Cherry Creek at 12-Mile Park
DRAFT FINAL Site Assessment Report

Prepared For:

CHERRY CREEK BASIN WATER QUAILTY AUTHORITY

Prepared By:

CH2MHILL

November 2010

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Purpose and Scope

The purpose of this Site Assessment Report (Report) is to document and present the stream and site conditions of Cherry Creek located at 12-Mile Park, at the upstream end of Cherry Creek State Park. Exhibit A shows the project area. The Site Assessment for Cherry Creek is part of a larger scope of work for the Cherry Creek Stream Reclamation at 12-Mile Park Project (Project), which is contracted between CH2M HILL and Cherry Creek Basin Water Quality Authority. The existing eastern or right bank of the channel has degraded in locations resulting in active erosion. The channel has also experienced a breakout or breach of the right bank of the low flow channel into the floodplain resulting in overbank erosion and additional environmental damage. This Project aims to develop a recommended plan to stabilize the eroded banks and restore the channel bed profile and channel to the historic alignment. Project objectives include:

- Develop alternatives to improve water quality in Cherry Creek.
- Develop alternatives to restore the low flow channel alignment to the historic flow path.
- Develop alternatives to stabilize and protect the eastern channel bank from erosion due to park use and hydraulic forces.
- Develop alternatives to enhance park users' interaction with the Creek.
- Select a preferred alternative to be carried forward into final design.

EXHIBIT A
Project Location Map
Cherry Creek Stream Reclamation at 12-Mile Park Project

Study Area

Cherry Creek is a major drainageway serving as the principal means of conveying runoff from south to north through Douglas, Arapahoe, and Denver Counties to the South Platte River. Cherry Creek Reservoir was constructed by the United States Army Corps of Engineers (USACE) as a flood control facility to protect downstream communities from catastrophic flooding. Since the construction of the reservoir, Cherry Creek State Park has become a premier recreational facility for the State of Colorado. The reservoir can experience significant nutrient loading from the contributing watershed that damages the health of the reservoir. The contributing area of the watershed from the upper reaches of Cherry Creek to the upstream limits of Cherry Creek State Park is approximately 361 square miles.

The project area is located at the 12-Mile Park Dog Off Leash Area (DOLA) located at the southern end of Cherry Creek Reservoir State Park. The project includes approximately 3,000 feet of stream bank restoration adjacent to the DOLA.

Park Use Characteristics

The 12-Mile Park DOLA was originally utilized as a sports dog training facility. As development around the park increased the park use changed to primarily an off leash dog park. Adjacent to the DOLA is an equestrian concessions area where many horses are stabled and horse owners can access the parks trails from the area. Social recreational trails through the DOLA have developed over time, primarily from pedestrian and dog traffic. The most frequented paths are those that lead from the parking area to Cherry Creek. The trail along the east bank of Cherry Creek is the location where most dogs and owners congregate. Park users tend to gather where there is the least vegetation on the creek bank where dogs can easily access the water in Cherry Creek.

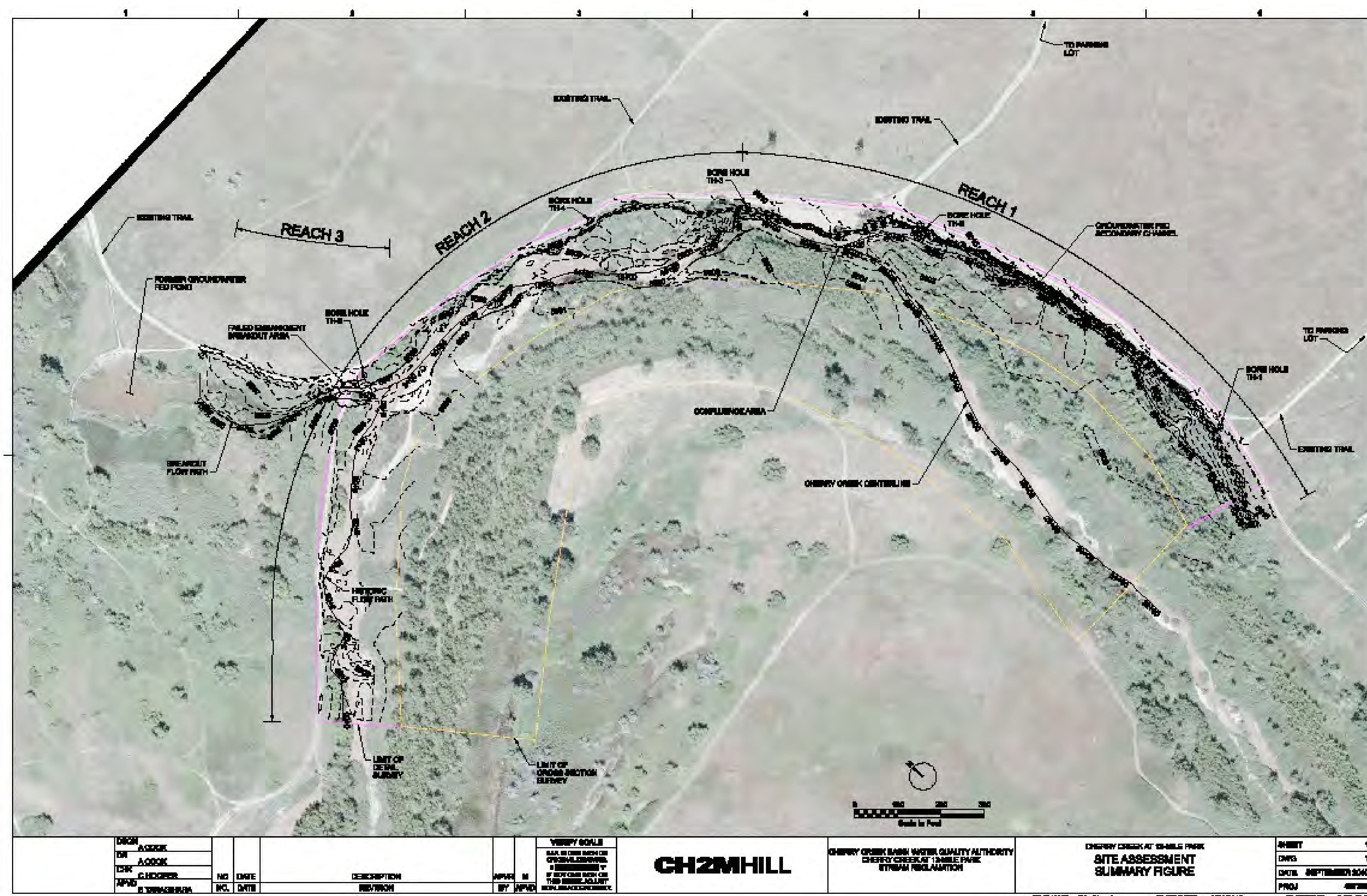
As the park has seen an increase in usage there has been an increase in channel bank degradation as well as conflicts between dogs and horses. In an effort to improve the recreational experience at the park, Colorado State Parks is working to develop a plan for improving the DOLA. The current plan is presented in Appendix F to this report. The plan, as of the date of this document, includes new dog waste stations, strategic fencing, improved trails, and new creek crossings. The "Creek Crossing" labels and symbols shown on the plan depict locations where park users are crossing the new location of Cherry Creek downstream of a breakout area. The depiction of these "Creek Crossing" locations is not intended to formalize these areas, but to simply show where crossing locations have developed due to the breakout. The breakout area is discussed in greater detail in the Site Review section below.

Survey

To provide an accurate plan on which to develop comprehensive solutions, a field survey of the project area was performed in August of 2010. The survey limits include the 3,000 feet of Cherry Creek from the existing trail on the east side to the west channel bank. In general, the survey services include the following:

- Provide 1-foot contour survey of the project area.
- Establish the current edges of the main channel.
- Capture any utilities located in the project reach.
- Locate and documenting the size of large diameter trees of potential value within the project reach.

Figure 1 is the Site Assessment Summary Figure and displays the survey contours, geotechnical boring locations, as well as site assessment area of concern.


REACH 1
REACH 2
REACH 3
EXISTING TRAIL
TO PARKING LOT
BORE HOLE
CONFLUENCE AREA
CHERRY CREEK CENTERLINE
HISTORIC FLOW PATH
BREAKOUT FLOW PATH
FAILED EMBANKMENT BREAKOUT AREA
FORMER GROUNDWATER FED POND
GROUNDWATER FED SECONDARY CHANNEL
LIMIT OF DETAIL SURVEY
LIMIT OF CROSS SECTION SURVEY
Scale in Feet
CH2MHILL
CHERRY CREEK BASIN WATER QUALITY AUTHORITY
CHERRY CREEK AT 12-MILE PARK
STREAM RECLAMATION
SITE ASSESSMENT
SUMMARY FIGURE
DESCRIPTION
REVISION
VERIFY SCALE

Geotechnical Evaluation

CH2M HILL engaged the services of CTL Thompson Inc. to perform a geotechnical evaluation of the project area. CTL Thompson Inc. performed five borings along the eastern channel bank and took soil samples on the channel bank for total phosphorus testing. Samples of the channel bed material were also taken to evaluate the channel material gradation. Specific geotechnical recommendations will be developed in conjunction with the design direction that is agreed upon during the alternative analysis phase of this project.

The geotechnical investigation determined that the borings contained 20 feet to more than 40 feet of silty to very clayey fine to medium grained sand with variable amounts of gravel. Sandstone bedrock was found in the southern most borings around 39 feet below the channel bank elevation.

Results from the phosphorus testing by ACZ Laboratories, Inc., are included at the back of the geotechnical report. It should be noted that the phosphorus results are given as a percentage, due to the sampling protocol used by the testing lab. To convert the results from percentage to parts per million, move the decimal four places to the right. For example 0.03% equals 300 ppm.

Recommendations and additional geotechnical detail can be found in the geotechnical report in Appendix A.

Site Review

Cherry Creek was observed for channel degradation, channel bank erosion and instability, and extreme degradation. There are no existing channel improvements or hydraulic structures within the project reach.

In general, Cherry Creek through the project area can be distinguished by three different channel reaches. The reaches were selected due to the similarities of channel characteristics through each channel reach. The east bank of Cherry Creek has experienced loss of vegetation and soil as a result of heavy traffic from park users through the entire project area. The following sections describe the findings for each of the three reaches.

Reach 1 – Upstream Reach

Cherry Creek through the upstream reach is located on the western side of the floodplain. On the eastern bank of the floodplain a groundwater fed secondary channel exists that has a lower channel invert than the main stem of Cherry Creek. The east bank of the floodplain is characterized by steep banks that are nearly vertical. The vegetation on the banks has been removed or damaged by park users, such as pedestrian and dog traffic. The loss of vegetation results in rapid erosion of the bank during minor storm events from surface runoff.

The eastern bank in Reach 1 is approximately 15 – 20 feet above the groundwater fed channel. To the west, the Cherry Creek channel is approximately two to three feet deep. The capacity of the low flow channel is such that flows from Cherry Creek infrequently leave the channel and flow toward the eastern bank. Due to the infrequent flows toward the east bank in this reach and the obvious eastern bank erosion, it is apparent the park use has caused the loss of vegetation and soil erosion on the eastern bank. Once the bank has been stabilized it is important to also manage the use of the bank to prevent this erosion from occurring again in the future. Photo 1 and Photo 2 depict the typical characteristics in the upstream reach.

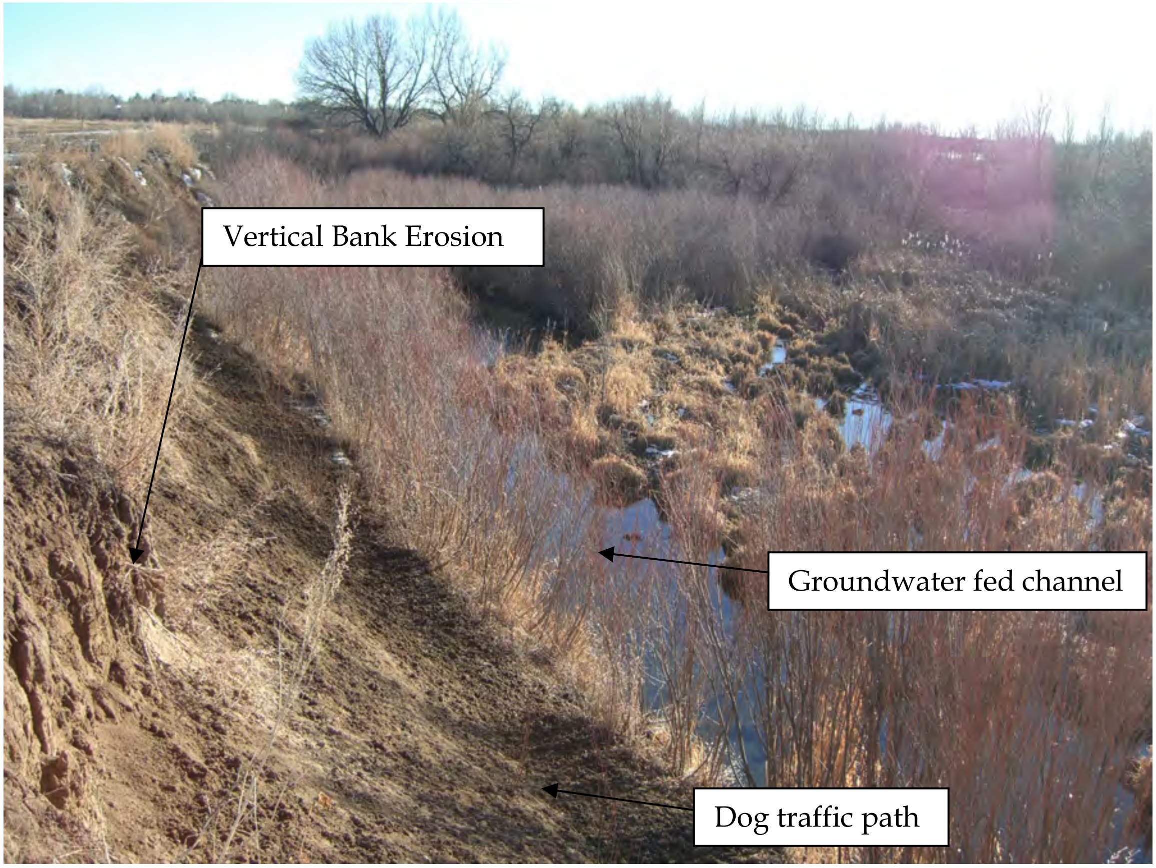


Photo 1 - Reach 1, Looking Upstream

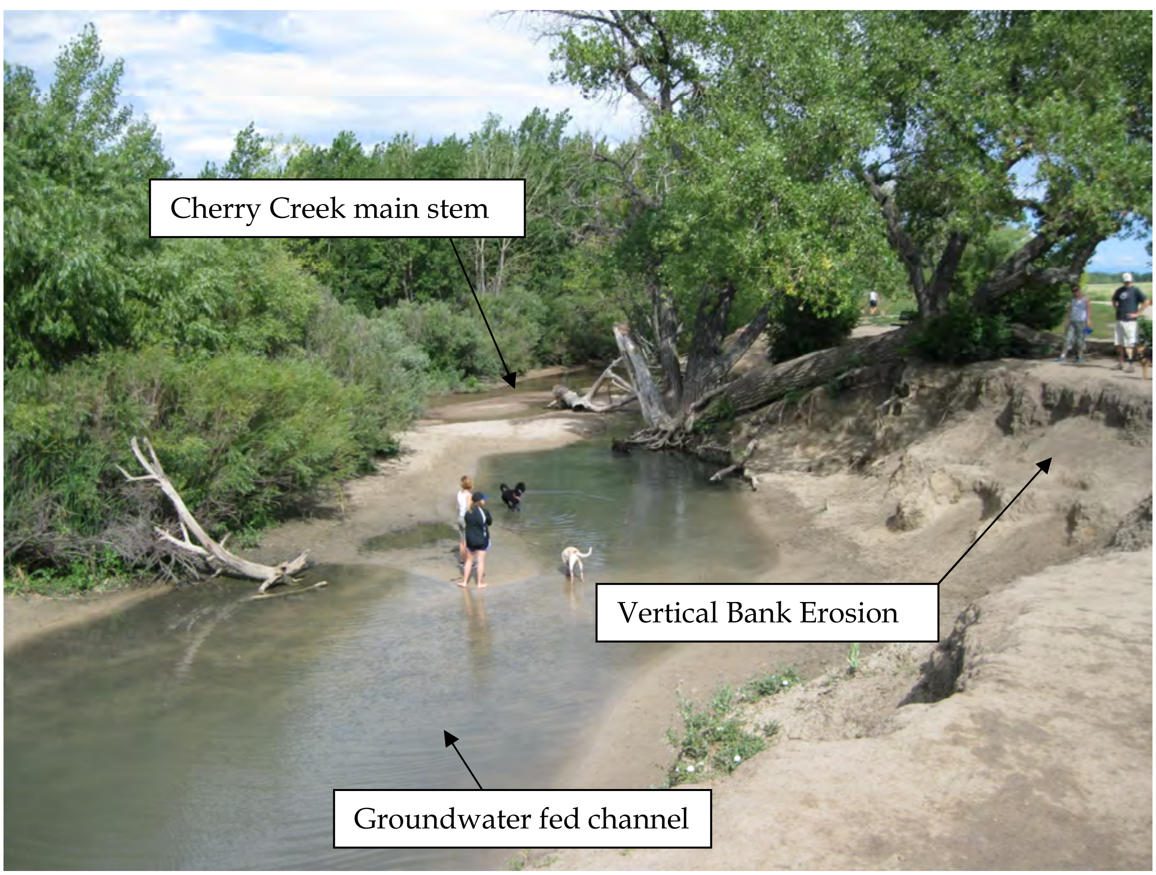


Photo 2 - Reach 1, Confluence Area

Reach 2 – Downstream Reach

At the downstream section of Reach 1 the groundwater fed channel joins with the main stem of Cherry Creek and flow continues downstream adjacent to the eastern bank of Cherry Creek. The eastern bank decreases in height and is between five and fifteen feet above the Cherry Creek invert upstream of the breakout location. As the channel reaches the breakout location the eastern bank height decreases to approximately three feet above the channel invert. The lower height of the eastern bank provides easier access to the channel and as a result there are numerous areas where users have trampled vegetation and soil erosion has resulted.

The eastern overbank in Reach 2 has lost a large amount of understory vegetation due to the user traffic in an effort to reach the water. The lower overbank and lack of adequate vegetation makes the area susceptible to erosion from higher flows in Cherry Creek. Restoration of the vegetative cover is recommended as well as management of access to the creek to prevent vegetation loss in the future. Photo 3 shows a typical overbank area in Reach 2.

In areas of Reach 2 sandy overbanks are present that create soft access points to the water and are buffers between vegetated banks and the creek. These areas will naturally degrade and aggrade with the channel. Since vegetation is not likely to take root in these areas, these access points are attractive to maintain for future use. Photo 4 shows a typical sandy overbank area in Reach 2.


Photo 3 - Reach 2, Cherry Creek Treed Overbank


Photo 4 - Reach 2, Sandy Overbank

Reach 3 – Channel Breakout Reach

Within Reach 2, Cherry Creek has experienced a breach of the eastern bank resulting in Cherry Creek leaving its historic flow path and flowing to the north rather than turning to the west as it has for the last 70 years. Based on discussion with the State Park staff and Park Concessionaires it appears that the loss of vegetation in the area due to heavy park use resulted in a vulnerable east bank. In the summer of 2009 a larger runoff event resulted in overtopping of the eastern bank. The overtopping caused localized erosion washing out the east bank and creating a channel invert lower than the historic flow path. This erosion continues to grow, creating a new flow path to the north. This new channel flows directly into the existing groundwater fed pond that can be seen in the aerial photos prior to 2009. This pond has now been completely filled with sediment due to the breakout. The breakout channel now flows into the groundwater fed wetland pond that exists near the 12-Mile Park northern entrance. This pond is experiencing heavy sediment loading and will likely be filled in as well if the channel is not repaired to return flow to the historic flow path. This is the most significant problem observed in the site assessment and should be repaired as quickly as possible to preserve the vegetation along the historic flow path and prevent the wetland pond from being filled in. Photo 5 and Photo 6 show the current breakout area at the historic channel and as the breakout channel flows north.

Additional site photos showing the different vegetative covers, banks conditions, erosion problems, and the break out area are included in Appendix B.

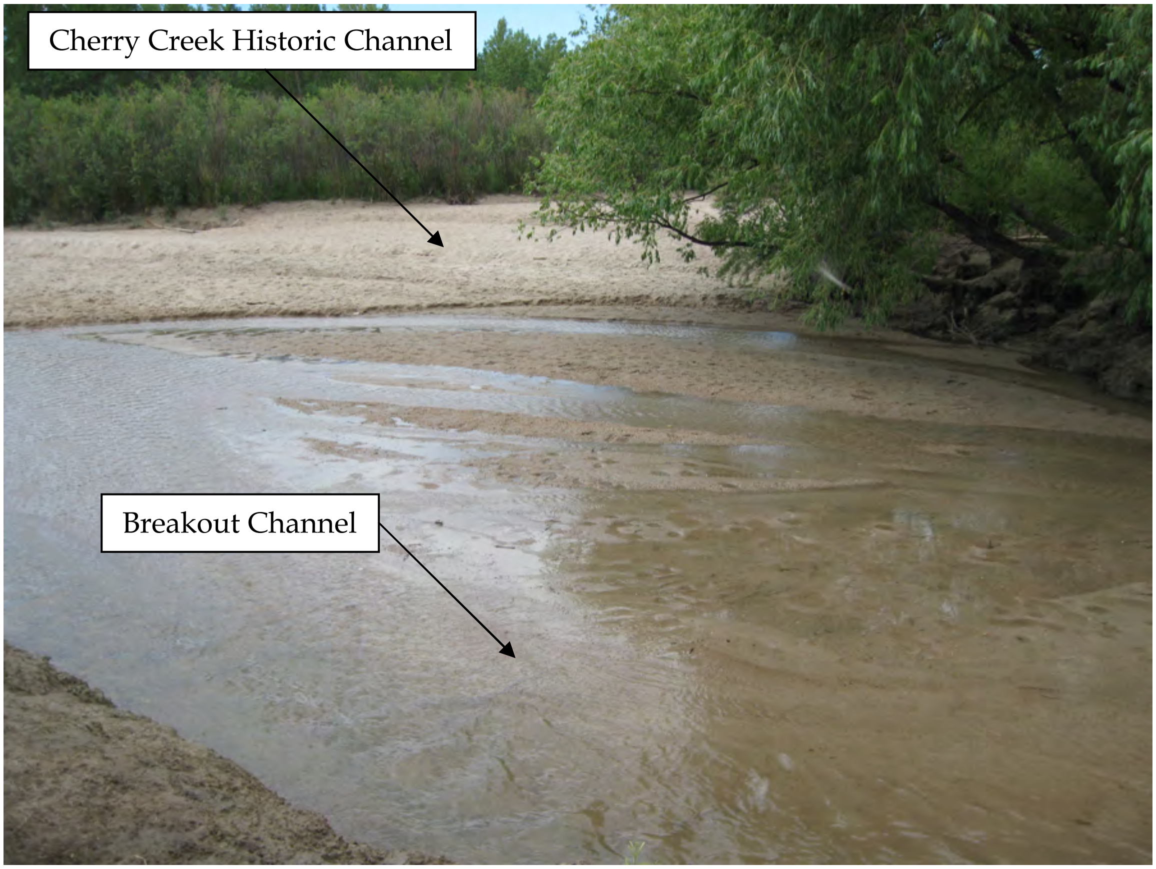


Photo 5 - Reach 3, Breakout from Historic Channel

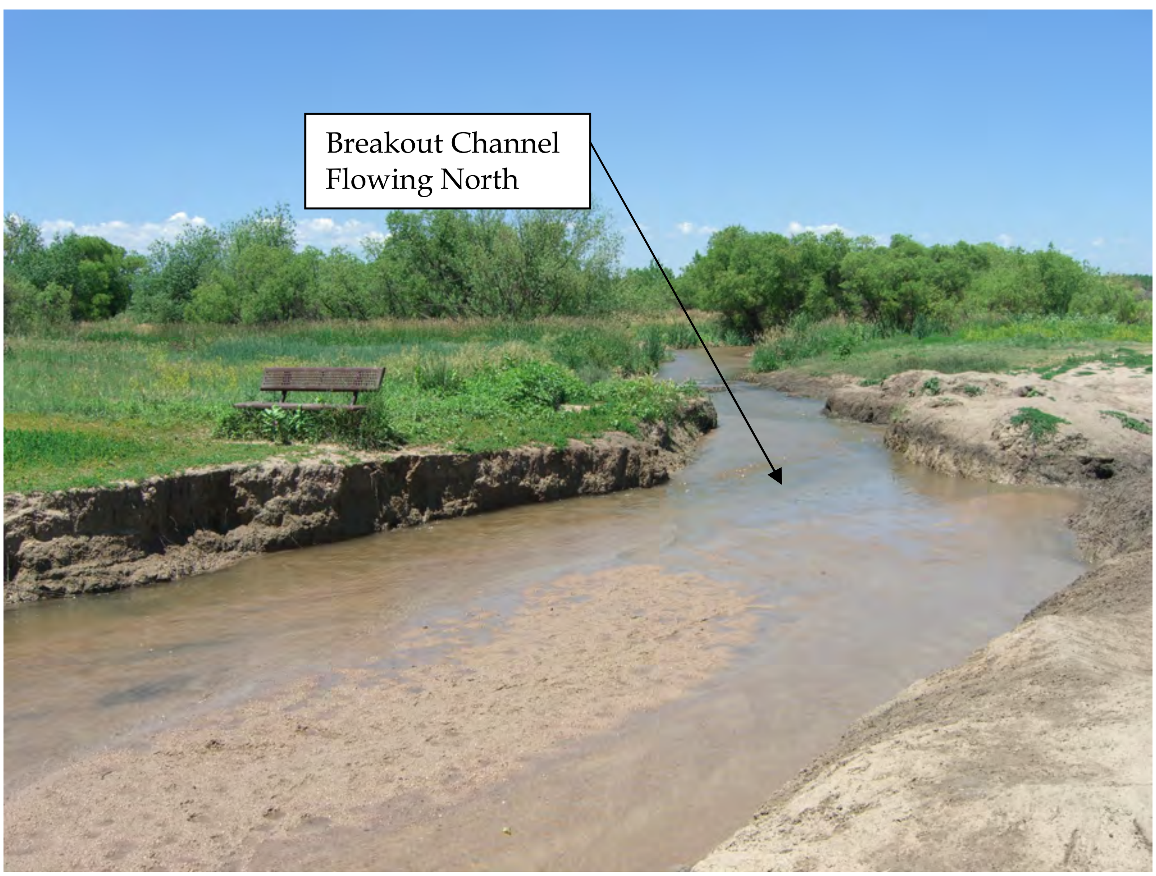


Photo 6 - Reach 3, Breakout Channel Downstream of Breakout

Environmental Evaluation

Through and in the vicinity of the project reach, Cherry Creek consists of a very active stream system with several braided channels, areas of sand deposition, vertical cut banks, several well-developed wetlands, and densely forested riparian areas. The various elements of the stream system create a mosaic of diverse habitat types.

As previously described, the project area consists of three stream reaches. In reach 1, wetlands extend across a broad, active floodplain. Wetlands in this reach are dominated by cattail (*Typhus latifolia*) and bulrush (*Schoenoplectus* spp.). Sandbar willow (*Salix exigua*), plains cottonwood (*Populus deltoides* subsp. *monilifera*) and peachleaf willow (*Salix amygdaloides*) create a dense overstory in places.

In reach 2, wetlands on the northeast bank are more confined to narrow margins along the channel and are dominated by sandbar willow and reed canarygrass (*Phalaroides arundanaceae)*. Wider sandbar willow and plains cottonwood wetlands occur along the southwest bank and along the toe of the south bank of a groundwater-fed channel just upstream of reach 2. West of the new breakout channel, surface water no longer consistently flows and shallow-rooted wetland vegetation along the historic channel will likely decrease. Deeper-rooted trees and shrubs will likely persist, but the number of new seedlings and saplings may decrease over time. Although, currently the damp sandy channel bottom provides an excellent growth medium for the establishment of willow and cottonwood seedlings.

The new channel in reach 3 flows through an area that was previously a cattail/bulrush wetland and a small pond surrounded by a broad sandbar willow wetland. Sediment deposited by the new channel has buried wetland vegetation along its length and in a wetland at its northern extent. If sediment deposition is eliminated and the sediment is not too deep, wetland vegetation will reestablish in the deposition areas. Figure 2 depicts the wetland areas within the project area.

The Cherry Creek riparian corridor provides potential habitat for two species listed as threatened under the Endangered Species Act: Ute ladies'-tresses orchid (*Spiranthes diluvialis*) and Preble's meadow jumping mouse (*Zapus hudsonius preblei*). Ute ladies'-tresses orchid (ULTO) occurs at elevations below 6,500 feet in moist to wet alluvial meadows, floodplains of perennial streams, and around springs and lakes. Generally, the preferred vegetative cover for ULTO is relatively open; dense overgrown sites are not conducive to establishment of the species. Although

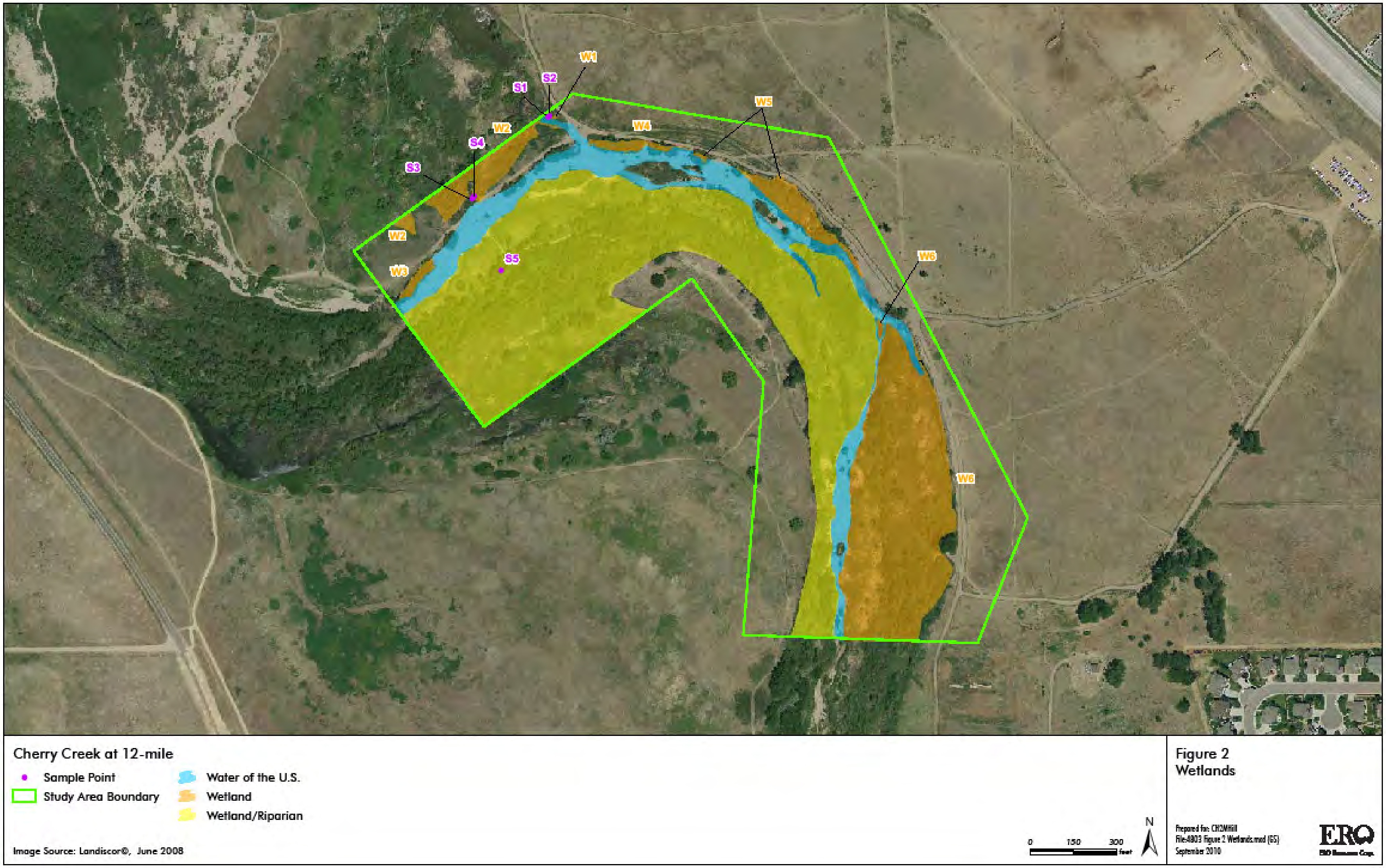


Figure 2
Wetlands

conditions along Cherry Creek in Douglas and Arapahoe counties appear to be suitable for ULTO, it is not known to be present. Along Colorado's Front Range, Preble's is found below 7,800 feet in elevation, generally in lowlands with medium to high moisture along permanent or intermittent streams. Preble's typically inhabits areas characterized by well-developed plains riparian vegetation with relatively undisturbed grassland and a water source nearby. Preble's is known to occur along Cherry Creek in Douglas County and was captured on Cherry Creek about four miles south of the project area in 2000. Although known to be present on Cherry Creek in Douglas County, Preble's has not been captured on Cherry Creek in Arapahoe County.

Hydrologic Evaluation

No new hydrologic modeling was performed as part of this site assessment. Rather, existing hydrologic data was reviewed to determine the most appropriate flow rates on which to base the design. Documents reviewed as part of this study are listed below:

- Cherry Creek Corridor – Reservoir to Scott Road Major Drainageway Planning Preliminary Design Report by URS (2004).
- FEMA FIS (as reported by URS Cherry Creek Corridor Study)
- Channel Forming Discharge (Ruzzo, 2010)

Additional data from these sources are included in Appendix C.

Table 1 shows a comparison of the hydrologic data within the project area.

TABLE 1
Comparison of Existing Hydrologic Data for Cherry Creek at 12-Mile Park

Recurrence Interval	Cherry Creek Corridor Report[2]	FEMA FIS
2-Year Existing	2,142	-
2-Year Developed	4,429	-
5-Year Existing	5,892	-
5-Year Developed	9,537	-
10-Year Existing	10,071	10,300
10-Year Developed	14,655	-
25-Year Existing	20,200	-
25-Year Developed	25,821	-
50-Year Existing	31,217	31,000
50-Year Developed	36,946	-
100-Year Existing	49,021	51,000
100-Year Developed	54,285	-
500-Year Existing	-	150,000

[1] Peak flow rates presented in cubic feet per second.
[2] Peak flow rates from URS (2004) at UDSWM Design Point 286, at the Cherry Creek Reservoir.

Because the results of the URS hydrologic analysis and the FEMA FIS are similar, only the values from the URS report will be used in the detailed hydraulic analysis. The 500-year existing flow rate from the FEMA FIS will not be used in the detailed hydraulic analysis.

In addition to the existing hydrologic data for Cherry Creek at 12-Mile Park, the mean annual flow, bank full flow, and base flow were determined for the project reach. The results of the mean annual flow analysis were presented in a Technical Memorandum by William P. Ruzzo titled *Cherry Creek at 12-Mile Park – Channel Forming Discharge*. The results of this analysis suggest a range for the mean annual flow. The results are presented in Table 2.

TABLE 2
Mean Annual Flow for Cherry Creek at 12-Mile Park

	Peak Flow (cfs)
Mean Annual Flow (min)	300
Mean Annual Flow (max)	800

Both the minimum and maximum mean annual flows are less than the 2-year existing peak flow, which is expected because the channel forming flow is typically less than the 2-year flow. Both the minimum mean annual flow and the maximum mean annual flow will be used in the detailed hydraulic analysis.

The bank full flow is defined as the flow contained in the low flow channel from top of bank to top of bank and was determined for representative cross sections within the project reach using the Hydrologic Engineering Center River Analysis System (HEC-RAS). Where one bank is at a higher elevation than the other bank, the bank full flow extends to the top of the lower bank. The bank full flow rates are presented in Table 3.

TABLE 3
Bank Full Flow Analysis for Cherry Creek at 12-Mile Park

River Station	Model	Q Total (cfs)
3119.66	Historic/Breakout	505
2821.608	Historic/Breakout	570
2490.509	Historic/Breakout	345
2367.207	Historic/Breakout	335
2042.742	Historic/Breakout	405
1605.955	Historic/Breakout	385
1303.384	Historic/Breakout	585
1150.922	Historic/Breakout	810
459.4117	Historic	70
343.4038	Historic	20
730.4002	Breakout	520
497.3197	Breakout	255

As expected, the bank full flow varies for each cross section due to differing cross sectional geometries, but the typical values for bank full flow range from approximately 350 cfs to 800 cfs. At cross sections 459.4117 and 343.4038 along the historic flow path, the low flow channel lacks the capacity of the other cross sections in the project reach meaning the flow spills into the floodplain more often at these locations.

Based on a monitoring station located downstream of the project reach near the reservoir, the base flow is in the range of 20 cfs. Approximately 80% of the flow duration since 1992 has a flow of 20 cfs or less, meaning 20 cfs is a good estimate for the base flow within the project reach. The detailed base flow analysis is presented in Appendix C.

Hydraulic Evaluation

A hydraulic model was created using the Hydrologic Engineering Center River Analysis System (HEC-RAS) published by the US Army Corps of Engineers (USACE 2008). Two HEC-RAS models were created. The first HEC-RAS model is aligned along the historic flow path while the second HEC-RAS model is aligned along the breakout flow path. Both models are the same upstream of the breakout area. The downstream boundary condition for the historic flow path model is normal depth with a slope of 0.0028 ft/ft and the downstream boundary condition for the breakout flow path is normal depth with a slope of 0.0075 ft/ft.

Cross sections were created at approximately 100 ft intervals throughout the project reach. Cross sections were imported from a Digital Terrain Model (DTM) of the project reach created in InRoads 2004 (Bentley, 2004). Each cross section extends far enough into the floodplain to the west to contain the 2-year developed peak flow. The 2-year developed peak flow is mostly contained within the east bank throughout the project area. Peak flows larger than the 2-year developed condition extend well outside the project limits and were input into the hydraulic model but are not used for analysis. There are no hydraulic structures within the project reach.

The Manning's n value, a key component in the hydraulic analysis, was determined throughout the project reach using the approach described in the report titled *Determination of Roughness Coefficients for Streams in Colorado,* produced by the United States Geological Survey (USGS). In this approach, the following equation is used to determine the Manning's n value.

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$$

Where:

n_0 = base value for straight uniform channels

n_1 = correction for variations in the size and shape of the channel

n_2 = correction for surface irregularities

n_3 = correction for obstructions

n_4 = corrections for vegetation and flow conditions

m = correction factor for channel meandering

The typical values input into the hydraulic model are summarized in Table 4. The large increases in the Manning's n values in the overbanks are caused by heavy vegetation at certain cross sections. The variation in the Manning's n value in the channel is due to islands within the low flow channel. The Manning's n calculations are included in Appendix D.

TABLE 4

Range of Manning's n values

Location	Manning's n
West Overbank	0.049 - 0.106
Channel	0.031 - 0.041
East Overbank	0.036 - 0.081

The results of the hydraulic analysis at representative cross sections are presented in Table 5. Events with peak flows larger than the 2-year developed are not presented in Table 5 because the floodplain boundaries for larger events extend well beyond the study area and survey limits. The results of the hydraulic analysis are used in determining the stable slope for the project reach.

TABLE 5

Hydraulic Evaluation Results for Cherry Creek at 12-Mile Park

River Station	Model	Profile	Q Total (cfs)	Water Depth (ft)	Channel Velocity (ft/s)	Top Width (ft)
3119.66	Historic/Breakout	2-Year Existing	2,142	2.9	4.3	492.4
3119.66	Historic/Breakout	2-Year Developed	4,429	4.2	5.9	531.0
3119.66	Historic/Breakout	Mean Annual-Min	300	1.9	4.0	42.7
3119.66	Historic/Breakout	Mean Annual-Max	800	4.2	1.1	531.7
3119.66	Historic/Breakout	Bank Full	505	2.5	5.1	43.1
2821.608	Historic/Breakout	2-Year Existing	2,142	2.8	3.9	498.8
2821.608	Historic/Breakout	2-Year Developed	4,429	4.0	5.5	614.0
2821.608	Historic/Breakout	Mean Annual-Min	300	2.0	3.2	66.1
2821.608	Historic/Breakout	Mean Annual-Max	800	2.7	1.5	453.6
2821.608	Historic/Breakout	Bank Full	570	2.4	4.3	93.9
2490.509	Historic/Breakout	2-Year Existing	2,142	3.5	4.3	549.3
2490.509	Historic/Breakout	2-Year Developed	4,429	4.6	5.8	959.2
2490.509	Historic/Breakout	Mean Annual-Min	300	2.0	5.9	33.4
2490.509	Historic/Breakout	Mean Annual-Max	800	2.6	2.3	291.4
2490.509	Historic/Breakout	Bank Full	345	2.2	6.0	33.6
2367.207	Historic/Breakout	2-Year Existing	2,142	3.7	5.0	539.6
2367.207	Historic/Breakout	2-Year Developed	4,429	4.8	6.4	987.2
2367.207	Historic/Breakout	Mean Annual-Min	300	2.8	1.4	212.3
2367.207	Historic/Breakout	Mean Annual-Max	800	2.7	3.7	212.3
2367.207	Historic/Breakout	Bank Full	335	2.6	3.9	24.3
2042.742	Historic/Breakout	2-Year Existing	2,142	3.9	8.4	534.3

TABLE 5
Hydraulic Evaluation Results for Cherry Creek at 12-Mile Park

River Station	Model	Profile	Q Total (cfs)	Water Depth (ft)	Channel Velocity (ft/s)	Top Width (ft)
2042.742	Historic/Breakout	2-Year Developed	4,429	4.8	9.8	1047.2
2042.742	Historic/Breakout	Mean Annual-Min	300	2.0	4.8	37.5
2042.742	Historic/Breakout	Bank Full	405	2.3	5.6	42.4
1605.955	Historic/Breakout	2-Year Existing	2,142	3.9	3.3	897.2
1605.955	Historic/Breakout	2-Year Developed	4,429	4.7	4.0	999.3
1605.955	Historic/Breakout	Mean Annual-Min	300	2.1	2.1	91.8
1605.955	Historic/Breakout	Mean Annual-Max	800	3.0	2.7	656.6
1605.955	Historic/Breakout	Bank Full	385	2.4	2.2	113.9
1303.384	Historic/Breakout	2-Year Existing	2,142	3.5	6.8	691.5
1303.384	Historic/Breakout	2-Year Developed	4,429	4.3	8.1	852.3
1303.384	Historic/Breakout	Mean Annual-Min	300	1.7	2.8	85.0
1303.384	Historic/Breakout	Mean Annual-Max	800	3.0	3.4	432.9
1303.384	Historic/Breakout	Bank Full	585	2.5	3.3	85.5
1150.922	Historic/Breakout	2-Year Existing	2,142	3.5	4.0	811.9
1150.922	Historic/Breakout	2-Year Developed	4,429	4.4	5.0	921.6
1150.922	Historic/Breakout	Mean Annual-Min	300	1.9	3.0	64.5
1150.922	Historic/Breakout	Mean Annual-Max	800	3.2	4.1	100.7
1150.922	Historic/Breakout	Bank Full	810	3.2	4.1	103.2
459.4117	Historic	2-Year Existing	2,142	2.0	4.3	729.4
459.4117	Historic	2-Year Developed	4,429	2.9	5.4	776.3
459.4117	Historic	Mean Annual-Min	300	1.6	0.8	685.2
459.4117	Historic	Mean Annual-Max	800	1.7	2.0	692.1
459.4117	Historic	Bank Full	70	0.8	2.5	81.6
343.4038	Historic	2-Year Existing	2,142	2.9	3.1	750.7
343.4038	Historic	2-Year Developed	4,429	3.9	4.2	834.3
343.4038	Historic	Mean Annual-Min	300	2.8	0.4	736.7
343.4038	Historic	Mean Annual-Max	800	2.8	1.2	739.1
343.4038	Historic	Bank Full	20	1.5	0.7	75.8
730.4002	Breakout	2-Year Existing	2,142	3.9	3.7	882.0
730.4002	Breakout	2-Year Developed	4,429	4.7	4.2	1020.2
730.4002	Breakout	Mean Annual-Min	300	2.2	5.5	28.8
730.4002	Breakout	Mean Annual-Max	800	3.5	2.8	763.4
730.4002	Breakout	Bank Full	520	4.1	7.6	34.6

TABLE 5

Hydraulic Evaluation Results for Cherry Creek at 12-Mile Park

River Station	Model	Profile	Q Total (cfs)	Water Depth (ft)	Channel Velocity (ft/s)	Top Width (ft)
497.3197	Breakout	2-Year Existing	2,142	4.6	2.9	500.5
497.3197	Breakout	2-Year Developed	4,429	5.9	3.9	640.8
497.3197	Breakout	Mean Annual-Min	300	2.3	1.6	379.6
497.3197	Breakout	Mean Annual-Max	800	3.2	2.0	419.4
497.3197	Breakout	Bank Full	255	1.7	3.6	60.4

As can be seen from the top width for each cross section and flow rate, the 2-year existing and 2-year developed peak flows extend well beyond the main channel at most locations. The mean annual flows, both minimum and maximum, also extend outside of the main channel at some locations within the project reach.

The values for flow depth and velocity from the hydraulic analysis are presented in Table 6. The values presented in Table 6 represent a range of values since the flow characteristics change between cross sections. The cross sections downstream of the breakout area, both along the historic flow path and the breakout flow path, have more variability in the depths and velocities than the cross sections upstream.

TABLE 6

Typical Depth and Velocity Values from HEC-RAS Analysis

	2-Year Existing	2-Year Developed	Mean Annual Min	Mean Annual Max	Bank Full
Depth (ft)	2 - 4	4 - 5	1 - 3	2 - 4	2 - 3
Velocity (ft/s)	3 - 4	4 - 6	2 - 6	2 - 6	3 - 6

The existing channel slope varies throughout the project reach from 0.015 ft/ft to 0.0015 ft/ft with an average channel slope through the project reach of approximately 0.003 ft/ft.

The HEC-RAS section locations and detailed output is included in Appendix D.

Stream Stability – Analytical Analysis

The best methods to predict sediment transport characteristics can be difficult and hard to quantify. The overall process and information required to perform typical sediment transport analysis is time consuming and extensive. A practical application for sediment transport is presented in the report titled *Design Guidelines and Criteria of Channels and Hydraulic Structures on Sandy Soil*, which was written for the Urban Drainage and Flood Control District in Denver Colorado. The determination of sediment transport is presented as a power relationship between sediment transport rate and velocity and depth. Equation 1 presents this relationship.

$$q = c_1 y^{C_2} v^{C_3} \qquad (1)$$

Where, q = sediment transport rate in cfs/foot, y = flow depth in feet, v = flow velocity in feet per second, c_1, c_2, and c_3 are constants that are defined in Table 7 below.

TABLE 7

Constants for Sediment Transport Equation taken from (Simons and Associates 1981)

Soil Classification	Size (mm)	Geometric Mean (mm)	C_1	C_2	C_3
Very Fine Sand	0.062 - 0.125	0.088	58.50×10^{-6}	1.040	3.20
Fine Sand	0.125 - 0.250	0.177	21.40×10^{-6}	0.837	3.59
Medium Sand	0.250 - 0.500	0.354	6.47×10^{-6}	0.535	4.05
Coarse Sand*	0.500 - 1.00	0.707	2.90×10^{-6}	0.239	4.36
Very Coarse Sand	1.000 - 2.000	1.41	2.37×10^{-6}	-0.044	4.44

*Selected Values for this Study

Based on site material characteristics observed in the field, a constant value of coarse sand is sufficient to represent the sediment transport rate through the study area.

Sediment Transport Calculations

Equation 1 was applied to each cross section of a detailed hydraulic analysis using the HEC-RAS model of Cherry Creek at 12-Mile Park. The depth and velocity values produced from the HEC-RAS model analysis were input into Equation 1 to compute the sediment transport rate at each section.

The natural construct of Cherry Creek includes a sandy stream bed and a floodplain that consists of wetlands and other plant species. The 2-year developed peak flow is mostly contained within the steep overbank on the east and extends into the floodplain on the west. Since the sediment carrying capacity of Cherry Creek is mostly within the low flow channel, the flow depth and channel velocity were assumed to be from the bank full flow. The power relationship of Equation 1 suggests that small changes in velocity can lead to large differences in the computation of the sediment transport rate. Tables 8, 9, and 10 present the results of the bank full, 2-year existing, and 2-year future flow conditions for sediment transport. The mean annual flow was not evaluated for sediment transport because the mean annual peak flow rates are very similar to the bank full flow rates for this project reach. For each case in Tables 8, 9, and 10, the peak flows presented are the peak flow in the low flow channel, not the peak flow along the cross section because the majority of the sediment transport will occur in the low flow channel.

TABLE 8
Computed Sediment Transport rate for Cherry Creek at 12-Mile Park using Bank Full Flows

Station	Bank Full Q (cfs)	Velocity (ft/sec)	Depth (ft)	q (cfs/ft)
28+21	570	4.3	2.44	0.00207
27+18	570	3.73	2.72	0.00115
20+42	405	5.65	2.26	0.00670
16+05	385	2.24	2.51	0.00012
13+03	585	3.34	2.47	0.00069
4+59	70	2.49	0.76	0.00014
4+97	255	3.65	1.73	0.00094

TABLE 9
Computed Sediment Transport rate for Cherry Creek at 12-Mile Park using 2-Year Existing Flows

Station	2-Year Existing Q (cfs)*	Velocity (ft/sec)	Depth (ft)	q (cfs/ft)
28+21	624	3.86	2.83	0.00134
27+18	689	3.71	3.22	0.00116
20+42	1190	8.39	3.87	0.04270
16+05	1120	3.29	3.86	0.00072
13+03	1779	6.83	3.47	0.01697
4+59	581	4.33	2	0.00239
4+97	715	2.86	4.55	0.00041

*Channel Flow

TABLE 10
Computed Sediment Transport rate for Cherry Creek at 12-Mile Park using 2-Year Developed Flows

Station	2-Year Developed Q (cfs)*	Velocity (ft/sec)	Depth (ft)	q (cfs/ft)
28+21	1391	5.47	4.02	0.00667
27+18	1412	4.98	4.41	0.00453
20+42	1814	9.75	4.84	0.08672
16+05	1768	4.05	4.7	0.00187
13+03	2663	8.08	4.27	0.03710
4+59	1182	5.44	2.94	0.00605
4+97	1294	3.86	5.88	0.00160

*Channel Flow

The results of Tables 8, 9, and 10 show that the velocity and sediment transport rate generally increase with increasing peak flow. The results also suggest that there are large variations in sediment transport capabilities between each cross section, caused by varying cross sectional geometry resulting in varying flow conditions.

Stable Slope Calculations

To determine the stable slope from the sediment transport analysis, cross section 4+59, directly downstream of the breakout area along the historic flow path, was determined to be at a stable condition. This cross section was selected based on observation from field visits showing no visible active downcutting of the channel before the breakout occurred. After the breakout occurred, the channel directly upstream of the breakout began to downcut in an attempt to reach a stable slope. The stable slope sediment transport rates assumed for the project reach for the bank full, 2-year existing, and 2-year developed peak flows are defined in Table 11.

TABLE 11

Stable Slope Sediment Transport Rate Values for Cherry Creek at 12-Mile Park

Flow Rates	Stable Transport Rate Value (cfs/ft)
Bank Full at Station 4+59	0.0001450
2-Year Existing at Station 4+59	0.0023875
2-Year Developed at Station 4+59	0.0060471

To determine the stable channel slope for the other cross sections presented in Tables 8, 9, and 10, the slope must adjusted until the sediment transport rate at a given cross section matches the stable sediment transport rate. The hydraulic properties of the cross sections presented in Tables 8, 9, and 10 were analyzed to determine the change in slope that will be required to match the stable transport rate. To do this, an optimization model was created to calculate normalized sections and determine a slope that would carry the stable sediment transport rate defined in Table 11.

In functional form, the value for velocity in an open channel assuming uniform flow can be written as, $v \sim f(S_f, A, n)$ and $A \sim f(y)$ In which, S_f = friction slope, A = cross sectional area of flow, n = Manning's roughness value, and y = flow depth. The process to create a normalized cross section and solve for a stable slope is outlined in the following steps:

1. Determine hydraulic characteristics and sediment transport rate of representative sections
2. Create a normalized section that has the same velocity and depth
3. Back calculate a normalized roughness value for the normalized section
4. Use optimization model to solve the normalized section such that the calculated sediment transport rate equals the stable sediment transport rate

The optimization model was programmed to determine the optimal slope that would create a sediment transport rate equal to the stable sediment transport rate. Table 12 shows the optimization parameters used to determine a stable slope.

TABLE 12

Optimization Parameters for Stable Slope Calculation

Objective Function	$q(calculated) = q(stable)$
Variables	• Representative section slope (S_2) • Representative Flow depth (y_2) • $v_2 = \frac{1.49}{n(normalized)}\left(\frac{A}{P}\right)^{2/3}\sqrt{S_2}$
Constraints*	$\|y_2 - v_2\| \le \|y_1 - v_2\| + \Delta\|y_1 - v_2\|$ *and* $\|y_2 - v_2\| \ge \|y_1 - v_2\| - \Delta\|y_1 - v_2\|$

*D = A percent value that the model is allowed to vary the difference between the optimized flow depth and velocity from the original difference between flow depth and velocity. For this study D =10%

Results

The stable slope sediment transport rate from cross section 4+59 for the bank full, 2-year existing, and 2-year future peak flows was applied to the other representative cross sections to determine the stable channel slope at each cross section. The results of the stable slope analysis are presented in Tables 13, 14, and 15. Cross section 20+42 is not included in this analysis because the results were not consistent with the other cross sections and it was determined to be an outlier that would skew the results. Average values are presented both with and without cross section 4+97 because that section is along the breakout flow path and may skew the results of the historic flow path analysis.

TABLE 13
Stable Slope Computation for the Bank Full Flow Rates for Cherry Creek at 12-Mile Park

Station	Depth (ft)	Velocity (ft/s)	slope (ft/ft)	Stable Slope (%)
28+21	0.80	2.48	0.0060	0.60%
27+18	1.49	2.40	0.0028	0.28%
16+05	2.11	2.35	0.0031	0.31%
13+03	1.57	2.39	0.0018	0.18%
4+59	0.86	2.47	0.0093	0.93%
4+97	0.74	2.49	0.0067	0.67%
			Average	**0.50%**
			Average without 4+97	**0.46%**

TABLE 14
Stable Slope Computation for the 2-Year Existing Flow Rates for Cherry Creek at 12-Mile Park

Station	Depth (ft)	Velocity (ft/s)	slope (ft/ft)	Stable Slope (%)
28+21	3.43	4.36	0.003	0.26%
27+18	3.58	4.35	0.004	0.36%
16+05	3.71	4.34	0.004	0.37%
13+03	1.47	4.57	0.006	0.65%
4+59	2.35	4.45	0.004	0.40%
4+97	5.76	4.24	0.010	0.98%
			Average	**0.50%**
			Average without 4+97	**0.41%**

TABLE 15
Stable Slope Computation for the 2-Year Developed Flow Rates for Cherry Creek at 12-Mile Park

Station	Depth (ft)	Velocity (ft/s)	slope (ft/ft)	Stable Slope (%)
28+21	4.04	5.35	0.003	**0.26%**
27+18	3.78	5.37	0.002	**0.20%**
16+05	4.72	5.30	0.004	**0.37%**
13+03	2.09	5.54	0.006	**0.58%**
4+59	3.17	5.42	0.004	**0.35%**
4+97	7.06	5.18	0.011	**1.06%**
			Average	**0.47%**
			Average without 4+97	**0.35%**

Non-linear optimization models, such as the one used for this study, have a tendency to converge on local maxima or minima as solutions that satisfy all constraints and optimality. A value of 0.40% was used as a beginning point for iterations to solve the objective function.

Conclusion

A qualitative and quantitative analysis was performed to determine the sediment transport rate and stable sediment transport rate for Cherry Creek at 12-Mile Park. Based on a review of aerial photographs and an analytical analysis to determine the stable slope based on a stable slope sediment transport rate, it has been determined that the project reach for Cherry Creek at 12-Mile Park is currently at a stable slope. The average results of the stable slope analysis are presented in Table 16. The results are the average of the stable slope determined using the bank full, 2-year existing, and 2-year future peak flows.

TABLE 16
Average Stable Slope for Cross Section for Cherry Creek at 12-Mile Park

Cross Section	Average Stable Slope (%)
28+21	0.37%
27+18	0.28%
16+05	0.35%
13+03	0.47%
4+59	0.56%
4+97	0.90%
Average by Cross Section	***0.48%***
Average without 4+97	**0.41%**

The stable slope analysis using the stable sediment transport rate for Cherry Creek at 12-Mile Park suggests that the stable slope along the historic flow path is approximately 0.4%. It must be understood that the concepts used for the computation of sediment transport innately include a margin of error and in general, the methods used in this analysis result in a slope that will reduce the degradation and aggradation of the main channel. Although the project reach as a whole has been determined to be at a stable condition, there may still be local areas of degradation and aggradation within the project reach caused by local changes in the main channel geometry and flow conditions. According to the *Cherry Creek Corridor – Reservoir to Scott Road Major Drainageway Planning Preliminary Design Report* (URS, 2004), the slope of this reach is 0.41% and the channel condition is aggrading to stable, which is consistent with the results of the analytical stable slope analysis performed for this study.

Because the historic channel has been determined to be in a stable condition, the downcutting observed directly upstream of the breakout area is most likely caused by the breakout flow path attempting to reach a stable slope. This is consistent with the aerial photography review which shows that the main channel has experienced little horizontal channel meandering over the last 20 years before the breakout occurred. The conclusion that the historic flow path is at a stable slope is also consistent with recent site visits in which the downcutting was not observed before the breakout occurred.

The stream stability geomorphic characteristics used for this analysis and the stable slope calculations are included in Appendix E.

Stream Stability - Aerial Review

Historic aerial photographs were analyzed to assess the performance of Cherry Creek over a period of time. Aerial photographs reviewed as a part of this analysis are from 1937, 1955, 1993, 1999, 2004, and 2007. The review of the historic photographs show that the Cherry Creek channel has maintained the existing flow path and channel meander for 70 years. Cherry Creek Reservoir was constructed in 1953 and filled in 1957. As a result of the reservoir there is a noticeable increase in vegetation along the channel, likely due to the increase in the ground water table. The 1955 aerial image show the creation of a pond in the east floodplain, north of the major bend in the channel. The creation of the wetland pond that is at the northern limits of the DOLA does not appear until the 1993 aerial photos. This suggests that this area is a result of elevated ground water caused by the reservoir.

Based on the available historic aerial imagery, the existing channel appears to be very stable. The channel is not actively moving outside of the historic flow path over time. The most significant geomorphic event to occur in the channel corridor is the construction of the Reservoir resulting in an elevated water table. This has resulted in overbank ponds and groundwater fed secondary channels forming through the project area. This has also created a vibrant riparian habitat with multiple areas of wetland vegetation. Aerial images are provided below for the project area.

Photo 7 - Aerial Photo 1, December 1937

Photo 8 - Aerial Photo 2, December 1955

Photo 9 - Aerial Photo 3, June 1993

Photo 10 - Aerial Photo 4, September 1999

Photo 11 - Aerial Photo 5, December 2004

Photo 12 - Aerial Image 6, July 2007

Site Assessment Summary

Cherry Creek within the project area is a popular recreation destination for the public and experiences high use along the trails, banks, and in the channel itself. In areas where the access to the water is easier, foot traffic has created social paths, limiting or destroying native vegetation. Even in areas where the side banks are steep, dogs are able to negotiate the bank to access the water and even these areas suffer from limited or no vegetation. The areas where the vegetation is limited or destroyed are vulnerable to bank erosion.

The soils in the project area consist of mostly sandy material in the creek bed whereas the channel banks vary from sandy areas in the north where the east bank is not as high above the water to more clayey areas in the south where the east bank is steep and significantly higher than the water. The bank soils and the accompanying vegetations will help guide the solutions to stabilize the slopes as well as provide continuing recreational access to the creek.

The entire project area corridor presents ample riparian and wetland habitat and is potential habitat for two potential species listed as threatened under the Endagered Species Act. These species are the Ute ladies'-tresses orchid and the Preble's meadow jumping mouse. Although conditions along Cherry Creek in the project area appear suitable for Ute ladies'-tresses orchid, it is not known to be present. Preble's have been captured south of the project area.

Historic imagery as well as analysis of the hydrology and hydraulics of the site indicate that the current flowpath of the creek downstream of the breakout area is not normal. The hydraulic analysis shows that the historic flow path is within the range of stable slopes, whereas the breakout flow path is steeper than the stable slope and if left uncorrected will result in the channel attempting to achieve a stable slope by cutting down through the project area causing channel and bank erosion. There are existing wetland ponds downstream of the breakout area that are now experiencing sedimentation due to the downcutting within the project area. The breakout channel is also depriving historic riparian and wetland areas of normal flows threatening the health of these areas. Repairing the breakout will allow the historic areas to recover as well as protecting the areas downstream of the breakout from sedimentation.

Recommendations

The first priority of effort should be to repair the breakout area to return the creek to its historic flow path. This work should be undertaken as soon as possible, in order to take advantage of low flows during the fall and winter, to limit damage to areas threatened by sedimentation downstream of the breakout, and to restore a source of water to the historic riparian and wetland areas of the channel.

The second priority of effort should be to address the channel banks that are steep and lack adequate vegetation to resist erosion. Left unchecked, these banks will continue to erode and contribute sediments to the creek. The approach to developing solutions to the bank erosion problems should be coordinated with Colorado State Parks and their improvement plans for the DOLA. Possible solutions may include maintaining existing access areas, limiting access to the creek in specific areas, improving access in other areas, revegetation, installation of water quality enhancing features, trail realignment, public education, and signage. Improvements should also seek to incorporate instream water quality enhancement features such as instream wetlands.

The third priority of effort should be to enhance the recreational experience for park users. The recreational value and experience will be improved through addressing the first two priorities, but may be strengthened through focused efforts such as incorporating ADA accessibility approaches.

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Appendices

Appendix A Geotechnical Report

Appendix B Site Photos

Appendix C Hydrology, FEMA Discharges, Base Flow Analysis, Mean Annual Flow Analysis

Appendix D Hydraulics, Manning's n and HEC-RAS Output

Appendix E Stream Stability Analysis, Geomorphic Characteristics and Stable Slope Calculations

Appendix F Dog Off Leash Area Maps

Appendix A

Geotechnical Report

Appendix B
Site Photos

Appendix C

Hydrology, FEMA Discharges, Base Flow Analysis, Mean Annual Flow Analysis

Appendix C - Hydrology

Information Presented in Cherry Creek Master Plan

TABLE B-1

FEMA FIS Discharge Summary, Existing Conditions

Flooding Source and Location	UDSWMM Design Point	10-Year	50-Year	100-Year	500-Year
At Reservoir	286	10,300	31,000	51,000	150,000
At Douglas/ Arapahoe Co. Limits	280	8,950	26,800	43,710	133,200
At Cottonwood Drive	337	8,670	25,940	42,200	129,700
At E-470	276	8,480	25,360	41,200	127,380
at Lincoln Avenue	274	8,100	24,200	39,190	122,740
At West Parker Road	266	7,730	23,040	37,180	118,100
At Stroh Avenue	262	6,610	19,570	31,510	104,200
at Scott Road	250	6,000	17,500	27,120	100,000
At State Highway 86	247	5,500	12,600	19,080	79,000

TABLE B-2

100-Year Discharge Comparison Summary, Existing Conditions

Flooding Source and Location	UDSWMM Design Point	Drainage Area (sq. mi.)	Simulated 100-Year Discharge (cfs)	FEMA FIS 100-Year Discharge (cfs)	Percent Difference
At Reservoir	286	361	49,021	51,000	-3.9
At Douglas/ Arapahoe Co. Limits	280	338	43,706	43,710	1.0
At Cottonwood Drive	337	333	39,895	42,200	-5.4
At E-470	276	310	39,887	41,200	-3.2
at Lincoln Avenue	274	305	39,628	39,190	1.1
At West Parker Road	266	288	35,000	37,180	-5.9
At Stroh Avenue	262	267	32,585	31,510	3.4
at Scott Road	250	241	29,442	27,120	8.6
At State Highway 86	247	204	19,941	19,080	4.5

TABLE B-3

10-Year Discharge Comparison Summary

Flooding Source and Location	UDSWMM Design Point	Drainage Area (sq. mi.)	Simulated 10-Year Discharge (cfs)	FEMA FIS 10-Year Discharge (cfs)	Percent Difference
At Reservoir	286	361	10,071	10,300	-2.2
At Douglas/ Arapahoe Co. Limits	280	338	8,125	8,950	-9.2
At Cottonwood Drive	337	333	8,966	8,670	3.4
At E-470	276	310	8,109	8,480	-4.4
at Lincoln Avenue	274	305	8,033	8,100	-0.8
At West Parker Road	266	288	7,112	7,730	-8.0
At Stroh Avenue	262	267	6,689	6,610	1.2
at Scott Road	250	241	6,051	6,000	0.9
At State Highway 86	247	204	4,995	5,500	-9.2

TABLE B-4

UDSWM Modeling Results Summary Table, Existing Condtions

Flooding Source and Location	UDSWMM Design Point	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
At Reservoir	286	2,142	5,892	10,071	20,200	31,217	49,021
At Douglas/ Arapahoe Co. Limits	280	1,798	5,035	8,125	17,330	27,105	43,706
At Cottonwood Drive	337	1,567	4,463	8,966	16,980	26,818	39,895
At E-470	276	1,558	4,451	8,109	16,650	24,063	39,887
at Lincoln Avenue	274	1,544	4,403	8,033	15,675	23,772	39,628
At West Parker Road	266	1,302	3,723	7,112	15,000	20,374	35,000
At Stroh Avenue	262	1,170	3,406	6,689	12,580	18,600	32,585
at Scott Road	250	972	2,964	6,051	11,500	16,257	29,442
At State Highway 86	247	664	1,785	4,995	9,050	10,365	19,941

TABLE B-5

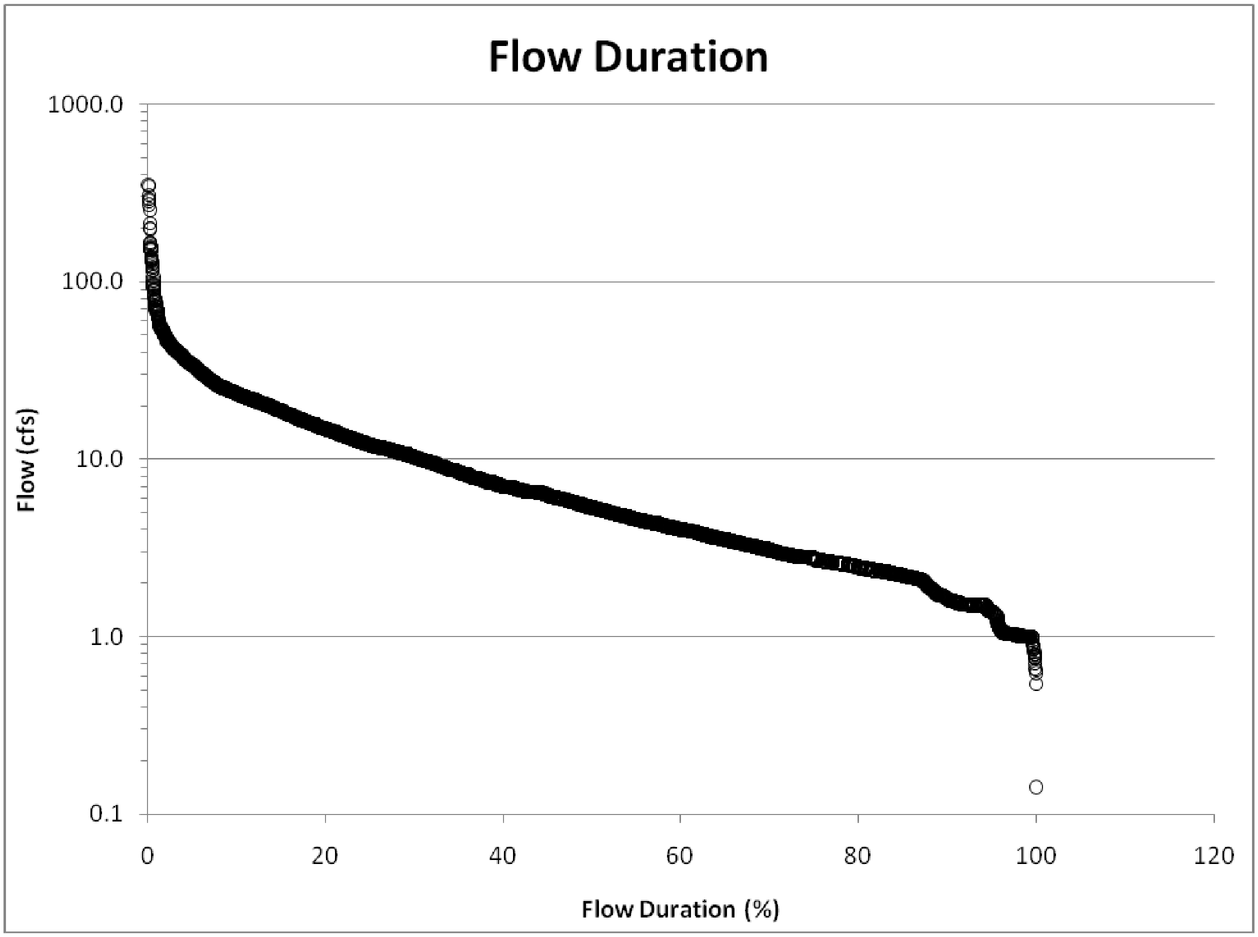
UDSWM Modeling Results Summary Table, Developed Conditions

Flooding Source and Location	UDSWMM Design Point	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
At Reservoir	286	4,429	9,537	14,655	25,821	36,946	54,285
At Douglas/ Arapahoe Co. Limits	280	3,968	8,432	12,852	22,625	32,435	48,378
At Cottonwood Drive	337	3,384	7,172	11,096	19,819	28,438	43,471
At E-470	276	3,303	7,009	10,950	19,624	28,222	43,299
at Lincoln Avenue	274	3,291	6,894	10,782	19,363	27,806	42,870
At West Parker Road	266	2,843	5,887	9,269	16,637	23,671	37,548
At Stroh Avenue	262	2,450	5,204	8,345	14,952	21,086	34,452
at Scott Road	250	1,605	3,797	6,615	12,305	17,262	30,188
At State Highway 86	247	784	1,765	4,945	7,990	10,237	19,813

Base Flow Analysis

TABLE B-6
Base Flow Analysis

	Mean		Median	
	cfs	**af/d**	**cfs**	**af/d**
1992	5.937	11.776	3.869	7.674
1993	4.945	9.808	3.869	7.674
1994	3.902	7.739	2.556	5.070
1995	5.401	10.713	3.404	6.752
1996	4.846	9.612	4.735	9.392
1997	3.973	7.881	3.446	6.836
1998	12.977	25.740	9.403	18.650
1999	16.707	33.138	14.886	29.526
2000	10.969	21.756	2.239	4.440
2001	7.287	14.453	2.575	5.108
2002	2.746	5.447	1.037	2.057
2003	9.367	18.578	6.371	12.637
2004	11.492	22.794	7.786	15.445
2005	14.256	28.276	7.720	15.313
2006	7.580	15.034	6.437	12.768
2007	25.648	50.873	13.090	25.964
2008	15.283	30.313	10.610	21.045
2009	24.279	48.156	17.741	35.189



Flow Duration
1000.0
100.0
10.0
1.0
0.1
Flow (cfs)
0
20
40
60
80
100
120
Flow Duration (%)

Mean Annual Flow Analysis

Appendix D

Hydraulics, Manning's n and HEC-RAS Output

Appendix D - Hydraulics

Manning's n Value Calculations

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$$

Where:

n_0 = base value for straight uniform channels

n_1 = correction for variations in the size and shape of the channel

n_2 = correction for surface irregularities

n_3 = correction for obstructions

n_4 = corrections for vegetation and flow conditions

m = correction factor for channel meandering

Main Channel

n_0 = 0.026 for sand channels (use 0.026 assuming sand with a mean diameter of 1 mm)

n_1 = 0 (gradual channel variations)

n_2 = 0.005 (minor irregularities, slightly eroded)

n_3 = 0 (minor obstructions)

n_3 = 0.01 (braided channels)

n_4 = 0 (no channel vegetation)

m = 1 (meandering picked up in HEC-RAS model)

Typical values for main channel:

TABLE C-1
Typical Manning's n values for Low Flow Channel for Cherry Creek at 12-Mile Park

Description	n_0	n_1	n_2	n_3	n_4	m	n
Typical Channel	0.026	0	0.005	0	0	1	0.031
Braided Channel	0.026	0	0.005	0	0.01	1	0.041

Overbanks/Floodplain

n_0 = 0.026 for sand channels (use 0.026 assuming sand with a mean diameter of 1 mm)

n_1 = 0 (gradual channel variations)

n_2 = 0.005 (minor irregularities)

n_3 = 0 (minor obstructions)

n_4 = 0 (no channel vegetation)

n_4 = 0.007 (short weeds and grasses)

n_4 = 0.018 (medium weeds and grasses)

n_4 = 0.05 (natural brush with willows)

n_4 = 0.075 (moderate brush with willows)

n_4 = 0.10 (dense brush with willows)

m = 1 (meandering picked up in HEC-RAS model)

Typical values for overbanks/floodplains:

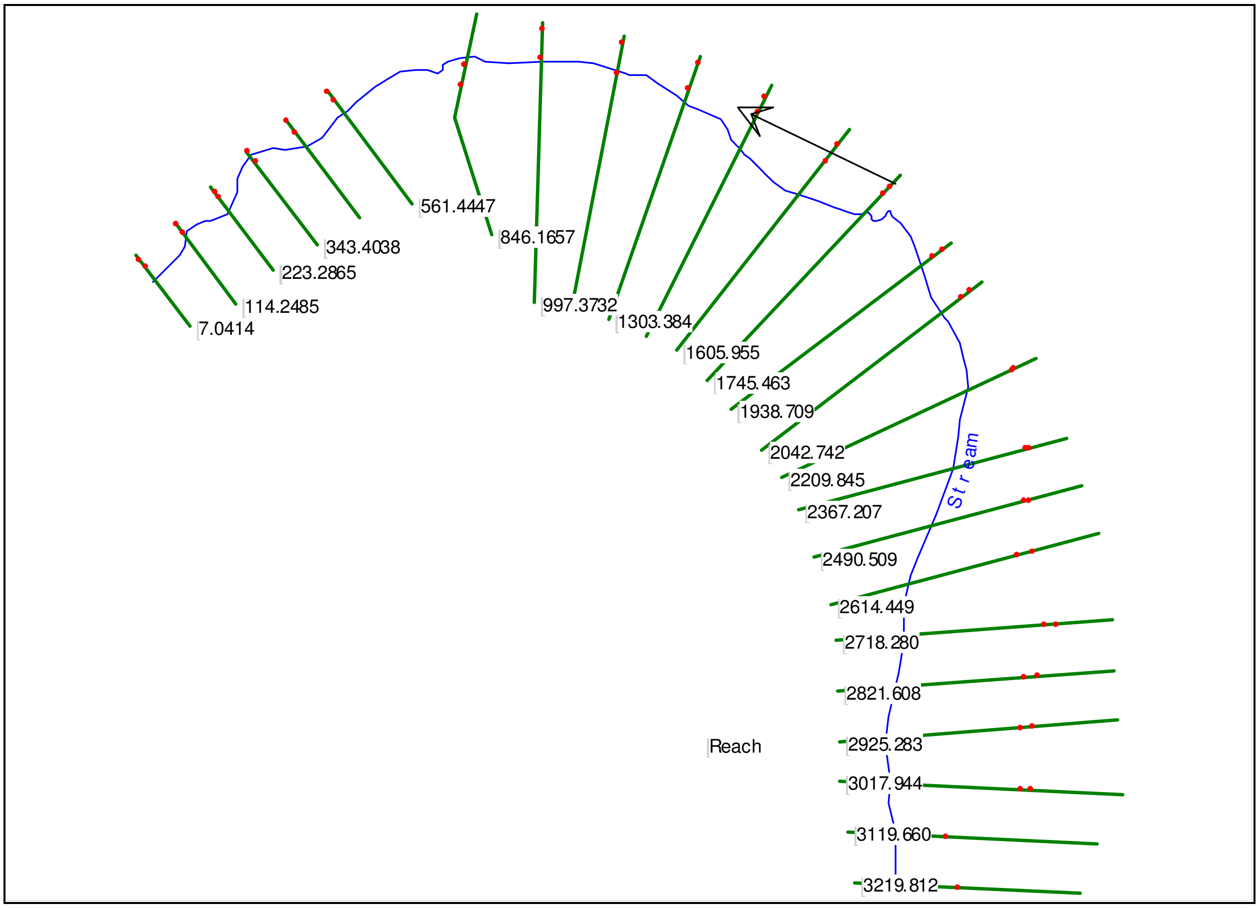
TABLE C-2

Typical Manning's n values for overbanks/floodplains for Cherry Creek at 12-Mile Park

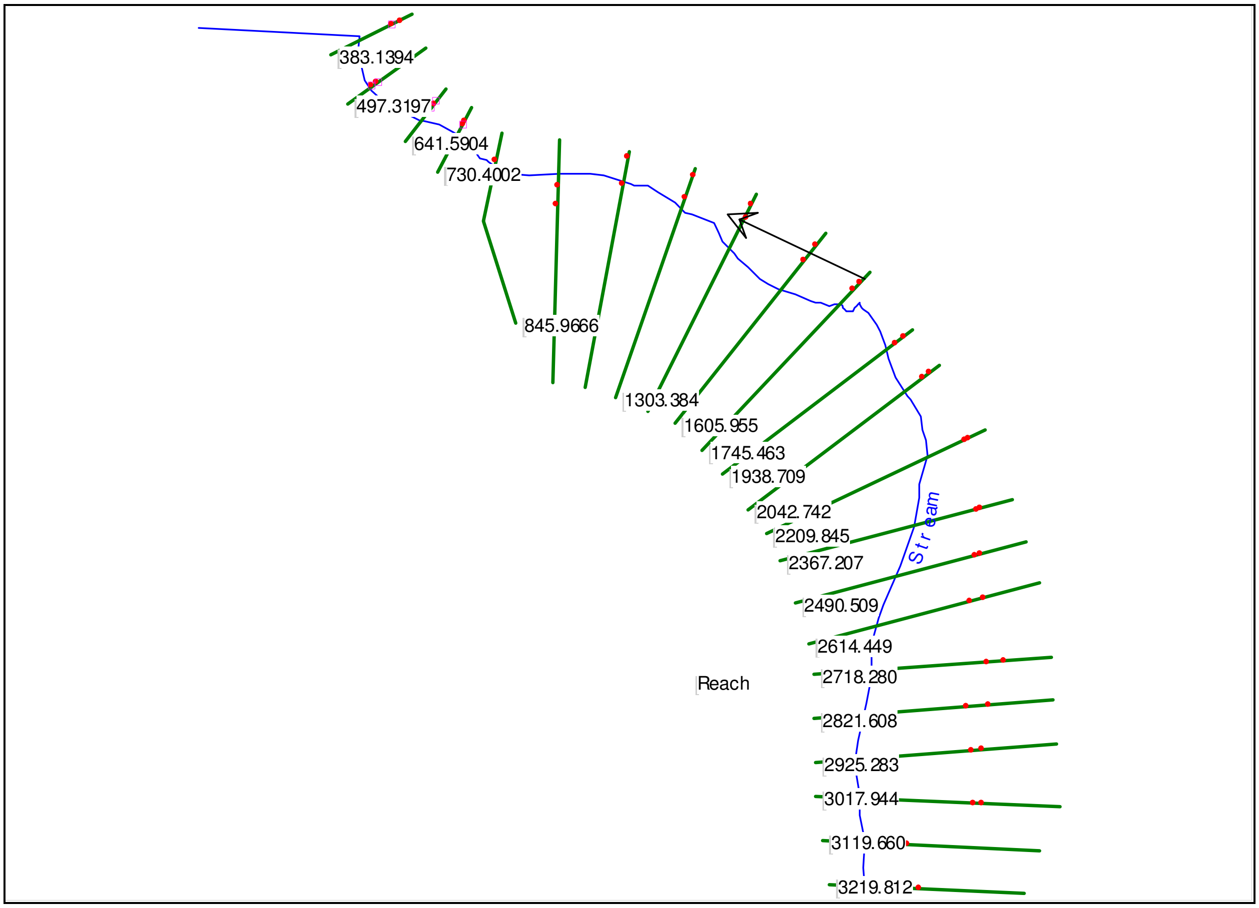
Description	n_0	n_1	n_2	n_3	n_4	m	n
Short Weeds and Grasses	0.026	0	0.005	0	0.007	1	0.038
Medium Weeds and Grasses	0.026	0	0.005	0	0.018	1	0.049
Natural Brush with Willows	0.026	0	0.005	0	0.05	1	0.081
Moderate Brush with Willows	0.026	0	0.005	0	0.075	1	0.106
Dense Brush with Willows	0.026	0	0.005	0	0.1	1	0.131

Plan View of Cross Sections

Plan View of Historic Flow Path

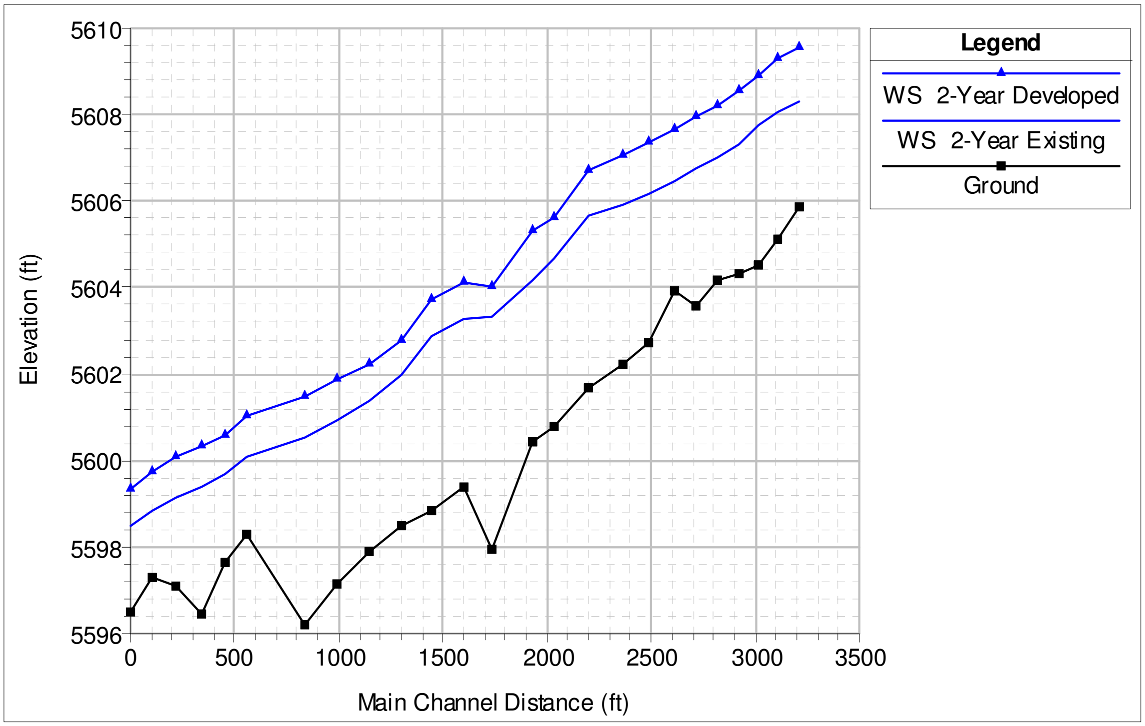


Plan View of Breakout Flow Path

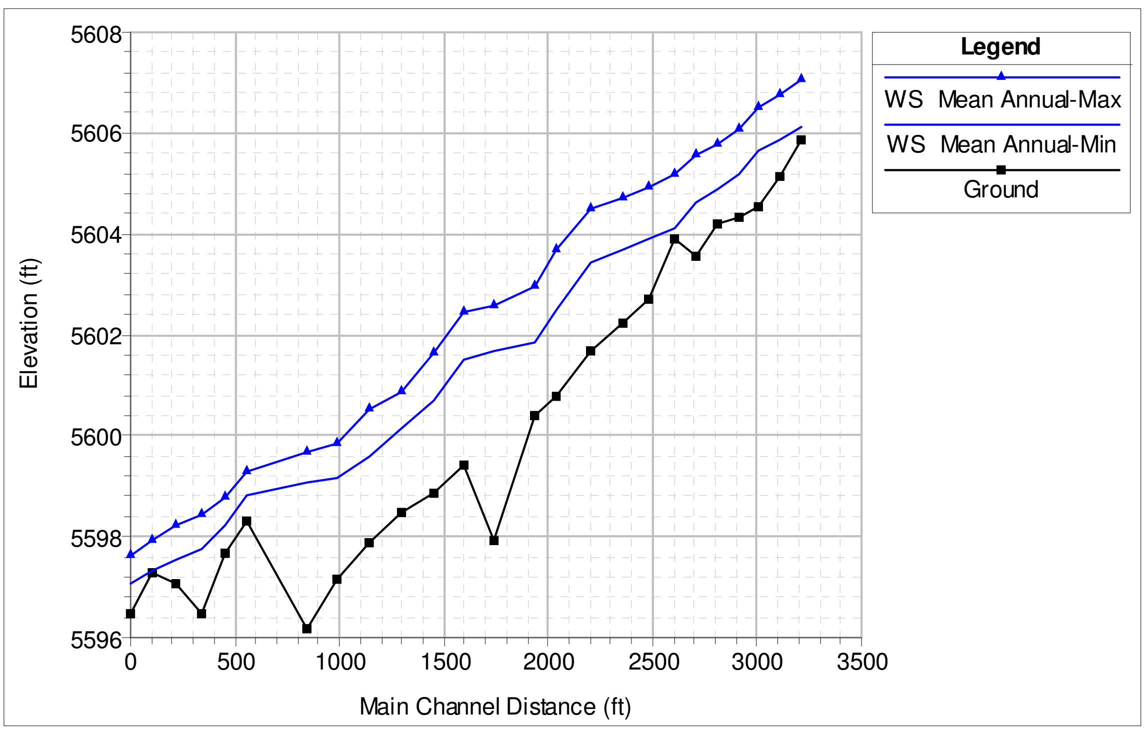


HEC-RAS Profiles

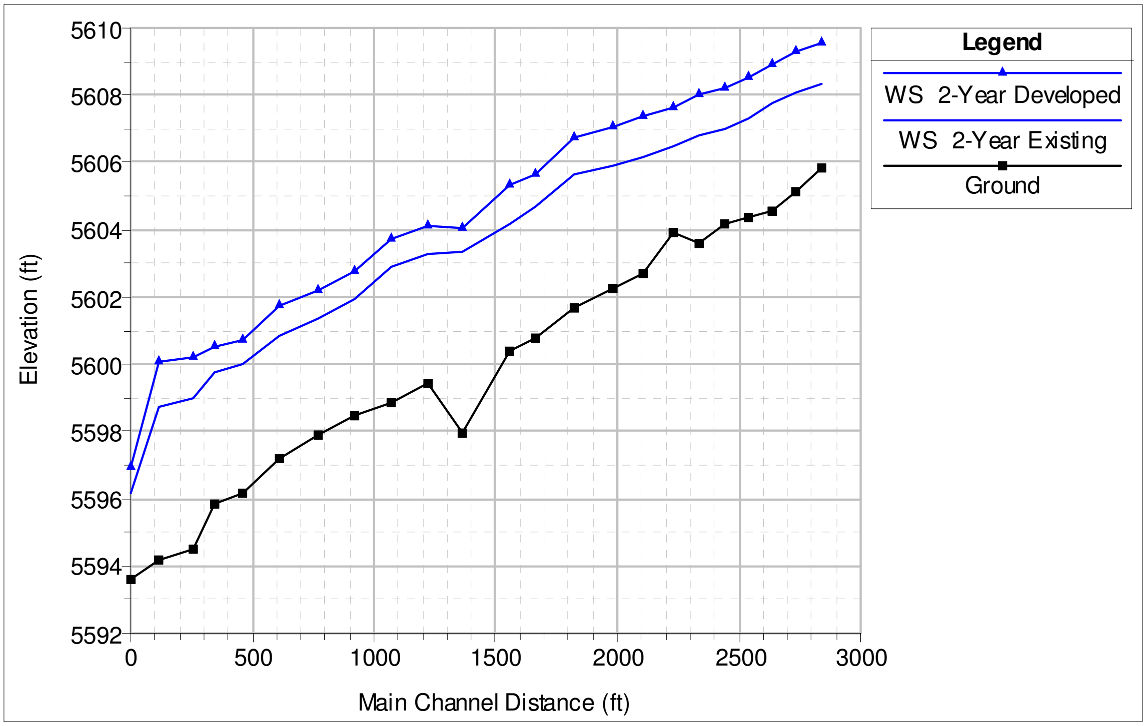
2-Year Existing and 2-Year Developed Flows for Historic Flow Path



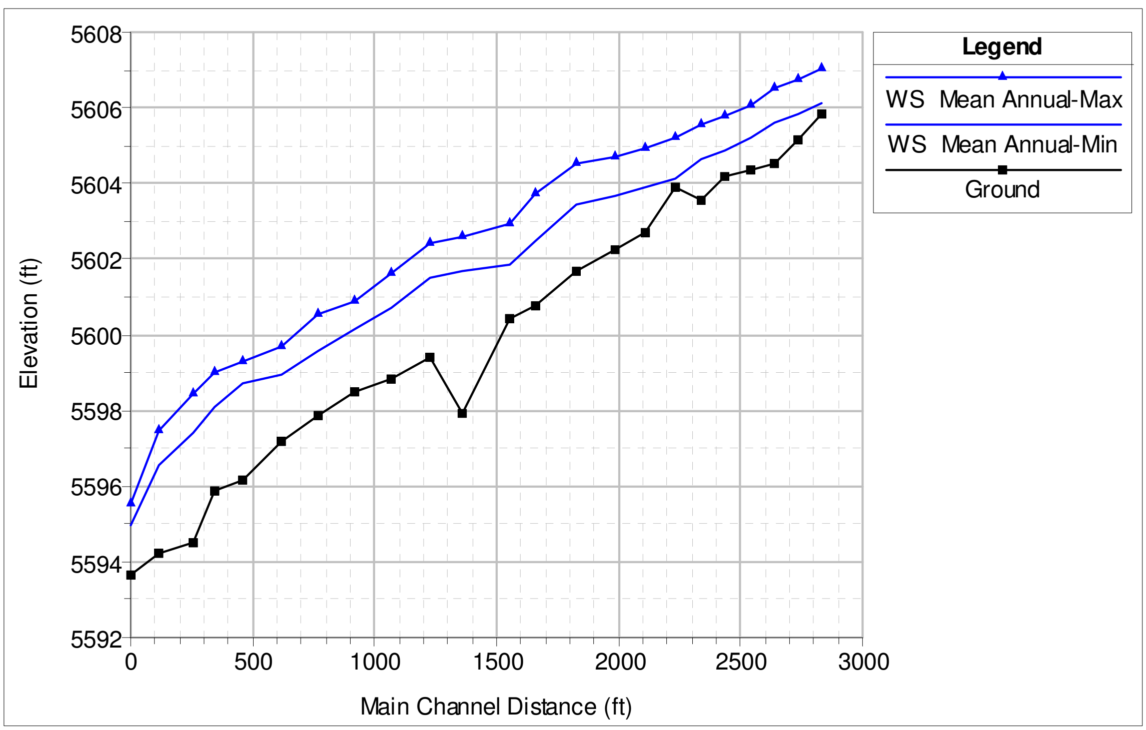
Minimum and Maximum Mean Annual Flows for Historic Flow Path



2-Year Existing and 2-Year Developed Flows for Breakout Flow Path



Minimum and Maximum Mean Annual Flows for Breakout Flow Path



HEC-RAS Output

2-YR Exst = 2-Year Existing

2-YR Dev = 2-Year Developed

MA-Min = Minimum Mean Annual

MA-Max = Maximum Mean Annual

TABLE C-3

Historic Flow Path HEC-RAS Output File

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
3219.812	2-YR Exst	2142	5605.9	5608.3	5608.5	0.0030	3.9	942.2	487.1	0.51
3219.812	2-YR Dev	4429	5605.9	5609.6	5609.8	0.0027	5.3	1551.5	497.8	0.53
3219.812	MA - Min	300	5605.9	5606.1	5606.2	0.0050	0.9	199.4	177.0	0.43
3219.812	MA - Max	800	5605.9	5607.1	5607.1	0.0044	2.3	432.5	333.3	0.52
3119.66	2-YR Exst	2142	5605.1	5608.1	5608.2	0.0023	4.3	911.1	492.4	0.46
3119.66	2-YR Dev	4429	5605.1	5609.3	5609.5	0.0027	5.9	1547.0	531.0	0.53
3119.66	MA - Min	300	5605.1	5605.9	5605.9	0.0016	1.3	187.8	237.5	0.3
3119.66	MA - Max	800	5605.1	5606.8	5606.8	0.0019	2.6	423.0	282.7	0.38
3119.66	31+19 BF	505	5605.1	5607.6	5608.0	0.0042	5.1	98.6	43.1	0.6
3017.944	2-YR Exst	2142	5604.5	5607.7	5607.9	0.0035	5.0	967.0	477.6	0.56
3017.944	2-YR Dev	4429	5604.5	5608.9	5609.2	0.0037	6.7	1627.9	636.0	0.62
3017.944	MA - Min	300	5604.5	5605.6	5605.7	0.0032	2.0	219.2	242.7	0.43
3017.944	MA - Max	800	5604.5	5606.5	5606.6	0.0033	3.1	464.5	332.3	0.48
2925.283	2-YR Exst	2142	5604.3	5607.3	5607.4	0.0033	3.6	918.4	494.2	0.51
2925.283	2-YR Dev	4429	5604.3	5608.5	5608.7	0.0032	5.2	1666.7	801.2	0.55
2925.283	MA - Min	300	5604.3	5605.2	5605.2	0.0029	1.8	162.5	235.8	0.41
2925.283	MA - Max	800	5604.3	5606.1	5606.1	0.0033	2.9	405.3	329.4	0.47
2821.608	2-YR Exst	2142	5604.2	5607.0	5607.1	0.0026	3.9	1018.9	498.8	0.47
2821.608	2-YR Dev	4429	5604.2	5608.2	5608.4	0.0028	5.5	1642.4	614.0	0.54
2821.608	MA - Min	300	5604.2	5604.9	5604.9	0.0035	1.6	200.6	235.4	0.43
2821.608	MA - Max	800	5604.2	5605.8	5605.8	0.0027	2.6	498.6	375.6	0.44
2821.608	28+21 BF	570	5604.2	5606.6	5606.9	0.0043	4.3	132.6	93.9	0.64

TABLE C-3

Historic Flow Path HEC-RAS Output File

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
2718.28	2-YR Exst	2142	5603.6	5606.8	5606.9	0.0021	3.7	1077.1	574.4	0.44
2718.28	2-YR Dev	4429	5603.6	5608.0	5608.1	0.0021	5.0	1960.8	967.5	0.47
2718.28	MA - Min	300	5603.6	5604.6	5604.7	0.0020	1.4	256.2	264.3	0.34
2718.28	MA - Max	800	5603.6	5605.6	5605.6	0.0019	2.3	530.5	346.6	0.38
2614.449	2-YR Exst	2142	5603.9	5606.5	5606.6	0.0025	3.8	1045.8	529.4	0.47
2614.449	2-YR Dev	4429	5603.9	5607.6	5607.8	0.0025	5.2	1827.4	798.8	0.51
2614.449	MA - Min	300	5603.9	5604.1	5604.2	0.0051	0.8	196.7	254.7	0.41
2614.449	MA - Max	800	5603.9	5605.2	5605.2	0.0027	2.2	515.1	352.7	0.42
2490.509	2-YR Exst	2142	5602.7	5606.2	5606.3	0.0021	4.3	915.4	549.3	0.45
2490.509	2-YR Dev	4429	5602.7	5607.3	5607.5	0.0025	5.8	1716.0	959.2	0.51
2490.509	MA - Min	300	5602.7	5603.9	5603.9	0.0013	1.4	172.2	150.6	0.28
2490.509	MA - Max	800	5602.7	5605.0	5605.0	0.0016	2.6	380.7	251.2	0.35
2490.509	24+90 BF	345	5602.7	5604.9	5605.5	0.0084	6.0	57.3	33.6	0.81
2367.207	2-YR Exst	2142	5602.2	5605.9	5606.0	0.0025	5.0	1049.1	539.6	0.48
2367.207	2-YR Dev	4429	5602.2	5607.1	5607.2	0.0029	6.5	1835.2	987.2	0.53
2367.207	MA - Min	300	5602.2	5603.7	5603.7	0.0025	2.7	144.2	126.2	0.42
2367.207	MA - Max	800	5602.2	5604.7	5604.8	0.0025	3.8	438.0	433.7	0.44
2367.207	23+67 BF	225	5602.2	5604.9	5605.1	0.0025	3.9	57.2	24.3	0.45
2209.845	2-YR Exst	2142	5601.7	5605.7	5605.7	0.0012	3.6	1354.3	593.2	0.32
2209.845	2-YR Dev	4429	5601.7	5606.7	5606.8	0.0017	5.1	2110.8	977.6	0.41
2209.845	MA - Min	300	5601.7	5603.4	5603.5	0.0010	1.9	253.2	348.6	0.27
2209.845	MA - Max	800	5601.7	5604.5	5604.6	0.0009	2.4	716.2	513.8	0.26
2042.742	2-YR Exst	2142	5600.8	5604.7	5605.3	0.0070	8.4	735.2	534.3	0.83
2042.742	2-YR Dev	4429	5600.8	5605.6	5606.3	0.0069	9.8	1443.0	1047.2	0.85
2042.742	MA - Min	300	5600.8	5602.5	5603.0	0.0097	5.9	50.5	34.6	0.87
2042.742	MA - Max	800	5600.8	5603.7	5604.2	0.0061	6.3	303.8	370.2	0.74
2042.742	20+42 BF	405	5600.8	5603.1	5603.6	0.0072	5.7	71.7	42.4	0.77
1938.709	2-YR Exst	2142	5600.4	5604.2	5604.4	0.0032	5.6	999.2	750.4	0.57

TABLE C-3

Historic Flow Path HEC-RAS Output File

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
1938.709	2-YR Dev	4429	5600.4	5605.3	5605.5	0.0025	6.1	1989.9	1057.1	0.53
1938.709	MA - Min	300	5600.4	5601.8	5602.1	0.0075	4.3	121.6	136.3	0.73
1938.709	MA - Max	800	5600.4	5603.0	5603.2	0.0038	4.4	402.3	351.9	0.57
1745.463	2-YR Exst	2142	5597.9	5603.3	5603.8	0.0034	6.8	714.3	529.1	0.6
1745.463	2-YR Dev	4429	5597.9	5604.0	5604.9	0.0055	9.7	1128.0	616.6	0.79
1745.463	MA - Min	300	5597.9	5601.7	5601.7	0.0006	2.1	180.5	94.2	0.24
1745.463	MA - Max	800	5597.9	5602.6	5602.8	0.0014	3.8	386.9	352.8	0.37
1605.955	2-YR Exst	2142	5599.4	5603.3	5603.4	0.0020	3.3	1135.2	897.2	0.34
1605.955	2-YR Dev	4429	5599.4	5604.1	5604.3	0.0022	4.1	1929.6	999.3	0.37
1605.955	MA - Min	300	5599.4	5601.5	5601.6	0.0020	2.1	141.0	91.8	0.3
1605.955	MA - Max	800	5599.4	5602.4	5602.5	0.0020	2.6	464.8	666.4	0.32
1605.955	16+05 BF	385	5599.4	5601.8	5601.9	0.0023	2.2	171.7	113.9	0.32
1454.871	2-YR Exst	2142	5598.9	5602.9	5603.1	0.0021	4.4	1080.3	884.8	0.46
1454.871	2-YR Dev	4429	5598.9	5603.7	5603.9	0.0023	5.4	1816.8	940.0	0.5
1454.871	MA - Min	300	5598.9	5600.7	5601.0	0.0086	4.5	66.5	62.6	0.77
1454.871	MA - Max	800	5598.9	5601.6	5602.0	0.0064	5.1	222.7	400.5	0.71
1303.384	2-YR Exst	2142	5598.5	5602.0	5602.6	0.0049	6.8	609.5	691.5	0.69
1303.384	2-YR Dev	4429	5598.5	5602.8	5603.4	0.0051	8.1	1258.7	852.3	0.73
1303.384	MA - Min	300	5598.5	5600.1	5600.3	0.0028	2.9	104.2	85.0	0.46
1303.384	MA - Max	800	5598.5	5600.9	5601.2	0.0042	4.8	179.4	138.6	0.6
1303.384	13+03 BF	585	5598.5	5601.0	5601.1	0.0020	3.3	175.0	85.5	0.41
1150.922	2-YR Exst	2142	5597.9	5601.4	5601.5	0.0027	4.1	1109.1	811.9	0.49
1150.922	2-YR Dev	4429	5597.9	5602.3	5602.4	0.0027	5.0	1857.8	921.6	0.51
1150.922	MA - Min	300	5597.9	5599.6	5599.8	0.0037	3.5	91.3	109.8	0.53
1150.922	MA - Max	800	5597.9	5600.5	5600.7	0.0026	3.7	476.1	643.4	0.46
1150.922	11+50 BF	810	5597.9	5601.1	5601.4	0.0033	4.1	197.7	103.2	0.52
997.3732	2-YR Exst	2142	5597.2	5600.9	5601.1	0.0032	4.6	1081.9	823.2	0.53
997.3732	2-YR Dev	4429	5597.2	5601.9	5602.0	0.0027	5.1	1906.0	897.4	0.49

TABLE C-3

Historic Flow Path HEC-RAS Output File

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
997.3732	MA - Min	300	5597.2	5599.2	5599.3	0.0024	3.3	153.1	178.0	0.44
997.3732	MA - Max	800	5597.2	5599.9	5600.2	0.0048	4.9	328.3	358.9	0.7
846.1657	2-YR Exst	2142	5596.2	5600.5	5600.7	0.0018	4.1	1257.6	887.3	0.42
846.1657	2-YR Dev	4429	5596.2	5601.5	5601.7	0.0019	5.1	2127.4	1016.9	0.46
846.1657	MA - Min	300	5596.2	5599.1	5599.1	0.0006	1.6	340.3	326.3	0.22
846.1657	MA - Max	800	5596.2	5599.7	5599.8	0.0012	2.7	611.0	502.6	0.33
561.4447	2-YR Exst	2142	5598.3	5600.1	5600.2	0.0032	3.5	1317.4	779.9	0.51
561.4447	2-YR Dev	4429	5598.3	5601.0	5601.1	0.0030	4.7	2042.4	798.8	0.54
561.4447	MA - Min	300	5598.3	5598.8	5598.9	0.0025	1.3	428.7	603.4	0.36
561.4447	MA - Max	800	5598.3	5599.3	5599.3	0.0032	2.3	722.5	673.0	0.46
459.4117	2-YR Exst	2142	5597.7	5599.7	5599.8	0.0047	4.3	1117.3	729.4	0.62
459.4117	2-YR Dev	4429	5597.7	5600.6	5600.8	0.0039	5.4	1839.0	776.3	0.61
459.4117	MA - Min	300	5597.7	5598.2	5598.3	0.0221	3.0	197.3	529.0	1.01
459.4117	MA - Max	800	5597.7	5598.8	5598.8	0.0079	3.3	518.2	627.8	0.7
459.4117	4+59 BF	70	5597.7	5598.4	5598.5	0.0112	2.5	28.1	81.6	0.75
343.4038	2-YR Exst	2142	5596.5	5599.4	5599.4	0.0020	3.1	1430.6	750.7	0.41
343.4038	2-YR Dev	4429	5596.5	5600.4	5600.5	0.0021	4.2	2209.2	834.3	0.46
343.4038	MA - Min	300	5596.5	5597.7	5597.7	0.0022	1.3	388.3	448.0	0.35
343.4038	MA - Max	800	5596.5	5598.4	5598.5	0.0021	1.8	773.0	618.1	0.37
343.4038	3+43 BF	20	5596.5	5598.0	5598.0	0.0007	0.7	30.3	75.8	0.18
223.2865	2-YR Exst	2142	5597.1	5599.1	5599.2	0.0025	3.4	1392.2	704.7	0.46
223.2865	2-YR Dev	4429	5597.1	5600.1	5600.2	0.0031	5.0	2098.2	805.4	0.55
223.2865	MA - Min	300	5597.1	5597.5	5597.5	0.0015	0.7	472.4	461.1	0.26
223.2865	MA - Max	800	5597.1	5598.2	5598.2	0.0020	1.7	810.7	545.2	0.35
114.2485	2-YR Exst	2142	5597.3	5598.8	5598.9	0.0035	2.4	1296.1	724.8	0.48
114.2485	2-YR Dev	4429	5597.3	5599.7	5599.8	0.0037	3.9	1979.8	777.3	0.55
114.2485	MA - Min	300	5597.3	5597.3	5597.3	0.0025	0.1	400.4	428.7	0.21
114.2485	MA - Max	800	5597.3	5597.9	5598.0	0.0034	1.4	687.0	505.5	0.41

TABLE C-3

Historic Flow Path HEC-RAS Output File

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
7.0414	2-YR Exst	2142	5596.5	5598.5	5598.6	0.0028	3.4	1233.7	763.9	0.48
7.0414	2-YR Dev	4429	5596.5	5599.4	5599.5	0.0028	4.6	1919.5	793.0	0.52
7.0414	MA - Min	300	5596.5	5597.1	5597.1	0.0028	0.9	338.4	480.4	0.34
7.0414	MA - Max	800	5596.5	5597.6	5597.6	0.0028	2.0	639.3	571.7	0.42

TABLE C-4

Breakout Flow Path HEC-RAS Output File

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
3219.812	2-YR Exst	2142	5605.9	5608.3	5608.5	0.0030	3.9	942.0	487.1	0.51
3219.812	2-YR Dev	4429	5605.9	5609.6	5609.8	0.0027	5.3	1548.8	497.7	0.53
3219.812	MA - Min	300	5605.9	5606.1	5606.2	0.0050	0.9	199.4	177.0	0.43
3219.812	MA - Max	800	5605.9	5607.1	5607.1	0.0044	2.3	432.5	333.3	0.52
3119.66	2-YR Exst	2142	5605.1	5608.1	5608.2	0.0023	4.3	910.6	492.3	0.46
3119.66	2-YR Dev	4429	5605.1	5609.3	5609.5	0.0027	5.9	1543.4	530.8	0.53
3119.66	MA - Min	300	5605.1	5605.9	5605.9	0.0016	1.3	187.8	237.5	0.3
3119.66	MA - Max	800	5605.1	5606.8	5606.8	0.0019	2.6	423.0	282.7	0.38
3119.66	31+19 BF	505	5605.1	5607.6	5608.0	0.0042	5.1	98.6	43.1	0.6
3017.944	2-YR Exst	2142	5604.5	5607.7	5607.9	0.0035	5.0	966.3	477.5	0.56
3017.944	2-YR Dev	4429	5604.5	5608.9	5609.2	0.0038	6.7	1621.1	634.6	0.62
3017.944	MA - Min	300	5604.5	5605.6	5605.7	0.0032	2.0	219.2	242.7	0.43
3017.944	MA - Max	800	5604.5	5606.5	5606.6	0.0033	3.1	464.5	332.3	0.48
2925.283	2-YR Exst	2142	5604.3	5607.3	5607.4	0.0034	3.6	917.0	494.0	0.51
2925.283	2-YR Dev	4429	5604.3	5608.5	5608.7	0.0032	5.2	1651.9	794.0	0.55
2925.283	MA - Min	300	5604.3	5605.2	5605.2	0.0029	1.8	162.5	235.8	0.41
2925.283	MA - Max	800	5604.3	5606.1	5606.1	0.0033	2.9	405.3	329.4	0.47
2821.608	2-YR Exst	2142	5604.2	5607.0	5607.1	0.0025	3.6	1022.3	499.8	0.52
2821.608	2-YR Dev	4429	5604.2	5608.2	5608.4	0.0027	4.5	1662.8	628.1	0.49
2821.608	MA - Min	300	5604.2	5604.9	5604.9	0.0035	1.6	200.6	235.4	0.43
2821.608	MA - Max	800	5604.2	5605.8	5605.8	0.0027	2.6	498.6	375.6	0.44
2821.608	28+21 BF	570	5604.2	5606.6	5606.9	0.0043	4.3	132.6	93.9	0.64
2718.28	2-YR Exst	2142	5603.6	5606.8	5606.9	0.0020	3.2	1085.8	578.3	0.44
2718.28	2-YR Dev	4429	5603.6	5608.0	5608.1	0.0020	3.9	2001.3	986.6	0.41
2718.28	MA - Min	300	5603.6	5604.6	5604.7	0.0020	1.4	256.2	264.3	0.34
2718.28	MA - Max	800	5603.6	5605.6	5605.6	0.0019	2.3	530.5	346.6	0.38

TABLE C-4

Breakout Flow Path HEC-RAS Output File

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
2614.449	2-YR Exst	2142	5603.9	5606.5	5606.6	0.0025	3.8	1046.1	529.5	0.47
2614.449	2-YR Dev	4429	5603.9	5607.6	5607.8	0.0025	5.2	1828.6	799.2	0.51
2614.449	MA - Min	300	5603.9	5604.1	5604.2	0.0051	0.8	196.7	254.7	0.41
2614.449	MA - Max	800	5603.9	5605.2	5605.2	0.0027	2.2	515.1	352.7	0.42
2490.509	2-YR Exst	2142	5602.7	5606.2	5606.3	0.0021	4.3	915.4	549.3	0.45
2490.509	2-YR Dev	4429	5602.7	5607.3	5607.5	0.0025	5.8	1716.0	959.2	0.51
2490.509	MA - Min	300	5602.7	5603.9	5603.9	0.0013	1.4	172.2	150.6	0.28
2490.509	MA - Max	800	5602.7	5605.0	5605.0	0.0016	2.6	380.7	251.2	0.35
2490.509	24+90 BF	345	5602.7	5604.9	5605.5	0.0084	6.0	57.3	33.6	0.81
2367.207	2-YR Exst	2142	5602.2	5605.9	5606.0	0.0025	5.0	1049.1	539.6	0.48
2367.207	2-YR Dev	4429	5602.2	5607.1	5607.2	0.0029	6.5	1835.2	987.2	0.53
2367.207	MA - Min	300	5602.2	5603.7	5603.7	0.0025	2.7	144.2	126.2	0.42
2367.207	MA - Max	800	5602.2	5604.7	5604.8	0.0025	3.8	438.0	433.7	0.44
2367.207	23+67 BF	225	5602.2	5604.9	5605.1	0.0025	3.9	57.2	24.3	0.45
2209.845	2-YR Exst	2142	5601.7	5605.7	5605.7	0.0012	3.6	1354.3	593.2	0.32
2209.845	2-YR Dev	4429	5601.7	5606.7	5606.8	0.0017	5.1	2110.8	977.6	0.41
2209.845	MA - Min	300	5601.7	5603.4	5603.5	0.0010	1.9	253.2	348.6	0.27
2209.845	MA - Max	800	5601.7	5604.5	5604.6	0.0009	2.4	716.2	513.8	0.26
2042.742	2-YR Exst	2142	5600.8	5604.7	5605.3	0.0070	8.4	735.2	534.3	0.83
2042.742	2-YR Dev	4429	5600.8	5605.6	5606.3	0.0069	9.8	1443.0	1047.2	0.85
2042.742	MA - Min	300	5600.8	5602.5	5603.0	0.0097	5.9	50.5	34.6	0.87
2042.742	MA - Max	800	5600.8	5603.7	5604.2	0.0061	6.3	303.8	370.2	0.74
2042.742	20+42 BF	405	5600.8	5603.1	5603.6	0.0072	5.7	71.7	42.4	0.77
1938.709	2-YR Exst	2142	5600.4	5604.2	5604.4	0.0032	5.6	999.2	750.4	0.57
1938.709	2-YR Dev	4429	5600.4	5605.3	5605.5	0.0025	6.1	1989.9	1057.1	0.53
1938.709	MA - Min	300	5600.4	5601.8	5602.1	0.0075	4.3	121.6	136.3	0.73
1938.709	MA - Max	800	5600.4	5603.0	5603.2	0.0038	4.4	402.2	351.9	0.57
1745.463	2-YR Exst	2142	5597.9	5603.3	5603.8	0.0034	6.8	714.9	529.3	0.6

TABLE C-4

Breakout Flow Path HEC-RAS Output File

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
1745.463	2-YR Dev	4429	5597.9	5604.1	5604.9	0.0055	9.7	1130.4	618.2	0.78
1745.463	MA - Min	300	5597.9	5601.7	5601.7	0.0006	2.1	180.5	94.2	0.24
1745.463	MA - Max	800	5597.9	5602.6	5602.8	0.0014	3.8	386.7	352.7	0.37
1605.955	2-YR Exst	2142	5599.4	5603.3	5603.4	0.0020	3.3	1136.5	897.5	0.34
1605.955	2-YR Dev	4429	5599.4	5604.1	5604.3	0.0022	4.0	1933.5	1000.3	0.37
1605.955	MA - Min	300	5599.4	5601.5	5601.6	0.0020	2.1	141.0	91.8	0.3
1605.955	MA - Max	800	5599.4	5602.4	5602.5	0.0020	2.6	464.5	666.2	0.32
1605.955	16+05 BF	385	5599.4	5601.8	5601.9	0.0023	2.2	171.7	113.9	0.32
1454.871	2-YR Exst	2142	5598.9	5602.9	5603.1	0.0021	4.4	1084.2	886.4	0.45
1454.871	2-YR Dev	4429	5598.9	5603.7	5603.9	0.0023	5.4	1824.2	940.5	0.49
1454.871	MA - Min	300	5598.9	5600.7	5601.0	0.0086	4.5	66.5	62.7	0.77
1454.871	MA - Max	800	5598.9	5601.6	5602.0	0.0064	5.1	222.7	400.5	0.71
1303.384	2-YR Exst	2142	5598.5	5602.0	5602.6	0.0050	6.9	600.4	683.4	0.7
1303.384	2-YR Dev	4429	5598.5	5602.7	5603.4	0.0052	8.2	1243.4	851.8	0.74
1303.384	MA - Min	300	5598.5	5600.1	5600.3	0.0028	2.9	104.1	85.0	0.46
1303.384	MA - Max	800	5598.5	5600.9	5601.2	0.0042	4.8	179.4	138.7	0.6
1303.384	13+03 BF	585	5598.5	5601.0	5601.1	0.0020	3.3	175.0	85.5	0.41
1150.922	2-YR Exst	2142	5597.9	5601.4	5601.5	0.0028	4.1	1101.9	810.7	0.49
1150.922	2-YR Dev	4429	5597.9	5602.2	5602.4	0.0029	5.1	1811.0	917.4	0.53
1150.922	MA - Min	300	5597.9	5599.6	5599.8	0.0039	3.5	89.4	103.1	0.54
1150.922	MA - Max	800	5597.9	5600.5	5600.7	0.0025	3.6	484.3	646.9	0.45
1150.922	11+50 BF	810	5597.9	5601.1	5601.4	0.0033	4.1	197.7	103.2	0.52
997.3732	2-YR Exst	2142	5597.2	5600.9	5601.0	0.0036	4.9	1033.1	816.5	0.56
997.3732	2-YR Dev	4429	5597.2	5601.7	5601.9	0.0032	5.5	1794.2	891.1	0.54
997.3732	MA - Min	300	5597.2	5599.0	5599.2	0.0038	3.9	120.1	155.8	0.54
997.3732	MA - Max	800	5597.2	5599.7	5600.1	0.0059	5.8	273.9	282.1	0.82
845.9666	2-YR Exst	2142	5596.2	5600.0	5600.4	0.0047	5.9	789.6	872.6	0.66
845.9666	2-YR Dev	4429	5596.2	5600.7	5601.2	0.0059	7.8	1384.6	893.0	0.78

TABLE C-4

Breakout Flow Path HEC-RAS Output File

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
845.9666	MA - Min	300	5596.2	5598.7	5598.8	0.0013	2.1	242.1	281.7	0.32
845.9666	MA - Max	800	5596.2	5599.3	5599.5	0.0025	3.5	438.9	455.4	0.46
730.4002	2-YR Exst	2142	5595.9	5599.8	5599.9	0.0028	3.7	1056.8	882.1	0.48
730.4002	2-YR Dev	4429	5595.9	5600.5	5600.7	0.0025	4.2	1789.9	1020.2	0.48
730.4002	MA - Min	300	5595.9	5598.1	5598.5	0.0051	5.2	78.1	267.6	0.65
730.4002	MA - Max	800	5595.9	5599.0	5599.1	0.0030	3.6	466.8	652.2	0.49
730.4002	7+30 BF	520	5595.9	5598.5	5599.4	0.0107	7.6	68.8	34.6	0.95
641.5904	2-YR Exst	2142	5594.5	5599.0	5599.4	0.0064	8.5	701.0	730.6	0.81
641.5904	2-YR Dev	4429	5594.5	5600.2	5600.4	0.0025	6.6	1865.9	1149.7	0.54
641.5904	MA - Min	300	5594.5	5597.4	5597.9	0.0073	6.0	64.8	83.4	0.78
641.5904	MA - Max	800	5594.5	5598.4	5598.8	0.0041	6.1	335.2	560.0	0.63
497.3197	2-YR Exst	2142	5594.2	5598.8	5598.8	0.0006	2.9	1287.8	500.5	0.25
497.3197	2-YR Dev	4429	5594.2	5600.1	5600.2	0.0007	3.9	2042.3	640.8	0.3
497.3197	MA - Min	300	5594.2	5596.6	5596.6	0.0005	1.5	342.3	381.6	0.21
497.3197	MA - Max	800	5594.2	5597.4	5597.5	0.0005	2.0	699.4	419.4	0.22
497.3197	4+97 BF	255	5594.2	5595.9	5596.1	0.0048	3.7	69.8	60.4	0.6
383.1394	2-YR Exst	2142	5593.6	5596.2	5596.5	0.0075	6.3	595.8	495.4	0.81
383.1394	2-YR Dev	4429	5593.6	5596.9	5597.4	0.0075	7.9	987.8	556.5	0.86
383.1394	MA - Min	300	5593.6	5594.9	5595.1	0.0075	3.8	122.8	215.0	0.72
383.1394	MA - Max	800	5593.6	5595.5	5595.7	0.0075	4.7	287.3	386.1	0.75

Appendix E

Stream Stability Analysis, Geomorphic Characteristics and Stable Slope Calculations

Appendix E – Stream Stability

Geomorphic Conditions from Cherry Creek Master Plan (URS, 2004)

TABLE D-1

Geomorphic Characteristics by Reach from Cherry Creek Master Plan (URS, 2004)

Reach	Reach Grade (%)	Channel Condition	Bank Erosion	Dominant Stream Form	Rosgen Classification
1*	**0.41**	**Aggrading to Stable**	**None**	**Braided**	**D5**
2	0.39	Aggrading - Degrading Stable	None to Minor	Braided-Meandering	D5
3	0.37	Entrenched Segments, Degrading to Stable	Minor to Severe	Meandering	C5
4	0.37	Entrenched Segments, Degrading to Stable	Minor with Healing Banks to Severe	Meandering	C5, C5 change to F5, F5
5	0.41	Entrenched Segments, Degrading to Stable	Minor with Healing Banks to Severe	Meandering, Short Braided Segment	C5, D5, C5 change to F5, F5
6	0.37	Entrenched Segments, Degrading to Stable	Minor with Healing Banks to Severe	Meandering, Short Braided Segment	C5, D5, F5
7	0.41	Entrenched Segments, Mostly Stable	Minor	Meandering, Short Braided Segment	C5, D5, F5
8	0.39	Entrenched Segments, Mostly Stable	Minor	Meandering, Short Braided Segment	C5, D5, F5

*Cherry Creek at 12-Mile Park is within Reach 1

Stable Slope Spreadsheets

28+21 Bank Full			
Initial Conditions and Normalized Calculations	b	64	feet
	y1	2.44	feet
	v1	4.3	feet/second
	qs	0.002074467	cfs/ft
	Energy Slope	0.004329	ft/ft
	RNormalized	2.267131243	feet
	nnormalized	0.039345589	-
	% To Allow V and Y to Vary	10	%
	D(VY)	1.86	-
	Upper D(vy)	2.046	-
	Lower D(vy)	1.674	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.004126221**	ft/ft
	y2	3.954441845	feet
	b	64	feet
	v2	5.628442213	feet/second
	q objective	0.007529982	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	1.674000368	

Color Key	
(green)	User Input
(light blue)	User Changes by Reach and Flow
(orange)	User Does Not Change Internal Calculation
(purple)	Fluctuates within Constraints of Optimization Model

(Typical for all spreadsheets)

28+21 2-Year Existing			
Initial Conditions and Normalized Calculations	b	64	feet
	y1	2.83	feet
	v1	3.86	feet/second
	qs	0.001342442	cfs/ft
	Energy Slope	0.002548	ft/ft
	RNormalized	2.600057422	feet
	nnormalized	0.036842914	-
	% To Allow V and Y to Vary	10	%
	D(VY)	1.03	-
	Upper D(vy)	1.133	-
	Lower D(vy)	0.927	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.002936559**	ft/ft
	y2	4.651572498	feet
	b	64	feet
	v2	5.578573059	feet/second
	q objective	0.007530003	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	0.927000561	

28+21 2-Year Developed			
Initial Conditions and Normalized Calculations	b	64	feet
	y1	4.02	feet
	v1	5.47	feet/second
	qs	0.006674716	cfs/ft
	Energy Slope	0.00274	ft/ft
	RNormalized	3.57134925	feet
	nnormalized	0.033314178	-
	% To Allow V and Y to Vary	10	%
	D(VY)	1.45	-
	Upper D(vy)	1.595	-
	Lower D(vy)	1.305	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.002777233**	ft/ft
	y2	4.152163925	feet
	b	64	feet
	v2	5.613366834	feet/second
	q objective	0.007529736	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	1.461202909	

27+18 Bank Full			
Initial Conditions and Normalized Calculations	b	71	feet
	y1	2.72	feet
	v1	3.73	feet/second
	qs	0.001145277	cfs/ft
	Energy Slope	0.003216	ft/ft
	RNormalized	2.526425955	feet
	nnormalized	0.042021657	-
	% To Allow V and Y to Vary	10	%
	D(VY)	1.01	-
	Upper D(vy)	1.111	-
	Lower D(vy)	0.909	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.003739017**	ft/ft
	y2	4.66845402	feet
	b	71	feet
	v2	5.577454448	feet/second
	q objective	0.007529939	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	0.909000427	

27+18 2-Year Existing			
Initial Conditions and Normalized Calculations	b	71	feet
	y1	4.41	feet
	v1	3.71	feet/second
	qs	0.001255709	cfs/ft
	Energy Slope	0.002056	ft/ft
	RNormalized	3.922701077	feet
	nnormalized	0.0452947	-
	% To Allow V and Y to Vary	10	%
	D(VY)	0.7	-
	Upper D(vy)	0.77	-
	Lower D(vy)	0.63	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.002997153**	ft/ft
	y2	6.258721753	feet
	b	71	feet
	v2	5.488721757	feet/second
	q objective	0.007530999	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	0.769999996	

27+18 2-Year Developed			
Initial Conditions and Normalized Calculations	b	71	feet
	y1	3.22	feet
	v1	4.98	feet/second
	qs	0.004204317	cfs/ft
	Energy Slope	0.0021	ft/ft
	RNormalized	2.952221074	feet
	nnormalized	0.028216241	-
	% To Allow V and Y to Vary	10	%
	D(VY)	1.76	-
	Upper D(vy)	1.936	-
	Lower D(vy)	1.584	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.002035014**	ft/ft
	y2	4.037996723	feet
	b	71	feet
	v2	5.621996841	feet/second
	q objective	0.007529995	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	1.584000117	

20+42 Bank Full			
Initial Conditions and Normalized Calculations	b	36	feet
	y1	2.26	feet
	v1	5.65	feet/second
	qs	0.006698247	cfs/ft
	Energy Slope	0.007227	ft/ft
	RNormalized	2.007897335	feet
	nnormalized	0.035681616	-
	% To Allow V and Y to Vary	10	%
	D(VY)	3.39	-
	Upper D(vy)	3.729	-
	Lower D(vy)	3.051	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.008397206**	ft/ft
	y2	2.09838812	feet
	b	36	feet
	v2	5.827387452	feet/second
	q objective	0.007529998	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	3.728999332	

20+42 2-Year Existing			
Initial Conditions and Normalized Calculations	b	36	feet
	y1	3.87	feet
	v1	8.39	feet/second
	qs	0.04270346	cfs/ft
	Energy Slope	0.00696	ft/ft
	RNormalized	3.185185185	feet
	nnormalized	0.032073921	-
	% To Allow V and Y to Vary	10	%
	D(VY)	4.52	-
	Upper D(vy)	4.972	-
	Lower D(vy)	4.068	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.016644804**	ft/ft
	y2	1.073477535	feet
	b	36	feet
	v2	6.045477542	feet/second
	q objective	0.00753	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	4.972000008	

20+42			
2-Year Developed			
Initial Conditions and Normalized Calculations	b	36	feet
	y1	4.84	feet
	v1	9.75	feet/second
	qs	0.086723374	cfs/ft
	Energy Slope	0.00685	ft/ft
	RNormalized	3.814360771	feet
	nnormalized	0.030877452	-
	% To Allow V and Y to Vary	10	%
	D(VY)	4.91	-
	Upper D(vy)	5.401	-
	Lower D(vy)	4.419	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.009685566**	ft/ft
	y2	1.513666864	feet
	b	36	feet
	v2	5.932666375	feet/second
	q objective	0.007529999	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	4.418999511	

16+05 Bank Full			
Initial Conditions and Normalized Calculations	b	110	feet
	y1	2.51	feet
	v1	2.24	feet/second
	qs	0.000121619	cfs/ft
	Energy Slope	0.002283	ft/ft
	RNormalized	2.400452095	feet
	nnormalized	0.056979666	-
	% To Allow V and Y to Vary	10	%
	D(VY)	0.27	-
	Upper D(vy)	0.297	-
	Lower D(vy)	0.243	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.005565161**	ft/ft
	y2	5.244887018	feet
	b	110	feet
	v2	5.541886749	feet/second
	q objective	0.007529433	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	0.296999731	

16+05 2-Year Existing			
Initial Conditions and Normalized Calculations	b	110	feet
	y1	3.86	feet
	v1	3.29	feet/second
	qs	0.000720388	cfs/ft
	Energy Slope	0.002011	ft/ft
	RNormalized	3.606863744	feet
	nnormalized	0.047765709	-
	% To Allow V and Y to Vary	10	%
	D(VY)	0.57	-
	Upper D(vy)	0.627	-
	Lower D(vy)	0.513	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.003189532**	ft/ft
	y2	6.122134128	feet
	b	110	feet
	v2	5.495133175	feet/second
	q objective	0.007529616	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	0.627000953	

16+05 2-Year Developed			
Initial Conditions and Normalized Calculations	b	110	feet
	y1	4.7	feet
	v1	4.05	feet/second
	qs	0.001868673	cfs/ft
	Energy Slope	0.002166	ft/ft
	RNormalized	4.32998325	feet
	nnormalized	0.045486719	-
	% To Allow V and Y to Vary	10	%
	D(VY)	0.65	-
	Upper D(vy)	0.715	-
	Lower D(vy)	0.585	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.003935288**	ft/ft
	y2	4.850789742	feet
	b	110	feet
	v2	5.565789305	feet/second
	q objective	0.007530154	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	0.714999564	

13+03 Bank Full			
Initial Conditions and Normalized Calculations	b	91	feet
	y1	2.47	feet
	v1	3.34	feet/second
	qs	0.000691492	cfs/ft
	Energy Slope	0.001961	ft/ft
	RNormalized	2.342818428	feet
	nnormalized	0.034847451	-
	% To Allow V and Y to Vary	10	%
	D(VY)	0.87	-
	Upper D(vy)	0.957	-
	Lower D(vy)	0.783	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.002431167**	ft/ft
	y2	4.745330186	feet
	b	91	feet
	v2	5.572423121	feet/second
	q objective	0.007529704	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	0.827092935	

13+03 2-Year Existing			
Initial Conditions and Normalized Calculations	b	91	feet
	y1	3.47	feet
	v1	6.83	feet/second
	qs	0.016967232	cfs/ft
	Energy Slope	0.004886	ft/ft
	RNormalized	3.224116806	feet
	nnormalized	0.033279961	-
	% To Allow V and Y to Vary	10	%
	D(VY)	3.36	-
	Upper D(vy)	3.696	-
	Lower D(vy)	3.024	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.004683485**	ft/ft
	y2	2.720979882	feet
	b	91	feet
	v2	5.744979698	feet/second
	q objective	0.007530004	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	3.023999816	

13+03 2-Year Developed			
Initial Conditions and Normalized Calculations	b	91	feet
	y1	4.27	feet
	v1	8.08	feet/second
	qs	0.037100844	cfs/ft
	Energy Slope	0.005077	ft/ft
	RNormalized	3.903656821	feet
	nnormalized	0.032575636	-
	% To Allow V and Y to Vary	10	%
	D(VY)	3.81	-
	Upper D(vy)	4.191	-
	Lower D(vy)	3.429	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.005452735**	ft/ft
	y2	2.360861545	feet
	b	91	feet
	v2	5.789861497	feet/second
	q objective	0.007530002	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	3.428999952	

4+97 Bank Full			
Initial Conditions and Normalized Calculations	b	61	feet
	y1	1.73	feet
	v1	3.65	feet/second
	qs	0.000935164	cfs/ft
	Energy Slope	0.004829	ft/ft
	RNormalized	1.637139311	feet
	nnormalized	0.039404495	-
	% To Allow V and Y to Vary	10	%
	D(VY)	1.92	-
	Upper D(vy)	2.112	-
	Lower D(vy)	1.728	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.004454312**	ft/ft
	y2	3.756719744	feet
	b	61	feet
	v2	5.64424762	feet/second
	q objective	0.007529735	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	1.887527876	

4+97 2-Year Existing			
Initial Conditions and Normalized Calculations	b	61	feet
	y1	4.55	feet
	v1	2.86	feet/second
	qs	0.000406835	cfs/ft
	Energy Slope	0.00582	ft/ft
	RNormalized	3.959343795	feet
	nnormalized	0.099471165	-
	% To Allow V and Y to Vary	10	%
	D(VY)	1.69	-
	Upper D(vy)	1.859	-
	Lower D(vy)	1.521	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.01309658**	ft/ft
	y2	6.976914659	feet
	b	61	feet
	v2	5.455915479	feet/second
	q objective	0.007529679	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	1.52099918	

4+97 2-Year Developed			
Initial Conditions and Normalized Calculations	b	61	feet
	y1	5.88	feet
	v1	3.86	feet/second
	qs	0.001598821	cfs/ft
	Energy Slope	0.0072	ft/ft
	RNormalized	4.929631666	feet
	nnormalized	0.094872758	-
	% To Allow V and Y to Vary	10	%
	D(VY)	2.02	-
	Upper D(vy)	2.222	-
	Lower D(vy)	1.818	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.011359121**	ft/ft
	y2	7.261993574	feet
	b	61	feet
	v2	5.443993799	feet/second
	q objective	0.007529934	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	1.817999775	

4+59 Bank Full			
Initial Conditions and Normalized Calculations	b	83	feet
	y1	0.76	feet
	v1	2.49	feet/second
	qs	0.000144991	cfs/ft
	Energy Slope	0.011188	ft/ft
	RNormalized	0.746332229	feet
	nnormalized	0.052077638	-
	% To Allow V and Y to Vary	10	%
	D(VY)	1.73	-
	Upper D(vy)	1.903	-
	Lower D(vy)	1.557	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.007171425**	ft/ft
	y2	3.87762711	feet
	b	83	feet
	v2	5.634464266	feet/second
	q objective	0.007529788	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	1.756837156	

4+59 2-Year Existing			
Initial Conditions and Normalized Calculations	b	83	feet
	y1	2	feet
	v1	4.33	feet/second
	qs	0.002387526	cfs/ft
	Energy Slope	0.004679	ft/ft
	RNormalized	1.908045977	feet
	nnormalized	0.036210466	-
	% To Allow V and Y to Vary	10	%
	D(VY)	2.33	-
	Upper D(vy)	2.563	-
	Lower D(vy)	2.097	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.003880366**	ft/ft
	y2	3.56363847	feet
	b	83	feet
	v2	5.660639302	feet/second
	q objective	0.007529984	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	2.097000832	

4+97 2-Year Developed			
Initial Conditions and Normalized Calculations	b	83	feet
	y1	2.94	feet
	v1	5.44	feet/second
	qs	0.006047059	cfs/ft
	Energy Slope	0.003886	ft/ft
	RNormalized	2.74549955	feet
	nnormalized	0.0334775	-
	% To Allow V and Y to Vary	10	%
	D(VY)	2.5	-
	Upper D(vy)	2.75	-
	Lower D(vy)	2.25	-
Calculated Stable Slope to Match Stable Sediment Transport Rate	S (Stable)	**0.003500341**	ft/ft
	y2	3.423136829	feet
	b	83	feet
	v2	5.673137135	feet/second
	q objective	0.007529999	cfs/ft
	q Stable	1.45E-04	cfs/ft
	D(vy)	2.250000306	

Appendix F

Dog Off Leash Area Maps