the flood maps, flood profiles, and models agree. Each cross-section is listed in this table and compares the distance between cross-sections, the cumulative distance, floodplain and floodway top widths, and water surface elevations.

#### 4.1 Evaluation of Existing Facilities

At each roadway crossing, a detailed survey of existing conveyance structures within the Project Area was provided by MHFD. Included with the survey were site photos, sketches of the entrance and outlet, detailed characteristics of the culvert's shape, size, length, inverts, overtopping elevations, and headwall/wingwall end treatments (if applicable). Photos of each crossing are included in Appendix C.

**Table 4-2** summarizes the inventory of the existing facilities with the general capacity of each structure. Only structures determined large enough to be modeled are listed in **Table 4-2**. All modeled tributaries and structure capacities are based on future conditions hydrology except for Kragelund Tributary which uses existing conditions hydrology. There are 20 existing crossings between the 5 tributaries, 15 of them are included in the HEC-RAS models, all of which are culverts. Culvert capacity was evaluated using peak flows obtained from the study's hydrology.

#### 4.2 Flood Hazards

The Project Area mostly consists of residential land use. There are small pockets of office, commercial, and industrial developments present, primarily along the major local thoroughfares. Large portions of Little Raven Creek, Suhaka Creek and Joplin Tributary basins are located within the Cherry Creek State Park.

If a 100-year flood occurred without any future improvements, a total of 17 structures would experience some level of flood inundation. Only three tributaries included in the FHAD have insurable structures in the 100-year floodplain: Little Raven Creek, Chenango Tributary, and Kragelund Tributary. Little Raven Creek has 3 residential structures and Chenango Tributary has 4 residential structures in the 100-year floodplain. Kragelund Tributary has 10 insurable structures in the 100-year floodplain; 9 of them are residential and 1 is commercial. The commercial structure is located within the 100-year shallow flooding. The Flood Maps in Appendix E show all insurable structures within the 100-year floodplain. The jurisdictions where the insurable structures are located are listed below:

- Little Raven Creek – 3 insurable structures located in unincorporated Arapahoe County
- Chenango Tributary – 4 insurable structures located in Town of Foxfield
- Kragelund Tributary – 10 insurable structures located in City of Centennial

**Table 4-2** Existing Facilities

Jurisdiction	Location	Survey Number	Crossing Type	Size	General Capacity
<b>Little Raven Creek (LR)</b>					
Greenwood Village	E. Belleview Avenue	42	Culvert	54" RCP & 66" x 48" HERCP	100 yr
Arapco	Park Trail	43	Culvert	48" RCP	< 10 yr
<b>Joplin Tributary (J)</b>					
Arapco	S. Parker Road	33	Culvert	2-14.2' x 4.1' RCBC	500 yr
<b>South Arapahoe Tributary (SA)</b>					
Foxfield	S. Norfolk Court	25	Culvert	42" CMP	10 yr
Foxfield	S. Buckley Road	24	Culvert	2-66" CMP	100 yr
Foxfield	S. Pitkin Street	23	Culvert	60" CMP	50 yr
<b>Chenango Tributary (C)</b>					
Arapco	S. Cherokee Trail	20	Culvert	22.5' x 5.7' RCBC	500 yr
Arapco/CDOT	S. Parker Road	19	Culvert	2-11' x 6' RCBC & 14' x 6' RCBC	500 yr
Foxfield	E. Hinsdale Way	18	Culvert	54" CMP	< 10yr
Foxfield	S. Richfield Street	11	Culvert	2-30" CMP	< 10 yr
Foxfield	S. Telluride Court	9	Culvert	3-30" CMP	< 10 yr
Foxfield	Private Drive	8	Culvert	30" CMP	< 10 yr
Foxfield	S. Yampa Street	4	Culvert	2-30" CMP	< 10 yr
Centennial	E. Hinsdale Avenue	46	Culvert	84" CMP	100 yr
<b>Kragelund Tributary (K)</b>					
Centennial	S. Parker Road	3	Culvert	22' x 7.4' RCBC	500 yr*

\*Existing Conditions

#### 4.3 Previous Analyses

This FHAD lies within the FEMA Flood Insurance Rate Maps for Arapahoe County, Map Number 08005C, map panels 0476L, 0477L, 0181K, 0481L, and 0484L revised February 17, 2017, and Map Number 08005C, map panel 0483K revised December 17, 2010. None of the project tributaries are mapped on the effective FIRM panels nor have been mapped by local studies. Therefore, comparisons between previous floodplain delineations cannot be made.

## 5.0 REFERENCES

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