GEOMORPHIC ASSESSMENT

Fountain Creek in Woodland Park between Aspen Garden Road and Crystola Road

REPORT

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Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 INTRODUCTION

This geomorphic assessment of Fountain Creek from Aspen Garden Road to Crystola Road has been prepared as part of the overall Town of Woodland Park Stormwater Master and Capital Improvement Plan, which is currently being prepared by Enginuity Engineering Solutions. The goal of this assessment is to:

- Perform a site visit and coordinate with private property owners
- Perform a plan form and bank stability analysis of the existing conditions and identify stability issues
- Evaluate the bed stability of the existing condition
- Identify problematic sediment production and depositional zones
- Identify infrastructure at risk
- Develop and recommend stable channel section and plan form alternatives
- Develop recommendations and conceptual capital cost estimates for channel stability improvements

1.1 Data Collection and Review

Prior to initiating the work, available data related to the geomorphology, sediment transport potential, hydrology, and hydraulic capacity of the existing system was obtained and reviewed. The data available included the following:

- Aerial photographs (dates)
- Ayres report
- FEMA effective hydraulic model
- Preliminary hydrology from Master Plan
- USGS Topographic Map
- USGS Stream Gauges
- Survey Data
- Published Articles (see References)

1.2 Site Visit

A site reconnaissance of the Study Reach of Fountain Creek was conducted on March 12, 2015, by Golder staff Mr. Robert Humphries and Mr. Steve Rogers, P.E. The upstream reaches of Fountain Creek were also visited. Adjacent property owners were notified prior to the site visit. During the site visit, the overall condition and geomorphologic stability of the reach of Fountain Creek were noted. Observations made during the site visit were incorporated into the overall evaluations and recommendations.

2.0   SITE CONDITIONS

This section describes the overall site conditions and discusses intermediate reaches that were established for purposes of the evaluations.

2.1   Reach Descriptions

The Study Reach (aka the Site) lies near the headwaters of the Fountain Creek Drainage. This proximity to the drainage divide from adjacent basins results in a relatively small catchment basin. Golder has divided the Study Reach into three sub-reaches for descriptive purposes. These sub-reaches are, starting from upstream; the Concrete Plant Reach (Reach 1), the Saddle Club Reach (Reach 2), and the Walmart Reach (Reach 3). A description of the reaches both upstream and downstream of the Study Reach and the three sub-reaches are given below. Throughout this report the terms river-right and river-left are used to refer to the land adjacent to the river, as though the observer was facing downstream.

Note: Flow is from Left to Right. Source: Google Earth

Figure 1   Reach Delineation

2.1.1 Upstream of the Study Reach

Large portions of the Fountain Creek Watershed upstream from the Site have been stabilized via culverts, drop structures, and hard stabilization techniques. The frequent use of culverts and grouted riprap have substantially stabilized the channel bed and banks upstream from the Study Reach and minimized the potential for bank erosion and lateral channel migration in large portions of the upstream basin (Figure 2). Additionally, the construction of two retention basins upstream of the site will likely attenuate the passage of a flood wave, consequently reducing peak discharges. However, in contrast to the largely protected channels of most of the drainage basin, the reach immediately upstream of the Study Reach has recently experienced significant erosion and has undergone substantial morphology change (Figure 3).

Figure 2   Typical Channel Upstream of the Study Reach; View Looking Downstream from Cavalier Park

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Note: The tree stump in the middle of the channel defined the former river-right bank.

Figure 3   Reach Immediately Upstream of the Study Reach; View Looking Downstream, Behind Safeway

Immediately upstream of the Aspen Garden Bridge is a drop structure that serves to control the channel gradient and dissipate hydraulic energy during high magnitude discharge events. The reach upstream from this drop structure is experiencing substantial erosion and channel change, likely associated with recent construction and high magnitude discharge events. Golder understands that the remediation of this reach is being designed by another consulting firm, and is outside the purview of this assessment (Ayers 2014).

2.1.2 Concrete Plant Reach

Generally the reach downstream from the bridge at Aspen garden Road, termed the Concrete Plant Reach is the most highly impacted within the Study Reach. The channel is highly armored with large riprap, poured concrete, and other construction debris. The bridge at the upstream end of the Study Reach on Aspen Garden Road serves as a point of flow constriction and a grade control structure. The relatively shallow and narrow passage under the bridge will be suitable for most flow conditions, but will likely result in over topping and bypass flow in high magnitude discharge events. The grade control function of the bridge is functioning as intended, however the downstream foundation of the bridge is being undercut (see Figure 4).

Figure 4   Undercutting of Aspen Garden Bridge on the Downstream Side

The right-of-way of the road parallel to the channel on the river-right side has been recently surveyed, as indicated by survey markers present during the site investigation. The right-of-way markers indicate that it is partially within the channel, such that the edge of the right-of-way marker is at the toe of the river-right bank (Figure 5). Additionally, the erosion of the river-left bank has undermined the foundation of a nearby utility pole (Figure 6).

Figure 5 Right-of-Way Marker at Toe of Bank Downstream from Aspen Garden Bridge; View Looking Downstream

Figure 6　　Erosion of a Utility Pole Foundation in the River-Left Bank

Substantial channel modifications have been made near the Concrete Plant. Beginning in the meander bend immediately upstream, and continuing to downstream of the Concrete Plant, large quantities of construction debris and un-designed revetment material have been added to both banks of the channel (Figure 7 and Figure 8). Additionally, near the Concrete Plant significant quantities of fill material have been added to the floodplain to elevate the portion of the land that previously made up the local flood plain (Figure 9). Immediately adjacent to the Concrete Plant's infrastructure on the river-right bank, concrete has been poured down the bank and allowed to harden in place as form of bank protection (Figure 10). Recently poured concrete was observed during the site visit.

Figure 7   Construction Debris, River-Left, Across From the Concrete Plant

Figure 8   Bank Protection at the Concrete Plant; View Looking Downstream

Figure 9   Fill Placed on Top of Former Floodplain; View is toward the River-Right Downstream of the Concrete Plant

Figure 10   **Poured Concrete on the River-Right Bank at the Concrete Plant; View Looking Upstream**

In the further downstream portions of the Concrete Plant Reach, the addition of fill material to the river-right bank ceases and a modern floodplain and channel bank have formed. However, this self-forming portion of the river is relatively short as the channel is constrained again shortly downstream, with construction debris stabilization material on the river-left and a natural sediment bluff on the river-right. The natural sediment bluff is being eroded by the channel, and has been stabilized at the toe by conventional riprap and construction debris (Figure 12). Within the downstream portion of the Concrete Plant Reach, the river contains such features as large sediment block failure of river-left bank, and an island separated from the higher banks by a secondary channel (Figure 11).

Figure 11   Sediment Block Erosion Pattern on River-Left Bank; View Looking Downstream

Note: Modern floodplain formation at the upstream, left hand side of the image, the island and back-bar channel in the center, and the riprap protection bluff on the right side of the image. Flow is from left to right.

Figure 12   Downstream Portion of Concrete Plant Reach; Saddle Club Reach

Starting in the downstream portion of the Concrete Plant Reach and continuing through the Saddle Club Reach and into the upper portion of the Walmart Reach, the river-left bank has had several feet of fill material added to the floodplain. Golder believed that a large portion of this fill material is associated with the construction of the reservoir on the river-left bank. According to the aerial imagery collected during this investigation, the reservoir was constructed sometime between 1954 and 1971 (see Figure 27 and Figure 28) and drained sometime between 1988 and 1999 (see Figure 31 and Figure 32). The reservoir embankments are still present on the floodplain and the long side of the trapezoidal shaped reservoir runs parallel to the channel for most of the downstream portion of the Saddle Club Reach.

At the upstream end of the Saddle Club Reach, a culvert outlet and surface channel join the main channel from the river left. The discharge point of the culvert is not flush with the channel and discharges several feet above the elevation of the channel bed. The surface channel is also associated with significant erosion. This has resulted in erosion and the remedial efforts, which consist of the addition of a large quantity of construction debris and large boulders within the surface channel and the culvert outlet (Figure 13).

Figure 13　Culvert Joins from River-Left; View is toward the River-Left

Figure 14   Saddle Club Reach is Lined on Both Sides by Large Quantities of Revetment Material; View Looking Downstream

Through most of the Saddle Club Reach and into the upper part of the Walmart Reach, the river-right bank is being eroded. The bank consists of a bluff made of in situ valley sediments. Along most of the Saddle Club Reach the toe of the bluff, where it meets the river banks, is protected by riprap, construction debris, and many very large tires, and in one instance, an old rusted car body (Figure 16). These tires likely came from nearby mining operations and have been chained together for the purpose of protecting the bank from erosion (Figure 15).

Figure 15   One of Several Sets of Large Tires Placed on the River-Right Bank with the Saddle Club Reach

Figure 16   Car Body Used as Bank Protection; View is toward the River-Left

The downstream end of the Saddle Club Reach is defined by the downstream end of the adjacent former Saddle Club. At the downstream end of the former reservoir, there are several structures associated with old outlets works and a retaining wall (Figure 17 and Figure 18).

Figure 17   Retaining Wall at Downstream End of Saddle Club Reach; View is toward the River-Left

Figure 18   Reservoir Downstream Outlet Structures

2.1.3   Walmart Reach

The upstream portion of the sub reach is characterized by the placement of a large quantity of grouted riprap on the river-left bank and the entry of a culvert. The culvert is integrated into the grouted riprap (Figure 20) and appears to be likely recently constructed (Figure 19). Five other defining features characterize the Walmart Reach; a retaining wall (Figure 22), several drop structures (Figure 21), erosion of the river-right bank (top right corner of Figure 21), the confluence of Silver Creek from the river-right (Figure 23), and the bridge at Crystola Road. The retaining wall defines the river-left bank of the channel for most of the reach. The wall is smooth and generally straight, except near the bridge. The low roughness of the smooth concrete likely accelerates the velocity of river in high discharge events. The thalweg of the channel is immediately at the toe of the retaining wall for its entire length. The large diameter grouted riprap ends upstream of the retaining wall. Only one drop structure was observed within the reach, however, in personal communication with Mr. William Alspach, Director and City Engineer for the City of Woodland Park, Golder was informed that there are other drop structures within the reach that are buried beneath the sand bed. It is important to note that the bridge at Crystola Road likely functions as a grade control structure and also likely provides a backwater effect that limits the velocities within the Walmart Reach.

Figure 19   Culvert Outlet at Upstream End of Walmart Reach on River-Left

Figure 20   Large Riprap on River-Left Bank at Upstream End of Walmart Reach

Note: The erosion is on the far bank.

Figure 21   The Drop Structure near the Upstream End of the Walmart Reach; View is toward the River-Right

Figure 22   River-Left Retaining Wall in Walmart Reach; View Looking Upstream

Figure 23   Confluence of Silver Creek; View is Looking Upstream of the Silver Creek Channel from the Confluence with the Main Channel

Figure 24   Upstream Side of the Bridge at Crystola Road

2.1.4   Downstream of the Study Reach

Downstream of the Study Reach, Fountain Creek remains a sand bedded channel for several miles before becoming a narrower, steeper, gravel and boulder bedded channel and subsequently a waterfall near the city of Green Mountain Falls. Within the sand bedded portion close to the Study Reach, Golder observed significant channel dynamics and bank erosion.

3.0   GEOMORPHIC ASSESSMENT

The geomorphic assessment of the Study Reach included:

- A review of historical aerial imagery
- A review of the hydrology and hydraulics associated with the existing system
- Development of hydraulic and sediment transport equations to evaluate the overall stability of the existing system
- Development of calculations for recommended stable channel sections

3.1   Historic Aerial Imagery

The following section presents a series of aerial imagery of the Site starting in 1953, with the latest image collected in 2011. In all of these images, the modern channel alignment within the Study Reach is depicted in yellow. Generally, the channel has remained in a similar alignment through time, with changes in channel alignment in the upstream half of the Study Reach being more substantial than those in the lower half. Caution must be used in correlating the modern channel with these historic alignments. While the historic images have been correlated to the modern landscape as precisely as possible without manipulating the images, the images have not been geospatially referenced, nor ortho-rectified to remove lens induced curvature.

3.1.1   1953

The characteristics of the Study Reach based on this historic aerial imagery indicate the following:

- Wide, sand bedded, multi-threaded channel, especially in the Concrete Plant and Saddle Club Reaches.
- Floodplain present on both sides of the channel in the Concrete Plant Reach.
- Small floodplain features on the river-right side in the Saddle Club Reach.
- Main channel not continuously adjacent to in situ sedimentary material on the river-right bank in the Saddle Club Reach, as occurs in modern condition.
- No channel armoring, floodplain infilling, nor channel encroachment.
- Channel is eroding the in situ material in some places, notable at the downstream end of the Concrete Plant Reach. On the right hand, side of Figure 12 the high, eroded bank present in 1953 can be seen in its present day form.
- Several minor tributaries join the main channel from the river-left side. The downstream-most tributary joins the main channel downstream of the Study Reach, but the Tributary upstream of this one joins enters the river-left flood plain and appears to bifurcate on the floodplain, forming multiple distributary channel on the floodplain surface. This depositional feature may have been channelized and diverted to the main channel.
- Note that Figure 26 does not match the modern landscape with sufficient precision to assess landscape change.
- Minimal development of floodplain in the form of buildings in the modern Walmart Reach.

Modern Channel Alignment

Figure 25   1953 No. 1 of 2
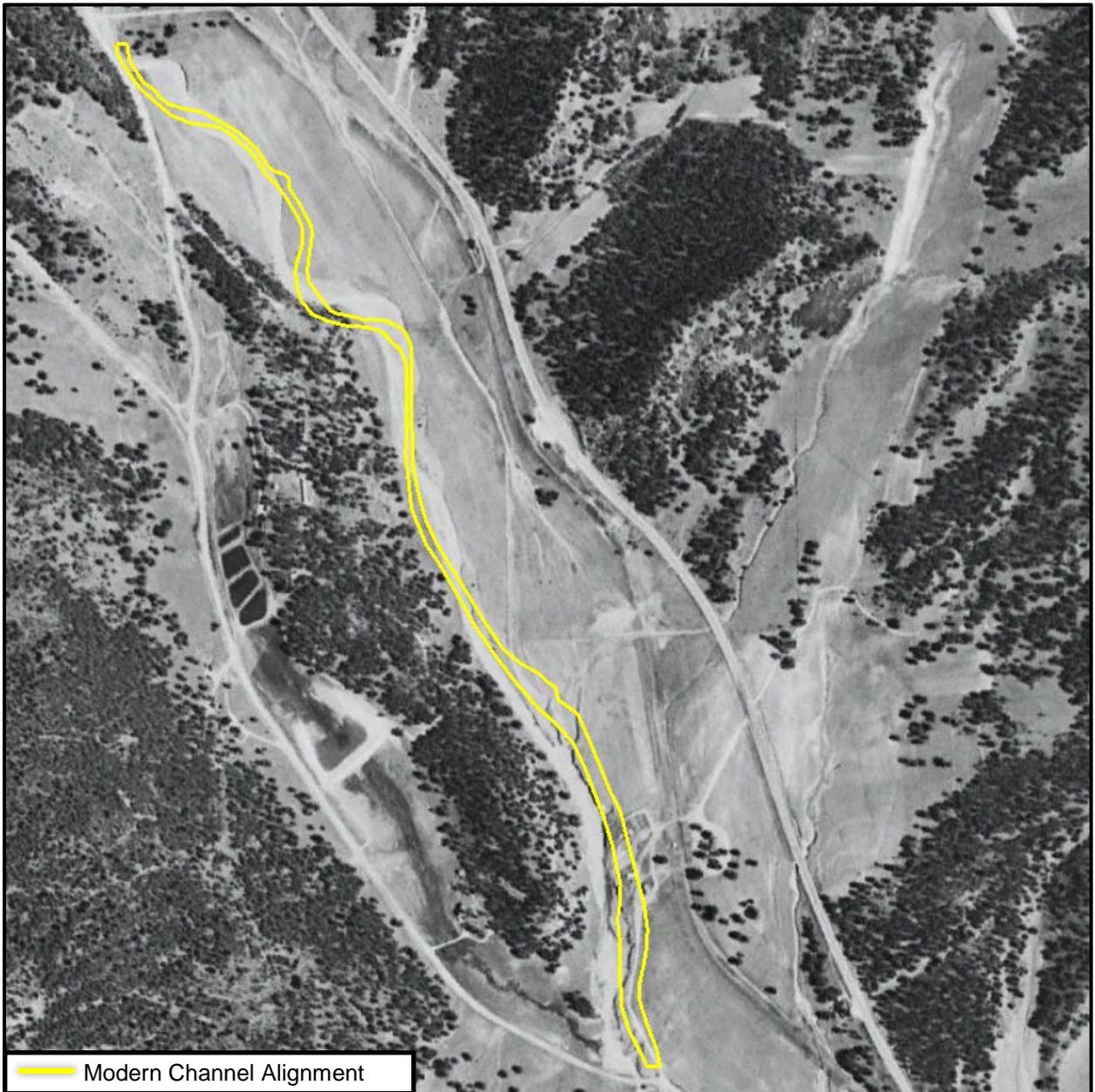
Figure 26   1953 No. 2 of 2

3.1.2　1954

The aerial imagery from 1954 is similar to 1953 with only some channel alignment changes in the Concrete Plant Reach:

- Similar to 1953

Modern Channel Alignment
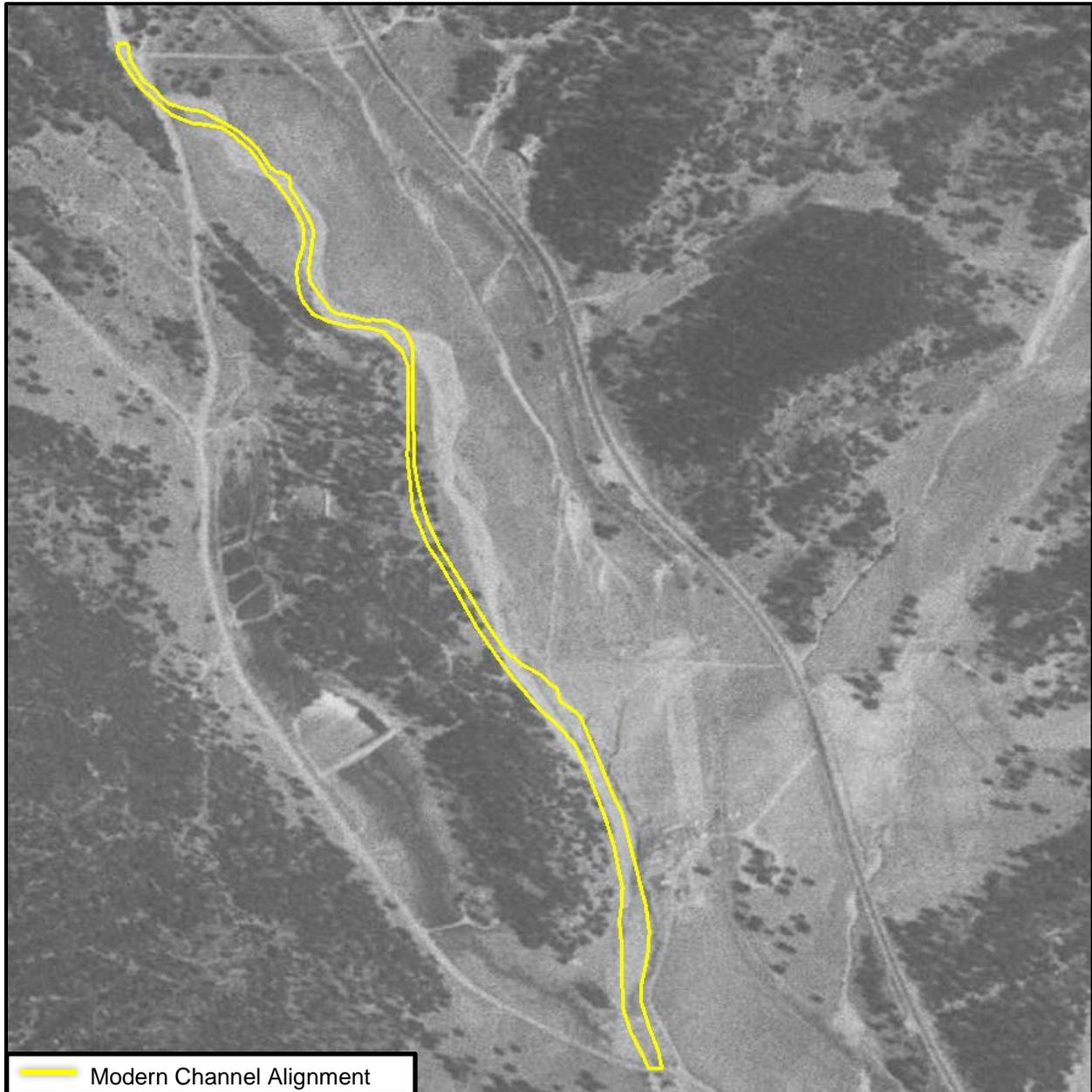
Figure 27　1954

3.1.3   1971

The characteristics of the Study Reach based on this historic aerial imagery indicate the following:

- A reservoir has been constructed in the Saddle Club Reach, consequently narrowing the channel in that reach

- The Concrete Plant has yet to be constructed and the channel in the Concrete Plant Reach is still wide

- Continued development of the river-left floodplain has occurred in the form of a trailer park adjacent to the reservoir and the addition of several buildings at the upstream end of the Study Reach
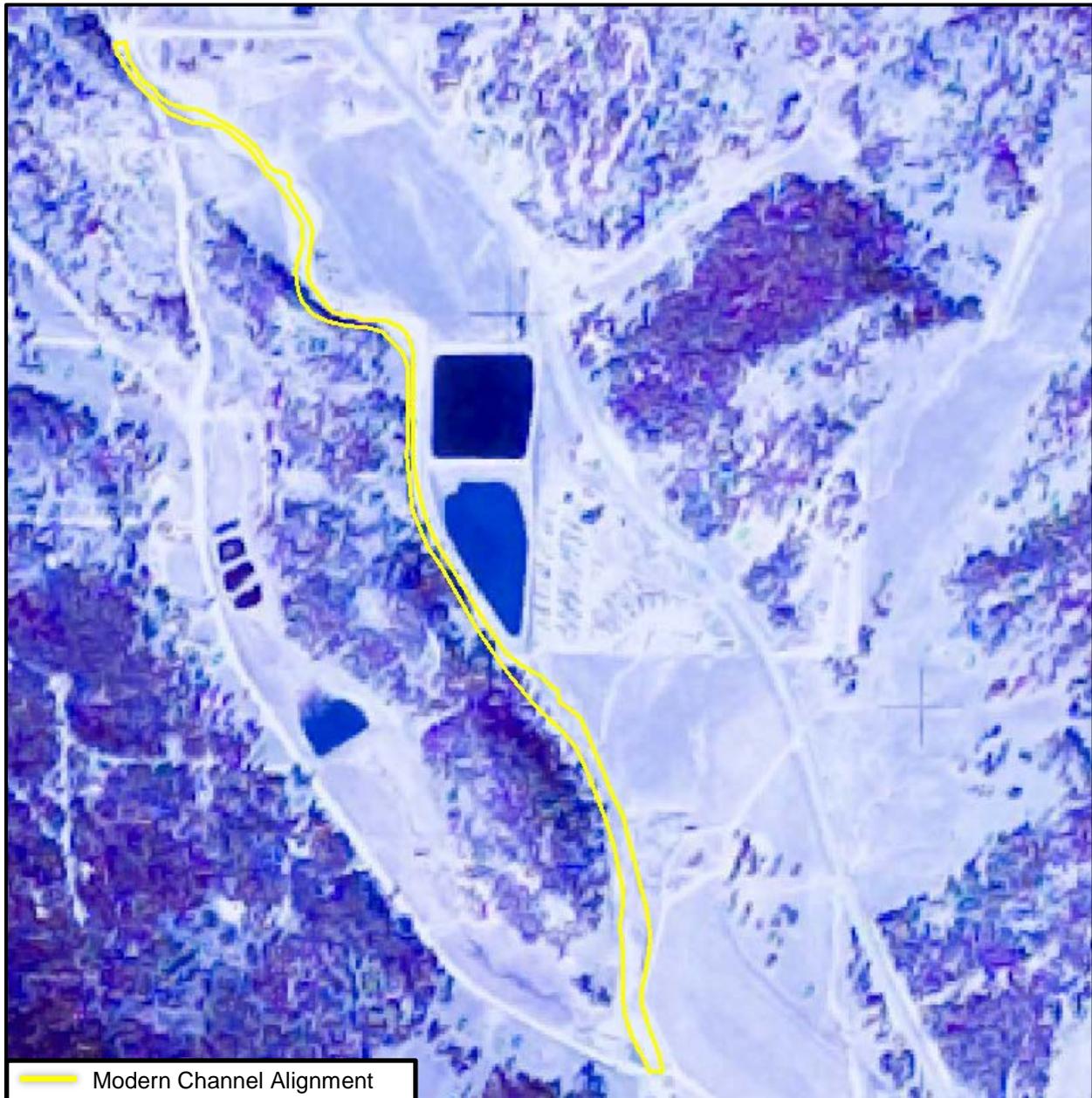
Figure 28   1971

3.1.4   1972

The aerial imagery from 1972 is similar to 1971 with no significant alterations in development and/or overall plan form.

Figure 29   1972

3.1.5 1988

The characteristics of the Study Reach based on this historic aerial imagery indicate the following:

- Low image resolution obscure interpretation
- Continued development of the river-left floodplain
- Possible construction of the Concrete plant
- Channel still wide in Concrete Plant Reach and narrow in Walmart Reach

Figure 30   1988

3.1.6 1999

The characteristics of the Study Reach based on this historic aerial imagery indicate the following:

- River-left reservoirs drained
- Concrete Plant encroaches on Concrete Plant Reach channel and constricts channel width
- Continued development of river-left floodplain
- Walmart Reach still has narrow channel
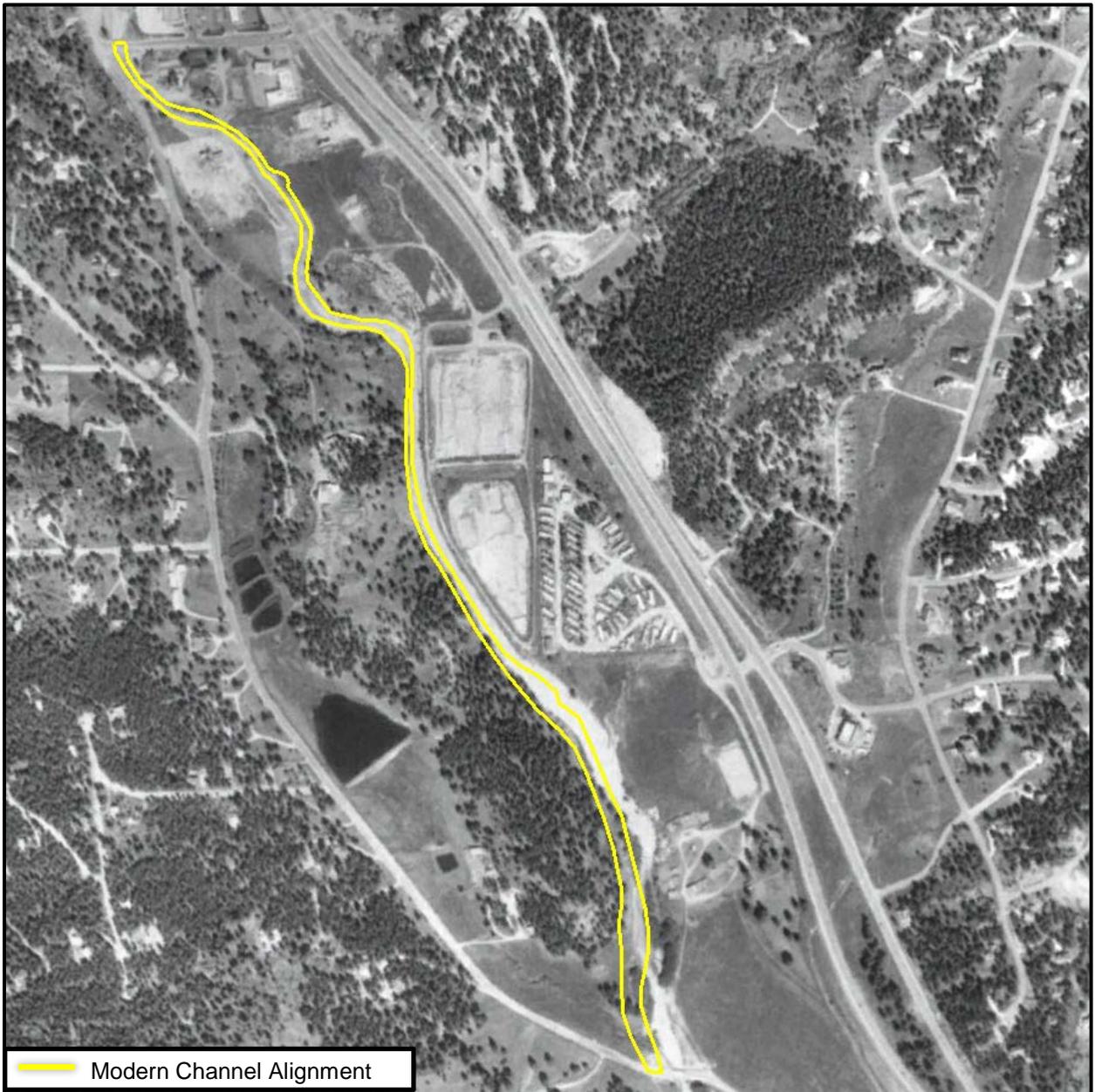
Source: Google Earth

Figure 31   1999

3.1.7 2003

The characteristics of the Study Reach based on this historic aerial imagery indicate the following:

■ Concrete Plant and Saddle Club Reaches attain modern morphology, while Walmart Reach remains narrow

Source: Google Earth

Figure 32   2003

3.1.8   2004

The characteristics of the Study Reach based on this historic aerial imagery indicate the following:

- Similar to 2003

- Concrete Plant and Saddle Club Reaches attain modern morphology, while Walmart Reach remains narrow
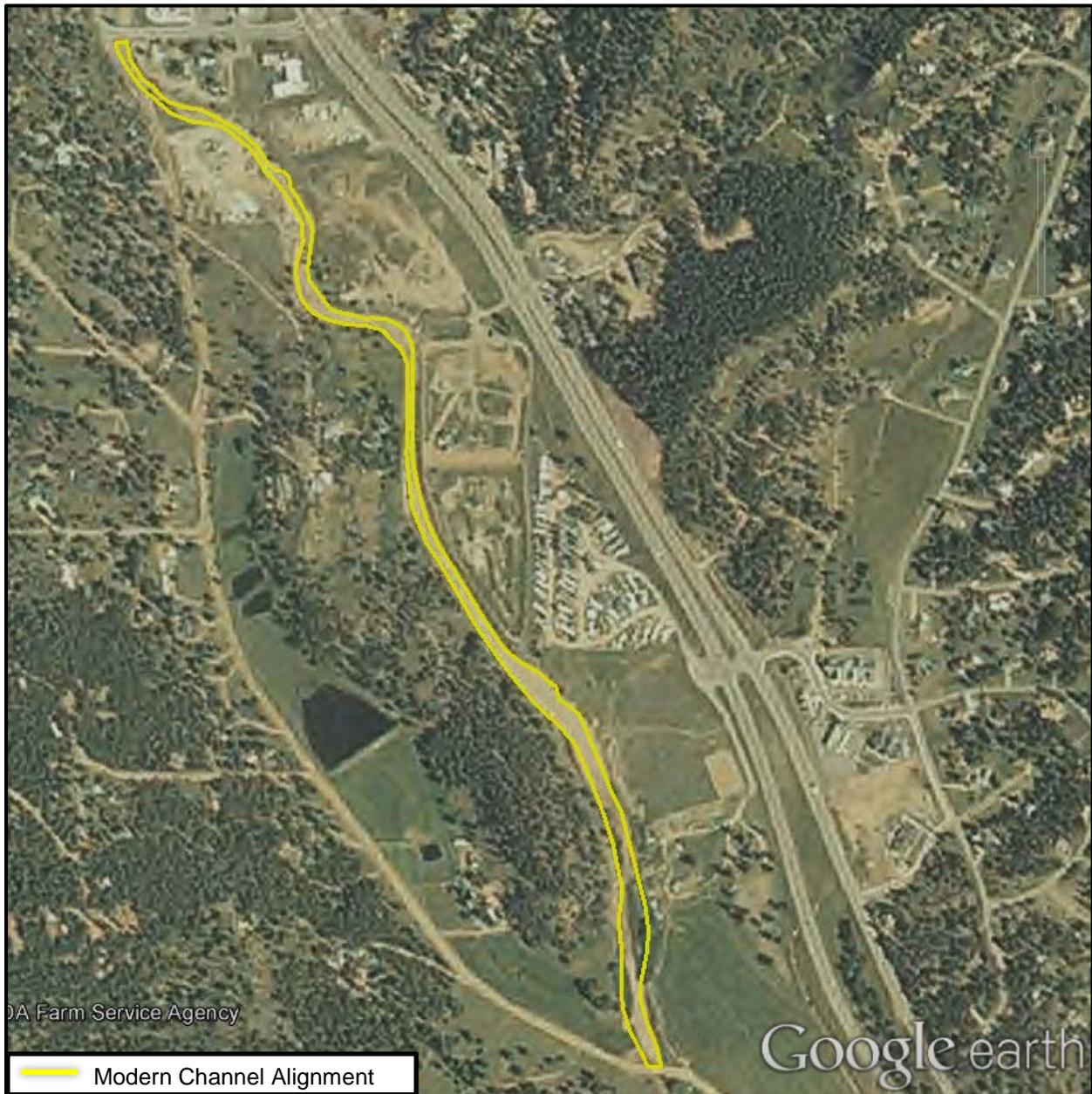
Source: Google Earth

Figure 33   2004

Source: Google Earth

Figure 34   2004

3.1.9   2005

The characteristics of the Study Reach based on this historic aerial imagery indicate the following:

- Similar to 2003 and 2004

- Concrete Plant and Saddle Club Reaches attain modern morphology, while Walmart Reach remains narrow
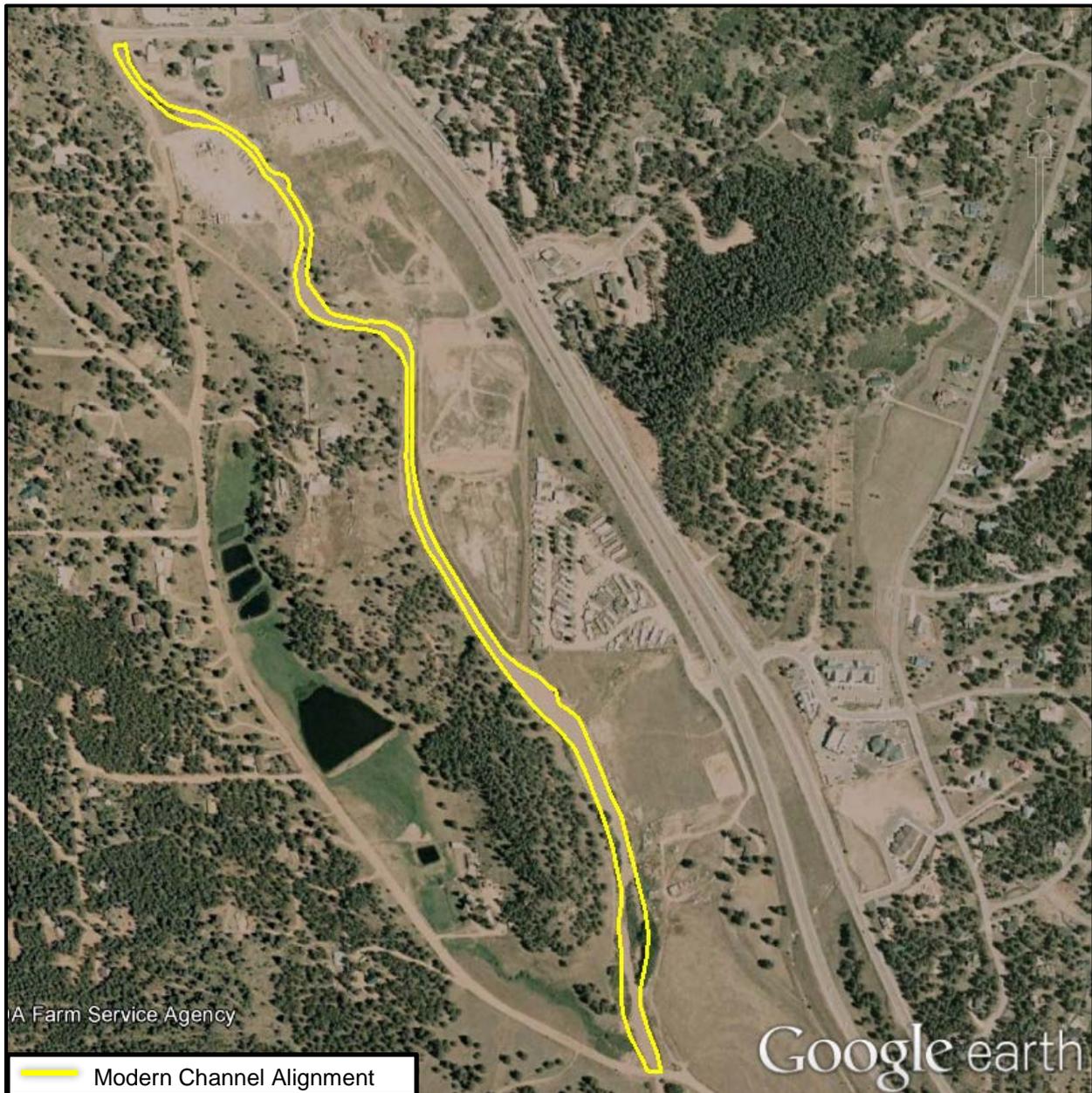
Source: Google Earth

Figure 35   2005

3.1.10 2011

The characteristics of the Study Reach based on this historic aerial imagery indicate the following:

- Channel has attained modern morphology

- The construction of the Walmart shopping center in the downstream portion of the Study Reach has likely resulted in the alteration of the channel banks and the widening of the channel

- Figure 37 and Figure 38 are both from the same source. Figure 37 includes overlays of other geographic information, including the source of the spring that feeds Spring Creek

Source: Google Earth

Figure 36   2011

Figure 37 USGS Topo Imagery 2011 Woodland Park Quad

Figure 38   USGS Topo Imagery Woodland Park, CO 2011

3.2   Hydrologic Setting

Although not directly observable in the preceding images, the urbanization and development of the watershed and growth of the Town of Woodland Park and the surrounding areas has resulted in an increased runoff coefficient that increases the rate at which water is delivered to the channel as the result of a precipitation event (Stogner 2000). Within the channel this has the effect of increased peak discharge rates, thereby increasing the sediment transport and erosive capacity of a given discharge event, which has had substantial consequences throughout the drainage.

While the occurrence of the increase in peak discharge within the Fountain Creek watershed over time due to urbanization has been well documented (Stogner 2000), the Study Reach is located in the upper portions of the watershed that are less developed than reaches further downstream. Additionally, much of the channel upstream of the Study Reach has been stabilized. This proximity to the headwaters of the drainage and the channel stabilization can potentially decrease the magnitude of the increased peak discharge trend that has been observed in the downstream reaches.

3.3   General Geomorphic Description

In the earliest photographic evidence (1953), Fountain Creek within the Study Reach has a wide multi-threaded sand bedded morphology with a floodplain present where ever the channel is not constrained by less erodible material. The intermittent discharge pattern of the Study Reach decreases the potential for vegetation to establish on the channel banks and bed, thereby decreasing bank cohesion and facilitating the formation of a wide multithreaded, sand bedded channel. The multiple channel threads are contained within the main channel, defined by a steep bank formed by floodplain sediments or less erodible material. The main channel dimensions are determined by the more erosion resistant bank material of the in situ sediments and the floodplain deposits. The banks of the main channel have substantially different characteristics from each other. The older, in situ sedimentary deposits and bedrock outcrop of the river-right bank, and the floodplain configuration and land use patterns on the river-left bank, interact with the river in fundamentally different patterns. Although, a small floodplain was present on the river-right side in the upstream reaches of the Study Reach in the earlier photographic images.

The river-right bank consists of older sedimentary material, likely deposited shortly after deglaciation approximately 10,000 years before present, for the majority of the Study Reach. However, a small outcrop of bedrock, of igneous origins, is present at the downstream most portion of the Study Reach immediately upstream of the confluence with Spring Creek and the Crystola Bridge. Only within the Concrete Plant Reach and for a small portion of the Reservoir Reach has there been historic fluvially deposited sediment on the river-right bank. For the rest of the Study Reach the river-right bank is essentially an erosional environment consisting of the deposited sediment that makes up the adjacent hillside. More recently, the river-right bank has been armored by construction material and debris. While it is likely that the in situ sediments served as a boundary for the river-right bank during the period of photographic record, once the encroachment of the river-left bank (discussed below) began, it is likely that the river ran closer to the river-right bank, resulting in more erosion and steepening of the bank. It is likely that this encroachment from the river-left, and consequent erosion of the river-right bank, took place sometime between 1954 and 1971. Within the Concrete Plant Reach the Concrete Plant was constructed sometime between 1988 and 1999, although it is possible that this took place earlier as the imagery from 1988 is inconclusive.

There have been significant changes in the land use patterns of the river-left bank that have likely had substantial influence on the channel morphology. Sometime between 1954 and 1971, the reservoir on the

river-left floodplain was constructed. It is likely that coincident with the construction of this reservoir that a large quantity of fill was placed on the river-left floodplain. This pattern is generally consistent across the time span of the historic aerial photographic record presented in this report.

3.3.1 Bankfull and Design Discharges

The two primary goals in assessing the discharge characteristics of the Study Reach are to determine the channel forming discharge and to determine a maximum discharge that the system is anticipated to withstand (stable channel system). The channel forming discharge, often referred to as the effective discharge and equated to the bankfull discharge, is that discharge that is thought to do the most geomorphic work. This discharge event will be large enough that it transports a significant quantity of sediment, but small enough such that it occurs frequently enough to be of significance. In practice, this discharge is often selected based on a recurrence interval analysis. The discharge corresponding to the 1 to 2.5 year discharge event is generally accepted as the design criteria for the bankfull channel, with the most commonly applied recurrence interval value for effective discharge being 2 years. The results from the research of Klasz et al. 2012 report that a value of 1.69 years is the most appropriate value to use when incorporating the influence of drainage area. For this investigation, the Draft Master Plan (Enginuity, 2015), Table 3-7 reports the results of the estimate discharge values for a range of return intervals, from 5 to 100 years. Golder has projected this relationship to smaller discharges based on the concept that this relationship has a y intercept of 0 discharge and 0 year, meaning that there are no years that have no discharge. While it is not impossible for Fountain Creek to remain dry through an entire wet season, Golder believes that this event is unlikely. Thus, the recurrence interval relationship, defined in the Master Plan (Enginuity, 2015) can be projected to the lower recurrence interval values. The results of this assessment are presented in Figure 39. Note that only the low recurrence interval discharge values are used from the Master Plan (2015), and that higher recurrence interval discharge values are sourced from FEMA modeling results (see Section 3.6).
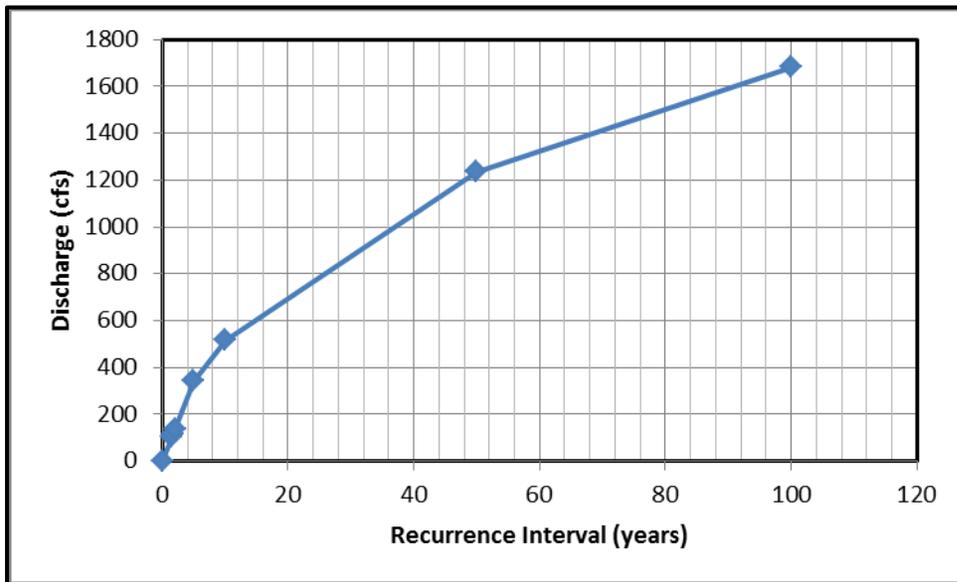
Based on Draft City of Woodland Park Stormwater Master Plan Jan. 2015

Figure 39   Recurrence Interval for Fountain Creek at Saddle Club Property

Based on the recurrence interval calculations presented in Figure 39, a discharge event with a 1.65-year recurrence interval would have a discharge of approximately 116 ft³/s. The implication of these discharge values to stable channel and infrastructure design are presented below.

3.3.2   Stream Gauge

Downstream from the Study Reach, the USGS operated a hydrometric station from 2001 to 2005. Although this period of record is not long enough to robustly assess the range of discharge values for a given recurrence interval, the record can provide other insight into the hydrology of Fountain Creek. The hydrograph for the period of record is presented in Figure 40.
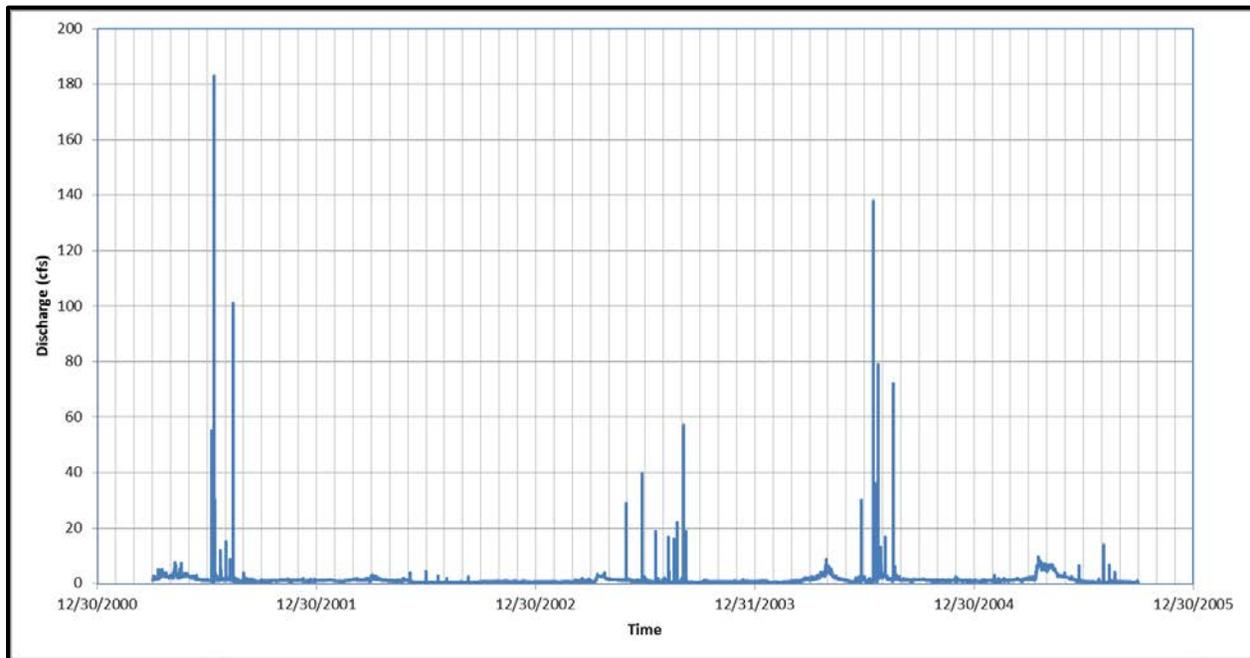
Figure 40   Hydrograph of USGS Station 07099990 Fountain Creek at Green Mountain Falls, CO

To compare the recurrence interval of the peak discharge events of each year of record to the recurrence interval curve presented in Section 3.3 the discharge values from the gauge are reduced proportionally by drainage area. The drainage area of the catchment at the gauge is 16.6 square miles according to the USGS website, and the drainage area at the Crystola Bridge is approximately 4.7 square miles according to a rough approximation of the drainage area in Google Earth. The correlation between drainage area and discharge is commonly represented as a linear relationship defined as:

$$Q = kA^c \tag{1}$$

In which Q is discharge (cms), k is a measure of the river base flow (m/s), A is the drainage area (m^2), and c is the scaling power dependency (*) (Glaster et al. 2006). In a simplifying approximation, k and c can be assumed to be equal to 1, and thus the discharges at the stream gauge can be scaled proportionately to the difference in drainage areas. The maximum discharge values at the gauge for each year, their drainage area proportionately scaled values and the recurrence interval of those scaled values are presented in ().

Table 1   **Scaled Discharges from Green Mountain Falls Gauge**

Year	Maximum Discharge for Each Year (cfs) at Green Mountain Falls Gauge (cfs)	Gauge Discharges Scaled Proportionately to the Drainage Area at Crystola Bridge (cfs)	Recurrence Interval of Scaled Discharges (years)
2001	183	50.6	0.7
2002	4.4	1.2	0.0
2003	57	15.8	0.2
2004	138	38.2	0.6
2005	14	3.9	0.1

Several conclusions can be drawn from the hydrograph at the Green Mountain Falls Gauge.

1. It is likely that none of the peak annual discharge values that occurred during the period of record resulted in discharges greater than the bankfull discharge at the Crystola Bridge.

2. Both the nival peak of the hydrograph associated with the annual snowmelt, and the storm hydrographs resulting from the winter precipitation events can be observed within the data set.

3. The high magnitude discharge events are more likely to be associated with the winter/spring storm events and not the snowmelt driven hydrograph peaks.

3.3.3 Existing Model Results

Based on the analysis present in the 100-year FEMA flood maps, which were last updated March of 2010, the Study Reach contains several of the cross sections modeled in the National Flood Insurance Program results. The results of the FEMA modeling and results of Golder calculations using this information are presented in Section 3.6.

3.3.4 Channel Slope

The channel slope was calculated using Google Earth and confirmed with available 2-foot contour interval topographic mapping. The profile tool was used to cut the channel profile presented in Figure 41. From this assessment, the average channel slope for the whole reach is 0.0283 or 2.83%. While sufficient for the level of analysis presented here, the slope value will need to be calculated using high precision survey data for design purposes.
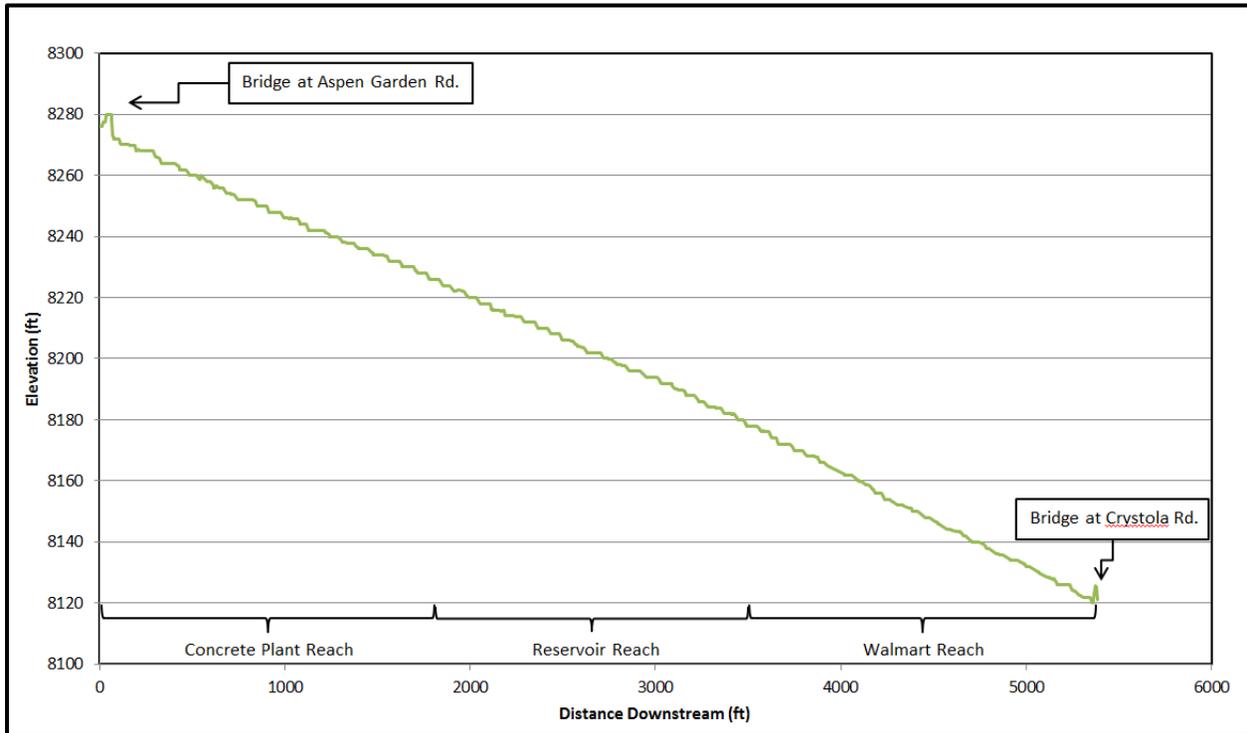
Figure 41   Channel Profile

3.3.5   Grain Size Distributions

From qualitative observation conducted during Golder's site visit, the material that composes the bed of the channel mostly consists of medium to coarse sand. For this assessment, Golder has assumed a median grain diameter of 0.001 m (or 1mm) for the bed material. Again, this parameter will need to be assessed more quantitatively for design purposes.

3.3.6   Channel Roughness

A channel roughness, in the form of a Manning's n value, is needed for the sediment transport and hydraulic assessments presented in the next section. Manning's n is an empirical variable that represents the roughness of the grains, the banks, the channel curvature, and the vegetation as a single value. The inclusion of all of these various materials into a single parameter, as well as the spatially variable roughness of the bed, banks, and overbank areas, makes selecting a value difficult. To represent the relatively low roughness of the sand bed without bedforms, the very rough various revetment features, and the lack of vegetation Golder has selected a value of 0.035 to represent the channel.

3.4   Sediment Transport

In this assessment, the sediment transport potential of Fountain Creek near the Saddle Club is presented for the 1.65-year discharge event. A simple approach that uses the Manning's equation, the continuity equation, the Shields criteria for the threshold of motion, and the Wong and Parker (2003) version of the

Meyer-Peter and Mueller equation is presented. This approach is based on some assumptions and approximations that will need to be refined before application of these principles to detailed design. The input parameters and the results of the applied equations are presented in Table 2.

3.4.1 Manning's and Continuity

The Manning's and the Continuity equations are simplified understandings of the relation of velocity to channel dimensions and bed roughness and the conservation of mass. When solved in relation to each other they provide a means of determining the flow depth and velocity, given a channel width, a total roughness, and a discharge.

Manning's equation takes the form of:

$$v = \frac{d^{2/3}S^{1/2}}{n} \tag{2}$$

In which v is the average velocity of the flowing water (m/s), d is the cross sectional averaged flow depth (m), S is the channel bed slope (m/m), and n is the Manning's roughness coefficient ($m^{-1/6}$).

The continuity equation takes the form of:

$$Q = vwd \tag{3}$$

In which Q is the discharge of channel (m³/s), v is the average velocity of the flowing water (m/s), and d is the cross sectional averaged flow depth (m).

The method for determining values for slope and roughness are presented in Sections 3.3.4 and 3.3.6. The method of determining the value for channel width is simply to take the average of multiple channel width from with the Saddle Club Reach via Google Earth. By setting the Manning's and continuity equations equal to each other they can be solved for bankfull flow. The results of this step in the assessment are presented in Table 2.

3.4.2 Shield's Threshold of Entrainment

Shield's (1936) seminal work on the threshold of sediment transport still stands as an effective method of assessing sediment transport potential. For this portion of our assessment, Golder has non-dimensionalized the Shear Stress at the bankfull flow for use in the sediment transport rate assessment in Section 3.4.3. This is accomplished via the following formulas:

$$\tau_b = \rho_w g dS \tag{4}$$

In which Tau (τ_b) is the boundary Shear Stress at bankfull flow (Pa), rho (ρ_w) is the density of water (1000 kg/m³), g is the acceleration due to gravity (9.81 m/s²), d is the cross sectional averaged flow depth, and S is the bed slope. This results in a boundary Shear Stress value of 53.5 Pa. This value is then non-dimensionalized via the following equation:

$$\tau^* = \frac{\tau}{(\rho_s - \rho_w)gD} \qquad (5)$$

In which Tau (τ^*) is dimensionless Shear Stress, rho (ρ_s) is the density of continental crust (2650 kg/m³), and D is the median grain diameter of the bed sediment (m). The result of this calculation is a dimensionless Shear Stress value of 3.3. This value is then used in the next section to determine a sediment transport rate for the bankfull flow condition.

3.4.3 Meyer-Peter and Müller by Wong and Parker (2003)

Wong and Parker (2003) reassessed the original Meyer-Peter and Müller (1948) equation defining bed material load sediment transport rate. The equation is a threshold – power law equation that uses a critical Shear Stress value to define the threshold of motion of the particle. For this investigation we have applied the Wong and Parker (2003) recommended value of 0.0495 for critical dimensionless Shear Stress (τ^*_{crit}). Their version of the equation takes the form:

$$q_b^* = 3.97(\tau^* - \tau^*_{crit})^{3/2} \qquad (6)$$

In which q_b^* is the specific dimensionless volumetric bed material load sediment transport rate. This value is then dimensionalized via the following equation:

$$q_b = q_b^* D\sqrt{1.65gD}$$

$$(7)$$

In which q_b is the specific dimensional volumetric bed material load sediment transport rate in m³/s. This value is then integrated by the channel width via the following equation:

$$Q_b = q_b w \qquad (8)$$

In which w is the bankfull channel width (m). Thus, Q_b is the volumetric bed material load sediment transport rate in m³/s. This parameter is also presented as mass per time and at different time scales in Table 2.

3.5 Suspended Sediment

The transport of a particle via bed load or in suspension can be assessed based on the ratio of the rate at which a particle settles through the water, and the turbulent forces within the flow. Quantitatively this ratio

is assessed by comparing the settling velocity of a particle to the shear velocity of the flow. The settling velocity is calculated using a relationship defined by Dietrich (1982). This relationship was applied via the use of a spreadsheet tool developed by Gary Parker. The tool is available at: http://hydrolab.illinois.edu/people/parkerg/excel_files.htm.

The shear velocity is defined by the following formula:

$$u^* = \sqrt{\frac{\tau}{\rho_w}} \tag{9}$$

The result of this calculation indicates that the particle in suspension at bankfull flow is likely to be 1.6 mm in diameter. As the median particle diameter present on the bed is estimated to be within this range it is possible that a large portion of the material present on the bed moves in suspension during bankfull flow. It is also possible that this material is re-deposited on the falling limb of the runoff hydrograph. During the site visit, Golder observed that the bed largely consisted of transportable medium sand. Given the recent high magnitude discharge events and the erosion from the reach upstream of the Study Reach, the presence of this mobile sediment indicates that sediment transport occurs with relatively high frequency and that more sediment is delivered to the channel than it can transport.

3.5.1 Discussion of Sediment Transport Calculations

The results presented in Table 2 are a capacity based sediment transport estimate. This means that the rate of sediment transport is based on several primary concepts, and is thereby constrained by the associated assumptions. These concepts and their limits are as follows:

1. Only bed material load is assessed in this process. Bed material load is defined as those particles that will, at some point in their passage through the fluvial system, come to rest on the bed of the river. Essentially this means that bed material load is equal to total load minus the wash load and the dissolved load.

2. The quantity of material estimated is based on the ability of flowing water to move sediment and not on the rate at which sediment is delivered to the channel for transport. In this analysis, the effective discharge has been defined by the discharge of a 1.69-year recurrence interval storm event. The cumulative sediment transport results presented in Table 2 are the result of a constant discharge of 2.91 m³/s (103 cfs) occurring for the duration defined by the recurrence interval of the storm event. In arid environments, and especially in ephemeral or intermittent streams, the quantity of sediment delivered to the channel can be greater than the ability of the flowing water to transport the sediment. Golder believes this may be the case in the Study Reach as the bed is composed almost entirely of sand sized particles. Thus, the use of the magnitude and the recurrence interval of the bankfull discharge may not be the correct approach. The small grain size distribution of the material on the bed indicates that a large portion of this material will likely move in suspension during bankfull flow conditions.

Table 2   **Sediment Transport**

Variable	Parameter Name	Metric	Unit	Standard	Unit
Qbf	Bankfull Discharge	2.91	m³/s	102.6	ft³/s
v	Velocity	1.60	m/s	5.2	ft/s
d	Width Averaged Bankfull Flow Depth	0.19	m	0.62	ft
w	Bankfull Width	9.41	m	30.5	ft
S	Bed Slope	0.0283	*	-	-
n	Manning's Roughness Coefficient	0.035	$m^{-1/6}$	-	-
rho w	Density of Water	1000	kg/m³	62.4	lbs/ft³
rho s	Density of Rock	2650	kg/m³	165.4	lbs/ft³
g	Acceleration due to Gravity	9.807	m/s²	32.17	ft/s²
Tau	Shear Stress	53.47	Pa	1.1167	lbs/ft^2
Tau*	Dimensionless Shear Stress	3.30	*		
SP	Stream Power	0.10	kW/m^2		
D50	Median Particle Diameter	0.001	m	0.0032	ft
u*	Shear Velocity	0.23	m/s	0.76	ft/s
d_{sus}	Diameter of Particle at Threshold of Suspension	0.0016	m	0.00513	ft
q*b	Specific Dimensionless Volumetric Bed Material Load Sediment Transport Rate	23.31	*		
Tau*$_{crit}$	Critical Shear Stress	0.0495	*		
q_b	Specific Dimensional Volumetric Bed Material Load Sediment Transport Rate	0.003	m³/s	0.10	ft³/s
Q_b	Total Dimensional Volumetric Bed Material Load Sediment Transport Rate	0.028	m³/s	0.99	ft³/s
s/day	Seconds Per Day	86400	s		
t	Days of Transport Per Year	0.67	days		
Q_b	Total Dimensional Volumetric Bed Material Load Sediment Transport Rate	1607	m³/year	56742	ft³/year
Q_b	Total Dimensional Volumetric Bed Material Load Sediment Transport Rate	4.26×10^6	kg/year	9.39×10^6	lbs/year

Golder Associates

3.6   FEMA 100-year Flood Analysis Assessment

In Figure 42 the plan view map of the FEMA 100-year discharge event flood map is presented. Golder did not used the published discharge values from this study to assess the hydraulic conditions of the 100-year recurrence interval flood and the stability of the channel during this discharge, but instead used those presented in the Master Plan (2015). The published results from the Master Plan and those of Golder analysis are presented in Table 3. The discharge values from the FEMA report have been adjusted proportionately to the discharge values from the Master Plan. The cross sections were assessed in a similar fashion, the results of this assessment are presented in Sections 3.4 and 3.5. However, instead of assessing the sediment transport capacity of a single point in the channel at multiple discharges, as we presented in the previous sections, these data are assessed for their potential to erode at the 100-year flood event.
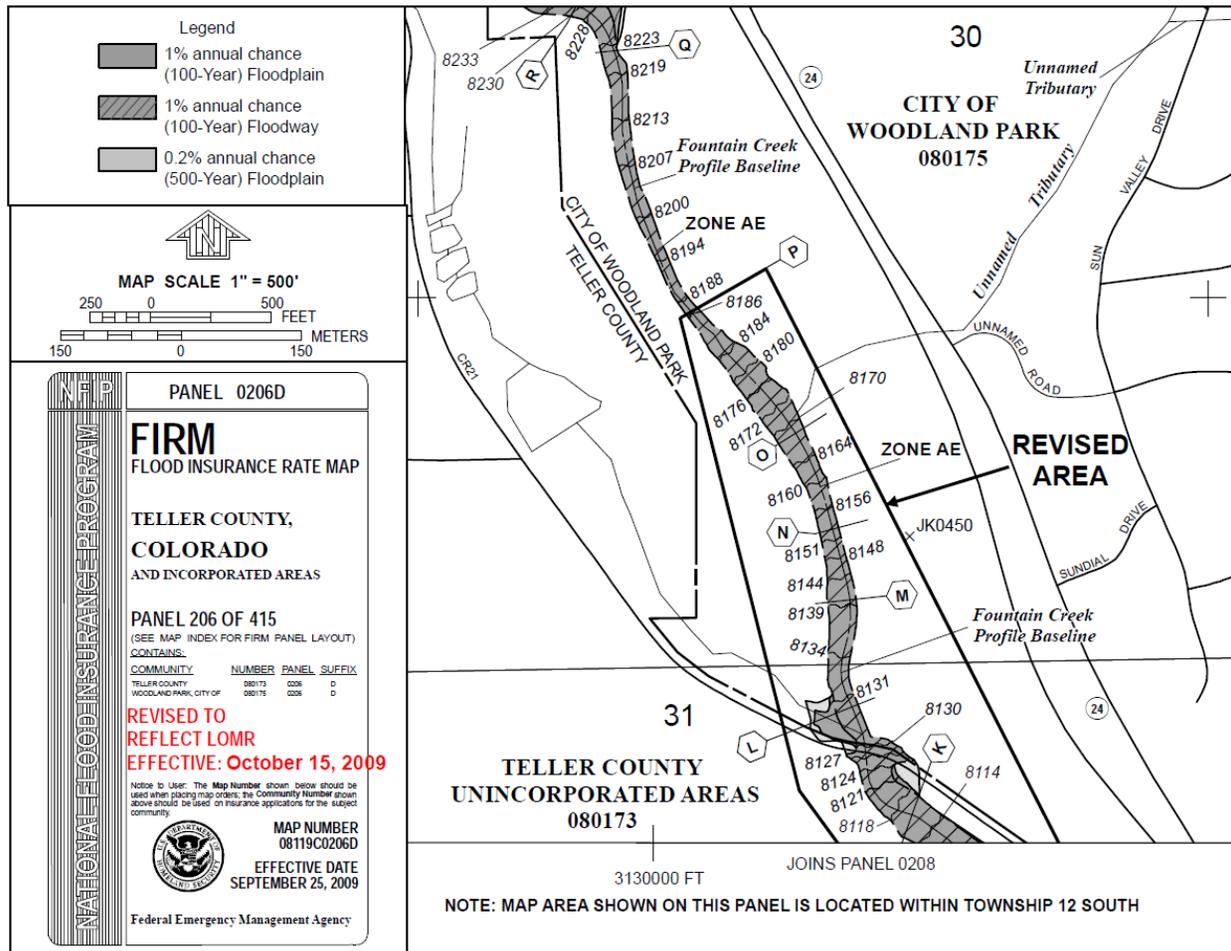
Figure 42   FEMA Q100 Flood Mapping

Similarly to the bankfull flow calculations, the 100-year discharge was assessed for shear stress on the bed. Table 3 reports these values.

Table 3   Hydraulic Properties of the 100-year flood

Cross Section	Distance	Distance	W	W	d	d	V	V	Qw	Qw	Slope	Shear Stress	Shear Velocity	Tau*	d sus	q*b	qb	Qb	Qb	Qb	Stream Power
	ft	m	ft	m	ft	m	ft/s	m/s	cfs	cms	*	Pa	m/s	*	m	*	m³/s	m³/s	m³/year	kg/year	kW/m²
K	7600	2340.8	183	56.4	2.3	0.7	8.6	3.8	2391.4	67.7	0.0237	165	0.406	10.2	0.003	128	0.016	0.92	47033	1.25E+08	0.53
L	8150	2510.2	69	21.3	8.3	2.5	6.3	9.0	2370.3	67.1	0.0249	623	0.789	38.5	0.011	946	0.120	2.56	130729	3.46E+08	3.86
M	8600	2648.8	119	36.7	3.1	0.9	9.8	4.6	2363.7	66.9	0.0200	186	0.431	11.5	0.004	153	0.020	0.72	36587	9.70E+07	0.63
N	8900	2741.2	80	24.6	4.0	1.2	11.0	5.5	2305.0	65.3	0.0430	516	0.719	31.9	0.009	714	0.091	2.24	114402	3.03E+08	2.91
O	9325	2872.1	122	37.6	3.0	0.9	9.8	4.6	2376.2	67.3	0.0386	352	0.593	21.7	0.006	401	0.051	1.92	97934	2.60E+08	1.64
P	10000	3080.0	54	16.6	4.1	1.3	11.4	5.7	1683.0	47.7	0.0262	329	0.573	20.3	0.006	362	0.046	0.77	39150	1.04E+08	1.48
Q	11150	3434.2	54	16.6	4.1	1.3	11.5	5.6	1682.3	47.6	0.0313	389	0.624	24.0	0.007	466	0.059	0.99	50413	1.34E+08	1.90
R	11450	3526.6	64	19.7	2.2	0.7	12.0	3.6	1681.0	47.6	0.0270	175	0.419	10.8	0.003	140	0.018	0.35	18009	4.77E+07	0.58

3.7   Channel Stability

Channel stability is determined by the ratio of the erosive capacity of the flowing water relative to the ability of the material that makes up the bank to resist erosion. Two methods were used to assess the ability of the bank material to resist erosion. These results were then compared to the erosive capacity of the bank full flow and the 100-year flood event.

The ability of the bank material to resist erosion is assessed via two methods. The first relies on published velocities at the threshold of erosion from Etcheverry (1915). The second relies on the erodibility index method developed by Annandale (2006). The erodibility index is a semi-empirical index method that uses the physical properties of an earth material to assess its ability to resist erosion. A robust presentation of the erodibility index method is beyond the scope of this report. However, the input variables and the formulas used to determine their ability to resist erosion are presented below. Table 4 summarizes the results from both these methods.

The erodibility index method assesses four primary parameters to determine the erosion resistance capacity of an earth material. Broadly, these parameters are the strength of material (M_s), the size of the block or particle of the material (K_b), the strength of the interparticle bonds (K_d), and the orientation of the discontinuities of the material relative to the hydraulic forces driving erosion (J_s). Many of these parameters are designed for use in fracture rock and are not directly applicable to cohesive granular material, thus the values of block size and discontinuity orientation are set to unity. These parameters are converted to an index value via the following equation.

$$K_h = M_s * K_b * K_d * J_s \qquad (10)$$

Where K_h is the index value of the erosion threshold. This index value is converted to a critical stream power via the following equation.

$$SP_{crit} = K_h^{0.75} \qquad (11)$$

In which SP_{crit} is the stream power at which the earth material will erode.

The calculation of the hydraulic forces applied to these earth materials at the bankfull flow and the 100-year flood are calculated via the following equations.

$$SP = 7.853 \left(\frac{\left(\tau^{3/2} \right)}{\sqrt{\rho}} \right) \qquad (12)$$

The results of these calculations are presented in Table 4. From these results, it is apparent that both the bankfull flow and the 100-year discharge are capable of eroding the bank material, with only the strongest estimate of the ability of the material to resist erosion, from the high estimate of the Annandale method, potentially being able to resist erosion at the bankfull discharge.

Table 4   Erodibility – Stream Power (kW/m²)

Qbf	Q100 (Max)	Etcheverry (1915)		Annandale (2006)	
		low	high	low	high
0.10	1.26	0.01	0.02	0.07	0.14

4.0 REMEDIAL RECOMMENDATIONS

The remediation approach presented herein prioritizes the stability of the landscape and the community interaction with the open space. Golder presents a range of alternatives to facilitate future design decision making. Golder also recommends that significant effort be invested in clearly and transparently communicating with stakeholders and interested parties so that attainable project goals can be defined and specific steps towards achieving those goals can be put into action.

The initial design decision to be made will be to determine channel form. To this end, we have developed three (3) channel geometry alternatives as described below:

- Alternative 1: Widening of the existing channel at its current gradient and including engineered bank protection
- Alternative 2: Raising the channel with drop structures
- Alternative 3: Controlling the channel incision with grade control structures

Regardless of which alternative is ultimately selected, there are some design recommendations that are common to all of the alternatives.

4.1 Channel Geometry

Only a limited portion of the Study Reach can have these remedial elements applied to it (Figure 45 and Figure 46). At the upstream end of the site, the widening of the channel and flood plain can be applied starting at the approximate middle of the mender bend containing the Concrete Plant and continuing downstream until the downstream end of the former reservoir. Upstream of the Concrete Plant, bank protection will likely have to be applied to minimize the ongoing erosion. Downstream of the widened reach Golder recommends that the post-remedial design conditions be assessed with an appropriate hydraulic model, but at this time, no remedial measures are recommended for the Walmart Reach.

4.1.1 Without Drop Structures

This channel geometry alternative involves the widening of the existing channel at the current grade, and the addition of a floodplain. The inset channel is designed to contain the bankfull flow, while the floodplain is sized to convey the 100-year flood event. These features will be carved out of the existing terrain and will likely not require any fill material. Both the banks of the inset channel and the larger floodplain will need to be supported by stabilized banks. The primary advantages of this alternative are the low cost and minimum construction material needed. Additionally, keeping the channel at the existing grade and widening it, will ensure that discharges larger than the 100-year flood can be contained within the channel. The disadvantages of this alternative are that it will likely make a larger portion of the landscape less accessible to the public and adjacent developments, and further isolate the river from the community.

A cross section depicting the geometry of the designed channel within the Concrete Plant and Saddle Club Reaches, as well as a plan view depiction of the area to be widened are presented in Figure 44.

Figure 43   Channel Cross-Section Locations
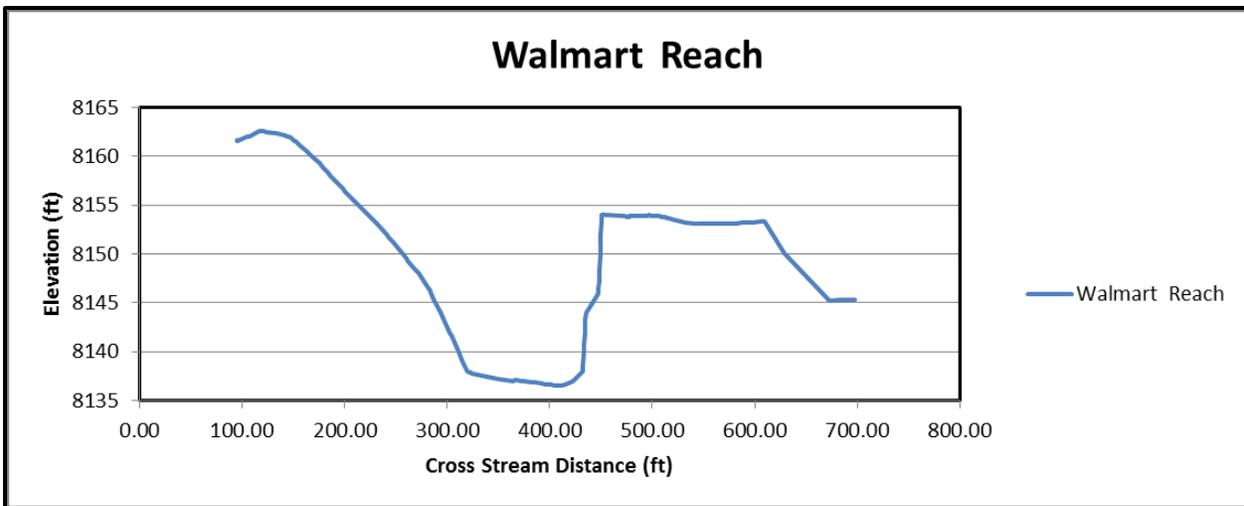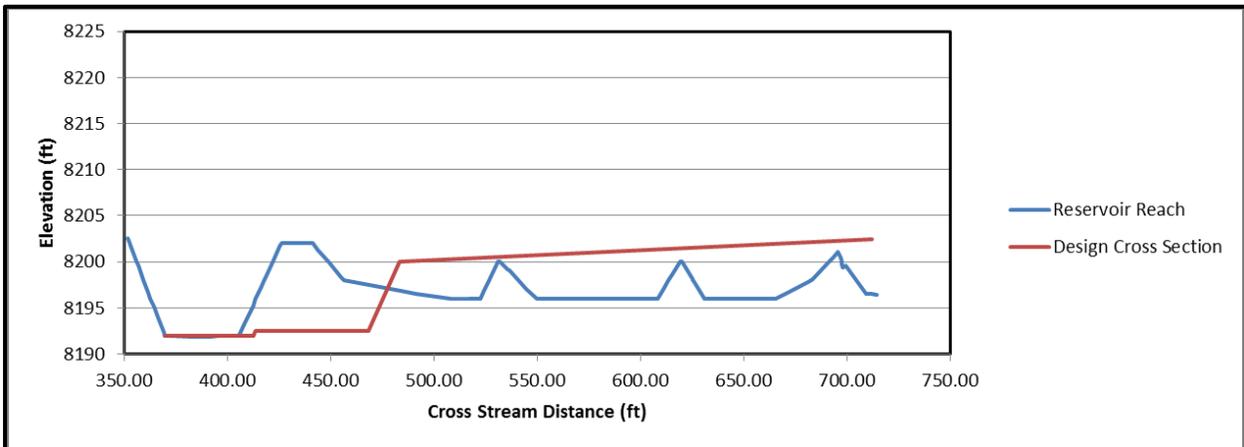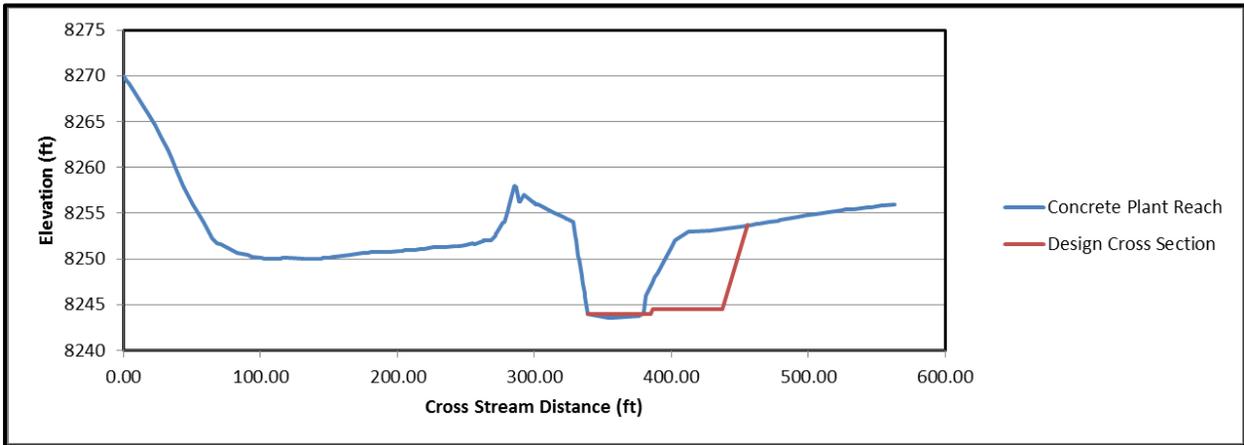
Figure 44   Cross Sections and Proposed Design Surface; View Looking Upstream

Modern Channel Alignment
Set Back Alignment
Cross Sections

Note: Locations and dimensions are preliminary.

Figure 45   Portion of Channel to be Widened Indicated in Red; with Drop Structures

This design alternative proposes to decrease the gradient of the channel within the widened reach through the construction of drop structures (Figure 46, Figure 47, Figure 48, and Figure 49). The installation of up to six drop structures will control the channel gradient, minimize erosion, and bring the

river level within the remediated reach up to the same level as the rest of the surrounding valley floor. This channel geometry alternative likely represents the most stable and costliest design alternative.

Note: Locations and dimensions are preliminary.
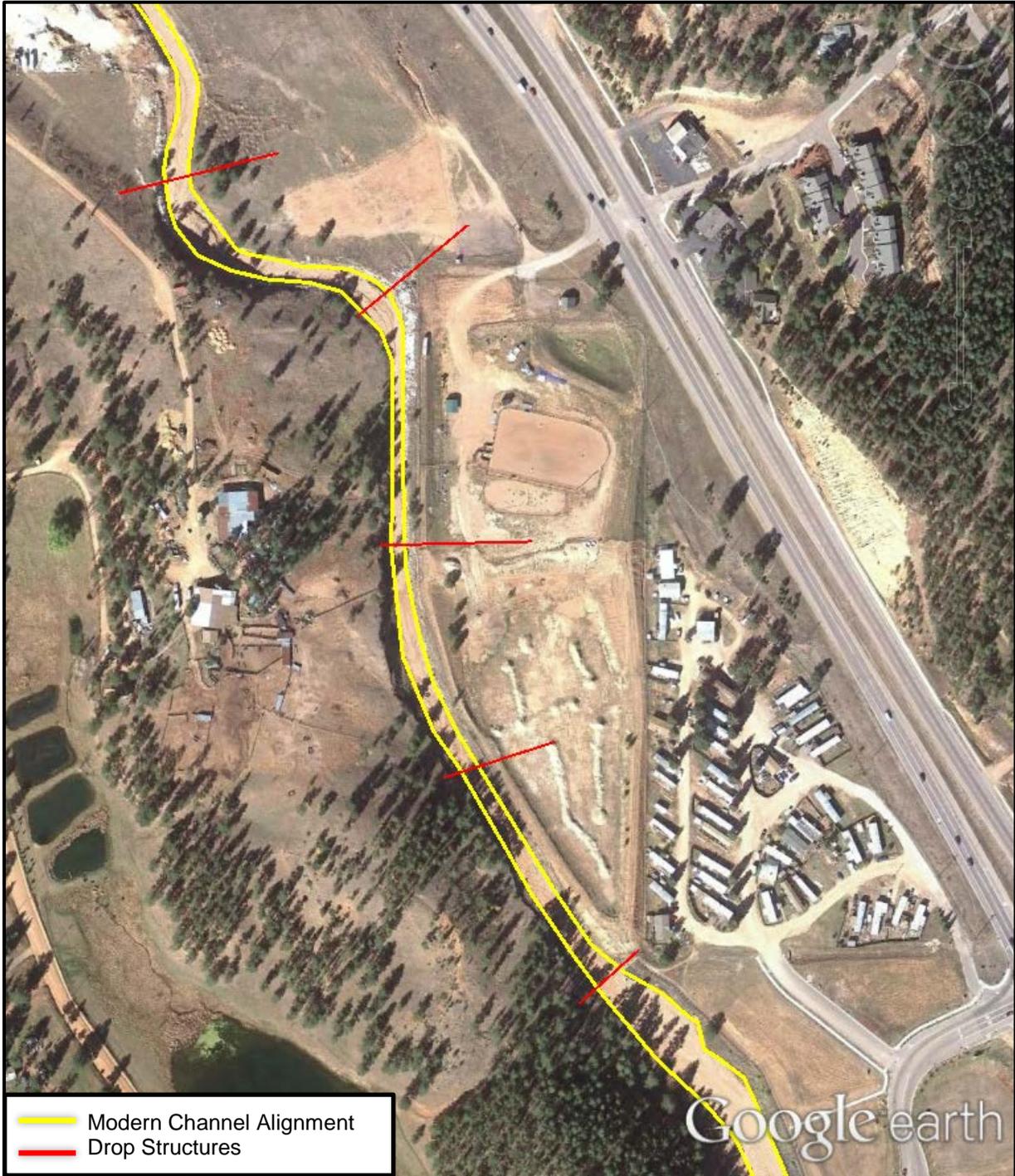
Figure 46   Drop Structures
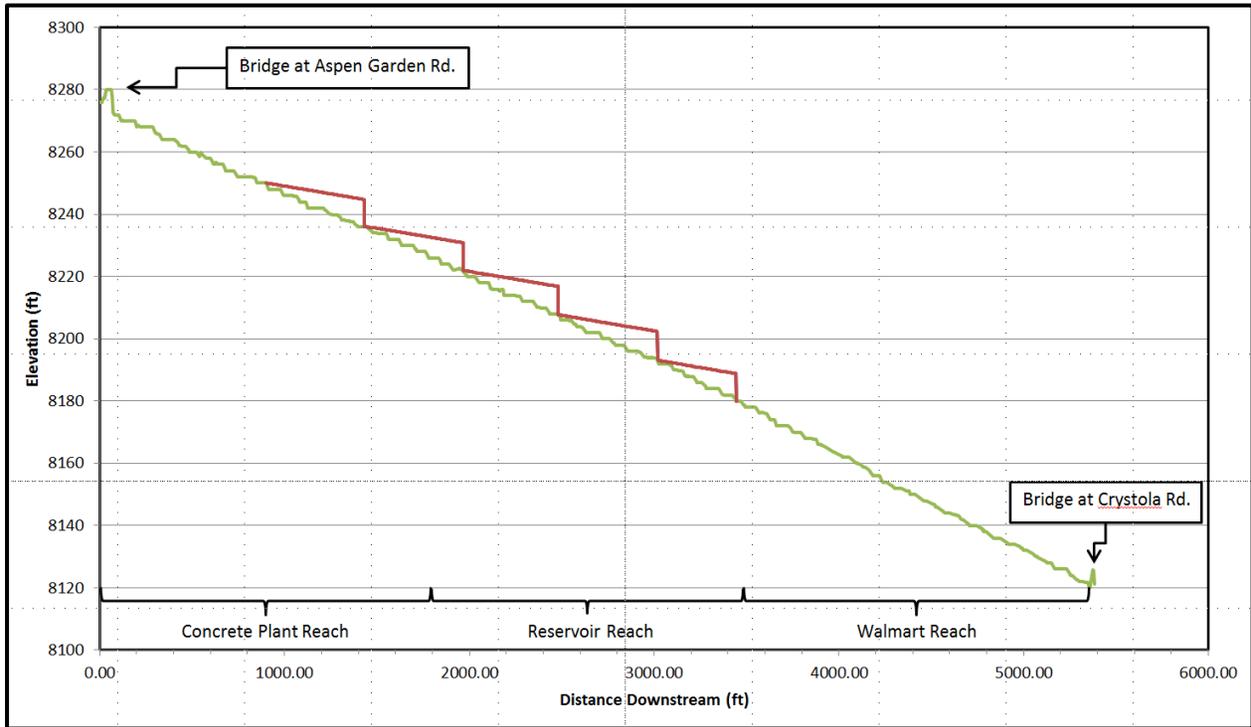
Note: Locations and dimensions of drop structures are preliminary.

Figure 47   Drop Structures Relative to Study Reach Channel Profile
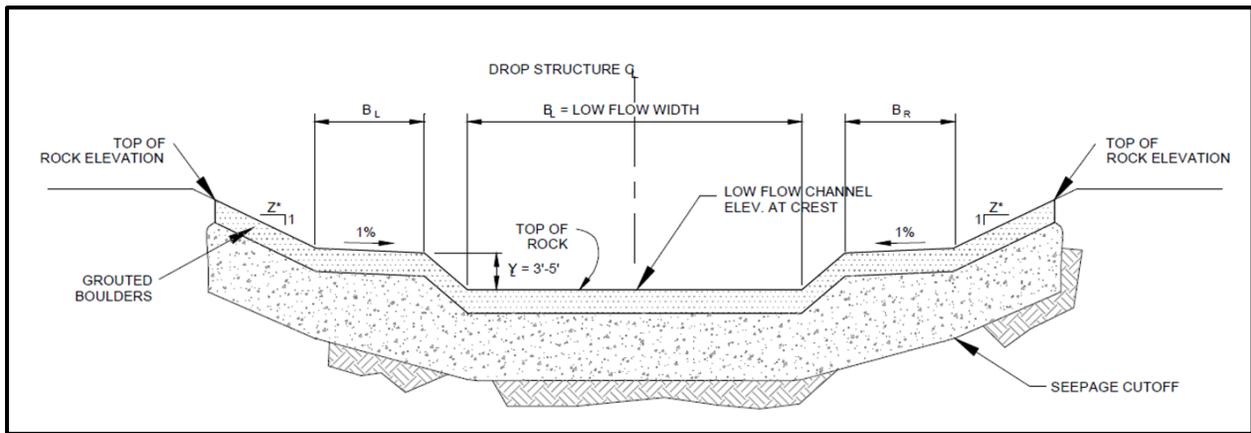
Source: CFSCM 2008.

Figure 48   Sketch of Proposed Drop Structure Cross Section at Crest
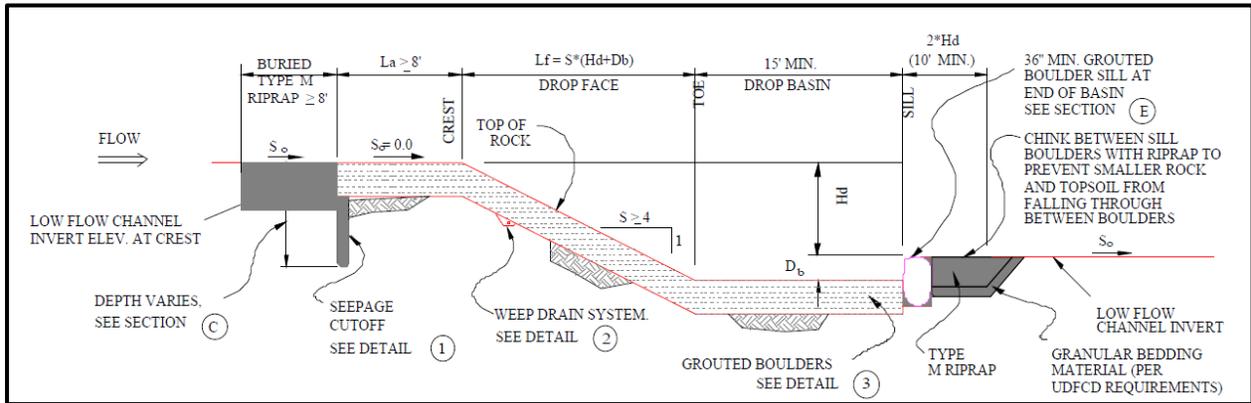
Flow is from Left to Right.

Figure 49   Drop Structure Schematic in Profile

4.1.2   Grade Control Alternative

The third alternative channel geometry that Golder proposes is an optimized design that combines features of the first and second alternatives. The exact specifications and prescribed elements will need to be determined for their ability to meet project goals, but the overall plan is to incorporate those elements of bank stabilization and gradient control that employ grade control structures as opposed to drop structures. It is likely that grade control structures could be used in combination with bank protection to achieve similar results to those of the other alternative approaches.

4.2   Revetment Removal and Re-design

For most of Study Reach from Aspen Garden Bridge to the top of the Walmart Reach, the banks and especially the toe of the banks have been lined with un-designed revetment material. This intention in placing this material was undoubtedly to protect the banks of the channel from further erosion. The material consists of construction debris, waste rock, left over concrete, old tires, car bodies, and an assortment of other items. While well intentioned, the placement of these materials in a haphazard fashion has resulted in insufficient erosion protection and a public eyesore. Golder recommends the complete removal and redesign of all of the bank protection and erosion revetment present between Aspen Garden Bridge and the downstream end of the Saddle Club Reach.

While in most river restoration plans vegetation is incorporated into the remediation plan to enhance stabilization efforts and aesthetics, the arid environment and the intermittent water regime make relying on vegetation as an erosion prevention mechanism impossible. To compensate for the lack of applicable bioremediation techniques, Golder proposes to implement standard bank protection measures in the form of a riprapped bank (Figure 50).
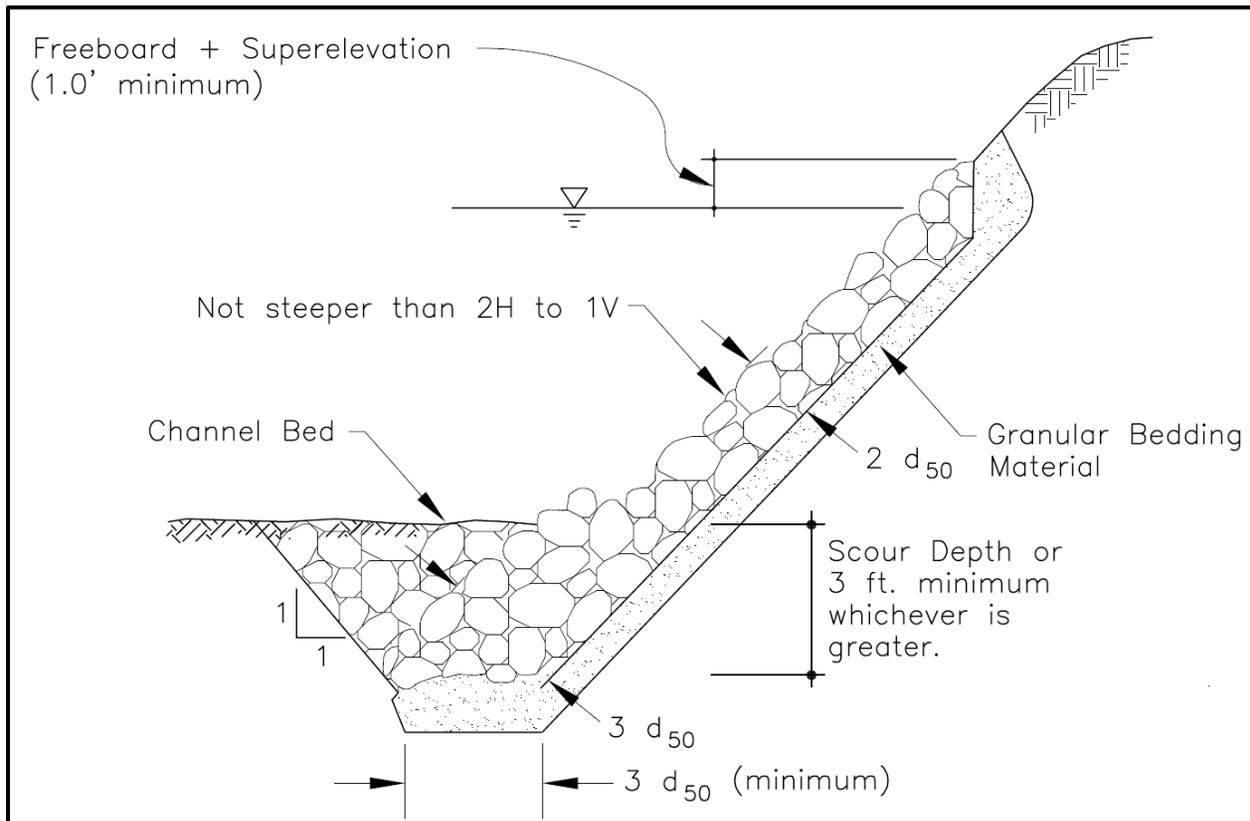
Source: CFSCM 2008.

Figure 50   Sketch of Proposed Riprapped Bank Protection

4.3   Tributary Confluences

In the modern configuration, three unnamed tributaries join the main stem of Fountain Creek from the river-left within the Study Reach. The first joins at the upstream end of the Saddle Club Reach at a heavily protected culvert outfall (see Figure 13). The second joins the river via the outlet works of the former reservoir (see Figure 18) and the third joins immediately downstream of the second via a grouted culvert (see Figure 19).

Golder does not recommend any changes to the tributary inlet works associated with confluence #3. The inlet works at confluence #2 should be assessed relative to the larger design decisions associated with the use of drop structures. The absence of drop structures may facilitate minimal alteration to the second confluence. Confluence #1 will have to be redesigned regardless of which design alternative is selected. Golder recommends that the confluence channels #1 and #2 be designed to include an outlet at the edge of the remediated area such that they enter the floodplain as open channels. These outlet works may require energy dissipating structures at the point of entry onto the floodplain. These channels should traverse the floodplain in designed channels that incorporate erosion protection and then join the main stem at an equally protected but still open channel confluence.

4.4 Recommendations for Final Design

All of the elements proposed within this report will need to be re-assessed with an appropriate hydraulic model to ensure that no increases in regulatory Base Flood Elevations (BFE) occur and that sufficient erosion protection and conformity to the pertinent hydrologic regulations is maintained. A Conditional Letter of Map Revision (CLOMR) will likely be required for any stream stability improvements.

In this report, Golder is not recommending that any changes be made to the Walmart Reach. However, we do recommend that the conditions in the Walmart Reach be assessed with a two-dimensional hydraulic model, as the changes to the upstream reach may influence this portion of the channel.

4.5 Recreational Trail

Golder recommends that a recreation trail be incorporated into these remedial works. The trail would be an extension of the existing trail upstream of Aspen Garden Way and will need to provide safe passage for recreational users, while also not interfering with the hydrology of the floodplain. Alternative 1 provides an opportunity to incorporate this trail onto the raised overbank/floodplain area that would be created. In addition, this area could be used for stormwater and water quality features that may be incorporated into future development within the Study Reach.

4.6 Implementation Cost Estimation

A cost estimate of the three alternatives is presented in Table 5. The cost alternatives presented here are based on preliminary construction volumes.

Table 5   **Alternatives Cost Estimate**

Reach	Alternative 1 Channel Setback	Alternative 2 Drop Structures	Alternative 3 Grade Control Structures
1	$681,240	$789,375	$458,220
2	$946,915	$782,085	$511,275
3	$33,275	$33,275	$33,275
Totals	**$1,661,430**	**$1,604,735**	**$1,002,770**

4.7 Recommendation Summary

Based on the evaluations undertaken, Golder recommends that the Alternative 1 (Combination of Stabilization and Channel Setback) be pursued for implementation as part of the overall Master Plan.

In addition, the modifications should include the following:

- To be incorporated into all alternatives:
  - Remove all un-designed revetment material.
  - Design revetment elements and install where appropriate.
    - Re-use existing material when suitable
    - Size revetment material using a 2D hydraulic model
    - Assess whether the use of grout between riprap clast is needed
  - Include recreational trail
    - Either within floodplain or outside of remediated area
    - Choose pathway construction material relative to location and hydraulics.
  - Incorporate tributary confluences into remedial plan
  - Use a 2D hydraulic model to assess design conditions for erosion potential.
  - Tie remedial works into the upstream end of the Walmart Reach
- Channel geometry alternatives
  - Without drop structures
    - Inset channel and floodplain, or just wide inset channel.
    - Substantial bank protection
  - With drop structures
    - Inset channel and floodplain, or just wide inset channel.
    - Less bank protection than without the drop structures, but still substantial
  - With grade control structures
    - This alternative will likely involve the use of grade control structure that are similar to drop structures, but will be constructed at the existing gradient, as well as substantial bank protection elements.

5.0 CLOSING

This geomorphologic assessment of Fountain Creek has been developed as part of the preparation of the overall Town of Woodland Park Stormwater Master and Capital Improvement Plan.

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APPENDIX A
CALCULATIONS

									From Sheet Vs_versus_D: settling velocity versus grain diameter
	0.308	m per foot							
	0.092903	feet squared to m squared							$y = 0.0152x^3 - 0.0014x^2 + 0.0061x + 4E-05$
rho w	1000	kg/m^3	density of water						0.0152 0.0014 0.0061 4.00E-05
rho s	2650	kg/m^3	density of rock						d = the grain size that is at the threshold of suspension based on the population (m)
g	9.81	m/s^2	acceleration due to gravity						
ks	0.15	m	Assumed roughness height						
D50	0.001	m							
Tau*crit	0.0495	*							
s in 7 hour	25200	s							
s/day	86400	s							
days of tra	0.59	d							

Cross section	Floodway												Base Flood Water Surface Elevation (feet NVAD88)																	Stream Power
	Distance	Distance	W	W	A	A	d	d	V	V	Qw	Qw	Reg	Reg	without floodway	without floodway	with floodway	with floodway	increase	Slope	Shear Stress	Shear Velocity	Tau*	d sus	q*b	qb	Qb	Qb	Qb	
	ft	m	ft	m	ft^2	m^2	ft	m	ft/s	m/s	cfs	cms	ft	m	ft	m	ft	m		*	Pa	m/s	*	m	*	m^3/s	m^3/s	m^3/year	kg/year	kW/m^2
K	7600	2340.8	183	56.4	422	39.21	1.4	0.4	8.6	2.8	2391.4	67.7	8116.4	2499.9	8116.4	2499.9	8116.4	2499.9	0.0	0.023684	101.1	0.32	6.25	0.00229	61.25	0.008	0.44	22456	5.95E+07	0.25
L	8150	2510.2	69	21.3	571	53.05	2.6	0.8	6.3	4.1	2370.3	67.1	8130.1	2504.1	8130.1	2504.1	8130.3	2504.1	0.2	0.024909	189.9	0.44	11.73	0.00365	158.56	0.020	0.43	21918	5.81E+07	0.65
M	8600	2648.8	119	36.7	366	34.00	1.8	0.6	9.8	3.3	2363.7	66.9	8139.1	2506.8	8139.1	2506.8	8139.1	2506.8	0.0	0.02	109.8	0.33	6.78	0.00242	69.35	0.009	0.32	16534	4.38E+07	0.29
N	8900	2741.2	80	24.6	318	29.54	2.3	0.7	11.0	3.8	2305.0	65.3	8152.0	2510.8	8152.0	2510.8	8152.0	2510.8	0.0	0.043	295.0	0.54	18.23	0.00534	307.69	0.039	0.96	49313	1.31E+08	1.26
O	9325	2872.1	122	37.6	368	34.19	1.8	0.6	9.8	3.2	2376.2	67.3	8168.4	2515.9	8168.4	2515.9	8168.4	2515.9	0.0	0.038588	209.3	0.46	12.93	0.00395	183.57	0.023	0.88	44867	1.19E+08	0.75
P	10000	3080.0	54	16.6	224	20.81	2.4	0.7	11.4	3.9	1683.0	47.7	8186.1	2521.3	8186.1	2521.3	8186.1	2521.3	0.0	0.026222	188.6	0.43	11.65	0.00363	156.89	0.020	0.33	16973	4.50E+07	0.64
Q	11150	3434.2	54	16.6	222	20.62	2.4	0.7	11.5	3.9	1682.3	47.6	8222.1	2532.4	8222.1	2532.4	8222.1	2532.4	0.0	0.031304	225.1	0.47	13.91	0.00420	204.79	0.026	0.43	22154	5.87E+07	0.84
R	11450	3526.6	64	19.7	234	21.74	2.2	0.7	12.0	3.6	1681.0	47.6	8230.2	2534.9	8230.2	2534.9	8230.2	2534.9	0.0	0.027	175.3	0.42	10.83	0.00342	140.46	0.018	0.35	18009	4.77E+07	0.58

Erodibility (Annandale 2006)			
EIM	low	high	
Ms	0.02	0.09	
Kb	1	1	
phi	28	33	
Kd	0.531709	0.649408	
Js	1	1	
K	0.010634	0.058447	*
SP crit	0.07	0.14	kW/m^2

Erodibility (Etcheverry 1915)			
	low	high	
V crit	2.00	2.75	ft/s
V crit	0.61	0.84	m/s
k	0.4		*
d	0.045166	0.072823229	m
Tau crit	12.53624	20.21256807	Pa
SP crit	0.01	0.02	kW/m^2

Recurrence Interval Calculations based on master plan				
RI	Q (cfs)			Q(cms)
0	0			0.00
1.5	102.6	slope	68.4	2.91
1.69	115.596			3.27
2	136.8	intercept	0	3.87
5	342	0	0	9.68
10	517	5	342	14.64
50	1237			35.03
100	1681			47.60

Continuity	Q = Vwd		
Qbf	2.91	cms	102.60 cfs
v	1.60	m/s	5.21 ft/s
d	0.19	m	0.63 ft
w	9.41	m	30.54 ft
S	0.0283	*	
n	0.035	m^-1/6	
Shear Stress		Tau = rho*g*d*S	
rho w	1000	kg/m^3	62.43 lbs/ft^3
rho s	2650	kg/m^3	165.43 lbs/ft^3
g	9.807	m/s^2	32.17 ft/s^2
Tau	53.47	Pa	1.12 lbs/ft^2
Tau*	3.30	*	
SP	0.10	kW/m^2	
D50	0.001	m	0.00 ft
u*	0.23	m/s	0.76 ft/s
d of suspended particle thresh	0.001564	m	0.01 ft
q*b	23.31	*	
Tau*crit	0.0495	*	
qb	0.003	m^3/s	0.10 ft^3/s
Qb	0.0279	m^3/s	0.99 ft^3/s
s/day	86,400	s	
days of transport per year	0.59	d	
Qb	1,426	m^3/year	50,363 ft^3/year
Qb	3,779,191	kg/year	8,331,697 lbs/year

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APPENDIX B
DETAILED BUDGET

COST ESTIMATE					
PROJECT: Fountain Creek-Aspen Garden Way to Crystola Road (Reach 1)		**DESIGN LEVEL:**	Planning	**PROJECT NO: 140-9863**	
ITEM: Alternative 1 - Channel Setback		**ESTIMATED BY:**	S. Rogers	**DATE:**	4/26/2015
NO	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT COST**	**TOTAL COST**
1	Mobilization/De-mobilization (10% approx.)	1	lump sum	$50,000	$50,000
2	Dewatering/Diversion/Erosion Control	1	lump sum	$25,000	$25,000
3	Earthwork				
3a	Debris Removal	2,400	cubic yards	$ 24.00	$57,600
3b	Excavation (Unclassified)	16,000	cubic yards	$ 11.00	$176,000
3c	Compacted Fill	0	cubic yards	$ 8.00	$0
4	Revetment				
4a	Bank Revetment (Riprap)	800	cubic yards	$ 75.00	$60,000
4b	Bank Revetment (Bedding)	600	cubic yards	$ 58.00	$34,800
4b	Grouted Riprap Drop Structure	0	each	$ 56,000.00	$0
4c	CIP Concrete Grade Control Structure	0	each	$ 33,700.00	$0
5	Other Items				
5a	Re-vegetation	3	acre	$ 10,000.00	$30,000
5b	Outlet Stabilization	1	each	$ 5,000.00	$5,000
5c				$0	$0
5d				$0	$0
5e				$0	$0
6	Unlisted Items (10%)				$44,000
Total Estimated Construction Costs					**$482,400**
	Contingency (25%)				$120,600
	Permitting/CLOMR (Est.)				$20,000
	Engineering Design (10%)				$48,240
	Legal Fees (Est.)				$10,000
Total Estimated Implementation Costs					**$681,240**

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COST ESTIMATE					
PROJECT: Fountain Creek-Aspen Garden Way to Crystola Road (Reach 2)			DESIGN LEVEL:	Planning	PROJECT NO: 140-9863
ITEM: Alternative 1 - Channel Setback			ESTIMATED BY:	S. Rogers	DATE: 4/26/2015
NO	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT COST**	**TOTAL COST**
1	Mobilization/De-mobilization (10% approx.)	1	lump sum	$50,000	$50,000
2	Dewatering/Diversion/Erosion Control	1	lump sum	$25,000	$25,000
3	Earthwork				
3a	Debris Removal	2,300	cubic yards	$ 24.00	$55,200
3b	Excavation (Unclassified)	30,000	cubic yards	$ 11.00	$330,000
3c	Compacted Fill	0	cubic yards	$ 8.00	$0
4	Revetment				
4a	Bank Revetment (Riprap)	767	cubic yards	$ 75.00	$57,500
4b	Bank Revetment (Bedding)	567	cubic yards	$ 58.00	$32,867
4b	Grouted Riprap Drop Structure	0	each	$ 56,000.00	$0
4c	CIP Concrete Grade Control Structure	0	each	$ 33,700.00	$0
5	Other Items				
5a	Re-vegetation	3	acre	$ 10,000.00	$30,000
5b	Outlet Stabilization	2	each	$ 5,000.00	$10,000
5c				$0	$0
5d				$0	$0
5e				$0	$0
6	Unlisted Items (10%)				$59,000
	Total Estimated Construction Costs				**$649,567**
	Contingency (25%)				$162,392
	Permitting/CLOMR (Est.)				$20,000
	Engineering Design (10%)				$64,957
	Legal Fees (Est.)				$50,000
	Total Estimated Implementation Costs				**$946,915**

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	COST ESTIMATE				
PROJECT:	Fountain Creek-Aspen Garden Way to Crystola Road (Reach 1)	**DESIGN LEVEL:**	Planning	**PROJECT NO: 140-9863**	
ITEM:	Alternative 2 - Drop Structures	**ESTIMATED BY:**	S. Rogers	**DATE:**	4/26/2015
NO	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT COST**	**TOTAL COST**
1	Mobilization/De-mobilization (10% approx.)	1	lump sum	$50,000	$50,000
2	Dewatering/Diversion/Erosion Control	1	lump sum	$25,000	$25,000
3	Earthwork				
3a	Debris Removal	2,400	cubic yards	$ 24.00	$57,600
3b	Excavation (Unclassified)	0	cubic yards	$ 11.00	$0
3c	Compacted Fill	24,000	cubic yards	$ 8.00	$192,000
4	Revetment				
4a	Bank Revetment (Riprap)	300	cubic yards	$ 75.00	$22,500
4b	Bank Revetment (Bedding)	300	cubic yards	$ 58.00	$17,400
4b	Grouted Riprap Drop Structure	2	each	$ 56,000.00	$112,000
4c	CIP Concrete Grade Control Structure	0	each	$ 33,700.00	$0
5	Other Items				
5a	Re-vegetation	3	acre	$ 10,000.00	$30,000
5b	Outlet Stabilization	1	each	$ 5,000.00	$5,000
5c				$0	$0
5d				$0	$0
5e				$0	$0
6	Unlisted Items (10%)				$51,000
	Total Estimated Construction Costs				**$562,500**
	Contingency (25%)				$140,625
	Permitting/CLOMR (Est.)				$20,000
	Engineering Design (10%)				$56,250
	Legal Fees (Est.)				$10,000
	Total Estimated Implementation Costs				**$789,375**

Appendix B
Detailed Budget
Alt 2 - Reach 2

COST ESTIMATE					
PROJECT: Fountain Creek-Aspen Garden Way to Crystola Road (Reach 2)		**DESIGN LEVEL:**	Planning	**PROJECT NO: 140-9863**	
ITEM: Alternative 2 - Drop Structures		**ESTIMATED BY:**	S. Rogers	**DATE:**	4/26/2015
NO	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT COST**	**TOTAL COST**
1	Mobilization/De-mobilization (10% approx.)	1	lump sum	$50,000	$50,000
2	Dewatering/Diversion/Erosion Control	1	lump sum	$25,000	$25,000
3	Earthwork				
3a	Debris Removal	2,300	cubic yards	$ 24.00	$55,200
3b	Excavation (Unclassified)	0	cubic yards	$ 11.00	$0
3c	Compacted Fill	16,000	cubic yards	$ 8.00	$128,000
4	Revetment				
4a	Bank Revetment (Riprap)	300	cubic yards	$ 75.00	$22,500
4b	Bank Revetment (Bedding)	300	cubic yards	$ 58.00	$17,400
4b	Grouted Riprap Drop Structure	3	each	$ 56,000.00	$168,000
4c	CIP Concrete Grade Control Structure	0	each	$ 33,700.00	$0
5	Other Items				
5a	Re-vegetation	3	acre	$ 10,000.00	$30,000
5b	Outlet Stabilization	2	each	$ 5,000.00	$10,000
5c				$0	$0
5d				$0	$0
5e				$0	$0
6	Unlisted Items (10%)				$51,000
Total Estimated Construction Costs					**$557,100**
	Contingency (25%)				$139,275
	Permitting/CLOMR (Est.)				$20,000
	Engineering Design (10%)				$55,710
	Legal Fees (Est.)				$10,000
Total Estimated Implementation Costs					**$782,085**

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	COST ESTIMATE				
PROJECT:	Fountain Creek-Aspen Garden Way to Crystola Road (Reach 1)	**DESIGN LEVEL:**	Planning	**PROJECT NO: 140-9863**	
ITEM:	Alternative 3 - Grade Control Structures	**ESTIMATED BY:**	S. Rogers	**DATE:**	4/26/2015
NO	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT COST**	**TOTAL COST**
1	Mobilization/De-mobilization (10% approx.)	1	lump sum	$50,000	$50,000
2	Dewatering/Diversion/Erosion Control	1	lump sum	$25,000	$25,000
3	Earthwork				
3a	Debris Removal	2,400	cubic yards	$ 24.00	$57,600
3b	Excavation (Unclassified)	0	cubic yards	$ 11.00	$0
3c	Compacted Fill	0	cubic yards	$ 8.00	$0
4	Revetment				
4a	Bank Revetment (Riprap)	400	cubic yards	$ 75.00	$30,000
4b	Bank Revetment (Bedding)	400	cubic yards	$ 58.00	$23,200
4b	Grouted Riprap Drop Structure	0	each	$ 56,000.00	$0
4c	CIP Concrete Grade Control Structure	2	each	$ 33,700.00	$67,400
5	Other Items				
5a	Re-vegetation	3	acre	$ 10,000.00	$30,000
5b	Outlet Stabilization	1	each	$ 5,000.00	$5,000
5c				$0	$0
5d				$0	$0
5e				$0	$0
6	Unlisted Items (10%)				$29,000
	Total Estimated Construction Costs				**$317,200**
	Contingency (25%)				$79,300
	Permitting/CLOMR (Est.)				$20,000
	Engineering Design (10%)				$31,720
	Legal Fees (Est.)				$10,000
	Total Estimated Implementation Costs				**$458,220**

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COST ESTIMATE					
PROJECT: Fountain Creek-Aspen Garden Way to Crystola Road (Reach 2)			**DESIGN LEVEL:** Planning		**PROJECT NO: 140-9863**
ITEM: Alternative 3 - Grade Control Structures			**ESTIMATED BY:** S. Rogers		**DATE:** 4/26/2015
NO	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT COST**	**TOTAL COST**
1	Mobilization/De-mobilization (10% approx.)	1	lump sum	$50,000	$50,000
2	Dewatering/Diversion/Erosion Control	1	lump sum	$25,000	$25,000
3	Earthwork				
3a	Debris Removal	2,300	cubic yards	$ 24.00	$55,200
3b	Excavation (Unclassified)	0	cubic yards	$ 11.00	$0
3c	Compacted Fill	0	cubic yards	$ 8.00	$0
4	Revetment				
4a	Bank Revetment (Riprap)	400	cubic yards	$ 75.00	$30,000
4b	Bank Revetment (Bedding)	400	cubic yards	$ 58.00	$23,200
4b	Grouted Riprap Drop Structure	0	each	$ 56,000.00	$0
4c	CIP Concrete Grade Control Structure	3	each	$ 33,700.00	$101,100
5	Other Items				
5a	Re-vegetation	3	acre	$ 10,000.00	$30,000
5b	Outlet Stabilization	2	each	$ 5,000.00	$10,000
5c				$0	$0
5d				$0	$0
5e				$0	$0
6	Unlisted Items (10%)				$32,000
	Total Estimated Construction Costs				**$356,500**
	Contingency (25%)				$89,125
	Permitting/CLOMR (Est.)				$20,000
	Engineering Design (10%)				$35,650
	Legal Fees (Est.)				$10,000
	Total Estimated Implementation Costs				**$511,275**

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COST ESTIMATE					
PROJECT: Fountain Creek-Aspen Garden Way to Crystola Road (Reach 3)		**DESIGN LEVEL:**	Planning	**PROJECT NO: 140-9863**	
ITEM: General Stabilization		**ESTIMATED BY:**	S. Rogers	**DATE:**	4/26/2015
NO	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT COST**	**TOTAL COST**
1	Mobilization/De-mobilization (10% approx.)	1	lump sum	$10,000	$5,000
2	Dewatering/Diversion/Erosion Control	1	lump sum	$5,000	$5,000
3	Earthwork				
3a	Debris Removal	0	cubic yards	$ 24.00	$0
3b	Excavation (Unclassified)	0	cubic yards	$ 11.00	$0
3c	Compacted Fill	0	cubic yards	$ 8.00	$0
4	Revetment				
4a	Bank Revetment (Riprap)	50	cubic yards	$ 75.00	$3,750
4b	Bank Revetment (Bedding)	15	cubic yards	$ 58.00	$870
4b	Grouted Riprap Drop Structure	0	each	$ 56,000.00	$0
4c	CIP Concrete Grade Control Structure	0	each	$ 33,700.00	$0
5	Other Items				
5a	Re-vegetation	0.5	acre	$ 10,000.00	$5,000
5b	Outlet Stabilization	1	each	$ 5,000.00	$5,000
5c				$0	$0
5d				$0	$0
5e				$0	$0
6	Unlisted Items (10%)				$2,000
	Total Estimated Construction Costs				**$26,620**
	Contingency (25%)				$6,655
	Permitting/CLOMR (Est.)				$0
	Engineering Design (10%)				$0
	Legal Fees (Est.)				$0
	Total Estimated Implementation Costs				**$33,275**

Typical Grouted Riprap Drop Structure

Dimensions

Slope	0.25	ft/ft
Length	50	feet
Height	8.5	feet
Slope Length	35	feet
Concrete Cutoff Thickness	2	feet
Concrete Cutoff Height	5	feet
Riprap Apron Length	20	feet
Riprap Thickness	2.5	feet

Unit Rates

Concrete	$	600.00	cubic yard
Grouted Riprap	$	190.00	cubic yard
Excavation	$	11.00	cubic yard
Riprap	$	75.00	cubic yard

Total Estimated Cost per drop	**$**	**56,000**

Cost per square yard	$	288

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Typical Grade Control Structure			
Dimensions			
Width		2	feet
Length		50	feet
Height		10	feet
Riprap Apron Length		20	feet
Riprap Apron Thickness		2	feet
Unit Rates			
CIP Concrete	$	600.00	cubic yard
Excavation	$	11.00	cubic yard
Riprap	$	75.00	cubic yard
Total Estimated Cost	**$**	**33,700**	

Cost per foot $ 674

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Unit Rates		
Debris Removal	$ 24.00	cubic yard
Excavation	$ 11.00	cubic yard
Compacted Fill	$ 8.00	cubic yard
Riprap	$ 75.00	cubic yard
Bedding	$ 58.00	cubic yard
Grouted Riprap/Boulders	$ 190.00	cubic yard
Concrete	$ 600.00	cubic yard
Re-vegetation	$ 10,000.00	acre
Outlet Stabilization	$ 5,000.00	each

Reach	Alternative 1-Channel Setback	Alternative 2-Drop Structures	Alternative 3-Grade Control Structures
1	$681,240	$789,375	$458,220
2	$946,915	$782,085	$511,275
3	$33,275	$33,275	$33,275
TOTAL	**$1,661,430**	**$1,604,735**	**$1,002,770**

Distance	3500 feet			
Cost per mile	$ 2,506,386	$ 2,420,857	$ 1,512,750	

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At Golder Associates we strive to be the most respected global group of companies specializing in ground engineering and environmental services. Employee owned since our formation in 1960, we have created a unique culture with pride in ownership, resulting in long-term organizational stability. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees now operating from offices located throughout Africa, Asia, Australasia, Europe, North America and South America.

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