CHERRY CREEK SEDIMENT ANALYSIS

TECHNICAL MEMORADA

Collection of investigations prepared by George K Cotton Consulting, Inc.

Cherry Creek Sedimentation Study
Reservoir to Pine Lane
Project Data and Evaluation

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CHERRY CREEK SEDIMENTATION STUDY

PROJECT DATA AND EVALUATION

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INTRODUCTION

This paper describes the data that was collected in support of analysis of the sediment transport in the Cherry Creek above Cherry Creek Lake. The data gathering effort focused on the segment of the Cherry Creek from the Pine Drive bridge in Parker, Colorado to the State Park perimeter road within the dam reservoir. Data gathering also includes sedimentation data for the reservoir pool itself.

Categories of data that were pursued for the project included: the surface geology; hydrology of the stream segment; topographic description of the stream channel and valley; and, measurements of sedimentation and erosion for the stream channel and reservoir pool. Published reports are discussed briefly in the context of what data they provide.

PERIOD OF RECORD

The period of data on the Cherry Creek is relatively recent and begins in 1940. This is ten years prior to the completion of the Cherry Creek dam by the U.S. Army Corps of Engineers in 1950. Prior to this period of data collection, we have only a qualitative understanding of the hydrologic history within the Cherry Creek watershed.

Western civilization has impacted the Cherry Creek basin for about 200 years. After the Lewis and Clark Expedition (1804 – 1806), the commercial fur trade expanded onto the plains west of the Mississippi River and later into the Rocky Mountains. The large-scale removal of beaver from western streams (no doubt including the Cherry Creek) impacted basin water storage, the extent of wetlands, and the character of riparian vegetation. Settlement of the Cherry Creek began in the 1870s and included the expansion of ranching throughout the watershed and the development of some irrigated farming in the valley. Over-grazing and periods of sustained drought in the Platte River basin impacted riparian areas of the Cherry Creek. Government sponsored erosion control programs began in the mid-1930's to help restore the lost productivity of basin rangelands due to gully erosion.

The drought on the plains of the United States in the late 1930's was the longest, driest and hottest of the 20th Century. Newly available rural electric power permitted deeper pumping of groundwater, which mitigated some of the drought impact within the Cherry Creek basin. The unregulated use of alluvial groundwater may be the reason for low base-flows in the Cherry Creek at the Melvin gage. Thus, at the beginning of the period of record for this study the basin hydrology was in a stressed state. Likewise, the riparian environment of stream channels was probably also in a stressed condition. The 1950s saw another period of sustained drought in the basin. So, the early period of the flow record reflects severe drought conditions and the unregulated use of alluvial groundwater.

Within the period of record, exurban development began on lands south of Cherry Creek Lake in the mid-1960s, which was followed by larger suburban development in the 1970's. Urbanization continues to expand steadily, mostly in the portions of the basin north of about Franktown. Water supply for this development has to date been largely from deep community wells that have been developed into the lower Dawson and Denver formations. This supplemental water enters the Cherry Creek via wastewater discharges and tailwater runoff from lawn irrigation. In addition, the increased impervious area that is associated with the urban development diverts rainwater that would have infiltrated to drainageways that are tributary to the Cherry Creek.

Because of the intense use of surface and groundwater resources, the State of Colorado strictly administers water rights on the Cherry Creek basin. As a result, base flows in the period of record may not accurately reflect the current water rights administration.

DESCRIPTION OF THE STUDY AREA

The study segment of the Cherry Creek is about eight (8.0) miles long. In this distance the valley of the Cherry Creek falls about 190 feet and has an average grade of 23.8 feet per mile (0.0045 feet/foot).

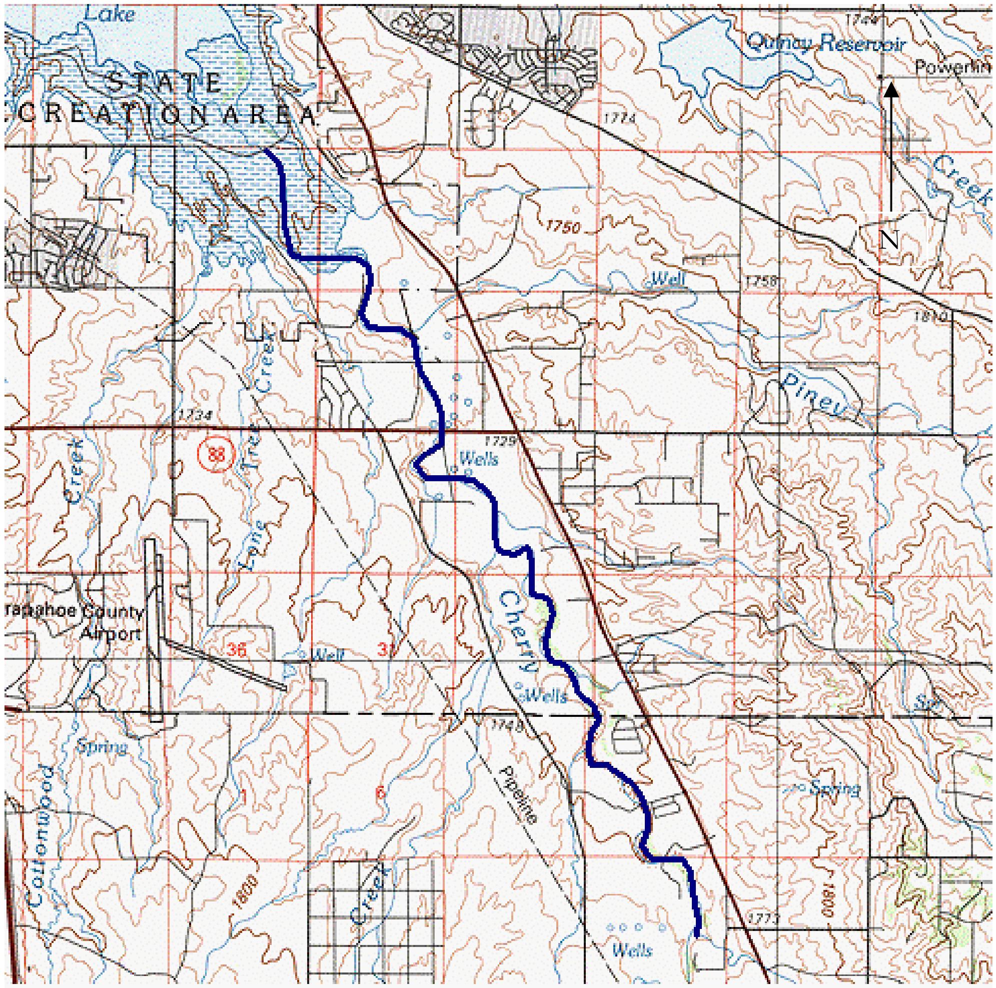


Figure 1. Approximate Limits of Study Segment (Section grid is approximately 1.0 mile)

The study segment is with the jurisdictions of Arapahoe Country and Douglas County. Both counties have completed detailed planning for the Cherry Creek stream corridor. The reservoir land is owned by the U.S. Army Corps of Engineers which leases the land within the reservoir to Colorado State Parks. City jurisdictions within the study segment include the Centennial, Aurora, and Parker.

Major tributaries that confluence with the Cherry Creek in this segment are Piney Creek, Happy Canyon Creek, and Baldwin Gulch / Newlin Gulch (right and left bank tributaries that confluence with the Cherry Creek at nearly the same location). The drainage area of the Cherry Creek at the Baldwin Gulch confluence is 310 square miles and at the reservoir it is 360 square miles.

GEOLOGY

One of the reasons that the study limits were chosen is that the geology of the segment is relatively consistent. Each side of the Cherry Creek valley has distinctly different characteristics. Near the floodplain, the east side of the valley is composed of aeolian (wind-blown) sands (Qes) that are more uniform in nature than alluvial sediments. Upper portions of the east valley are within the Dawson formation (Tkd and Tkda), which formed as a series of ancient coalesced alluvial fans that overlie the Denver formation.

The west side of the valley consists of colluvial deposits that are derived from erosion of the Castle Rock conglomerate (Tkr) and Denver formation (Tkd). The Louviers alluvium (Qlo) borders much of the west valley and forms a gravelly terrace that is about 60 feet above the modern valley of the Cherry Creek.

With the exception of the aeolian sands, erosion of these base formations produces mostly coarse sands with some gravel sediments.

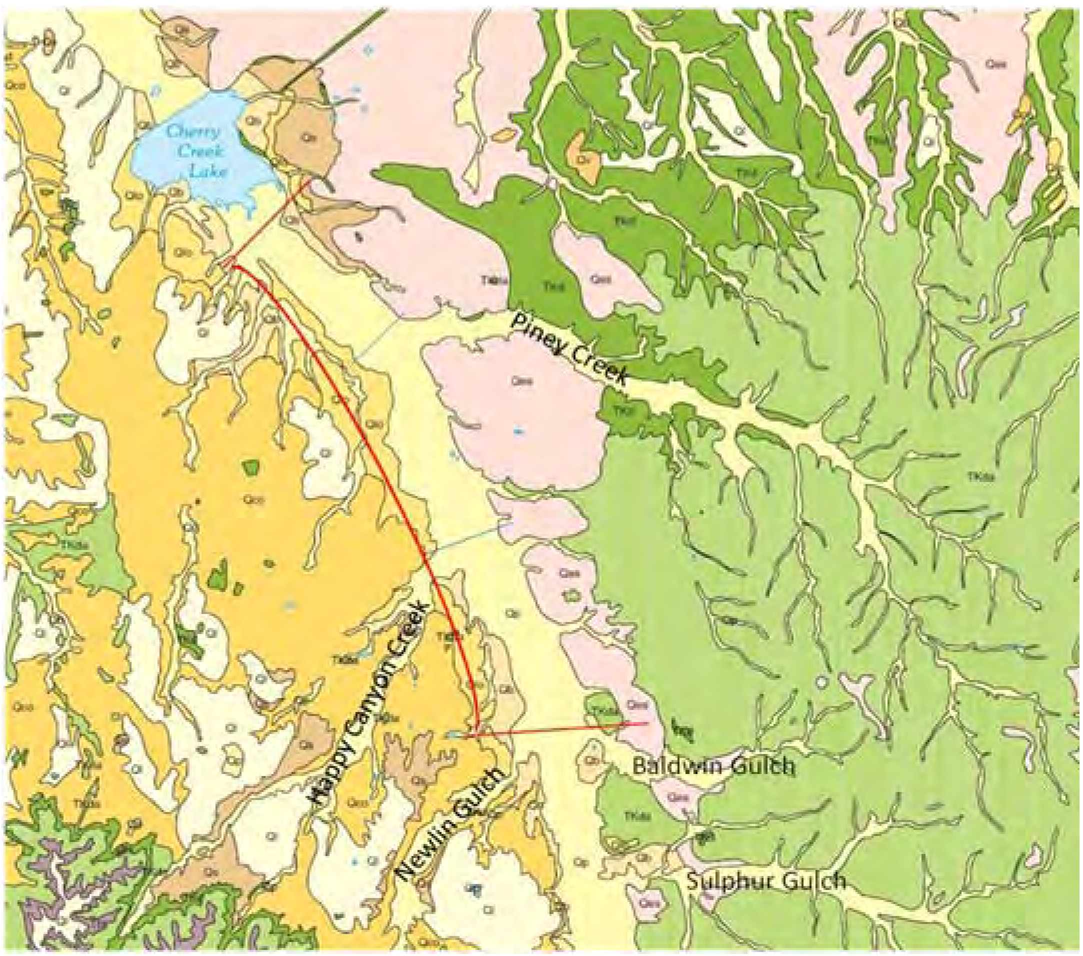


Figure 2. Segment Geology (USGS I-856-H Version 1.1 "Geologic Map of the Greater Denver Area, Front Range Urban Corridor, Colorado" by D.E. Trimble and M.N. Machette)

FLOW DATA

STREAM GAGES

There are three Cherry Creek steam flow gages near the study segment. Records include mean daily flow and annual flow peaks. USGS metadata for each site is provided in Table 1 (a, b and c). The Melvin gage ceased operation at the end of water year 1969 and resumed briefly May and September of 1984. The CC-10 gage is located at the crossing of the state park perimeter road near the location of the previous Melvin gage. This gage has operated continuously since January 1992.

Table 1a. USGS 06712500 CHERRY CREEK NEAR MELVIN, CO.

DESCRIPTION:

Latitude 39°36'18", Longitude 104°49'19" NAD27
Arapahoe County, Colorado, Hydrologic Unit 10190003
Drainage area: 360 square miles
Datum of gage: 5,608.21 feet above sea level NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Daily Data			
Discharge, cubic feet per second	1939-10-01	1984-09-24	11075
Daily Statistics			
Discharge, cubic feet per second	1939-10-01	1984-09-24	11075
Monthly Statistics			
Discharge, cubic feet per second	1939-10	1984-09	
Annual Statistics			
Discharge, cubic feet per second	1940	1984	
Peak streamflow	1933-08-03	1969-08-21	30
Field measurements	1985-10-16	1985-12-16	10
Field/Lab water-quality samples	1964-12-03	1986-09-24	31

Table 1b. USGS 393109104464500 CHERRY CREEK NEAR PARKER, CO

DESCRIPTION:

Latitude 39°31'09", Longitude 104°46'45" NAD27
Douglas County, Colorado, Hydrologic Unit 10190003
Drainage area: 287 square miles
Datum of gage: 5,805 feet above sea level NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Daily Data			
Discharge, cubic feet per second	1991-10-01	2010-10-26	6966
Daily Statistics			
Discharge, cubic feet per second	1991-10-01	2010-04-28	6785
Monthly Statistics			
Discharge, cubic feet per second	1991-10	2010-04	
Annual Statistics			
Discharge, cubic feet per second	1992	2010	
Peak streamflow	1992-07-12	2009-06-23	18
Field measurements	1991-10-22	2010-10-04	251
Field/Lab water-quality samples	1991-12-03	2003-03-17	160

Table 1c. USGS 06712000 CHERRY CREEK NEAR FRANKTOWN, CO.

DESCRIPTION:

Latitude 39°21'21", Longitude 104°45'46" NAD27
Douglas County, Colorado, Hydrologic Unit 10190003
Drainage area: 169 square miles
Datum of gage: 6,150.00 feet above sea level NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Daily Data			
Discharge, cubic feet per second	1939-11-21	2010-10-26	25908
Daily Statistics			
Discharge, cubic feet per second	1939-11-21	2010-04-15	25714
Monthly Statistics			
Discharge, cubic feet per second	1939-11	2010-04	
Annual Statistics			
Discharge, cubic feet per second	1940	2010	
Peak streamflow	1940-06-06	2009-06-01	70
Field measurements	1956-07-02	2010-10-04	347
Field/Lab water-quality samples	1963-10-15	2003-09-17	438

STREAM GAGE STATISTICS

The Melvin, Parker and Franktown gages provide a record of the wet and dry periods of the Cherry Creek basin climate over the past 70 years. Figure 3 shows the accumulated flows at these gages. As shown by parallel traces of wet and dry periods in the flow record (red for dry and blue for wet periods), there is good agreement between upper and lower basin gages through most of the record. The exception is the recent deviation at the Parker gage that seems to show increased base flow relative to the Franktown gage (see vertical line in chart near 2004). The 1965 flood (see vertical line in chart) was a lower basin storm event that shows up in the Melvin gage record but not at the Franktown gage.

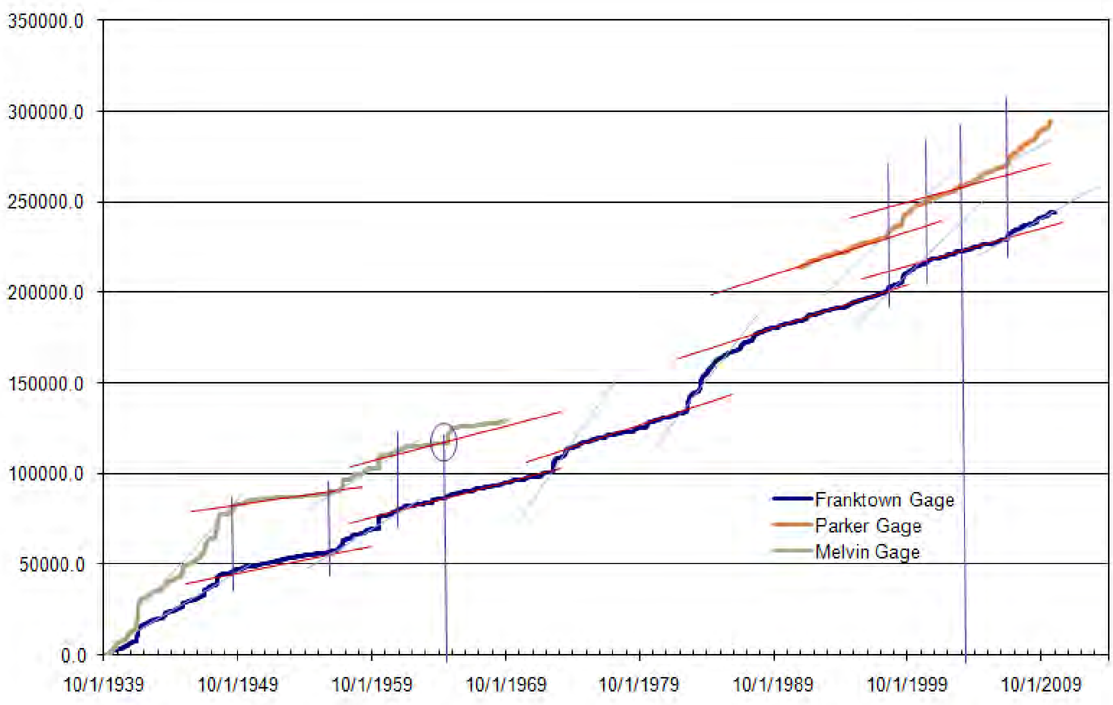


Figure 3. Accumulated flow at Franktown, Parker and Melvin gages

Comparison of the Franktown (over the period of operation), Melvin, and the newer C-10 gages (Figure 4) shows that mean daily flows have increased at the Franktown gage. Both distributions show that the most frequent range of flow is near 5 cfs-day but there are now fewer days with only 1 cfs-day and more days with 10 to 20 cfs-day.

Comparing the Franktown gage to the Melvin gage (Figure 5) over the period of operation of the Melvin gage shows that there was a significant loss of base flow between the two gages. About half of the days in the Melvin gage record showed no stream flow. [Note: this is supported by anecdotal evidence from Valley Country Club, which is just south of the Cherry Creek reservoir, where until the mid-1970s Club members were able to drive across the dry Cherry Creek stream bed at Caley Avenue much of the time.]

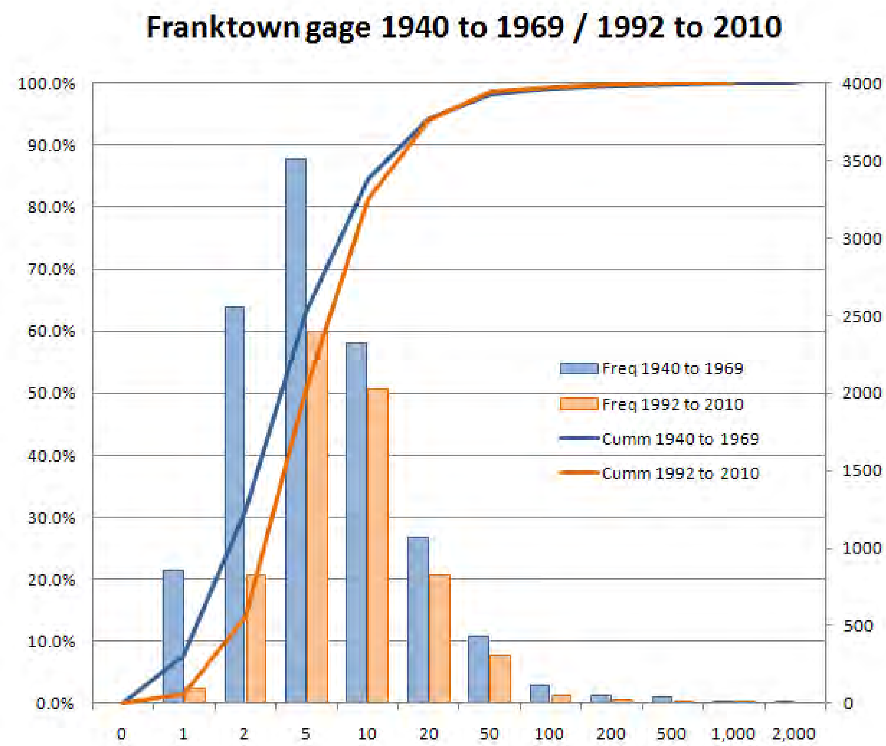


Figure 4. Frequency of Mean daily flow at the Franktown gage for two periods of record

Comparison of the C-10 gage and Franktown gage (Figure 6) shows that the frequency of low base flow is essentially the same for both gages. The C-10 gage shows more days in the 20 to 50 cfs-day range than the Franktown gage. This is a new pattern of flow into the reservoir that has continual base flow and no time when the stream bed is dry. It appears that the distribution of days where there is less than 5 cfs-day is the same in the stream segment from Franktown to the reservoir.

The U.S. Army Corps of Engineers Omaha District has conducted six reservoir capacity surveys at approximately 10 year intervals since the reservoir was completed in 1950. The flow record overlaps two of these surveys (performed in April 1961 and August 1965). There are incomplete records of inflow for the reservoir surveys in 1974 and 1988. The two most recent reservoir capacity surveys in 1997 and 2008 appear to have survey errors and data has not been verified by the Omaha District.

There is good record of an erosion event in the Cherry Creek channel that occurred after the completion of the 17 Mile House stream reclamation project in 2006. Mapping was completed before and after the project which allows the calculation of channel scour volume.

The mean flow statistics for the three sedimentation periods are shown in Figure 7. The period from 1950 to 1965 was very dry with about 80 percent of the record having no-flow days. In contrast, the period from 2006 to 2008 was very wet with 20 percent of the days exceeding a mean daily flow of 50 cfs-day. There were no days with flows less than 5 cfs-day for this period. Table 2 summarizes flow statistics for sedimentation periods.

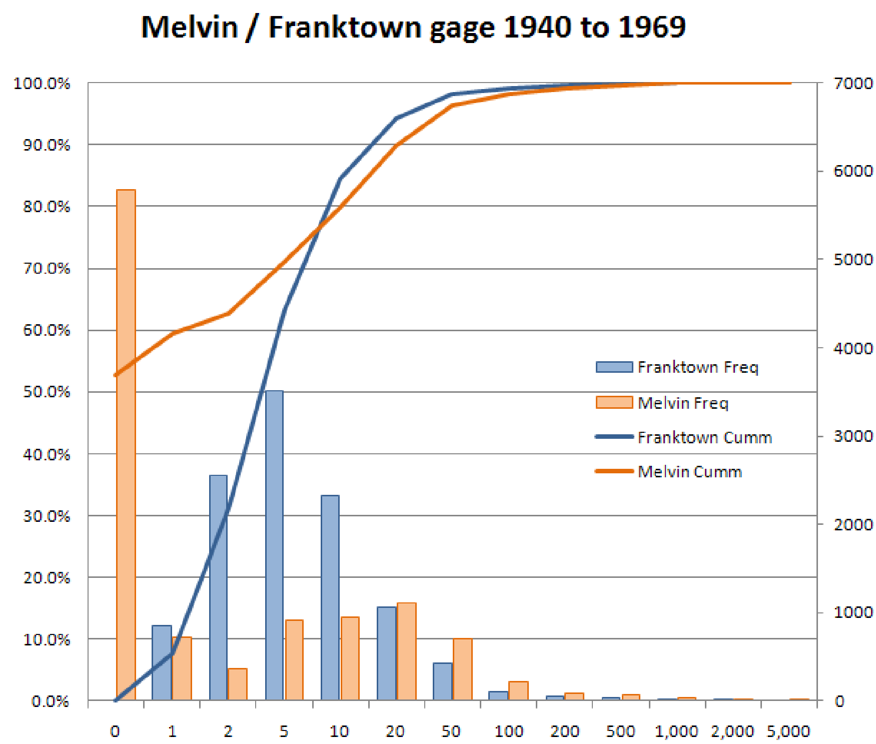


Figure 5. Comparison of mean daily flow frequency between Franktown and Melvin gages

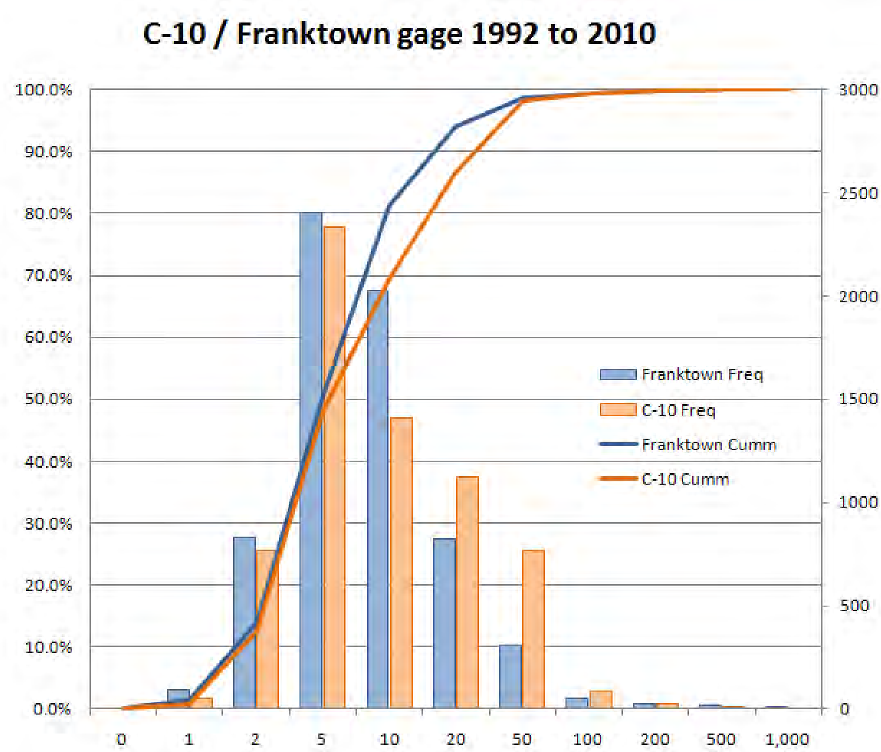


Figure 6. Comparison of mean daily flow frequency between Franktown and C-10 gages

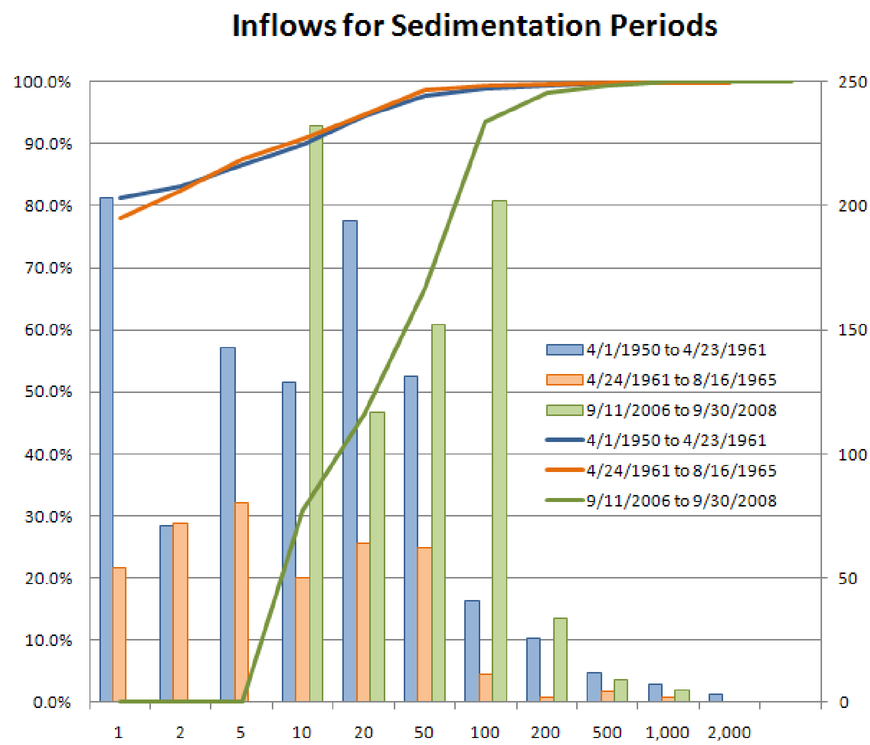


Figure 7. Inflows between periods of sediment reservoir sediment surveys

Stream flow and flood periods are identified for each of the three sedimentation periods (Table 2). The period from 1950 to 1965 had a significant amount of runoff attributable to storm runoff even though only about 11% of days with stream flow could be associated with storms. In contrast, the period from 2006 to 2008 had high base flows and only 5% of flows are associated with storms. The fraction of days with flow increased from about 24% to 100% in the period from 1965 to 1992.

Table 2. Flow Statistics for Sedimentation Periods (1 cfs-day = 1.98 ac-ft)

Date of Survey	Water Inflow (cfs-day)	Storm Inflow (cfs-day)	% Inflow from Storms	Average non-Storm Flow (cfs-day)	# Non-Zero Flow Days	# Storm Days	# Storms
1-Apr-1950				Melvin Gage			
24-Apr-1961	27,456.5	11,526.7	42.0%	18.6	960	105	11
17-Aug-1965	11,700.7	7,703.6	65.8%	11.3	402	49	4
11-Sep-2006				C-10 Gage			
30-Sep-2008	14,873.1	3,376.3	22.7%	16.1	751	36	2

URBAN DEVELOPMENT

The Town of Parker is used as a proxy for the pattern of growth in the northern portion of the Cherry Creek to the reservoir. In 2008 the demographics of Parker were compiled by the Parker Economic Development Council in 2008. This analysis compiles economic statistics within three different radii from downtown Parker (0.0 to 0.5 miles, 0.0 to 10.0 miles and 0.0 to 15.0 miles). The 10.0 mile radius just reaches the location of the Cherry Creek Dam.

Year	Population	Households
2008 (Estimate)	368,881	128,918
2000 (Census)	254,116	88,195
1990 (Census)	139,427	47,475

Period	Housing Units Built
1999 to 2008	55,683
1995 to 1999	20,609
1990 to 1994	11,566
1980 to 1989	25,968
1970 to 1979	19,175
1960 to 1969	1,700
1950 to 1959	2,99
1940 to 1949	60
1939 or earlier	207
Total to 2008	135,267

BRW-WRC (1985) reported the following development projections for the Cherry Creek basin by DRCOG ("Cherry Creek Reservoir Clear Lakes Study", April 1984).

Year	% Impervious
1985	13
1990	16
2000	19
2010	23

There is an expectation that increasing development and basin population will result in increased in the impervious area of the basin. Figure 8 plots population, housing units and impervious area, which show a strong relationship between the three parameters. Logically it can be assumed that increased housing units should correspond to increased impervious area. Figure 9 shows that for every 11,600 housing units built in the Cherry Creek basin the fraction of impervious area will increase by 1.0%.

Prior to 1965, the Cherry Creek basin south of the reservoir was effectively completely rural (the first two sedimentation periods) and basin imperviousness was about 11% (with about 1,700 housing units). In 2006 the basin imperviousness had increased to 21% (about 125,000 housing units).

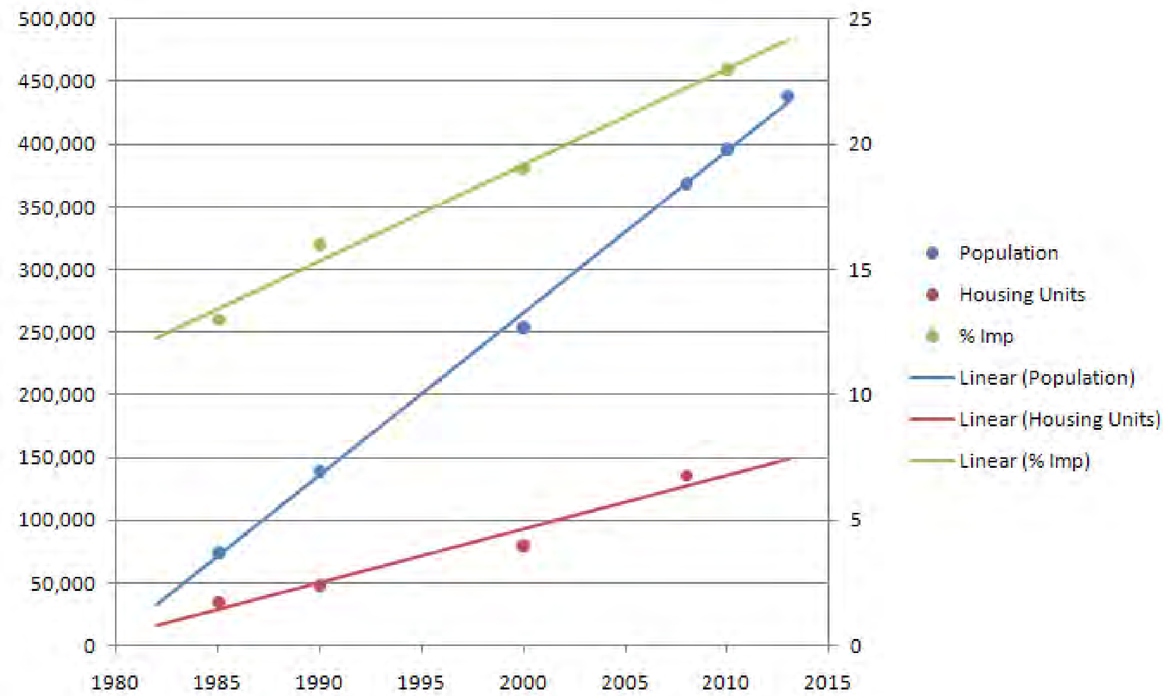


Figure 8. Change in basin population, housing units and imperviousness

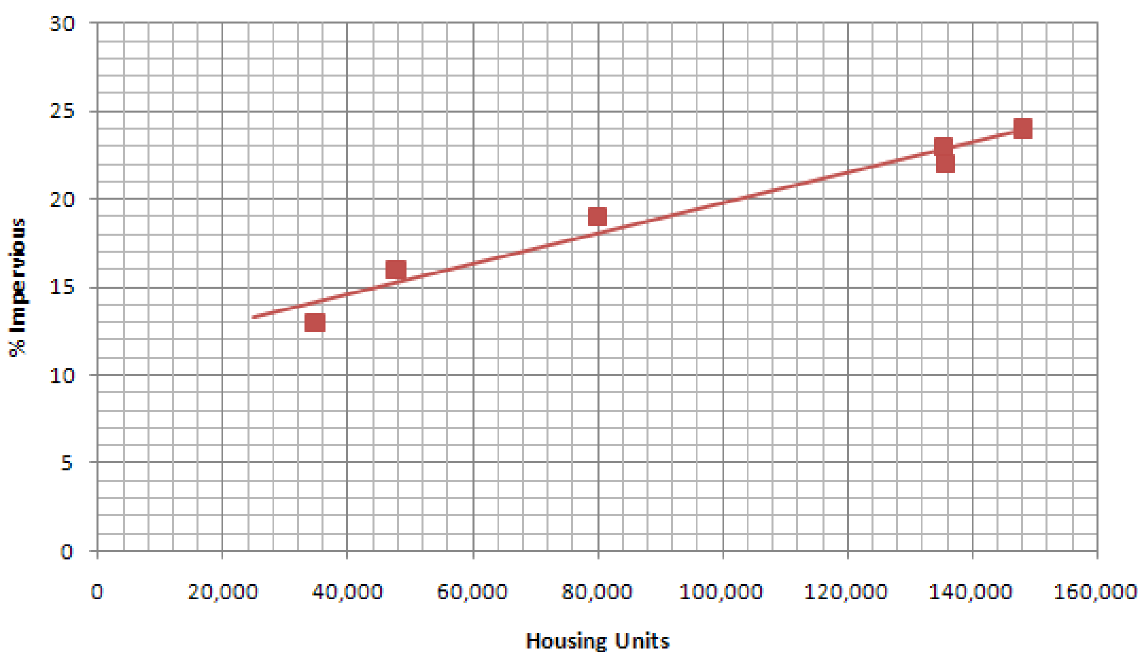


Figure 9. Relationship of Housing Units versus Imperviousness in the Cherry Creek basin

INFLOW TIME SERIES

Three inflow time series that correspond to reservoir sedimentation surveys in 1961 and 1965 are charted for the Melvin (Figures 10 and 11). Data from the C-10 gage is used to chart flows for the 2006 to 2008 channel erosion event (Figure 12). Flood peak data are available for the Melvin gage (Tables 3 and 4).

There is not a strong correlation between the flood-volume on the day of flood-peak (Figure 13). Most of the peak flows are in the range of 7 to 10 times the mean daily flow for the day of the flood peak.

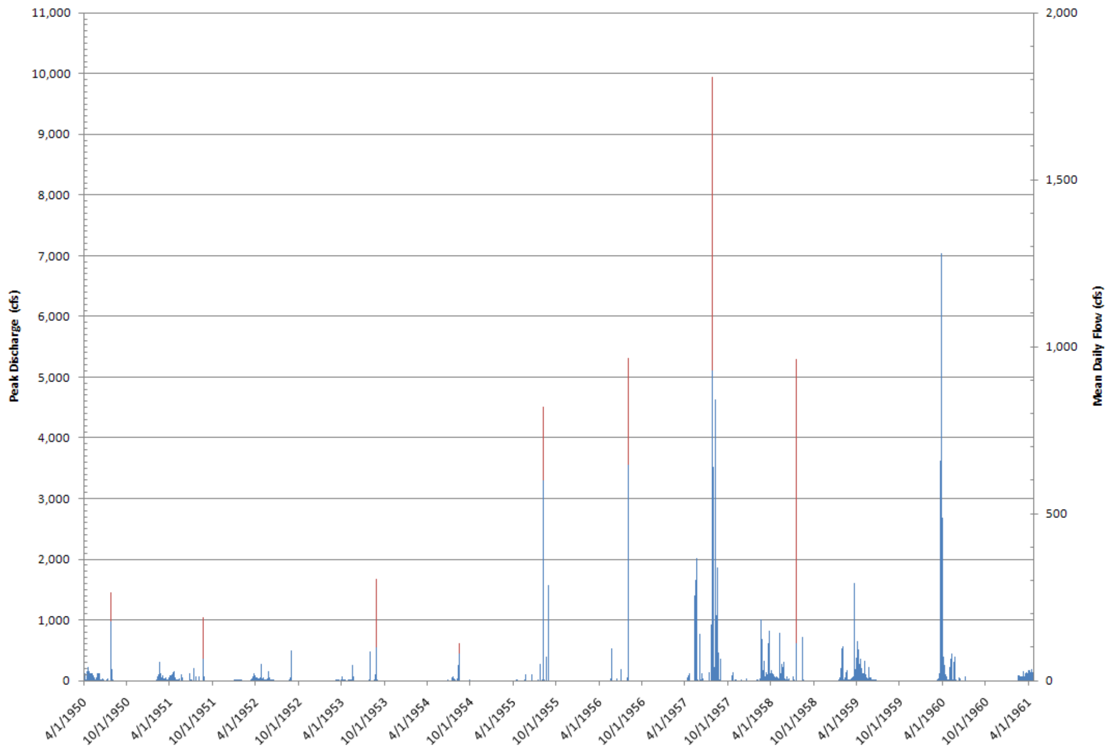


Figure 10. Mean daily flow time series and flood peak events 1950 to 1961

Table 3. Flood Peaks and Corresponding daily flow volume 1950 to 1961

Flood Date	Flood Peak (cfs)	Mean Daily Volume (cfs-day)
1950-07-25	1450	170
1951-08-22	1040	66
1952-08-29	321	90
1953-08-27	1670	101
1954-08-13	611	81
1955-08-05	4510	599
1956-07-31	5310	389
1957-07-26	9950	929
1958-07-18	5290	111
1959-03-22	558	291
1960-03-24	2720	1080

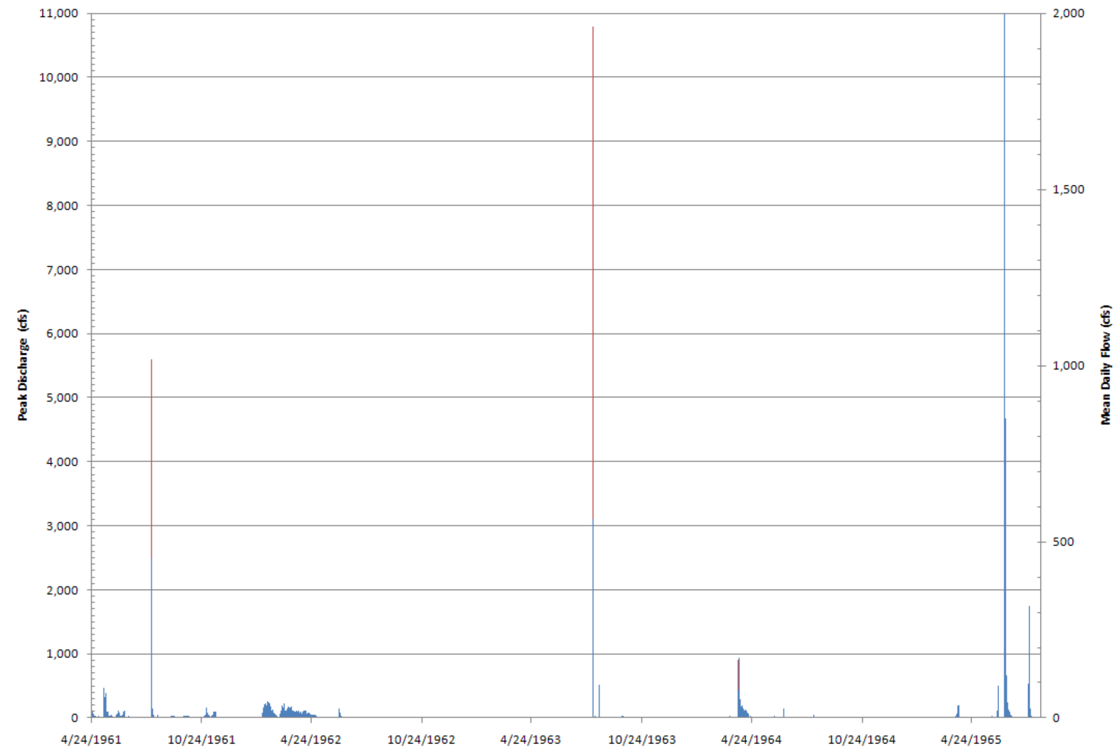


Figure 11. Mean daily flow time series and flood peak events 1961 to 1965

Table 4. Flood Peaks and Corresponding daily flow volume 1961 to 1965

Flood Date	Flood Peak (cfs)	Mean Daily Volume (cfs-day)
1961-07-31	5600	452
1963-08-03	10800	566
1964-03-31	910	80
1965-06-16	39900	4000

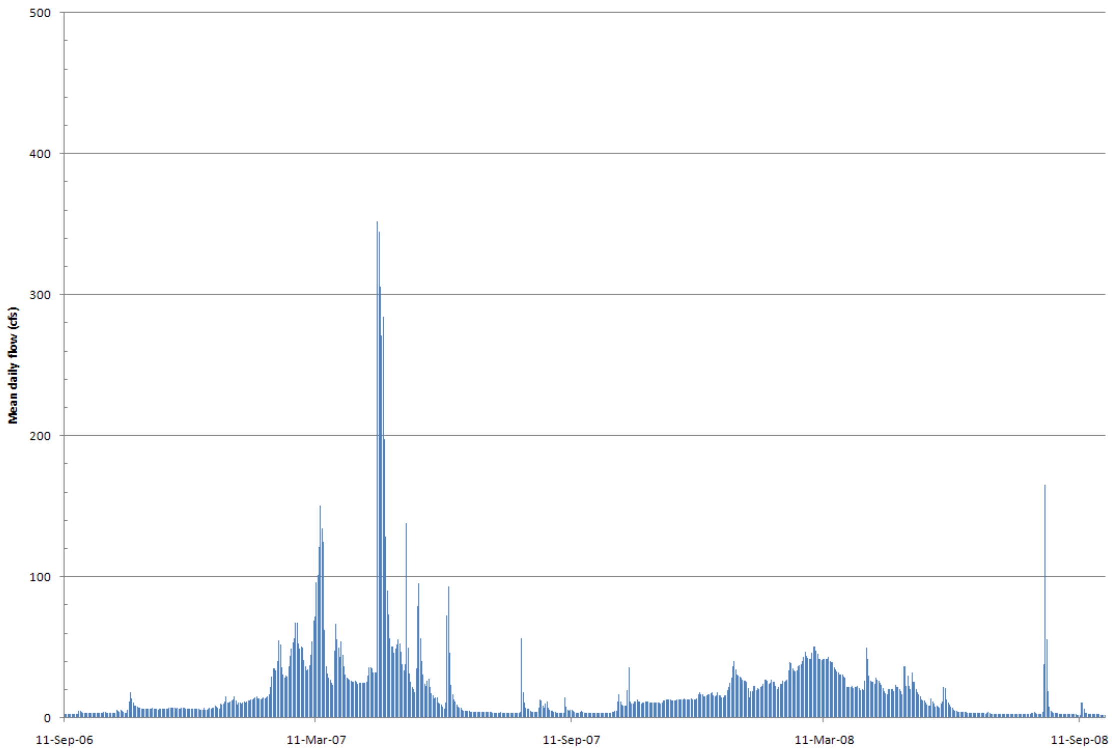


Figure 12. Mean daily flow time series 2006 to 2008

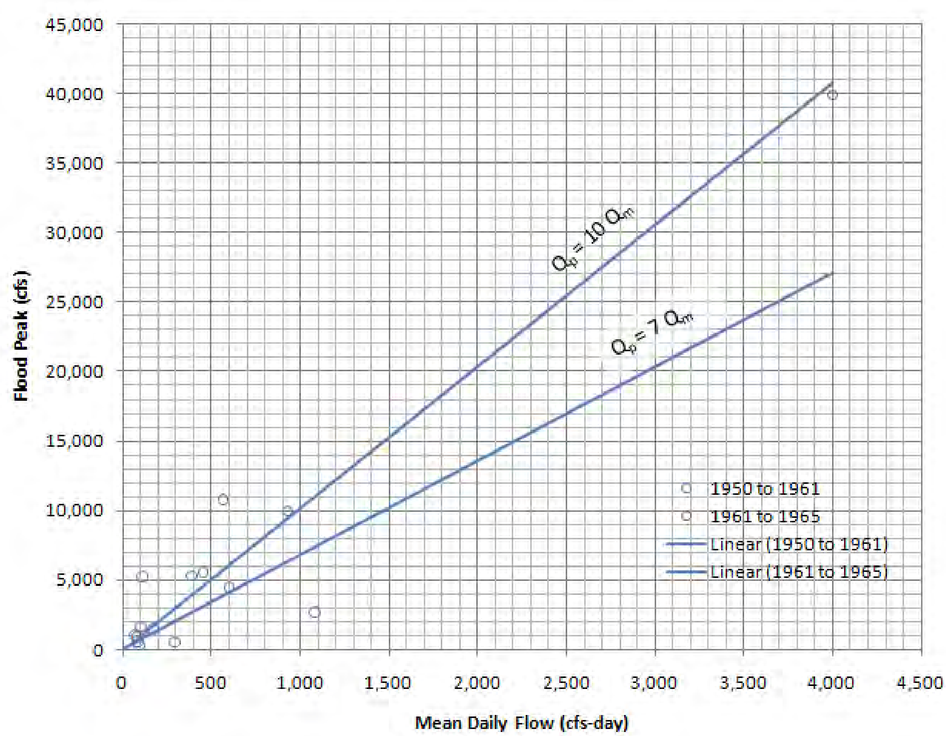


Figure 13. Comparison of Flood Volume (mean daily flow for day of flood event) and Flood Peak Flood peaks are roughly 7 to 10 times larger than the mean daily flow.

TERRAIN MODELS

LIDAR mapping was conducted for the Denver metropolitan area in the summer of 2008. Cross sections of the Cherry Creek valley were developed from aerial mapping in 2000 for an update to the FEMA flood insurance study and UDFCD Drainageway Master Planning. Other sources of topography include project plans and associated FEMA CLOMR submittals.

CHANNEL GEOMETRY

LONGITUDINAL SLOPE

The valley of the Cherry Creek falls nearly 200 feet through the study segment. The 2008 LIDAR mapping was used to evaluate the channel gradient. An isopach calculation was used to estimate channel gradient. An analysis surface was created which was a flat plane at a constant down-valley slope. This surface was then compared to the mapped terrain. The isopach showed a uniform channel width. The channel grade was assumed to equal the gradient of the analysis surface. This method of calculating stream gradient avoids uncertainly that is associated with finding the correct low-flow channel alignment and interpreting minor variations in the bed profile.

Table 5 summarizes the results of this analysis of longitudinal slopes for stream segments in the study segment.

Table 5. Longitudinal Slope of the Cherry Creek

Location	Gradient (ft/ft)
Reservoir perimeter road	
	0.0045
Caley Avenue	
	0.0040
Arapahoe Road	
	0.0035
Broncos Parkway	
	0.0040
Drop Structure (S of PJMD)	
	DTM Gap
Cottonwood Creek confluence	
	0.0040
Cottonwood Bridge	
	0.0040
Treatment Plant	
	0.0035
Pine Lane Bridge	

STREAM SECTIONS

The active sediment transporting width of the Cherry Creek channel was recorded during sediment sampling. Table 6 summarizes these field observations.

Table 6. Observed Active Channel Width

Site #1 (in State Park)	25.0 feet
Site #2 (at Valley Country Club)	41.0 feet
Site #3 (on Piney Creek)	19.5 feet
Site #4 (at Broncos Parkway)	21.0 feet
Site #5 (Happy Canyon Creek)	30.3 feet
Site #6 (above Broncos trailhead)	29.0 feet
Site #7 (above PJMD drop structure)	35.0 feet
Site #8 (at Pine Drive bridge)	10.0 feet

Conceptually the active channel of the Cherry Creek is located within fairly steep valley that has a narrow floodplain. Floodplain vegetation is typically riparian along the banks of the active channel with Cottonwood riparian forest communities on the remainder of the floodplain. Beyond the Cottonwood forest the plant community on sides of the valley is high plains upland grasses. Urban development is outside of the 100-year flood hazard zone and several hundred feet from the active channel of the Cherry Creek.

ALLUVIAL SEDIMENT GRADATIONS

Alluvial sediments of the Cherry Creek were sampled at ten locations in the study segment. (for locations and site photos see Appendix A). Six samples were taken from the stream bed of the Cherry Creek, two samples were taken from the stream bed of each of the tributaries, and two were taken from the stream banks near bed sampling location for the Cherry Creek. Detailed gradation analysis is given in Appendix B.

BED MATERIAL

Sediment samples taken from the stream bed show that the Cherry Creek sediments conform well to a log-normal type gradation with slight deviation from the distribution for the smallest and largest sizes. This indicates a uniform sorting of all sediment sizes with little lag or armoring by larger sizes or hiding of smaller grain sizes. Table 7 summarizes the gradation properties.

Table 7. Alluvial Sediment Properties - Cherry Creek

Sample	G	$D_{15.1}$ (mm)	D_{50} (mm)	$D_{84.9}$ (mm)	Sample Location
2	1.8	0.51	0.93	1.69	Piney Creek
1	2.3	0.54	1.25	2.89	
3	2.3	0.47	1.09	2.54	Cherry Creek
4	2.2	0.47	1.04	2.32	
5	2.1	0.44	0.92	1.91	Happy Canyon Creek
6	2.2	0.72	1.55	3.36	
7	3.4	0.58	1.95	6.62	Cherry Creek
8	3.1	0.61	1.90	5.88	

Sediment properties are fairly uniform for much of the Cherry Creek with the 17 Mile House drop structure separating a difference in sediment properties. Table 8 shows averages of sediment properties for stream reaches. These distributions are plotted in Figure 14 along with data from Table 8.

Table 8. Average Properties of Alluvial Sediments

Sample	G	$D_{15.1}$ (mm)	D_{50} (mm)	$D_{84.9}$ (mm)	Reach
2	1.8	0.51	0.93	1.69	Piney Cr.
1 3 4 5 6	2.2	0.53	1.17	2.60	Cherry Cr. below 17 Mile House Drop Structure and Happy Canyon Cr.
7 8	3.2	0.60	1.93	6.25	Cherry Cr. above 17 Mile House Drop Structure

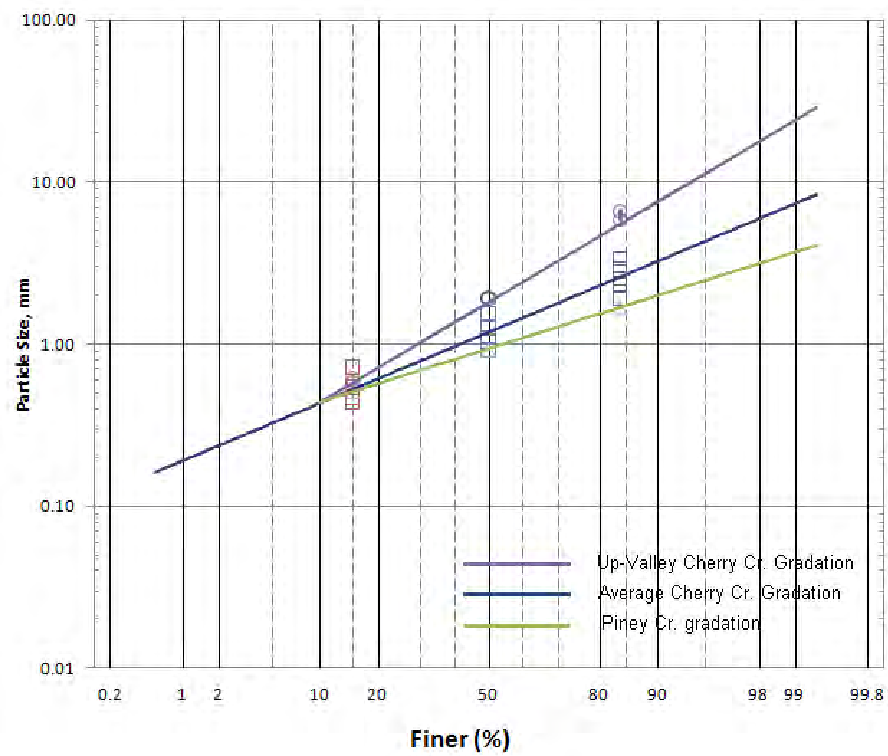


Figure 14. Cherry Creek Bed Material Sediment Gradations

BANK MATERIAL

Sediment samples taken from the stream bank show that the Cherry Creek sediments tend to be finer grained although not silty. Table 9 summarizes the gradation properties. Samples 6, TH-1 and TH-4 show the range of valley alluvium sediments. In the State Park, alluvial sediments are finer grained because of a wider outcrop of loess formation that overlies the valley alluvium. Samples 1 and TH-2 are probably typical of the loess soil found in the State Park. Up valley from Piney Creek the loess outcrop is narrower and has less influence on the gradation of the valley alluvium.

Table 9. Alluvial Sediment Properties - Cherry Creek

Sample	G	$D_{15.1}$ (mm)	D_{50} (mm)	$D_{84.9}$ (mm)	Sample Location
1	2.8	n/a	0.22	0.62	Cherry Creek (GKCC Samples)
6	3.1	0.31	0.96	2.92	
TH-1	3.7	0.2	0.55	2.6	Cherry Creek (CH2M Hill Samples)
TH-2	2.8	0.085	0.26	0.65	
TH-4	2.2	0.36	0.75	1.8	

RESERVOIR SEDIMENTATION

The U.S. Army Corps of Engineers Omaha District has conducted six reservoir capacity depletion surveys at approximately 10 year intervals since the reservoir was completed in 1950. The first two surveys coincide with flow records from the Melvin gage. There are no inflow gage records for reservoir capacity surveys conducted in 1974 and 1988. The two most recent reservoir capacity surveys in 1997 and 2008 appear to have survey errors and data has not been verified by the Omaha District. Table 10 summarizes USACE Omaha District depletion survey data.

Table 10. Cherry Creek Reservoir Capacity Depletion Surveys

Date of Survey	Period (years)	Depletion (ac-ft)
1-Apr-1950		
24-Apr-1961	11.15	862
17-Aug-1965	4.24	1406
11-Jul-1974	8.90	1056
15-Jul-1988	13.94	698
1-Sep-1997	9.22	Errors in survey
1-Sep-2008	11.00	Errors in survey

CHANNEL EROSION

In September 2006, work on the 17 Mile House stream reclamation project was completed. The downstream limit of this project includes a sheet pile drop structure (Figure 15). Following construction the channel downstream of the drop structure to approximately Broncos Parkway scoured. The scour was recorded by aerial LIDAR mapping that was conducted in 2008. The volume of scour was measured by isopach calculation (the analysis surface was a uniformly sloping plane at 0.0040 ft/ft). Table 11 summarizes the results of the isopach calculations. The depth of scour is fairly clear in the field at 4.0. But since this observation is approximate the isopach calculation was also bracketed at $\pm$ 1.0 foot.

Table 11. Channel Scour

Date of Survey	Period (years)	Scour Vol. (ac-ft)	Scour Depth (ft)
11-Sep-2006			
30-Sep-2008	2.05	**14.4**	**4.0**
		8.7	3.0
		21.5	5.0

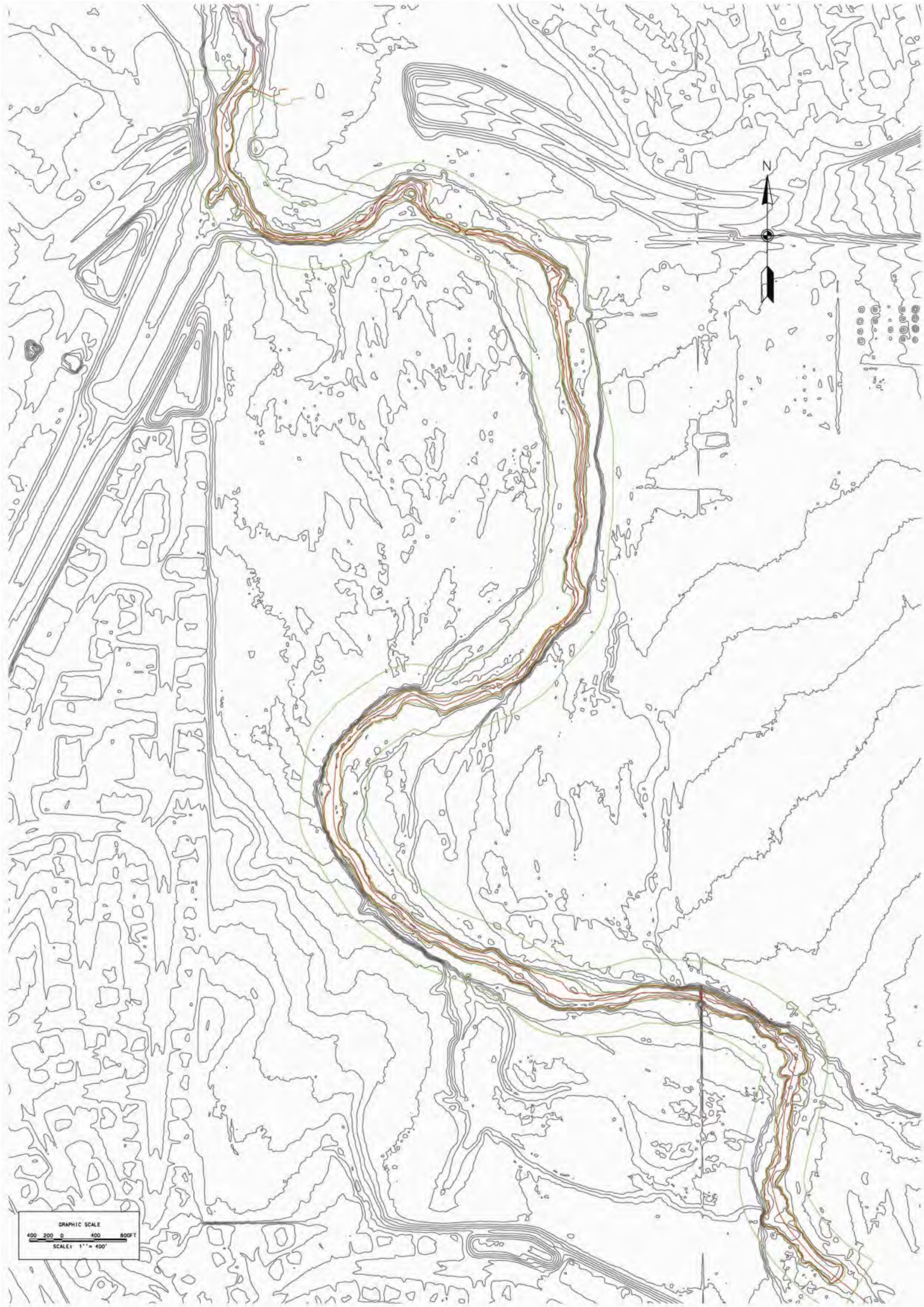


Figure 15. Isopach of channel erosion 17 Mile House Drop Structure to Broncos Parkway (green boundary is the analysis surface and brown contours are for the isopach surface).

1985 BRW-WRC, FEASIBILITY STUDY FOR THE CHERRY CREEK BASIN DRAINAGEWAY

Figure 2. "Project Area Map" shows existing topography and property boundaries for lands north of Douglas County line to Arapahoe Road.

Figure 3. "Cherry Creek / River Morphology" shows an overlay of the 1937 and 1983 stream alignments at a scale of 1" to 400'.

Figure 5. "Sedimentation Data" presents 18 stage-discharge relationships for the Melvin gage and gradations of sediment samples for the study reach. Three samples are plotted with very similar distributions. Graphically the following sediment sizes can be read from the chart: D_{15} = 0.35 mm D_{50} = 0.6 mm and D_{85}= 1.5 mm with a gradation coefficient of G = 1.9.

2001 ACE-OMAHA, TRI-LAKES SEDIMENT STUDIES

Plate V-1. "Cherry Creek Reservoir Sedimentation Ranges" shows the locations of range monuments.

Table V-2. Summarizes reservoir volume depletion according to survey period.

2002 URS, CHERRY CREEK RESERVOIR TO SCOTT ROAD MAJOR DRAINAGEWAY PLANNING STUDY

Table 5-1. "Geomorphic Characteristics" tabulates channel grade, average low-flow channel width, average low-flow channel depth, average bankfull channel width, and average bankfull channel depth.

Table 5-2. "Geomorphic Conditions by Reach" tabulates reach grade, channel conditions, bank erosion, dominant stream form and Rosgen classification.

2006 TETRA TECH, DESIGN OF THE CHERRY CREEK SEDIMENT BASIN AND STABILIZATION MEASURES

Table 1. "Comparison of Sediment Loading" tabulates estimates of sediment loading rates Cherry Creek reservoir from previous completed studies, including USACE 2001, BRW-WRC 1985, and Ruzzo 2005.

2006 MULLER, CHERRY CREEK OPEN SPACE RESTORATION PROJECT

Sheet 2. "General Notes, Legend and Boring Logs" provides eight boring logs

Sheet 7. "Primary Channel Profile" shows existing and constructed channel profiles.

Photos 7 through 12. Sequence of aerial photos of the 12-Mile Park study area (December 1937, December 1955, June 1993, September 1999, December 2004, and July 2007).

Appendix A. "Geotechical Report" Includes 5 streambed samples through the study area. Sample locations are shown in Figure 1 and bed material gradations are plotted in figures 5 to 7. Three of these samples have a high fraction of fine sands (TH-1, TH-2 and TH-4).

Sample	G	D_{15} (mm)	D_{50} (mm)	D_{85} (mm)
TH-1	3.7	0.2	0.55	2.6
TH-2	2.8	0.085	0.26	0.65
TH-3	2.7	0.4	1.1	3.0
TH-4	2.2	0.36	0.75	1.8
TH-5	2.5	0.5	1.3	3.1

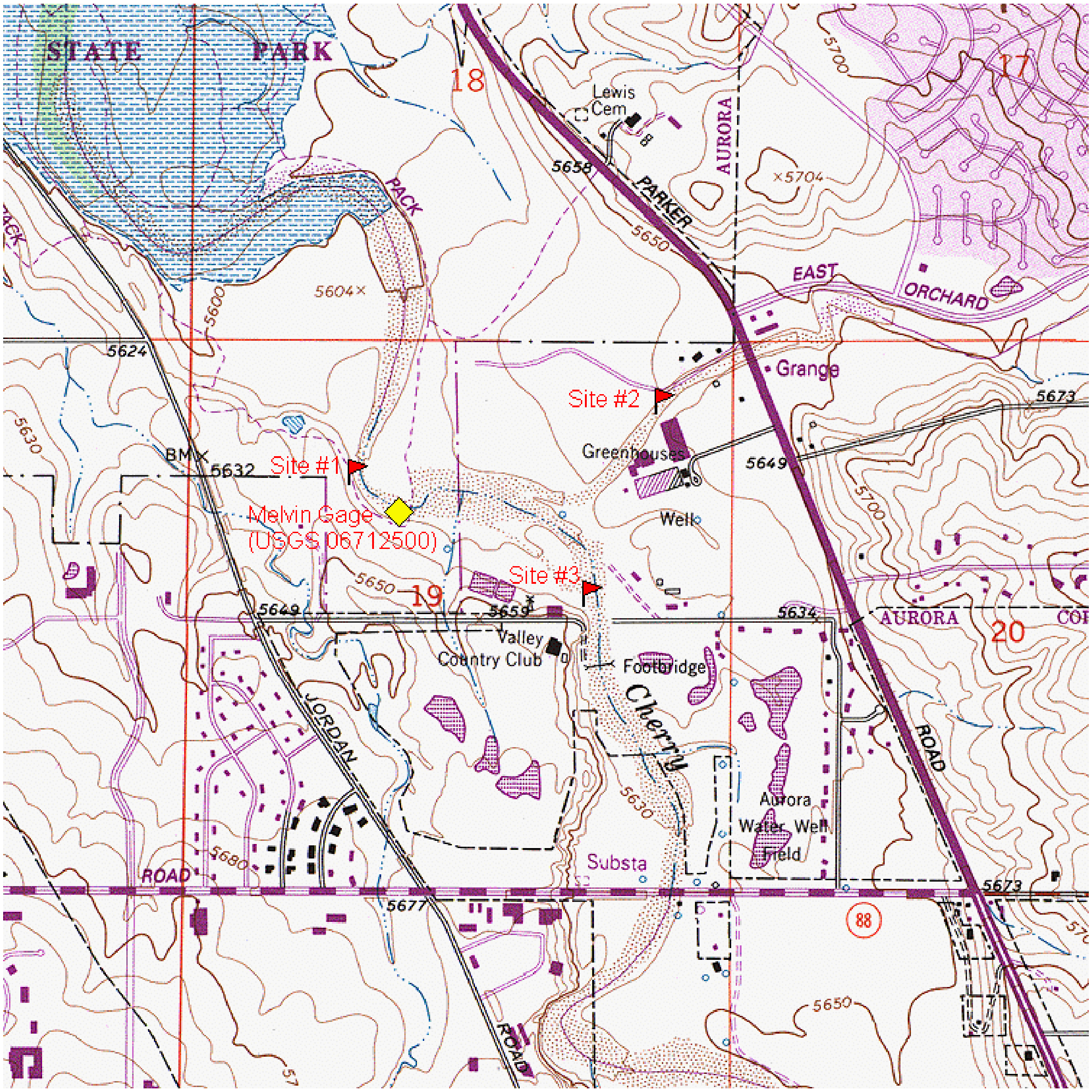


Figure 16. Location of Sediment sampling sites 1, 2 and 3.

Figure 17. Site #1 – Stream bed material sample in Cherry Creek State Park

Figure 18. Site #1 – Bank material sample (left bank)

Figure 19. Site #2– Stream bed material sample near E. Caley Avenue at Valley Country Club

Figure 20. Site #3 – Stream bed material sample on Piney Creek at Fraser Street

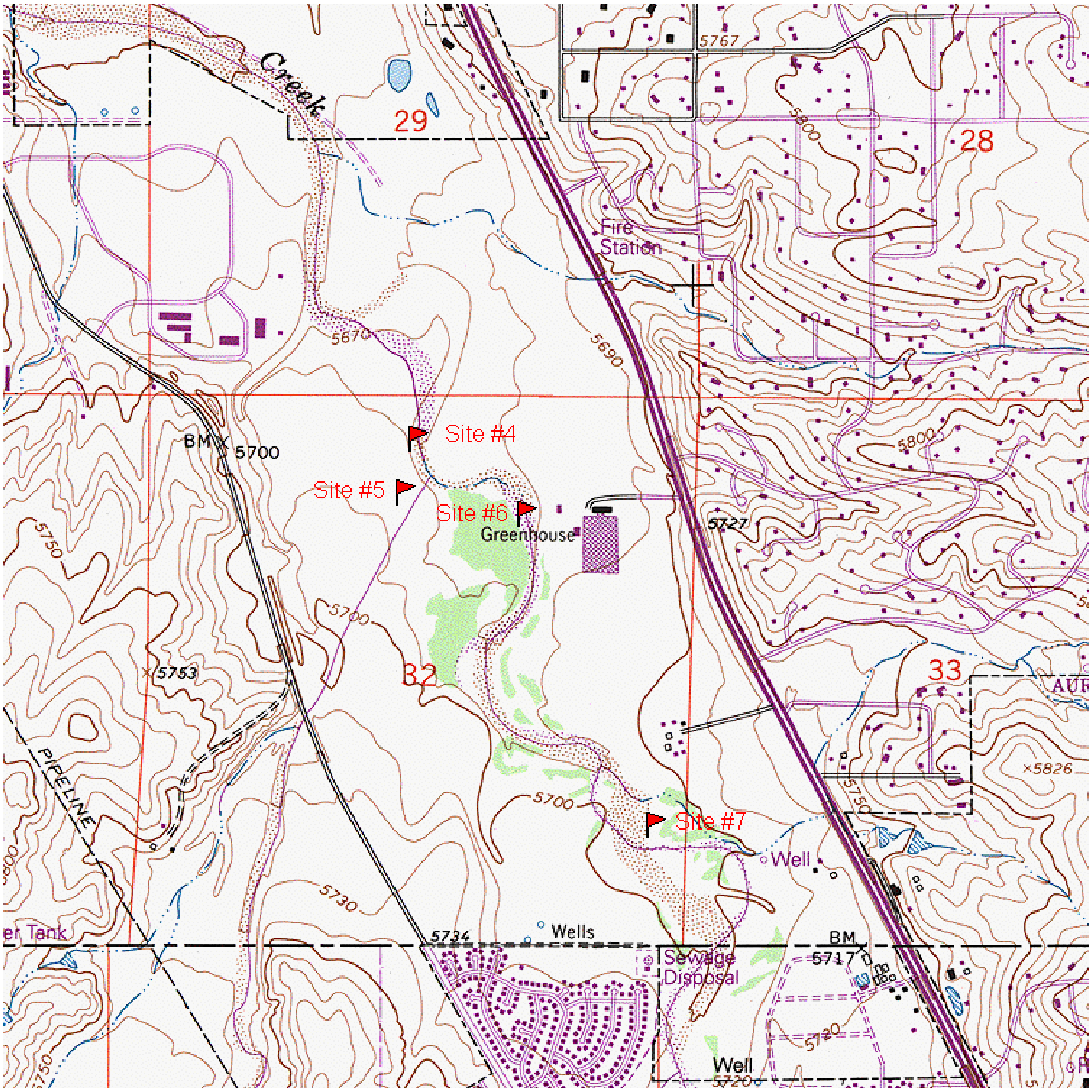


Figure 21. Location of Sediment sampling sites 4, 5, 6 and 7.

Figure 22. Site #4 – Stream bed material sample at Broncos Parkway

Figure 23. Site #5 – Stream bed material sample at Cherry Creek Trail on Happy Canyon Creek

Figure 24. Site #6 – Stream bed material sample near Tagawa Garden Center

Figure 25. Site #6 – Bank material sample near Tagawa Garden Center. Note that three strata have been exposed by recent lowering of the Cherry Creek channel. The upper layer was probably the stream bed prior to 2006, the center layer may be associated with the 1965 flood, and the lower strata are older valley sediments.

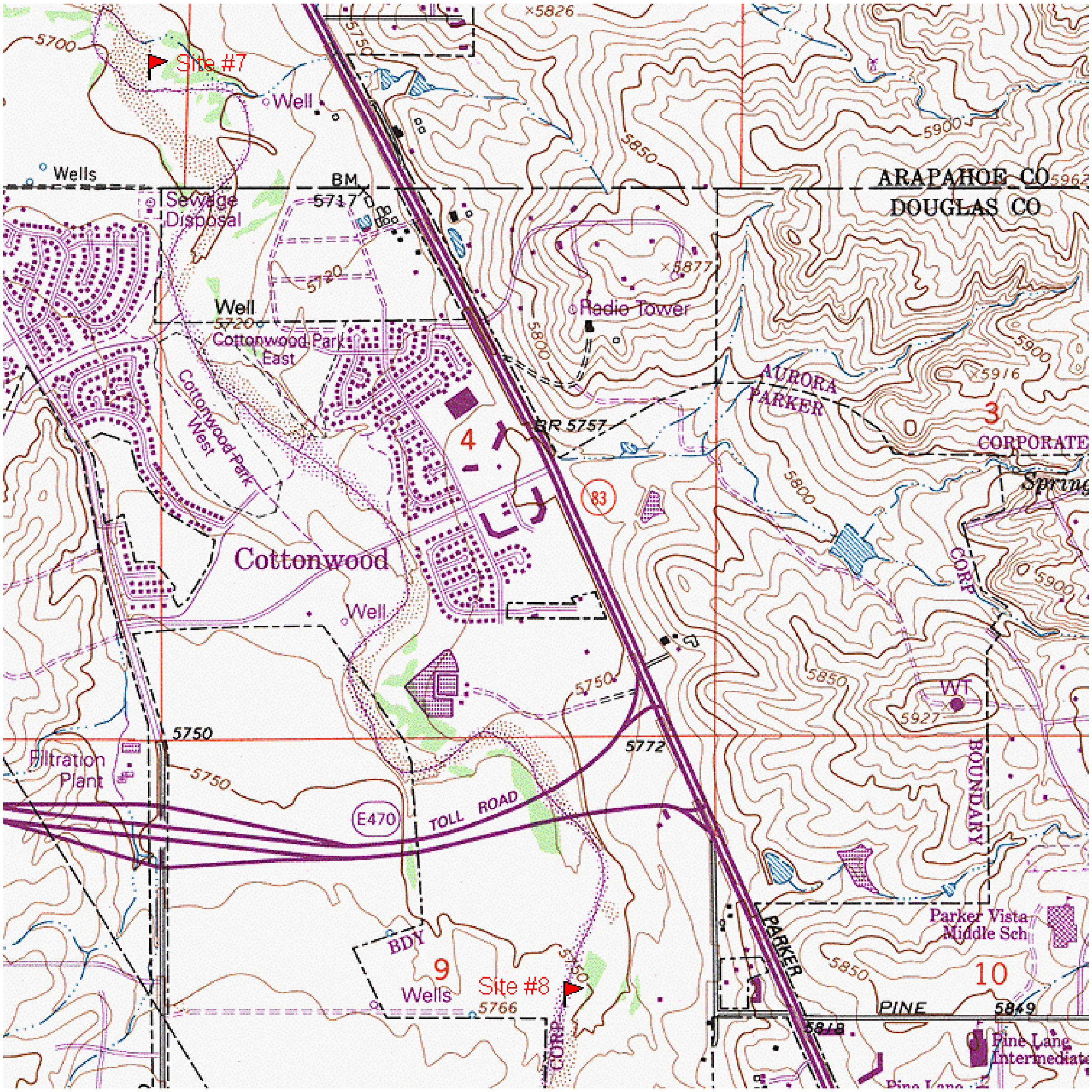


Figure 26. Location of Sediment sampling sites 7 and 8.

Figure 27. Site #7 – Stream bed material sample upstream of Cherry Creek Trail drop structure (south boundary of Parker-Jordan Metro District property).

Figure 28. Site #8 – Stream bed material sample downstream of Pine Lane bridge

APPENDIX B. CHANNEL SEDIMENT SAMPLES

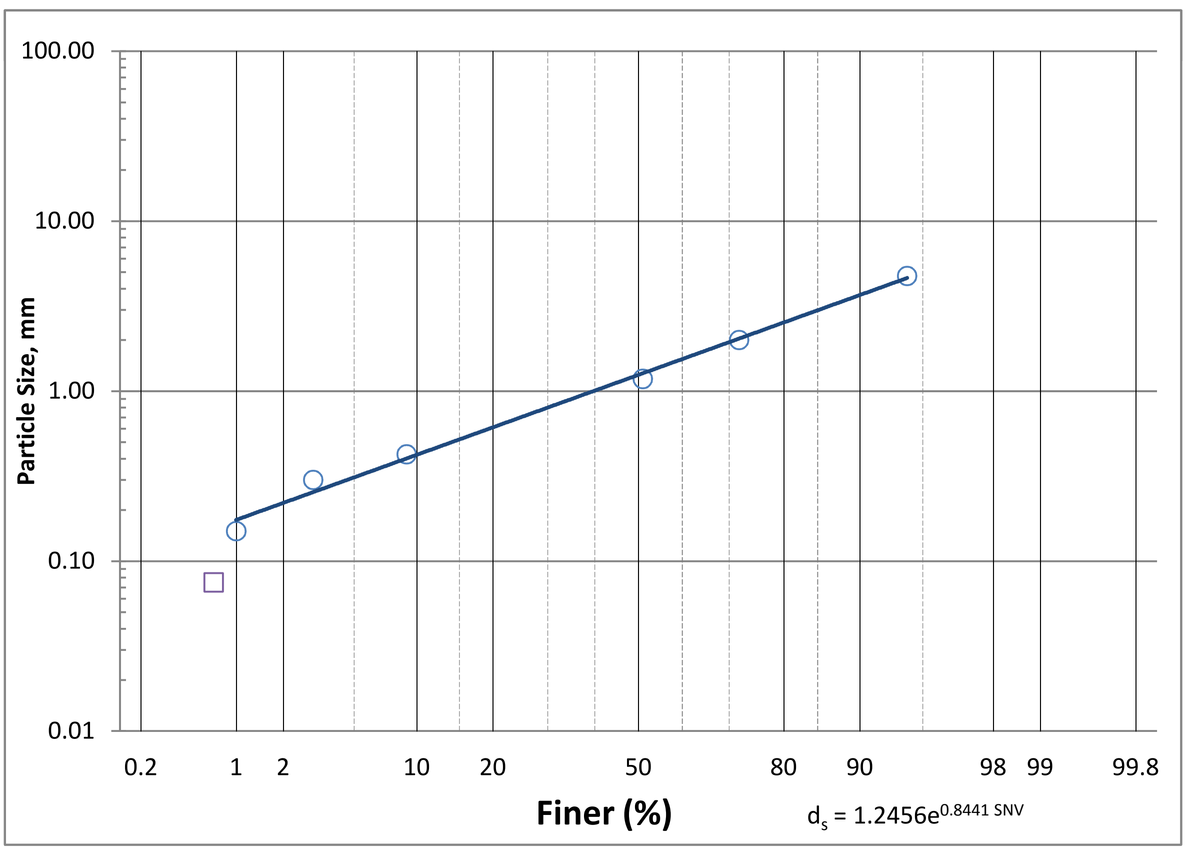
Grain Size Distribution

Description: Cherry Creek Sedimentation Study, Gradation Testing
Sample Location: **#1 - Bed Cherry Creek**
Testing by: Ground Engineering Consultants
Last revised: 16/Nov/2010
Printed: 19/Nov/10 9:37

Gradation Attributes:

Gradation Coef, G =	2.3				
d_{50} =	1.25	mm	d_{90} =	3.67	mm
$d_{84.1}$ =	2.89	mm	d_{65} =	1.72	mm
$d_{15.9}$ =	0.54	mm	d_{02} =	0.22	mm

Sieve Size (opening)	Particle Size, d (mm)	Fraction Finer	SNV
2.0	50.0	1.000	
1.5	37.5	1.000	
1.0	25.0	1.000	
0.75	19.0	1.000	
0.50	12.5	1.000	
0.375	9.5	1.000	
#4	4.75	0.940	1.555
#10	2.00	0.720	0.583
#16	1.18	0.510	0.025
#40	0.425	0.090	-1.341
#50	0.300	0.030	-1.881
#100	0.150	0.010	-2.326
#200	0.075	0.007	-2.457



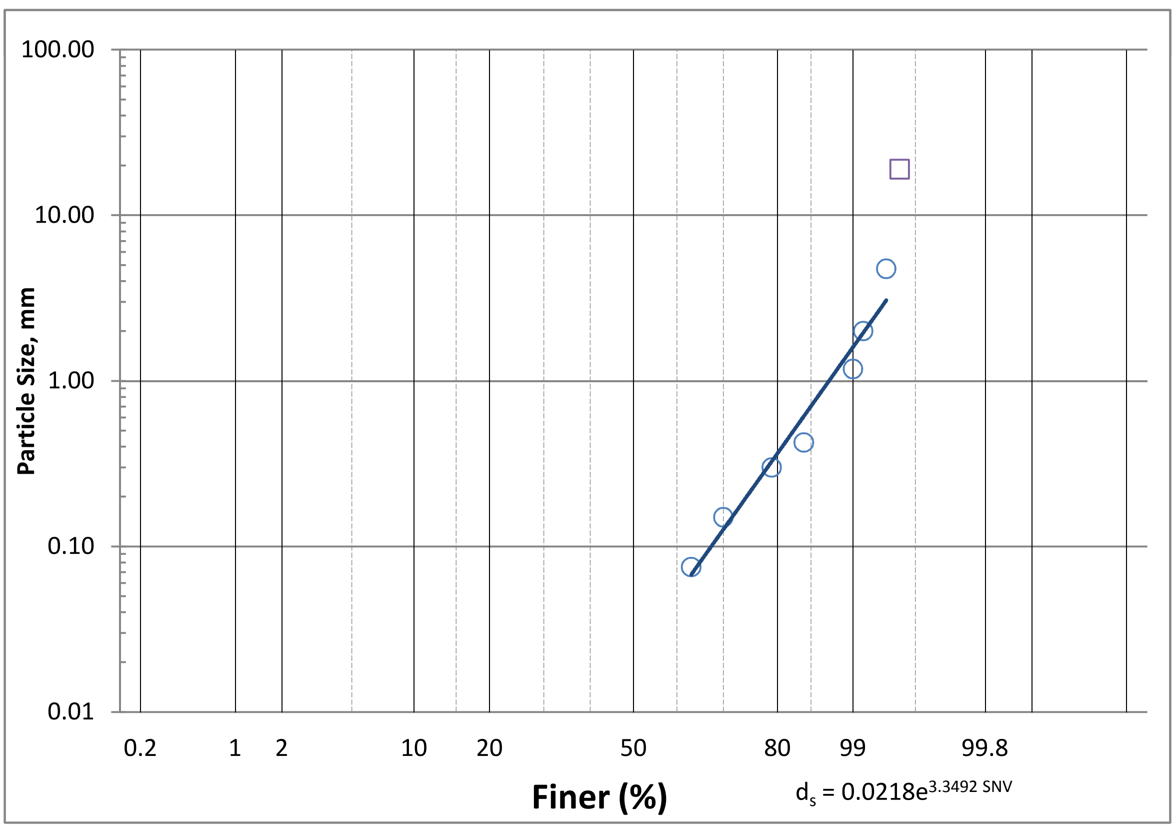
Grain Size Distribution

Description: Cherry Creek Sedimentation Study, Gradation Testing
Sample Location: **#1 - Bank Cherry Creek**
Testing by: Ground Engineering Consultants
Last revised: 16/Nov/2010
Printed: 19/Nov/10 9:37

Gradation Attributes:

Gradation Coef, G =	27.8	
d_{50} =	0.022	mm
$d_{84.1}$ =	0.62	mm
$d_{15.9}$ =	0.00	mm

Sieve Size (opening)	Particle Size, d (mm)	Fraction Finer	SNV
2.0	50.0	1.000	
1.5	37.5	1.000	
1.0	25.0	1.000	
0.75	19.0	0.940	1.555
#4	4.75	0.930	1.476
#10	2.00	0.910	1.341
#16	1.18	0.900	1.282
#40	0.425	0.840	0.994
#50	0.300	0.790	0.806
#100	0.150	0.700	0.524
#200	0.075	0.632	0.337



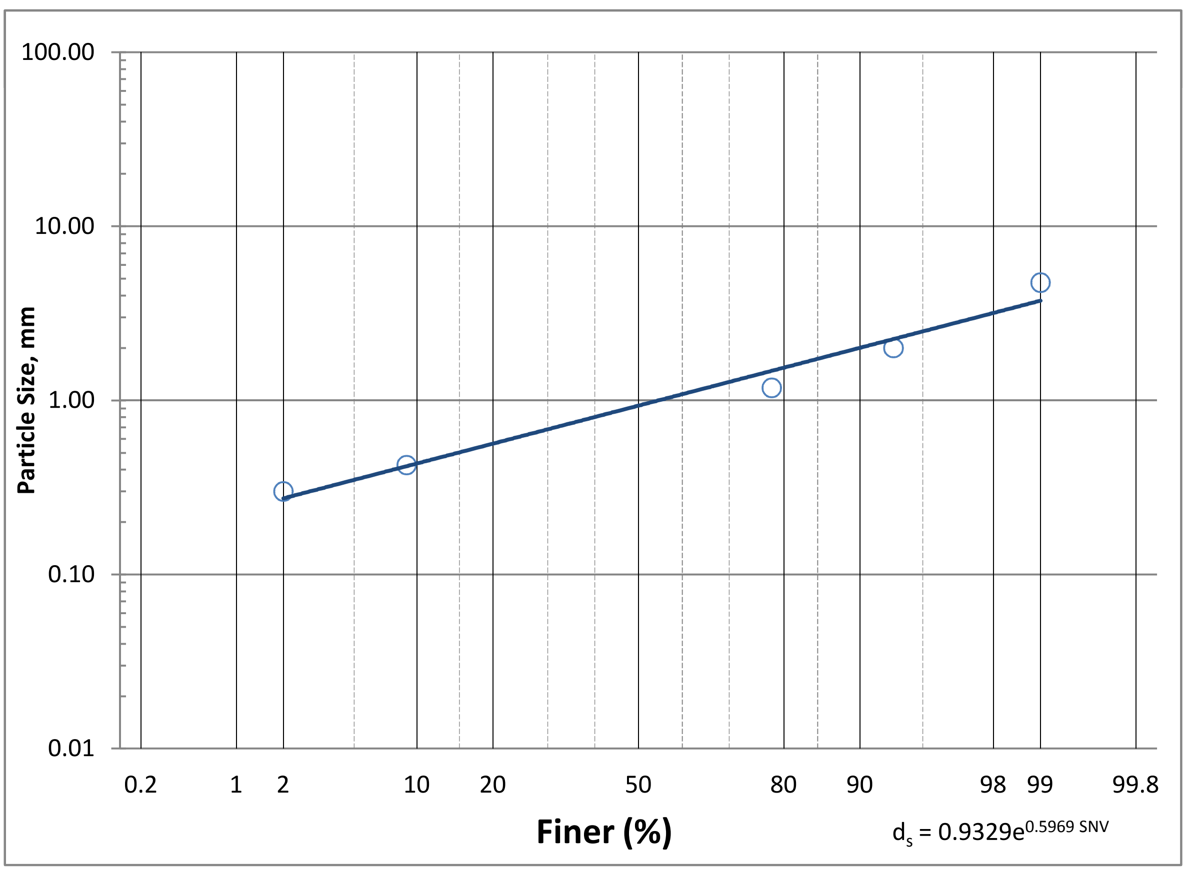
Grain Size Distribution

Description: Cherry Creek Sedimentation Study, Gradation Testing
Testing by: Ground Engineering Consultants
Sample Location: **#2 - Bed Piney Creek**
Last revised: 16/Nov/2010
Printed: 19/Nov/10 9:37

Gradation Attributes:

Gradation Coef, G =	1.8				
d_{50} =	0.93	mm	d_{90} =	2.00	mm
$d_{84.1}$ =	1.69	mm	d_{65} =	1.17	mm
$d_{15.9}$ =	0.51	mm	d_{02} =	0.27	mm

Sieve Size (opening)	Particle Size, d (mm)	Fraction Finer	SNV
2.0	50.0	1.000	
1.5	37.5	1.000	
1.0	25.0	1.000	
0.75	19.0	1.000	
0.50	12.5	1.000	
0.375	9.5	1.000	
#4	4.75	0.990	2.326
#10	2.00	0.930	1.476
#16	1.18	0.780	0.772
#40	0.425	0.090	-1.341
#50	0.300	0.020	-2.054
#200	0.075	0.001	-3.090



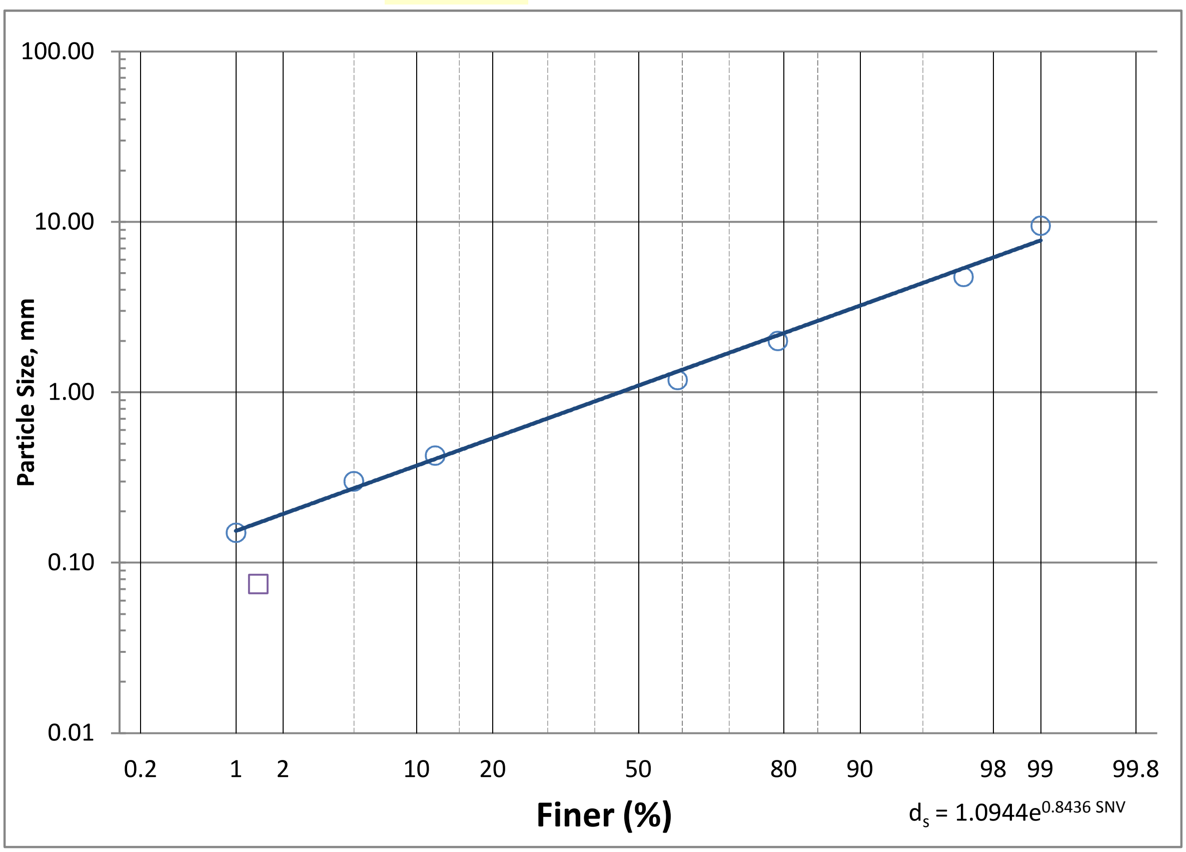
Grain Size Distribution

Description: Cherry Creek Sedimentation Study, Gradation Testing
Sample Location: **#3 - Bed Cherry Creek**
Testing by: Ground Engineering Consultants
Last revised: 16/Nov/2010
Printed: 19/Nov/10 9:37

Gradation Attributes:
Gradation Coef, G = 2.3

d_{50} =	1.09	mm	d_{90} =	3.23	mm
$d_{84.1}$ =	2.54	mm	d_{65} =	1.51	mm
$d_{15.9}$ =	0.47	mm	d_{02} =	0.19	mm

Sieve Size (opening)	Particle Size, d (mm)	Fraction Finer	SNV
2.0	50.0	1.000	
1.5	37.5	1.000	
1.0	25.0	1.000	
0.75	19.0	1.000	
0.50	12.5	1.000	
0.375	9.5	0.990	2.326
#4	4.75	0.970	1.881
#10	2.00	0.790	0.806
#16	1.18	0.590	0.228
#40	0.425	0.120	-1.175
#50	0.300	0.050	-1.645
#100	0.150	0.010	-2.326
#200	0.075	0.014	-2.197



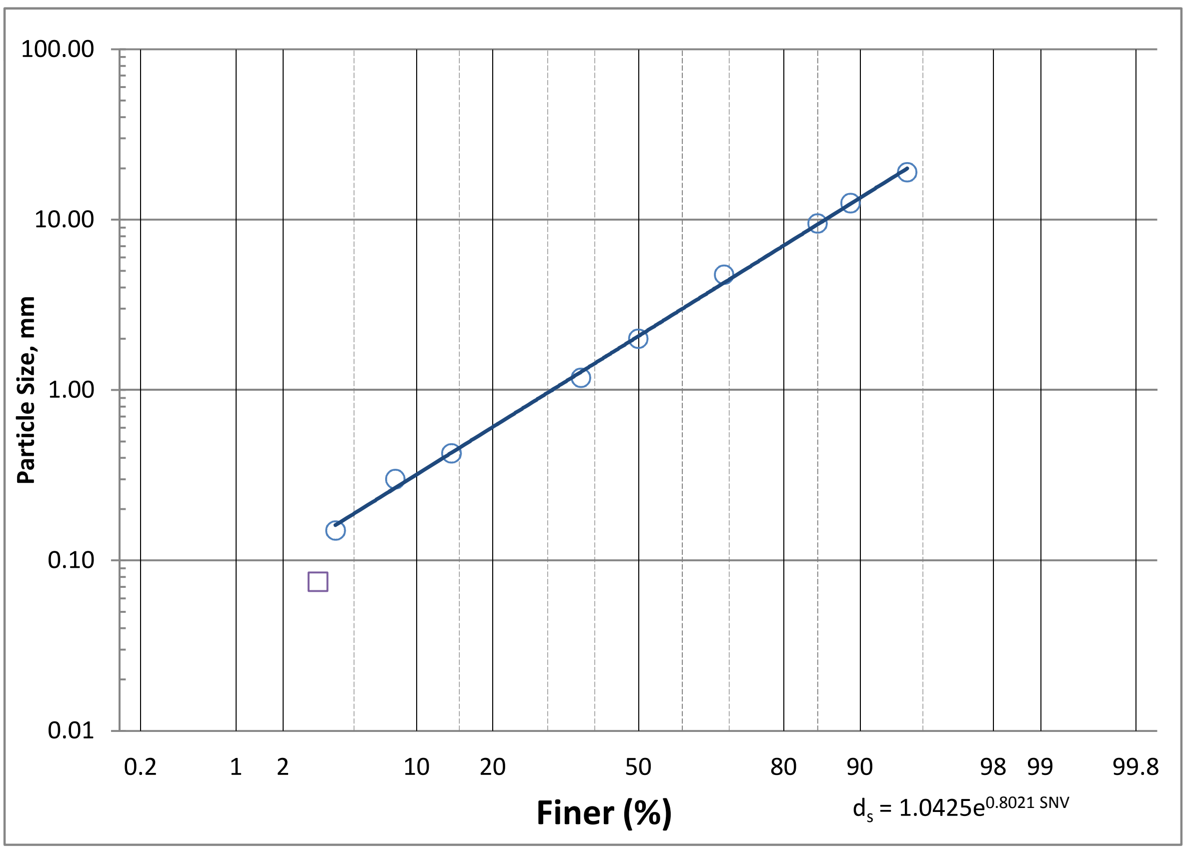
Grain Size Distribution

Description: Cherry Creek Sedimentation Study, Gradation Testing
Sample Location: **#4 - Bed Cherry Creek**
Testing by: Ground Engineering Consultants
Last revised: 16/Nov/2010
Printed: 19/Nov/10 9:37

Gradation Attributes:
Gradation Coef, G = 2.2

d_{50} =	1.04	mm	d_{90} =	2.91	mm
$d_{84.1}$ =	2.32	mm	d_{65} =	1.42	mm
$d_{15.9}$ =	0.47	mm	d_{02} =	0.20	mm

Sieve Size (opening)	Particle Size, d (mm)	Fraction Finer	SNV
2.0	50.0	1.000	
1.5	37.5	1.000	
1.0	25.0	1.000	
0.75	19.0	0.940	1.555
0.50	12.5	0.890	1.227
0.375	9.5	0.850	1.036
#4	4.75	0.690	0.496
#10	2.00	0.500	0.000
#16	1.18	0.370	-0.332
#40	0.425	0.140	-1.080
#50	0.300	0.080	-1.405
#100	0.150	0.040	-1.751
#200	0.075	0.032	-1.852



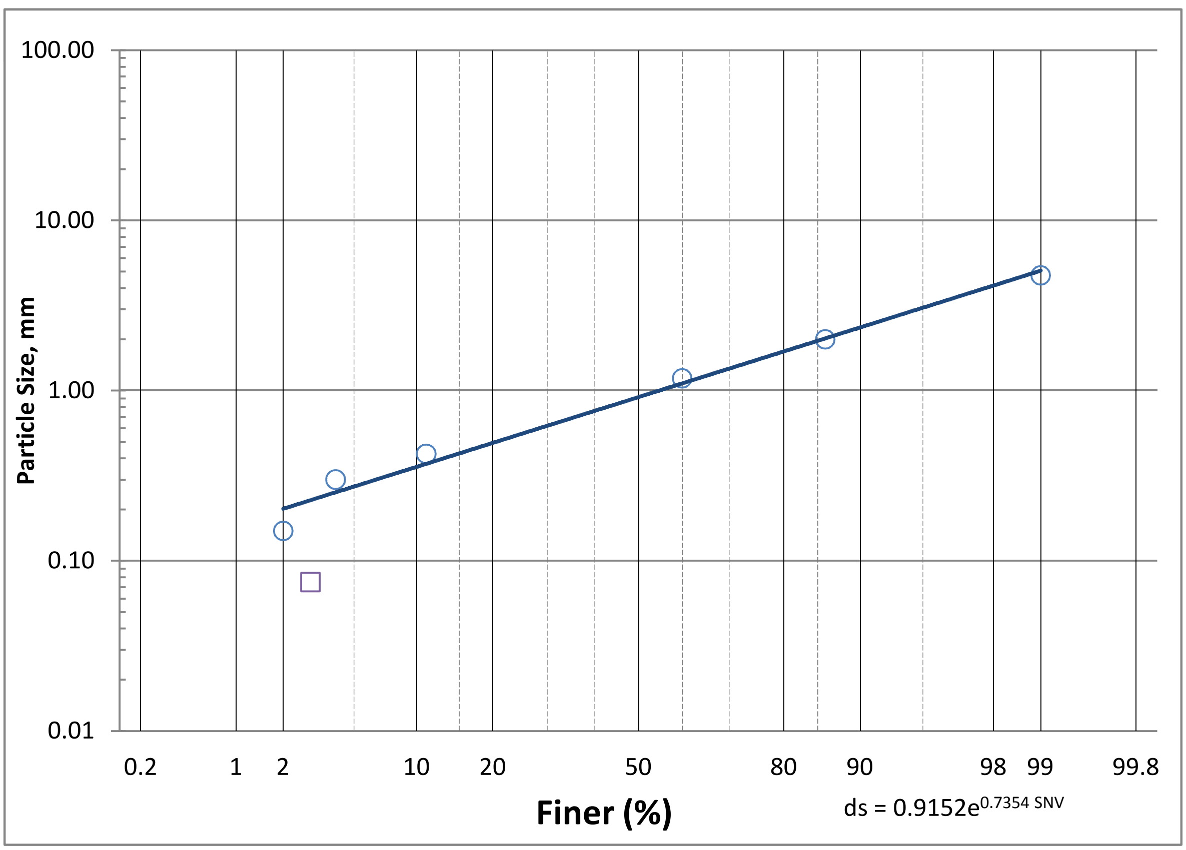
Grain Size Distribution

Description: Cherry Creek Sedimentation Study, Gradation Testing
Sample Location: **#5 - Happy Canyon Creek**
Testing by: Ground Engineering Consultants
Last revised: 16/Nov/2010
Printed: 19/Nov/10 9:37

Gradation Attributes:
Gradation Coef, G = 2.1

d_{50} =	0.92	mm	d_{90} =	2.35	mm
$d_{84.1}$ =	1.91	mm	d_{65} =	1.22	mm
$d_{15.9}$ =	0.44	mm	d_{02} =	0.20	mm

Sieve Size (opening)	Particle Size, d (mm)	Fraction Finer	SNV
2.0	50.0	1.000	
1.5	37.5	1.000	
1.0	25.0	1.000	
0.75	19.0	1.000	
0.50	12.5	1.000	
0.375	9.5	1.000	
#4	4.75	0.990	2.326
#10	2.00	0.860	1.080
#16	1.18	0.600	0.253
#40	0.425	0.110	-1.227
#50	0.300	0.040	-1.751
#100	0.150	0.020	-2.054
#200	0.075	0.029	-1.896



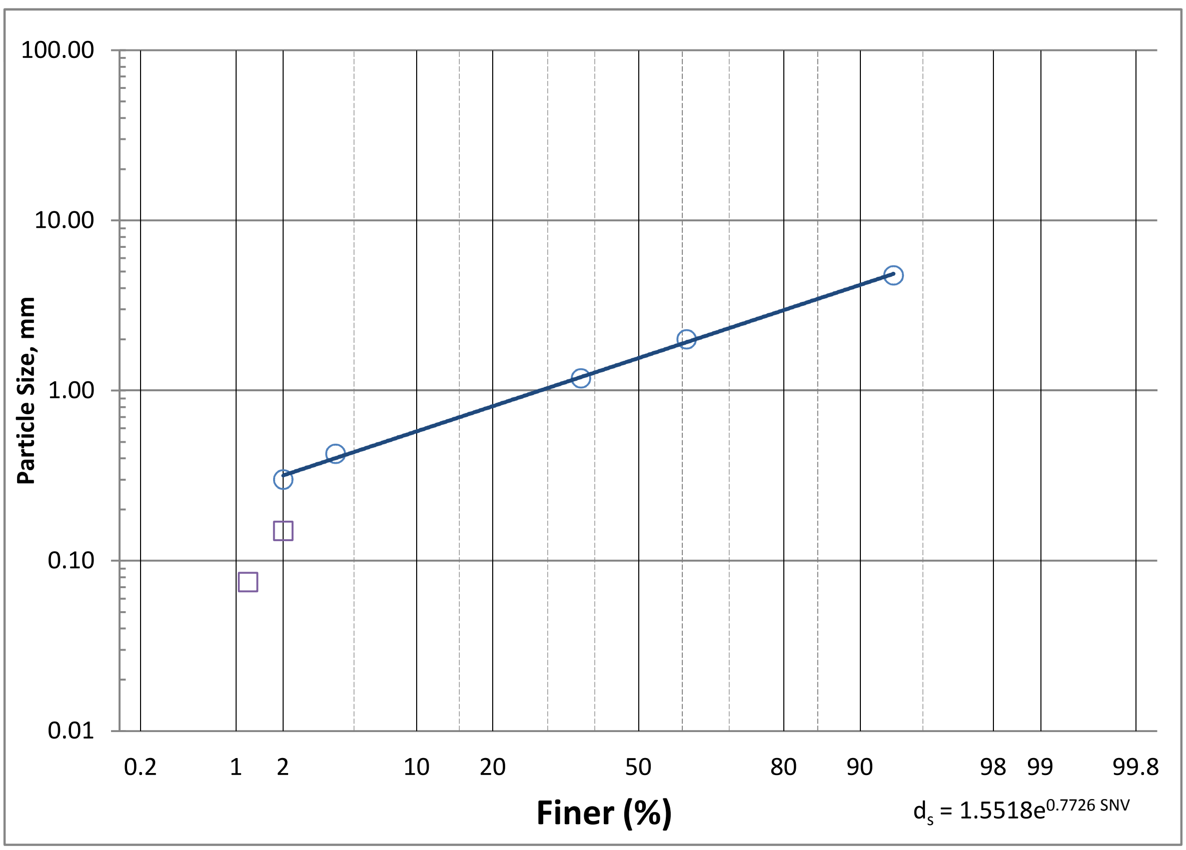
Grain Size Distribution

Description: Cherry Creek Sedimentation Study, Gradation Testing
Sample Location: **#6 - Bed Cherry Creek**
Testing by: Ground Engineering Co
Last revised: 16/Nov/2010
Printed: 19/Nov/10 9:37

Gradation Attributes:
Gradation Coef, G = 2.2

d_{50} =	1.55	mm	d_{90} =	4.18	mm
$d_{84.1}$ =	3.36	mm	d_{65} =	2.09	mm
$d_{15.9}$ =	0.72	mm	d_{02} =	0.32	mm

Sieve Size (opening)	Particle Size, d (mm)	Fraction Finer	SNV
2.0	50.0	1.000	
1.5	37.5	1.000	
1.0	25.0	1.000	
0.75	19.0	1.000	
0.50	12.5	1.000	
0.375	9.5	1.000	
#4	4.75	0.930	1.476
#10	2.00	0.610	0.279
#16	1.18	0.370	-0.332
#40	0.425	0.040	-1.751
#50	0.300	0.020	-2.054
#100	0.150	0.020	-2.054
#200	0.075	0.012	-2.257



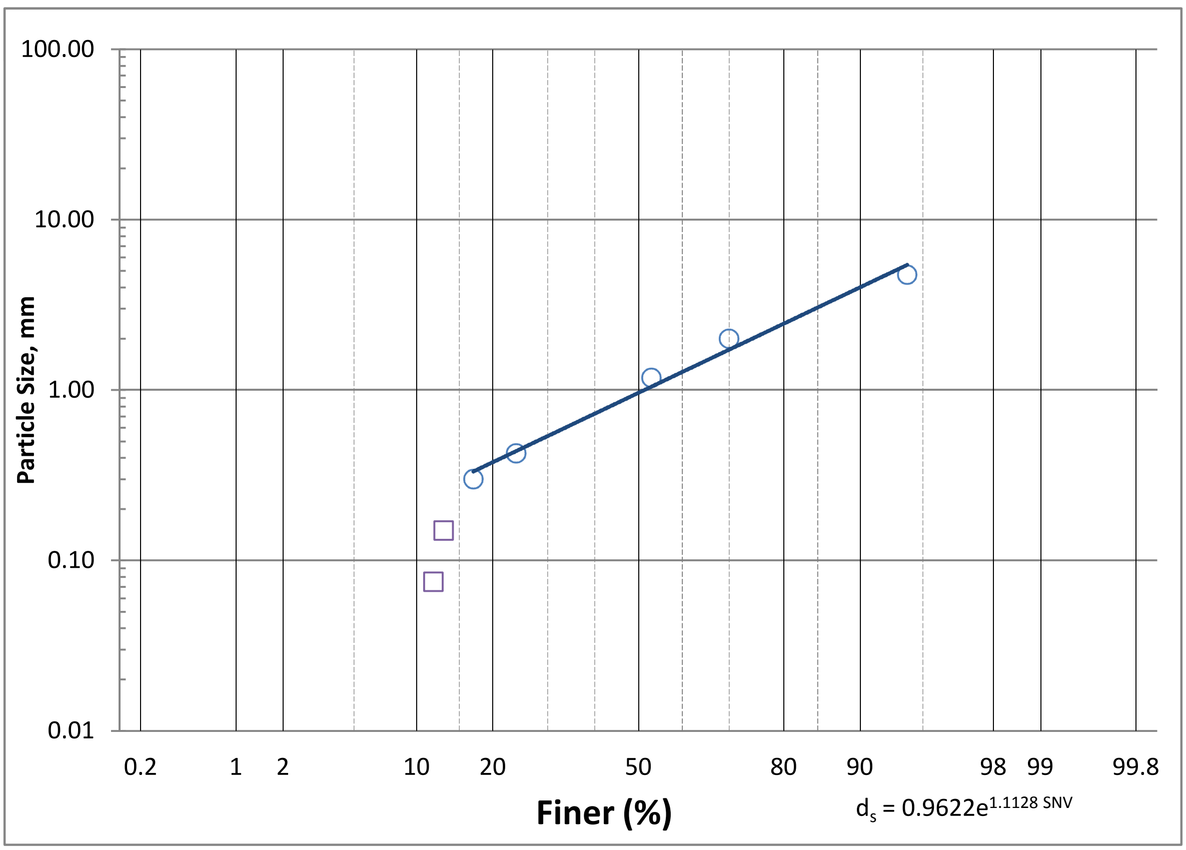
Grain Size Distribution

Description: Cherry Creek Sedimentation Study, Gradation Testing
Sample Location: **#6 - Bank Cherry Creek**
Testing by: Ground Engineering Consultants
Last revised: 16/Nov/2010
Printed: 19/Nov/10 9:37

Gradation Attributes:
Gradation Coef, G = 3.0

d_{50} =	0.96	mm	d_{90} =	4.01	mm
$d_{84.1}$ =	2.92	mm	d_{65} =	1.48	mm
$d_{15.9}$ =	0.32	mm	d_{02} =	0.10	mm

Sieve Size (opening)	Particle Size, d (mm)	Fraction Finer	SNV
2.0	50.0	1.000	
1.5	37.5	1.000	
1.0	25.0	1.000	
0.75	19.0	1.000	
0.50	12.5	1.000	
0.375	9.5	1.000	
#4	4.75	0.940	1.555
#10	2.00	0.700	0.524
#16	1.18	0.530	0.075
#40	0.425	0.240	-0.706
#50	0.300	0.170	-0.954
#100	0.150	0.130	-1.126
#200	0.075	0.118	-1.185



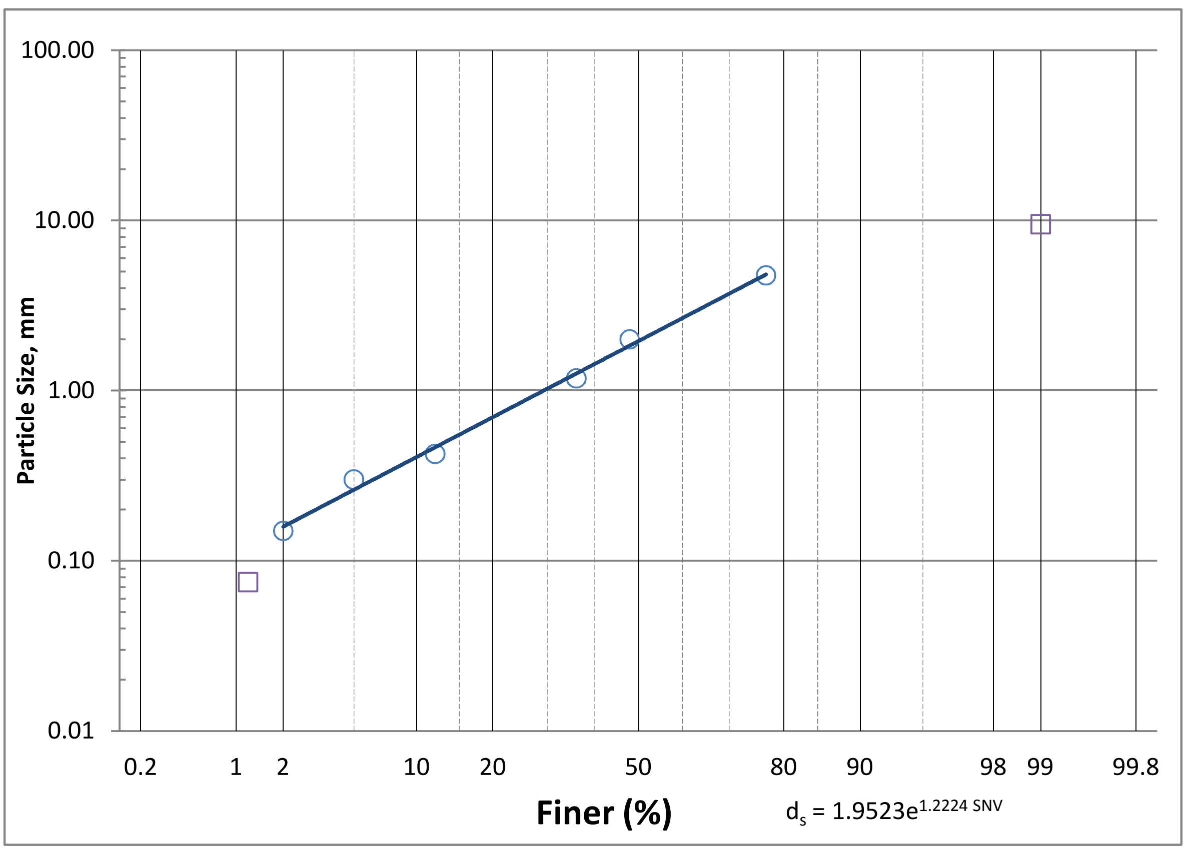
Grain Size Distribution

Description: Cherry Creek Sedimentation Study, Gradation Testing
Sample Location: **#7 - Bed Cherry Creek**
Testing by: Ground Engineering Consultants
Last revised: 16/Nov/2010
Printed: 19/Nov/10 9:37

Gradation Attributes:
Gradation Coef, G = 3.4

d_{50} =	1.95	mm	d_{90} =	9.35	mm
$d_{84.1}$ =	6.62	mm	d_{65} =	3.13	mm
$d_{15.9}$ =	0.58	mm	d_{02} =	0.16	mm

Sieve Size (opening)	Particle Size, d (mm)	Fraction Finer	SNV
2.0	50.0	1.000	
1.5	37.5	1.000	
1.0	25.0	1.000	
0.75	19.0	1.000	
0.50	12.5	1.000	
0.375	9.5	0.990	2.326
#4	4.75	0.770	0.739
#10	2.00	0.480	-0.050
#16	1.18	0.360	-0.358
#40	0.425	0.120	-1.175
#50	0.300	0.050	-1.645
#100	0.150	0.020	-2.054
#200	0.075	0.012	-2.257



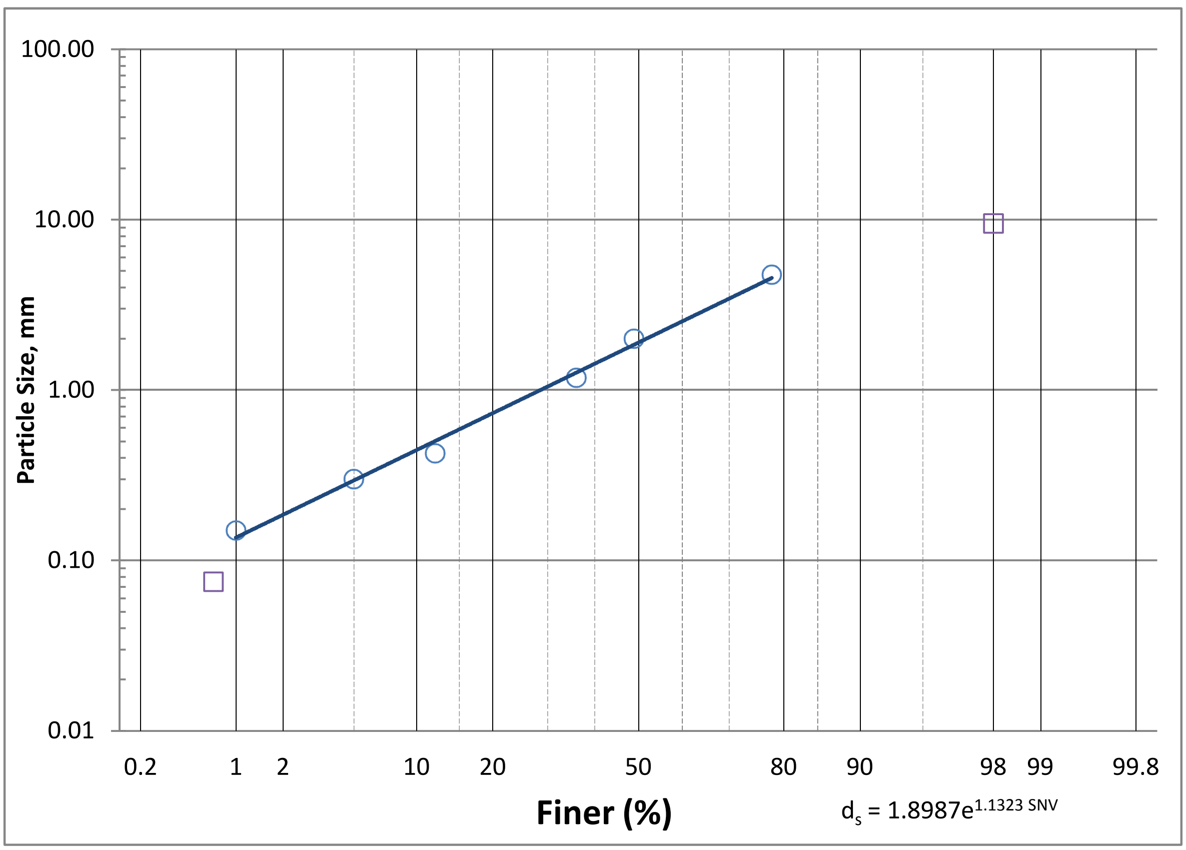
Grain Size Distribution

Description: Cherry Creek Sedimentation Study, Gradation Testing
Sample Location: **#7 - Bed Cherry Creek**
Testing by: Ground Engineering Consultants
Last revised: 16/Nov/2010
Printed: 19/Nov/10 9:37

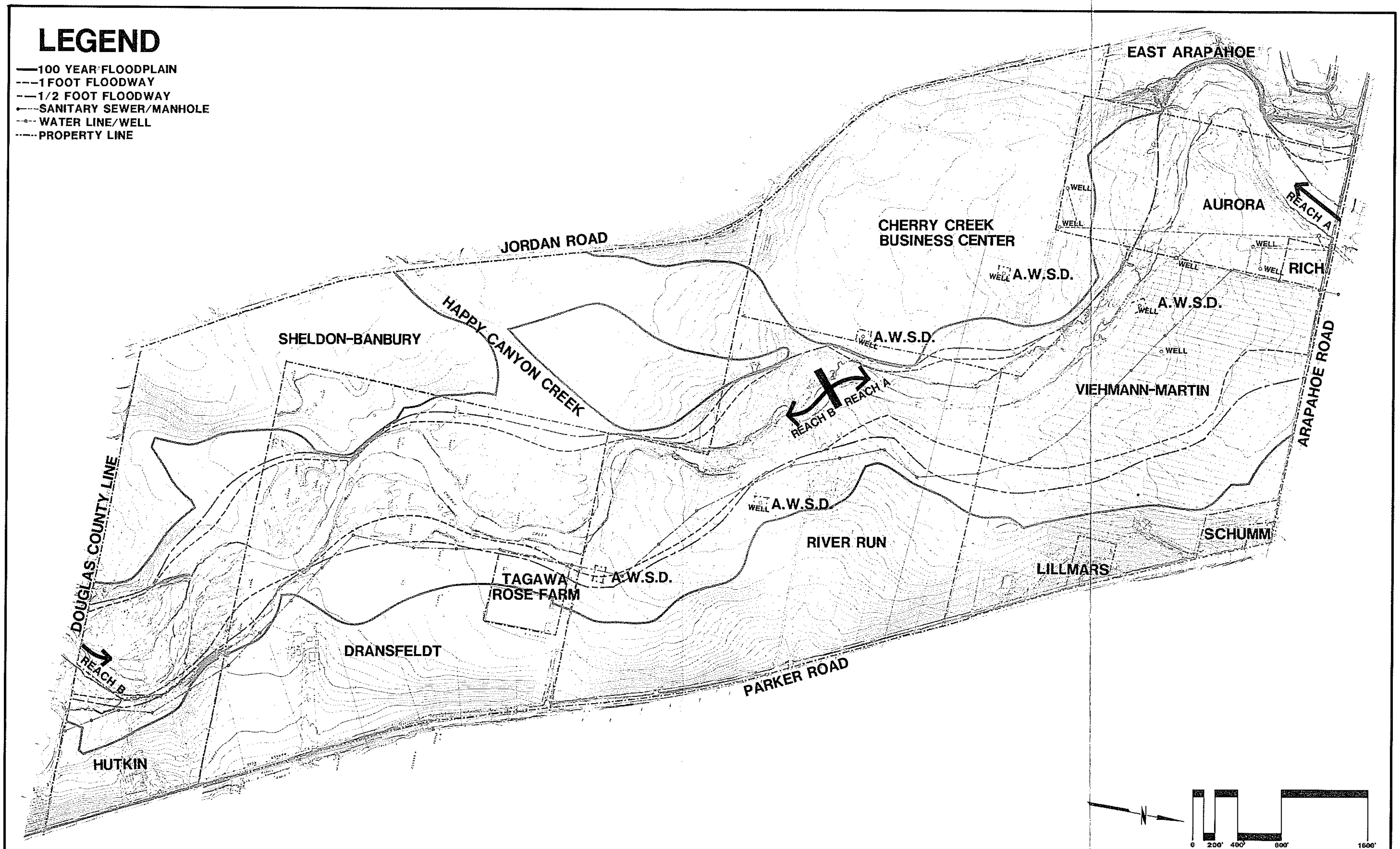
Gradation Attributes:
Gradation Coef, G = 3.1

d_{50} =	1.90	mm	d_{90} =	8.10	mm
$d_{84.1}$ =	5.88	mm	d_{65} =	2.94	mm
$d_{15.9}$ =	0.61	mm	d_{02} =	0.19	mm

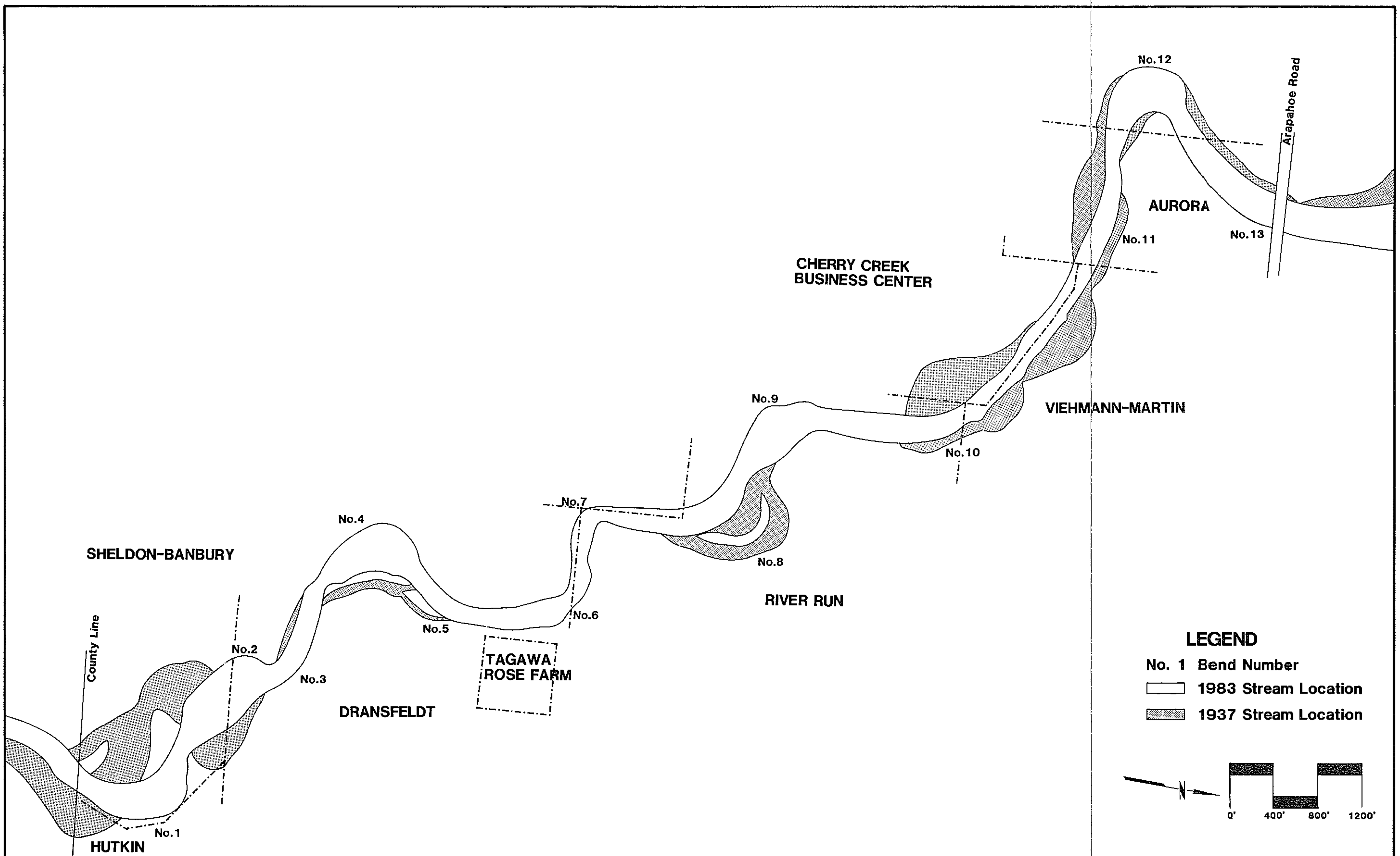
Sieve Size (opening)	Particle Size, d (mm)	Fraction Finer	SNV
2.0	50.0	1.000	
1.5	37.5	1.000	
1.0	25.0	1.000	
0.75	19.0	1.000	
0.50	12.5	1.000	
0.375	9.5	0.980	2.054
#4	4.75	0.780	0.772
#10	2.00	0.490	-0.025
#16	1.18	0.360	-0.358
#40	0.425	0.120	-1.175
#50	0.300	0.050	-1.645
#100	0.150	0.010	-2.326
#200	0.075	0.007	-2.457



APPENDIX C. EXTRACTS FROM OTHER STUDIES



BRW	WRC ENGINEERING, INC. 1660 SOUTH ALBION STREET SUITE 500 DENVER, COLORADO 80222 (303) 757-8513	CHERRY CREEK BASIN STUDY	PROJECT AREA MAP	PROJECT NUMBER	FIGURE NUMBER 2



BRW — PLANNING, TRANSPORTATION, ENGINEERING, ARCHITECTURE

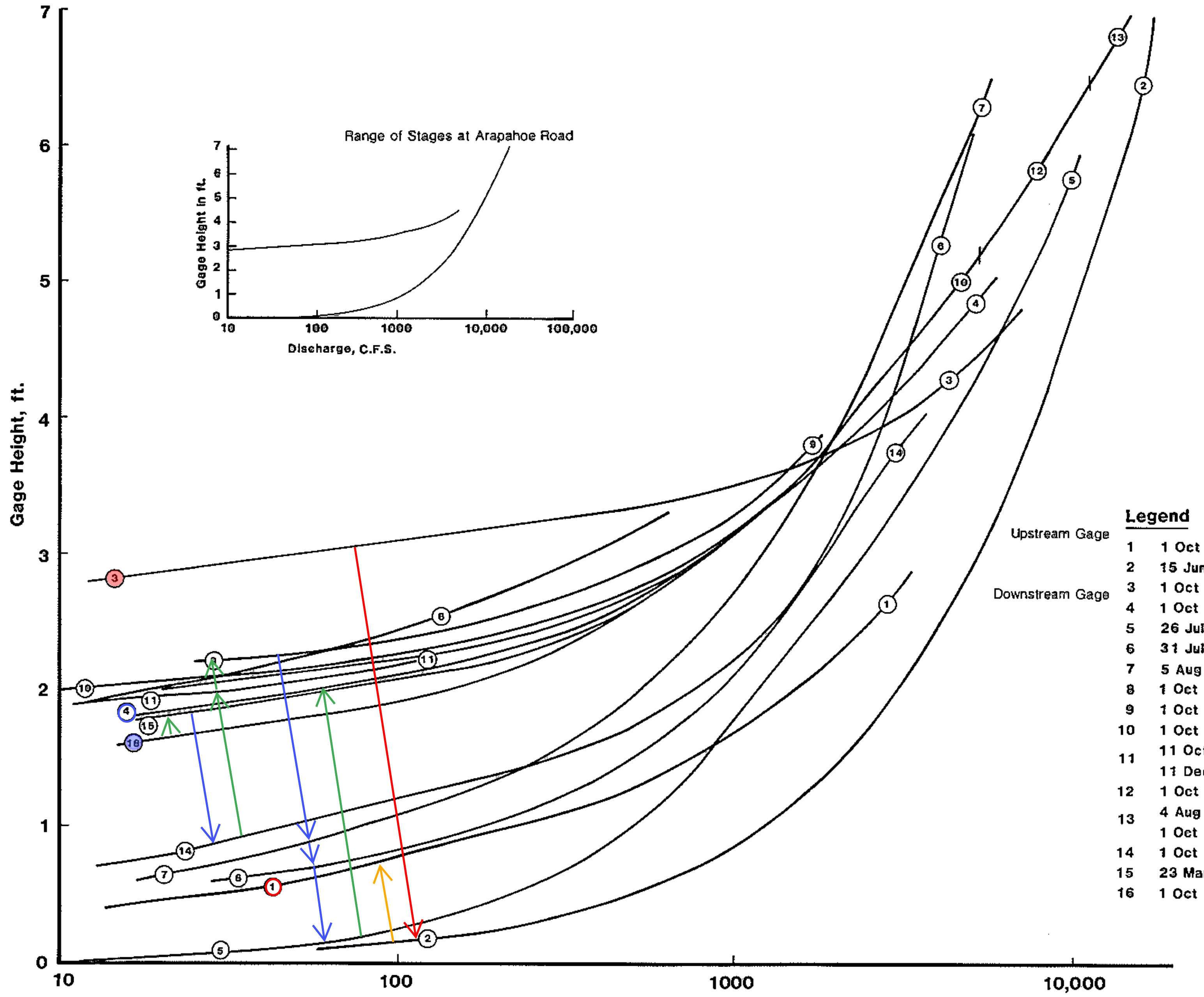
WRC ENGINEERING, INC.
1660 SOUTH ALBION STREET SUITE 500
DENVER, COLORADO 80222
(303) 757-8513

CHERRY CREEK BASIN STUDY

CHERRY CREEK - RIVER MORPHOLOGY

PROJECT NUMBER

FIGURE NUMBER 3



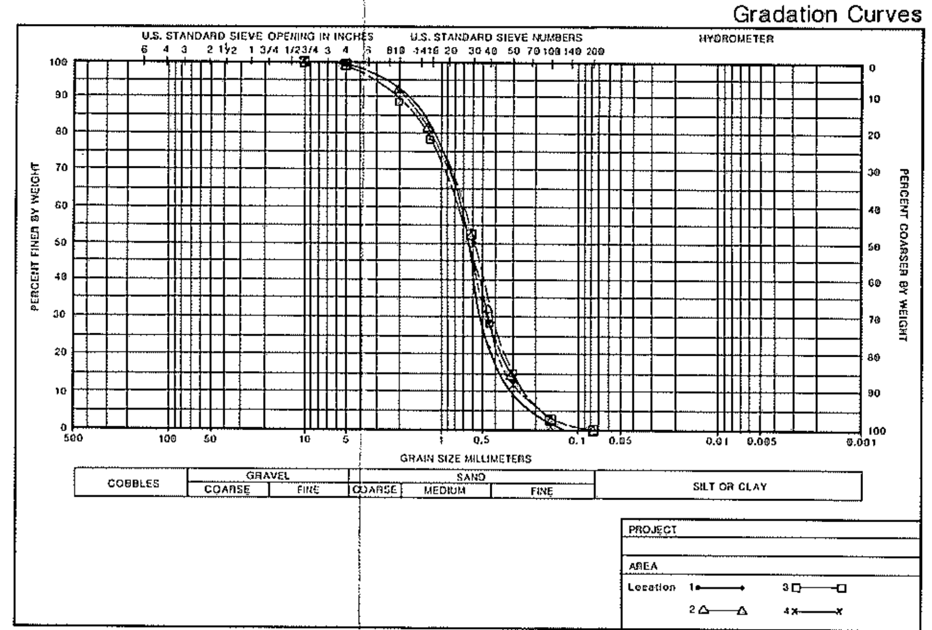
Legend

1	1 Oct 1965 - 30 Sept 1969
2	15 June 1965 - 30 Sept 1965
3	1 Oct 1960 - 15 June 1965
4	1 Oct 1957 - 30 Sept 1960
5	26 July 1957 - 30 Sept 1957
6	31 July 1956 - 25 July 1957
7	5 Aug 1955 - 30 July 1956
8	1 Oct 1953 - 5 Aug 1955
9	1 Oct 1948 - 30 Sept 1953
10	1 Oct 1947 - 30 Sept 1948
11	11 Oct 1946 - 30 Sept 1947 11 Dec 1943 - 30 Sept 1945
12	1 Oct 1945 - 30 Sept 1946
13	4 Aug 1943 - 10 Dec 1943 1 Oct 1940 - 30 Sept 1941
14	1 Oct 1941 - 3 Aug 1943
15	23 March 1940 - 5 June 1940
16	1 Oct 1939 - 22 March 1940

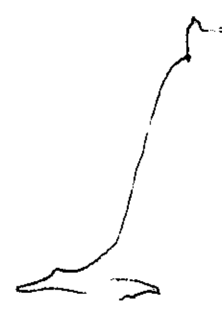
A. Stage versus discharge curves for Cherry Creek near Melvin

NOTE: On 1 October 1960, the gage was moved upstream 1 mile to Arapahoe Road changing the gage datum from 5608.21 to 5625.81 feet above mean sea level

Gradation Curves



B. Gradation of bed sediment in the study Reach



BRW PLANNING TRANSPORTATION ENGINEERING ARCHITECTURE

WRC ENGINEERING, INC.
1660 SOUTH ALBION STREET SUITE 500
DENVER, COLORADO 80222
(303) 757-8513

CHERRY CREEK BASIN STUDY

SEDIMENTATION DATA

PROJECT NUMBER

FIGURE NUMBER 5

lower sediment inflow rates during the late 1970's and early 1980's. Better sediment control throughout the watershed will likely occur as the development continues upstream of Cherry Creek Dam.

PROFILE PLOTS

Profile plots listed as Plate V-4 compares the average reservoir bed elevations during each of the survey years. The largest change in thalweg elevation is in the lake, as expected, showing almost 19 feet of build up between 1950 and 1988.

SEDIMENT VOLUME

Plate V-5 represents the change in sediment volume between 1950 and 1988. The quantity of sediment that entered the reservoir per survey period is shown in Table V-2. The total sediment change and the depletion rate for the range of years is shown below.

Survey Period	Total Volume Depletion (AF)	Depletion Rate (AF/YR)
1950-1961	862	78.4
1961-1965	1406	351.5
1965-1974	1056	117.3
1974-1988	698	49.9
1950-1988	4022	105.8

AREA AND CAPACITY TABLES

Area and capacity tables computed at 1-foot increments are located in Appendix D.

CROSS SECTION DATA

Cross-sectional plots are shown on Plates V-6 through V-24.

ENG FORM 1787 – RESERVOIR SEDIMENT DATA SUMMARY

ENG FORM 1787, "Reservoir Sedimentation Data Summary". Is presented in Appendix E. The purpose of this form is to provide a means for the uniform documentation of pertinent Cherry Creek Lake sedimentation data.

Cherry Creek Sedimentation Ranges

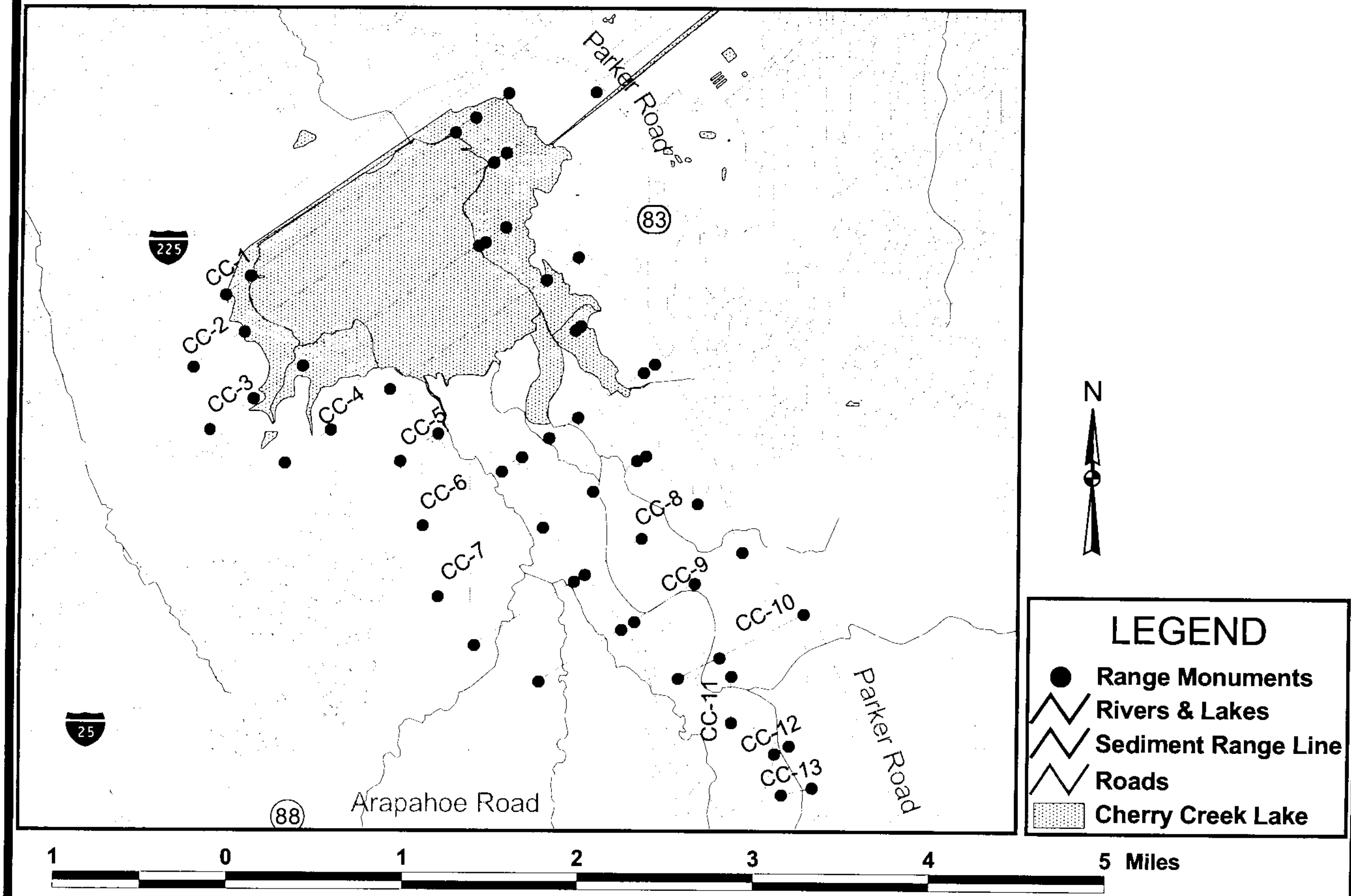


Plate V-1

When streambanks in the Cherry Creek watershed are cut by meandering streams or if they become unstable due to other human-induced disturbances, large amounts of easily eroded sediment become exposed for erosion and transport. This geomorphic phenomenon is important for purposes of identifying viable alternatives for this study area and is discussed below.

5.1 GEOMORPHOLOGY OVERVIEW

The Cherry Creek watershed is underlain by easily eroded bedrock units including the Dawson Arkose (Tetiary - Paleocene) and several younger alluvial unconsolidated units (Quaternary – Pleistocene and Holocene) (Blatt, et.al., 1980). These bedrock units are largely made up of sands and fine gravels.

Aggradation and degradation in the Cherry Creek Corridor commonly occurs during low and high flood flows. Flood flows can scour the channel bed and banks with high velocity water and deposit sediment in overbank areas where velocities are reduced or in channel areas that aggrade due to downstream baselevel control.

With the construction of the Cherry Creek Dam, sediment deposition in the bed and floodplain of Cherry Creek is increased due to backwater effects of the dam. As Cherry Creek enters the Reservoir, stream velocities slow and sediment particles are deposited. A delta has formed at the inlet of the Reservoir, and it causes additional sedimentation in the channel upstream of the Reservoir pool because aggradation has lowered the channel slope, thereby reducing sediment transport capacity. A sediment wedge, similar in profile to the delta at the Reservoir inlet and in effectively an upstream extension of the sediment body, is slowly prograding upstream as the Cherry Creek channel aggrades.

Increasing stream baseflow and changes to stream planform combine to cause geomorphic changes in the Corridor. Urbanization along the Corridor has added many discharge points that add baseflow to Cherry Creek. Baseflow in tributaries is also increased by groundwater seepage from alluvial and shallow aquifer units where water levels have risen due to lawn watering in the area. These surface water inputs have effectively changed the Cherry Creek system hydrology. As a result, channel stability is out of the equilibrium in many reaches within the fluvial geomorphology that formed during recent geologic time. In addition, several road crossings and municipal facilities have altered the planform of Cherry Creek. At several locations, the Creek main channel was straightened to accommodate new constructions. This planform restriction redefines the stream geomorphology and causes several channel segments to be out of balance with the historical stream geometry. The most prominent result is degradation of the stream channel, that in turn causes instability and erosion of stream banks.

An increase in riparian vegetation density is another important factor that may affect channel geomorphology. Prior to urban development the active floodplain in Cherry Creek was likely less vegetated because baseflow was less and flashy discharge events periodically scoured streambank vegetation. Water available to plants during low flow periods tends to enhance riparian vegetation. Stands of vegetation along the creek may be much denser in some channel reaches than they were prior to community development. In those reaches, enhanced vegetation tends to stabilize the channel and creates a filter, or depositional area, for sediment being transported from the upstream reach. In contrast, enhanced vegetation stands at other locations tend to confine the creek to a narrower path, thus enhancing sediment transport by concentrating stream power. Much of Cherry Creek used to be a braided sand bed stream and stream flow could spread over a wide area. The sediment carrying capacity of the stream was less than the available sediment being transported. Under perennial low flow conditions existing today, the stream can continuously move sediment in contrast to flashy sediment transport under ephemeral flow conditions that historically occurred.

Stabilization of the wide sand bed channel by vegetation has concentrated the stream in several reaches to a narrow corridor, thus allowing continuous sediment transport that exceeds sediment supply, thereby causing channel degradation. Invasive species, such as Russian Olive and Tamarisk (Salt Cedar) with their ability to out-compete native plants, have also contributed to the increase of riparian vegetation density.

Added to this imbalance of physical factors, sediment availability is also reduced in some areas by housing developments and detention pond storage. The end result is that some reaches may be aggrading while other reaches may be degrading depending on the dominant conditions in that reach. Similar channel instability and geomorphic changes have occurred on other streams in the area, including Fountain Creek and Monument Creek in Colorado Springs, Colorado.

Table 5-1 summarizes the existing geomorphic properties by reach within the Corridor. The values for "Bankfull" Channel and Average "Bankfull" Depth are taken from the hydraulic modeling results and refer to values modeled for the 2-year event, which approximate accepted bankfull flow frequency.

Table 5-1
Geomorphic Characteristics

Reach	Channel Grade (%)	Average "Low Flow" Channel Width (ft)	Average "Low Flow" Channel Depth (ft)	Average "Bankfull" Channel Width (ft)	Average "Bankfull" Channel Depth (ft)
1	0.409	30	2.9	300	3.6
2	0.394	28	3.4	280	4.2
3	0.369	21	4.0	210	4.9
4	0.369	22	3.4	220	4.3
5	0.414	27	3.0	270	3.8
6	0.365	16	3.8	165	4.8
7	0.408	24	3.1	240	3.9
8	0.392	16	3.7	160	4.6

5.2 AVAILABLE INFORMATION

5.2.1 USGS Gage Data

As described in Section 2.2, historic flows along Cherry Creek have been recorded by the USGS since 1939 (USGS, 2002). In October 1939, a gauging station was installed one mile downstream of the Arapahoe Road bridge. The gage was moved to Arapahoe Road in October 1960 and operated at this location until 1969. The USGS periodically monitored the physical changes in the channel and developed a series of rating curves that relate the water level readings and flow rates. From these curves the USGS was able to estimate streamflow data from October 1939 through September 1969. Tables summarizing this data are presented in Appendix I.

5.2.2 Aerial Photographs

In January 2002, aerial photography was taken to provide an overall view of the creek system from Cherry Creek Reservoir to Scott Road. Topographic data was produced from the photography fly-over, and this data was used to collect channel geometry data for geomorphic analysis and hydraulic modeling.

5.2.3 Site Visits

Several site visits to the Corridor were conducted throughout the evaluation stages of the study. The site visits were conducted to visually inspect areas of instability within the Corridor and in assisting with the development of conceptual alternatives.

5.3 GEOMORPHIC CONDITIONS

The geomorphic evaluation was divided into the same eight (8) reaches defined in prior assessments and evaluations outlined in this report. Geomorphic characteristics of the study, Reaches 1 through 8, are summarized in Table 5-2 below.

Reach 1 Cherry Creek Reservoir to Arapahoe Road

Reach 1 is different from the other reaches identified in that sedimentation, not erosion, dominates stream processes. As mentioned previously, Cherry Creek Reservoir provides baselevel control for the streambed in this reach. Cherry Creek has historically conveyed large amounts of sediment, and anthropogenic factors have helped to increase the already high sediment discharge rates. As flow velocities decrease near the inlet, sediment delivered by Cherry Creek cannot be transported efficiently further downstream and, subsequently, a large delta has formed at the upstream end of the Reservoir. Presumably, the channel slope in the delta segment is slightly flatter than the natural channel slope, therefore the sediment carrying capacity is somewhat less than the original channel bed. In this case the channel is naturally storing more sediment, the resulting sediment wedge is gradually prograding upstream, and the channel bed elevation below Arapahoe Road is slowly rising.

The channel slope in this reach is approximately 0.0041 ft/ft, however it appears that sedimentation has not caused a large reduction in the average channel slope in the study reach of 0.004 ft/ft. This condition suggests that channel aggradation of the bed is not occurring rapidly, otherwise channel slopes in this reach would be expected to be lower than the reaches immediately upstream.

The COE has monitored aggradation of the channel bed and Cherry Creek Reservoir at 13 cross-sections below Arapahoe Road. In general, surveys indicate that the sediment wedge has not prograded up to Arapahoe Road. It is likely that existing downstream controls will prevent degradation of the channel bed above Arapahoe Road, and that small rises in the channel bed may occur as the sediment wedge becomes thicker downstream and progrades upstream. Downstream of Arapahoe Road, the channel and floodplain of Cherry Creek will grow wider as more sediment is delivered to the Cherry Creek Reservoir delta and the channel areas upstream of the current sedimentation area.

As would be expected in an aggrading stream, there is not much relief between the Cherry Creek floodplain and the channel, and the active sand bed channel is relatively wide. Due to the lack of elevation difference between the channel and floodplain, large flood events could spread over wide areas with small rises in streambed elevation. Therefore, reductions in channel conveyance capacity due to aggradation will affect a limited number of structures in this reach.

Reach 2 Arapahoe Road to Happy Canyon Outfall

The reach from Arapahoe Road to the Happy Canyon outfall has an average slope of approximately 0.0039 ft/ft and the channel has a braided channel pattern, similar to Reach 1. Cross-section surveys by the COE indicate that this reach is not aggrading and that there does not appear to be areas of significant erosion and degradation. The relatively constant channel slope is indicative of the lack of downcutting and erosion problems that are occurring on other upstream reaches of Cherry Creek.

Streamflow in this reach, similar to other nearby reaches, was likely intermittent before other development. Channel alluvium is deep, as is in Reach 1, and the potential for channel transmission losses is high. Stream flow is still intermittent or seasonal in this reach, but flow most likely occurs on a more frequent basis and the water table is likely higher in this reach than it was historically. Shallow groundwater pumping within the reach also impacts the hydrology. Enhanced water availability has likely enhanced the growth of riparian vegetation. Dense vegetation tends to constrain the active channel, and it is likely that today's sand bed channel is more narrow in some places than the braided sand bed channel of the distant past. Flooding is controlled by upstream detention reservoirs associated with development and other small stock water ponds in the basin, therefore the flashiness of major flow events are less frequent and scoured less frequently in comparison to historical conditions.

Reach 3 Happy Canyon Outfall to County Line

Extending from the Happy Canyon Outfall upstream to the Arapahoe-Douglas County Line, Reach 3 maintains a relatively constant stream channel slope similar to Reach 2. It measures approximately 0.0037 ft/ft over the entire length. However, unlike Reach 2, the stream channel in the upper half of this reach is incised more than four feet from what it was approximately 5 years ago. A sanitary sewer line crossing at the upper end of this reach was buried below the stream bed several years ago, but is now completely exposed and the creek has cut a deeper channel such that it is running underneath. Due to channel incision and the concentration of channel flow, this reach does not have a braided channel type as it probably once did. Low flow energy is concentrated in a narrow channel, and it generally has a perennial flow character. Channel banks are gradually being cut back, such that the channel will gradually become wider and deeper as the channel seeks equilibrium with the new hydrology of the stream. If the channel were still braided and baseflow was not has high as it is now, transmission losses to alluvium would retain the intermittent flow character as is the case in Reaches 1 and 2.

Reach 4 County Line to Cottonwood Bridge

Reach 4 from the County Line boundary to Cottonwood Bridge has downcut over the last several years, such that channel constriction, bank erosion, and the losses of riparian vegetation are problems over essentially the entire reach. As with Reach 3, the channel has lost its braided appearance due to being lower in the alluvium and closer to the groundwater table and that flow is not lost to the alluvium. As a result, this reach experiences mostly perennial flows. The channel slope in the reach is a relatively constant 0.0037 ft/ft.

Reach 5 Cottonwood Bridge to Lincoln Avenue Bridge

Reach 5 extends from the Cottonwood Bridge to the Lincoln Avenue Bridge and has several areas of instability and potential for future instability. The channel slope in this reach has several segments of varying channel slopes ranging from 0.0024 to 0.0064 ft/ft, along with a large headcut. The average channel slope is 0.0041 ft/ft.

The Cherry Creek channel is directly upstream of the Cottonwood Bridge is one of the worst problem areas in the Corridor. A headcut of approximately four feet in height is slowly progressing upstream. The channel banks directly downstream of the headcut are steep and unstable. It is unclear what precisely caused the head cut to form but it may be that the floodplain was constricted when the Cottonwood Bridge was constructed. This caused flow to be concentrated in one channel whereas it may have originally been multiple channels or a braided pattern. This condition combined with the change in low flow character of the creek effectively caused over-steepening of the channel at the bridge area.

The channel has a slope of 0.0064 ft/ft for approximately 1,000 feet upstream of the headcut. This channel segment is part of a large wetland that occupies the channel. The lush vegetation serves to stabilize the channel bed and slow the upstream progression of the headcut. The wetland and the channel cross-section are wide for approximately 2,500 feet upstream of the headcut. The large wetland and the spreading of the channel into the wide cross-section serves to filter out sediment being transported from upstream reaches. The uppermost 1,500 feet of the wetland may reflect a zone of aggradation in that the channel slope is flattened and measures approximately 0.0024 ft/ft. The channel is not incised in this part of the reach.

The channel from the upstream end of the wetland to the E-470 bridge is again relatively steep at 0.006 ft/ft. The channel in this area is incised a few feet, but the banks appear to have healed and have attained relative stability for the time being.

The next 1,700 feet upstream of the E-470 bridge is again flattened somewhat at 0.00235 ft/ft, then becomes steepened in the next 1,300 feet to 0.0054 ft/ft. The upper 3,200 feet of the reach has a slope of approximately 0.0036 ft/ft, which is close to the slope of the more stable reaches within the Corridor.

Reach 6 Lincoln Avenue to Sulphur Gulch

From Lincoln Avenue to the confluence with Sulphur Gulch, the channel becomes steeper than downstream reaches, with a slope of 0.0037 ft/ft. Approximately 800 feet of channel at the Main Street bridge crossing is over-steepened to 0.005 ft/ft, possibly as a result of channel re-routing when the bridge was constructed. The floodplain at the Main Street bridge is constricted to a 175 foot width, whereas the undisturbed floodplain is approximately 350 feet wide or more both upstream and downstream of this bridge.

The active channel in Reach 6, like that in Reaches 3 through 5, is confined to a narrow width and is mostly incised. It appears that channel flow is perennial in this reach due to the effluent treatment plant discharge at Sulphur Gulch. It is probable that stream flow within this reach was historically intermittent, or even ephemeral in flow character during dry years. For the most part, banks have stabilized in this reach as vegetation has been re-established after the initial channel incision.

Reach 7 Sulphur Gulch to Lemon Gulch

Channel incision from Reach 6 caused by perennial flows in Sulphur Gulch has moved up Reach 7 for approximately 3,000 feet. The channel is incised by several feet and has an approximate channel slope ranging from 0.0042 to 0.0048 ft/ft. Stream flow appears to be perennial to intermittent and the banks are well vegetated and stable for the most part. At the upper end of this 3,000 foot segment channel incision gradually ends and the channel is sand-bedded and shallow. This transition area may be a segment that deserves attention for grade control. The slope in this segment steepens to 0.0082 ft/ft, partly because of the transition from incised to unincised channel, but also because this is the site of a meander cutoff. The channel has naturally reduced its length with a shorter route across the floodplain, thus steepening the slope locally. Above this area, Reach 7 maintains a channel slope between 0.0036 to 0.0043 ft/ft, with the exception of a 700 foot segment just below Stroh Road where the slope is 0.0064 ft/ft. This reach has an alternating character of incised meanders to braided channel with an average slope of 0.0041 ft/ft.

Reach 8 Lemon Gulch to Scott Road

The slope in this reach varies over a small range from 0.0034 to 0.0043 ft/ft at the upstream end of the channel. The narrow range in channel grade reflects the overall stability of this reach. Above Lemon Gulch the stream is generally small in width and well-defined. It is incised a small amount in some segments, sandbedded in others, and is a grassy swale in other locations. The average slope for Reach 8 is 0.0039 ft/ft.

Table 5-2 summarizes the geomorphic characteristics for each of the eight reaches. The Rosgen stream classification is used to show the corresponding channel types that are present in the more unstable reaches of Cherry Creek. "Channel Condition" and "Bank Erosion" use generalized descriptors to provide an overview of existing channel stability. Overall channel reach slope does not apparently reflect the overall stability of the channel reach; however, a more detailed accounting of channel slope for short segments would probably show that steep reaches are more unstable.

Table 5-2
Geomorphic Characteristics by Reach

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

GENERAL NOTES

1. THE LOCATIONS OF EXISTING UTILITIES SHOWN ON THE DRAWINGS ARE APPROXIMATE AND WERE BASED ON THE BEST AVAILABLE INFORMATION. LOCATION OF EXISTING UTILITIES SHALL BE VERIFIED BY THE CONTRACTOR PRIOR TO ACTUAL CONSTRUCTION. CONTACT THE UTILITY NOTIFICATION CENTER OF COLORADO TOLL FREE AT 1-800-922-1987.
2. EXCEPT WHERE OTHERWISE PROVIDED FOR IN THESE PLANS AND SPECIFICATIONS, THE COLORADO DEPARTMENT OF TRANSPORTATION (CDOT) STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE CONSTRUCTION, 2005 EDITION, SHALL APPLY.
3. TOPOGRAPHIC MAPPING SHOWN ON THE DRAWINGS WAS PREPARED BY CARROLL AND LANGE, INC. AND LANDMARK MAPPING (AERIAL) BASED ON AERIAL (7/13/04) AND FIELD SURVEY, AUGUST 2004. ACTUAL FEATURES AND TOPOGRAPHY MAY VARY. THE CONTRACTOR SHALL VERIFY SITE CONDITIONS BEFORE THE START OF WORK.
4. PROJECT FACILITIES ARE TO BE LOCATED BASED ON THE SURVEY COORDINATES, ELEVATIONS, DIMENSIONS, AND/OR GEOMETRIC DESIGN DATA PROVIDED ON THE DRAWINGS.
5. THE CONTRACTOR IS SOLELY RESPONSIBLE FOR PROVIDING STABLE EXCAVATIONS AND TEMPORARY SLOPES AND FOR SATISFYING ALL APPLICABLE OSHA, FEDERAL, STATE, AND LOCAL REGULATIONS. TEMPORARY EXCAVATIONS SHALL PROVIDE, AT MINIMUM, THE TRENCH DIMENSIONS AND CLEARANCES SHOWN OR SPECIFIED. TEMPORARY CONSTRUCTION SLOPES SHALL BE SLOPED, SHORED, SHEETED, AND/OR BRACED IN ACCORDANCE WITH STABILITY REQUIREMENTS AND APPLICABLE REGULATIONS, AND SHALL BE NO STEEPER THAN THE SLOPES SHOWN OR SPECIFIED WITHOUT THE APPROVAL OF THE ENGINEER. ANY SUCH APPROVALS BY THE ENGINEER WILL NOT RELIEVE THE CONTRACTOR FROM SOLE RESPONSIBILITY FOR PROVIDING STABLE EXCAVATIONS AND TEMPORARY SLOPES.
6. ALL EXISTING UTILITIES SHALL BE PROTECTED IN PLACE BY THE CONTRACTOR.
7. EXISTING FACILITIES NOT INDICATED TO BE REMOVED SHALL BE PROTECTED IN PLACE OR REMOVED AND REPLACED IN KIND, AS APPROVED BY ENGINEER.
8. THE WORK WILL TAKE PLACE IN AND AROUND A STREAM, SUBJECT TO PERIODIC FLOODING. THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE CONTROL OF SURFACE AND SUBSURFACE WATER DURING THE COURSE OF THE WORK. ANY DAMAGE TO THE WORK RESULTING FROM SURFACE FLOWS, BASE FLOWS OR FLOOD FLOWS INCLUDING BOUYANCY FORCES ON PIPELINES AND OTHER FACILITIES SHALL BE CORRECTED BY THE CONTRACTOR AT THE CONTRACTOR'S SOLE COST. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING AND SATISFYING THE REQUIREMENTS OF ANY APPLICABLE PERMITS PERTAINING TO WATER AND EROSION CONTROL. GESC PLANS HAVE BEEN APPROVED BY ARAPAHOE COUNTY AND SHALL BE FULLY COMPLIED WITH. THE COST OF THE GESC PERMIT AND ALL OTHER INCIDENTAL COSTS ASSOCIATED WITH PERMIT COMPLIANCE SHALL BE PAID FOR UNDER "WATER AND EROSION CONTROL."
9. A GEOTECHNICAL REPORT IS AVAILABLE AT THE CONTRACTOR'S REQUEST. THE BORING LOGS CONTAINED IN THIS REPORT WERE DEVELOPED BY GROUND ENGINEERING, AND HAVE BEEN REPRODUCED ON THIS SHEET FOR CONVENIENCE.
10. CONTACT THE ENGINEER FOR CLARIFICATIONS OF ANY INFORMATION SHOWN ON THE DRAWINGS.
11. CONTRACTOR SHALL CONFINE WORK TO THE CONSTRUCTION LIMITS SHOWN ON SHEET 3.
12. ALL TREES ARE TO BE PROTECTED DURING CONSTRUCTION UNLESS IDENTIFIED ON THE PLANS FOR REMOVAL.
13. STAGING AREAS, STOCKPILE AREAS, AND ACCESS/HAUL ROADS ARE TO BE AT SPECIFICALLY DESIGNATED LOCATIONS AS SHOWN ON THE GESC PLANS, UNLESS OTHERWISE APPROVED BY THE ENGINEER.
14. SEE TECHNICAL SPECIFICATIONS SECTION 02315 FOR ALL COMPACTION CRITERIA.
15. ALL REINFORCING STEEL SHALL BE EPOXY COATED, GRADE 60 (ASTM 615). MINIMUM CONCRETE COVER FOR REINFORCING STEEL SHALL BE 3" FOR ALL CONCRETE PLACED ON AND PERMANENTLY EXPOSED TO EARTH, AND 2" FOR ALL OTHER CONCRETE UNLESS OTHERWISE NOTED ON THE PLANS.
16. UNLESS OTHERWISE NOTED ON THE PLANS, THE LAP SPLICE LENGTH FOR REINFORCING BARS SHALL BE AS FOLLOWS: #4 BARS 28", #5 BARS 36", #6 BARS 42".
17. ALL EXPOSED CONCRETE CORNERS SHALL BE CONSTRUCTED WITH 3/4" CHAMFERS UNLESS OTHERWISE NOTED ON THE DRAWINGS.
18. THE BIKE PATH SURFACE SHALL RECEIVE A BROOM FINISH, AND THE CONCRETE EDGES AND JOINTS SHALL BE TOOLED AFTER THE BROOM FINISH.
19. WALLS TO BE COVERED WITH EARTH SHALL BE GIVEN A CLASS 1 FINISH IN ACCORDANCE WITH CDOT 601.14(b)1.
20. TOPSOIL (NOT SHOWN ON DRAWINGS) SHALL BE STRIPPED, STOCKPILED, AND REPLACED OVER ALL DISTURBED AREAS AND SOIL RIPRAP AREAS IN ACCORDANCE WITH THE PROJECT SPECIFICATIONS.
21. CONTRACTOR SHALL SUBMIT TO LANAE RAYMOND (ARAPAHOE COUNTY) A PLAN TO SAFELY MAINTAIN PEDESTRIAN ACCESS BETWEEN THE NEIGHBORHOODS AND THE EXISTING CHERRY CREEK BIKE PATH. CONSTRUCTION SHALL NOT BEGIN UNTIL PLAN HAS BEEN APPROVED IN WRITING AND INSPECTED. ALL COSTS FOR SIGNAGE, FENCING, ETC. REQUIRED TO IMPLEMENT PLAN SHALL BE PAID FOR UNDER "MOBILIZATION".
22. DISTURBED AREAS TO RECEIVE EROSION CONTROL BLANKET SHALL BE AS SHOWN ON THE LANDSCAPE PLANS.
23. SEE TECHNICAL SPECIFICATION SECTION 02360 FOR H-PILE INSTALLATION INSTRUCTIONS.

PROJECT CONTROL

	NORTHING	EASTING	ELEVATION	DESC.	MONUMENT
CP 1	1,632,299.52	3,200,204.70	5713.86	NE COR. SEC 5 T6S R66W	#4 REBAR
CP 2	1,632,301.65	3,200,466.67	5707.19	SW COR. SEC 33 T5S R66W	3 1/4 ALUM CAP
CP 3	1,632,327.22	3,201,015.82	5708.29	CENTERPOINT SAN MH LID	

SURVEY NOTE:
COORDINATE VALUES, BEARINGS AND ELEVATIONS ARE BASED UPON THE ARAPAHOE COUNTY CONTROL NETWORK PHASE 1, REVISED. PREPARED BY JOHN E. CHANCE & ASSOCIATES, INC. DATED OCTOBER, 1995.

TOPOGRAPHIC SURVEY PROVIDED BY:
CARROLL AND LANGE INC.
PROFESSIONAL ENGINEERS AND LAND SURVEYORS
165 SOUTH UNION BLVD, SUITE 156
LAKEWOOD, CO. 80228
(303)980-0200

GEOTECHNICAL INVESTIGATION PROVIDED BY:
GROUND ENGINEERING CONSULTANTS
41 INVERNESS DRIVE EAST
ENGLEWOOD, CO. 80112-5412
(303) 289-1989

UTILITY CONTACTS

COTTONWOOD WATER AND SANITATION DISTRICT
SCOTT BARNETT 303-649-9857

IREA (ELECTRIC)
LES TURNER 303-688-3100

ACCESS CONTACTS

CONTRACTOR IS TO OBTAIN CLEARANCES FOR ACCESS TO THE SITE PRIOR TO CONSTRUCTION.
CONTACTS:
ARAPAHOE COUNTY: LANAE RAYMOND 720-874-6504
COTTONWOOD WATER AND SANITATION DISTRICT:
SCOTT BARNETT (MULHERN MRE) 303-649-9857
RON LAMBERT (MULHERN MRE) 303-649-9857

TEST HOLE LEGEND:

Topsoil

Sand: Slightly gravelly to clayey, non to medium plastic, fine to coarse grained with gravel, loose to dense, moist to wet, tan in color.

Sand and Clay: Sandy clay to clayey sand, low to medium plastic, fine to medium grained, medium to stiff, moist to wet, brown to gray in color.

Weathered Siltstone: Sandy, medium to highly plastic, fine grained, weathered, moist, olive to brown in color with occasional iron staining.

Claystone Bedrock: Occasional sandstone lenses, medium to highly plastic, fine grained, hard to very hard, moist, brown to gray in color.

Sandstone/Claystone Bedrock: Silty sandstone to sandy claystone, low to highly plastic, fine to coarse grained, hard to very hard, moist, gray to dark gary in color.

Drive sample, 2-inch I.D. California liner sample

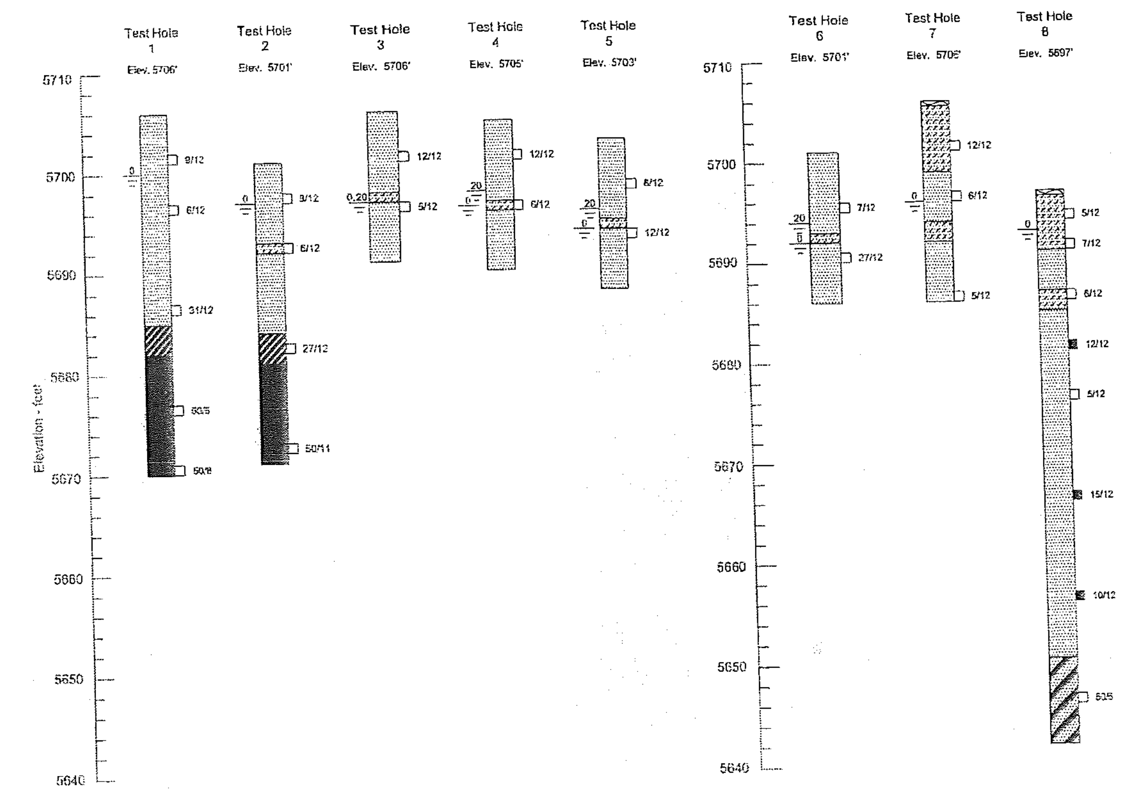
Drive sample, 1-3/8 inch I.D. standard sample

23/12 Drive sample blow count, indicates 23 blows of a 140-pound hammer falling 30 inches were required to drive the samplor 12 inches.

0 Depth to water level and number of days after drilling that measurement was taken.

NOTES:

1) Test holes were drilled on 06/23/04 and 04/15/05 with 7-inch diameter hollow stem continuous power augers.
2) Locations of the test holes were measured approximatoly by pacing from features shown on the site plan provided.
3) Elevations of the test holes wore measured by the representative of the Client, and the logs of the test holes are drawn to elevation.
4) The test hole locations and elevations should be considered accurate only to the degree implied by the method used.
5) The lines between materials shown on the test hole logs represent the approximate boundaries between material types and the transitions may be gradual.
6) Groundwater level readings shown on the logs were made at the time and under the conditions indicated. Fluctuations in the water level may occur with time.
7) Testhole #8 drilled on 4/15/05. All others drilled on 6/23/04.



LEGEND

VEGETATED BENCH AREA
VOID-FILLED RIFFLE MATERIAL
RIPRAP
SCULPTED CONCRETE AND CHANNEL FILL ZONE
EXISTING TREES AND SHRUBS
SURVEY CONTROL POINT
DESIGN CONTROL POINT
BOULDER CLUSTER
SOIL BORING/TESTHOLE LOCATION
C1 HORIZONTAL CONTROL CURVE (SEE TABLES IN PLANS)
L1 HORIZONTAL CONTROL LINE (SEE TABLES IN PLANS)

CONCRETE BIKE PATH
EXISTING TRAIL/BIKE PATH
SOFT SURFACE TRAIL
1000 cfs FLOODPLAIN LIMITS
100-YR FLOODPLAIN LIMITS
EXISTING FENCE
EXISTING SANITARY SEWER
EXISTING ELECTRIC (OVERHEAD)
EXISTING EASEMENT
PROPERTY BOUNDARY
SECTION LINE
BASE FLOW LIMITS
5600 EXISTING MAJOR CONTOUR
EXISTING MINOR CONTOUR
5600 FINISHED MAJOR CONTOUR
FINISHED MINOR CONTOUR

RECORD DRAWING
9/11/06
THIS RECORD DRAWING HAS BEEN PREPARED, IN PART, BASED UPON INFORMATION FURNISHED BY OTHERS. WHILE THIS INFORMATION IS BELIEVED TO BE RELIABLE, MULLER ENGINEERING COMPANY, INC. CANNOT ASSURE IT'S ACCURACY, AND THUS IS NOT RESPONSIBLE FOR THE ACCURACY OF THIS RECORD DRAWING OR FOR ANY ERRORS OR OMISSIONS WHICH MAY HAVE BEEN INCORPORATED INTO IT AS A RESULT. THOSE RELYING ON THIS RECORD DRAWING ARE ADVISED TO OBTAIN INDEPENDENT VERIFICATION OF IT'S ACCURACY BEFORE APPLYING IT FOR ANY PURPOSE.

DESIGNED: GBH DATE: 04/18/D5
DRAWN: MAM DATE: 04/18/05
CHECKED: GBH DATE: 09/29/05
REVISED: 1 DATE: 09/11/06
REVISED: DATE:

MULLER ENGINEERING CO., INC.
CONSULTING ENGINEERS
IRONGATE 4, SUITE 100
777 SOUTH WADSWORTH BLVD.
LAKEWOOD, COLORADO 80226
(303) 988-4939
PROJECT NO. 04032.01

ARAPAHOE COUNTY

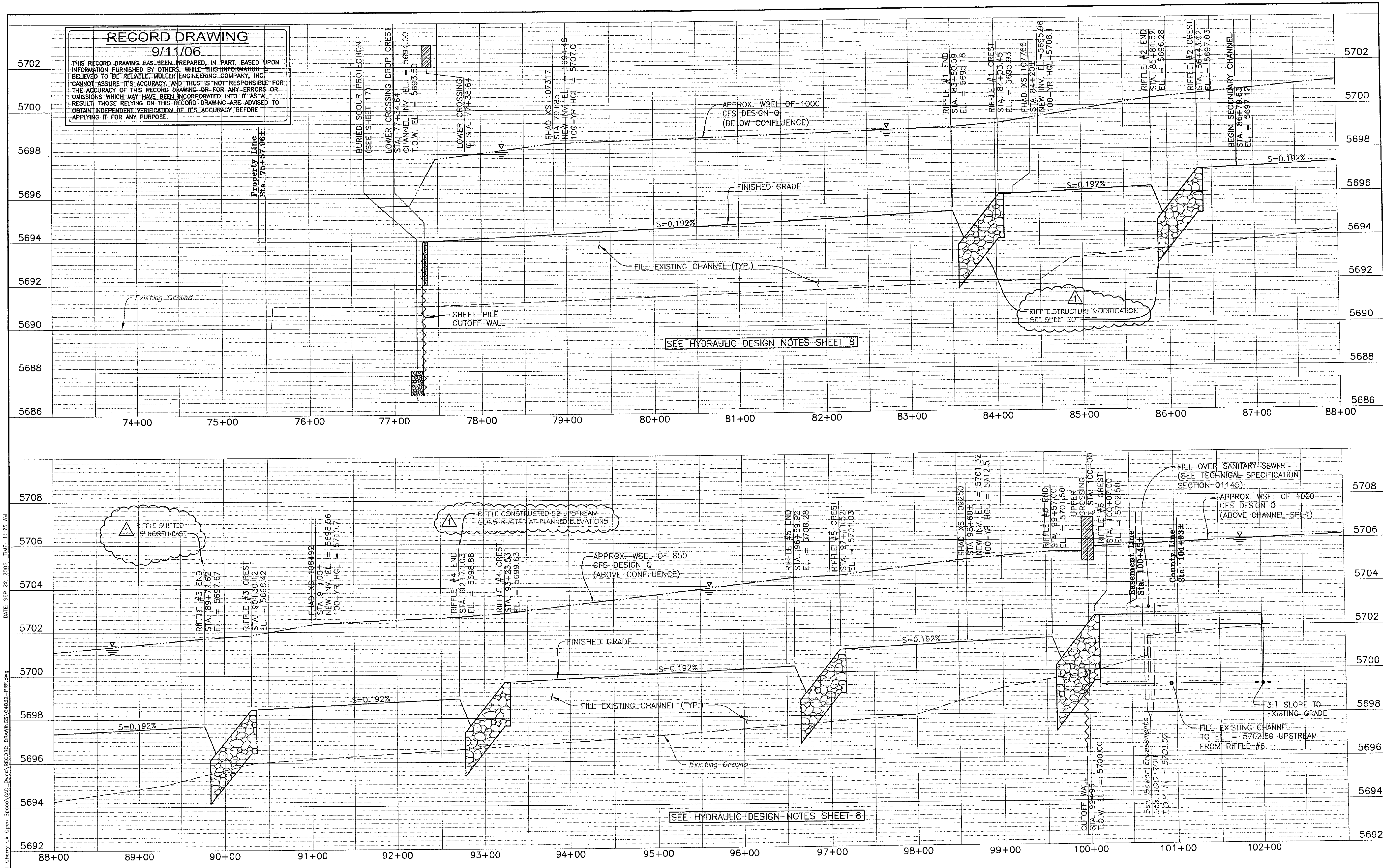
URBAN DRAINAGE AND FLOOD CONTROL DISTRICT
UDFCD PROJECT No. 05-07.25

CHERRY CREEK OPEN SPACE RESTORATION PROJECT

GENERAL NOTES, LEGEND AND BORING LOGS

SHEET 2 OF 32

NAME: P:\04-032.01 Cherry Ck Open Space\CAD_Dwgs\RECORD DRAWINGS\04032-GEN.dwg DATE: SEP 22, 2006 TIME: 11:19 AM



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DESIGNED: GBH DATE: 5/16/05 DRAWN: MAM DATE: 5/16/05 CHECKED: GBH DATE: 09/29/05 REVISED: △ DATE: 09/11/06 REVISED: DATE:	MULLER ENGINEERING CO., INC. CONSULTING ENGINEERS IRONGATE 4, SUITE 100 777 SOUTH WADSWORTH BLVD. LAKEWOOD, COLORADO 80226 (303) 988-4939 PROJECT NO. 04032.01	Arapahoe County Colorado's First ARAPAHOE COUNTY	URBAN DRAINAGE AND FLOOD CONTROL DISTRICT UDFCD PROJECT No. D5-07.25	CHERRY CREEK OPEN SPACE RESTORATION PROJECT	PRIMARY CHANNEL PROFILE	SHEET 7 OF 32

2.5.2 Recommendation for Additional Analysis

The estimate of annual sediment deposited in the sediment basin should be reviewed. Based on the annual sedimentation rates in Cherry Creek reservoir, the maintenance requirement could be significantly greater than those reported in the Estimate of Sediment Basin Performance Technical Memorandum (Ruzzo 2005). This memorandum indicates that the average annual volume of sediment removal would be 3,600 cubic yards. However, based on sediment accumulation in the reservoir it would be expected to be greater than this value. Table 1 summarizes the various information and sources available and reviewed regarding depositional volumes for Cherry Creek and the Reservoir. Note that the USACE Report reflects sediment in the reservoir whereas the remaining studies estimate loads in Cherry Creek. Although it is not expected they be equal, Cherry Creek is estimated to contribute the majority of the reservoir's sediment loading.

Table 1 - Comparison of Sediment Loading

COMPARISON OF SEDIMENT LOADING ESTIMATES FROM PREVIOUS STUDIES			
Study	Sediment	Reported Amount	Tons/year *
Tri-Lakes Sediment Studies (USACE 2001)	average cumulation rate to reservoir 1950-1988**	106 ac-ft/yr	138,521
Tri-Lakes Sediment Studies (USACE 2001)	lowest cumulation rate to reservoir 1974-1988	50 ac-ft/yr	65,340
Ruzzo (2005) (Halepaska Data 1984-2002)	average sediment at CC-8	3600 cu yds/yr	2,916
BRW/WRC (1985)	deposited volume over 17.4 years**	3035 ac-ft	227,939

* based on a dry unit weight of 60 lbs/cu ft
**volumes include sediment deposition from 1965 flood

- In addition to the refinement of the estimate of the amount of sediment that will typically be deposited in the sediment basin, identifications of the changes that will occur in the stream reaches downstream of the sediment basin as a result of the reduction in sediment supply should be made. In performing this work, a range of discharges should be investigated including low, moderate and flood flows. Significant movement of sand as bed load was observed during the winter flow of approximately 20 cfs.

- If readily available, an investigation of historical aerial photographs, flow records and other information on the changes that have occurred in Cherry Creek should be investigated to better understand the factors that have resulted in the development of the low flow channel and establishment of vegetation on what was once the bed of a braided channel.

2.6 Normal Water Surface Elevations in Cherry Creek Reservoir and the Proposed Sediment Basin

The USACE is currently contemplating the lowering of the normal water levels in Cherry Creek Reservoir by 1-1/2 feet to 2 feet. The purpose of this section is to qualitatively address the potential impacts of a lower water level in the reservoir on the sediment basin proposed in this study at Arapahoe Road.

The study reach lies approximately 1 ½ miles upstream of the southern end of the reservoir. Channel morphology within the study reach is governed by aggradational processes due primarily from high sediment loads being deposited from channel flows. Deposition occurs from base 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

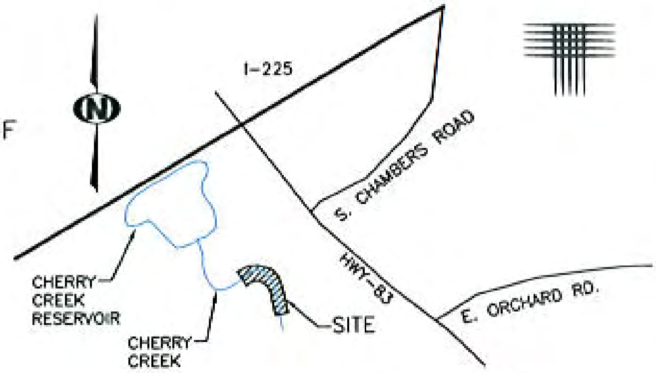
Photo 12 - Aerial Image 6, July 2007

0 150 300

SCALE: 1" = 300'

LEGEND:

TH-1 ● APPROXIMATE LOCATION OF EXPLORATORY BORING

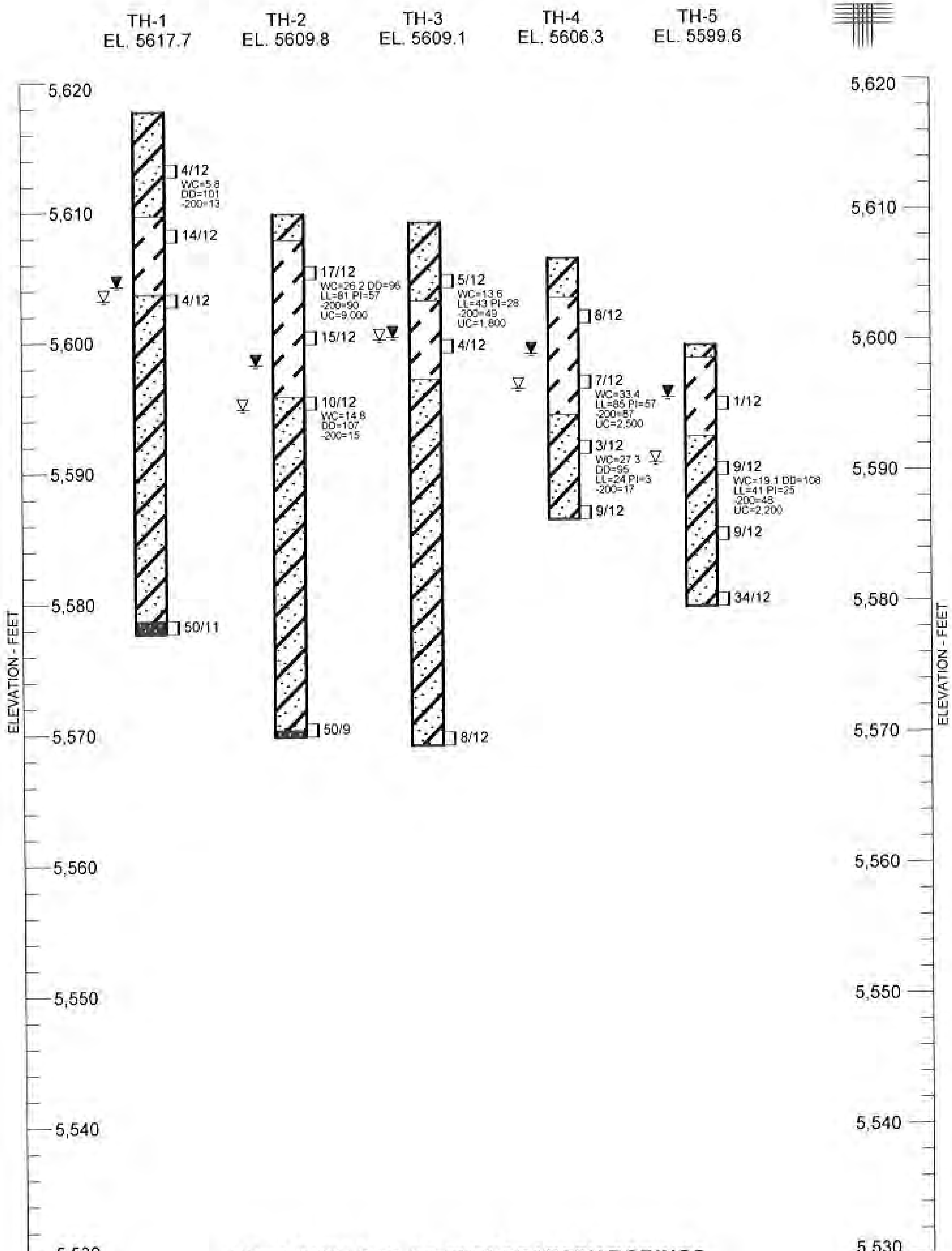


VICINITY MAP
NOT TO SCALE

Locations of Exploratory Borings

CH2M HILL, INC.
12-MILE PARK CHERRY CREEK STREAM RECLAMATION
Project No. DN45,052-125

Fig. 1



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SUMMARY LOGS OF EXPLORATORY BORINGS

CH2M HILL, INC.
12-MILE PARK CHERRY CREEK STREAM RECLAMATION
PROJECT NO. DN45,052-125

FIG. 3

LEGEND:

CLAY, SLIGHTLY SANDY TO SANDY, VERY SOFT TO VERY STIFF, MOIST TO WET, BROWN, GRAY, RUST, CALCAREOUS (CL OR CH).

SAND, FINE TO MEDIUM GRAINED, SILTY TO VERY CLAYEY, VARIABLE AMOUNTS OF GRAVEL, VERY LOOSE TO DENSE, MOIST TO WET, BROWN, GRAY (SP, SM, SC).

BEDROCK, SANDSTONE, HARD, MOIST, BROWN, RUST.

DRIVE SAMPLE. THE SYMBOL 4/12 INDICATES 4 BLOWS OF A 140-POUND HAMMER FALLING 30 INCHES WERE REQUIRED TO DRIVE A 2.5-INCH O.D. SAMPLER 12 INCHES.

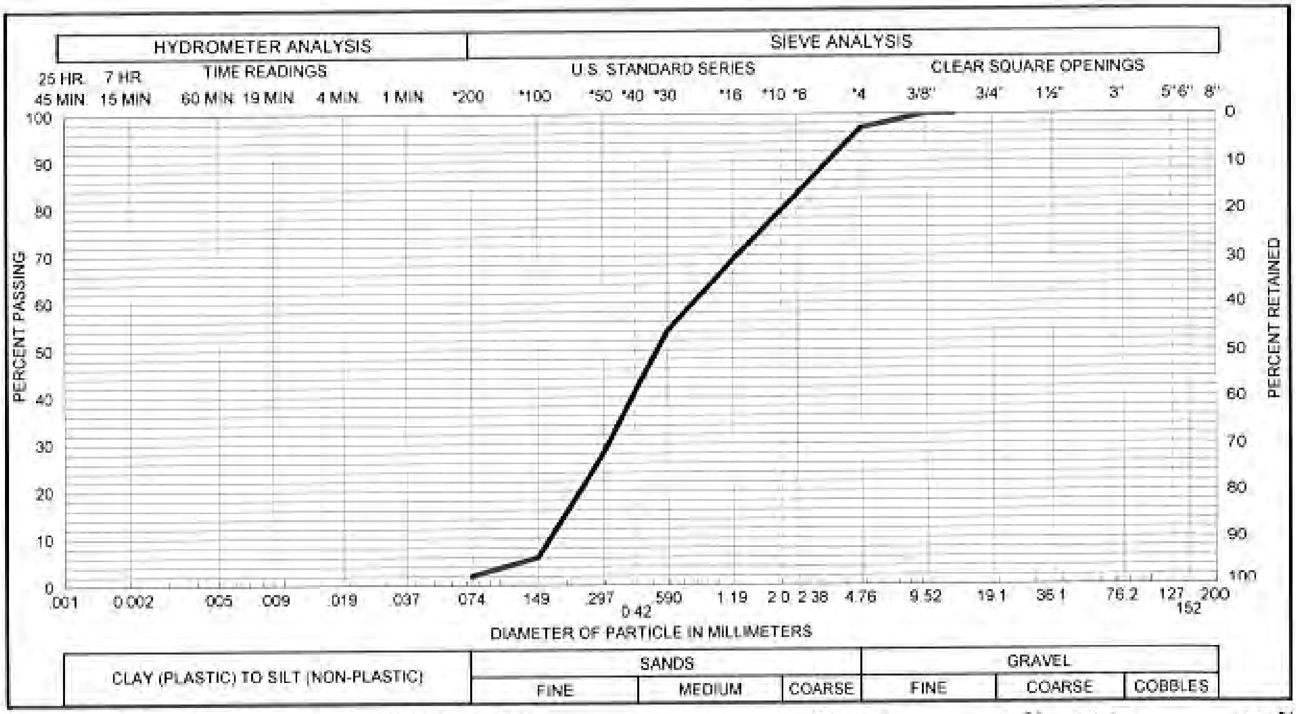
∇ WATER LEVEL MEASURED AT TIME OF DRILLING.

▼ WATER LEVEL MEASURED 3 DAYS AFTER DRILLING ON JULY 15, 2010.

NOTES:

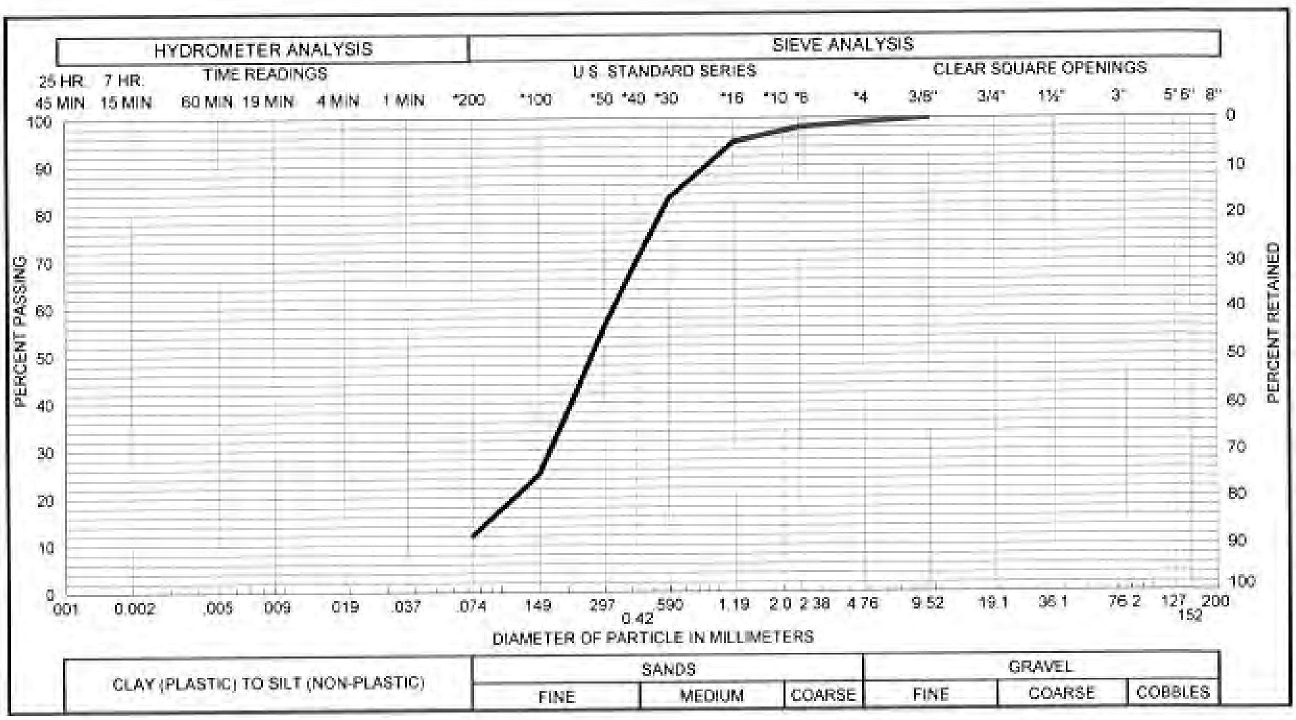
1. THE BORINGS WERE DRILLED ON JULY 12, 2010 USING 4-INCH DIAMETER, CONTINUOUS-FLIGHT AUGER AND A TRUCK-MOUNTED CME-45 DRILL RIG.
2. BORING LOCATIONS WERE DETERMINED BY A REPRESENTATIVE OF OUR FIRM AND A REPRESENTATIVE OF CH2M HILL. BORING ELEVATIONS WERE PROVIDED TO US BY CH2M HILL.
3. WC - INDICATES MOISTURE CONTENT (%).
   DD - INDICATES DRY DENSITY (PCF).
   LL - INDICATES LIQUID LIMIT (%).
   PI - INDICATES PLASTICITY INDEX (%).
   -200 - INDICATES PASSING NO. 200 SIEVE (%).
   UC - INDICATES UNCONFINED COMPRESSIVE STRENGTH (psf).
4. THESE LOGS ARE SUBJECT TO THE EXPLANATIONS, LIMITATIONS AND CONCLUSIONS CONTAINED IN THIS REPORT.

SUMMARY LEGEND OF EXPLORATORY BORINGS



Sample of SAND, SLIGHTLY SILTY (SP)
From STREAMBED SAMPLE ADJACENT TO TH-1

GRAVEL 3 % SAND 95 %
SILT & CLAY 2 % LIQUID LIMIT - %
PLASTICITY INDEX - %

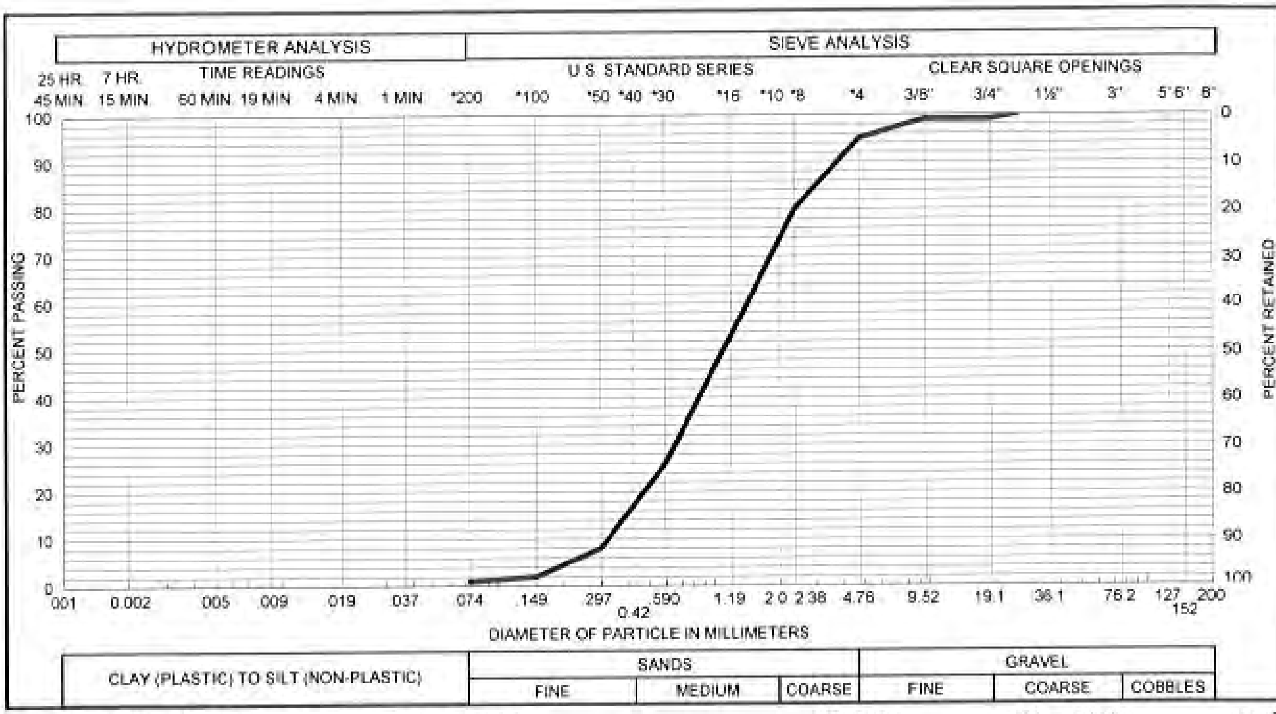


Sample of SAND, SILTY (SM)
From STREAMBED SAMPLE ADJACENT TO TH-2

GRAVEL 1 % SAND 87 %
SILT & CLAY 12 % LIQUID LIMIT - %
PLASTICITY INDEX - %

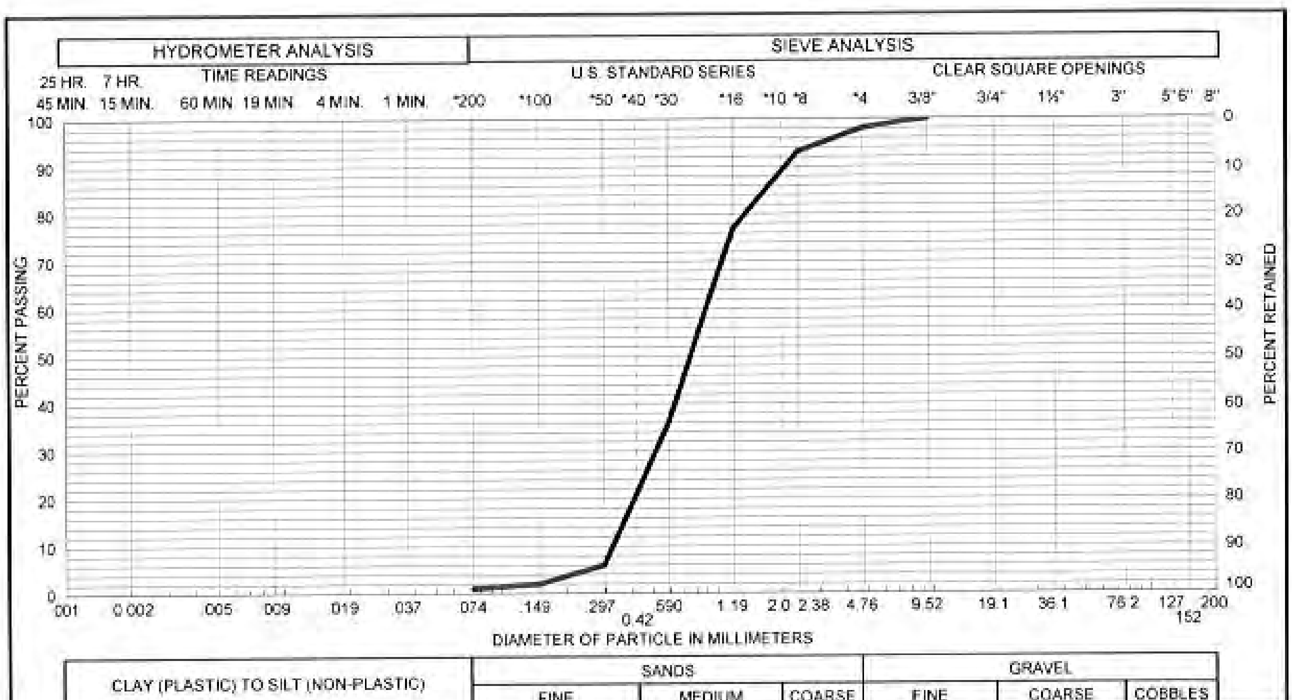
Gradation Test Results

FIG. 5



Sample of SAND, SLIGHTLY SILTY (SP)
From STREAMBED SAMPLE ADJACENT TO TH-3

GRAVEL	5 %	SAND	94 %
SILT & CLAY	1 %	LIQUID LIMIT	- %
PLASTICITY INDEX	- %		



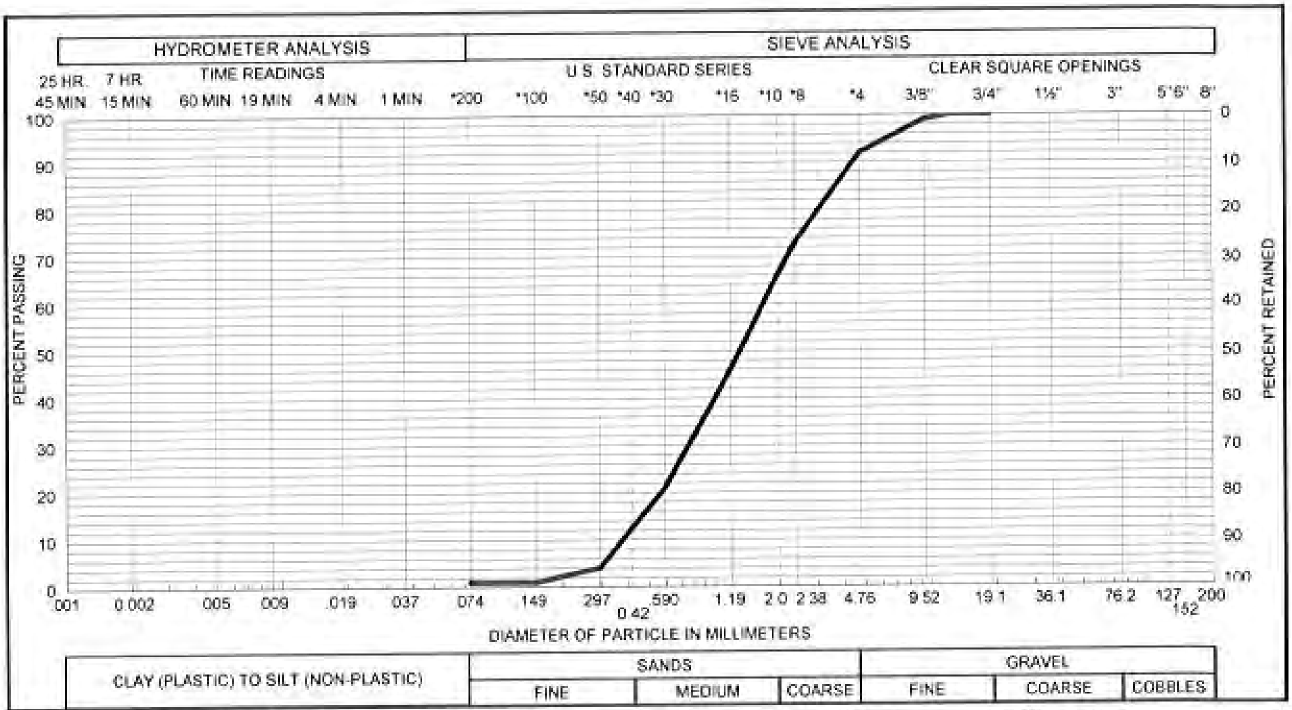
Sample of SAND, SLIGHTLY SILTY (SP)
From STREAMBED SAMPLE ADJACENT TO TH-4

GRAVEL	2 %	SAND	97 %
SILT & CLAY	1 %	LIQUID LIMIT	- %
PLASTICITY INDEX	- %		

Gradation Test Results

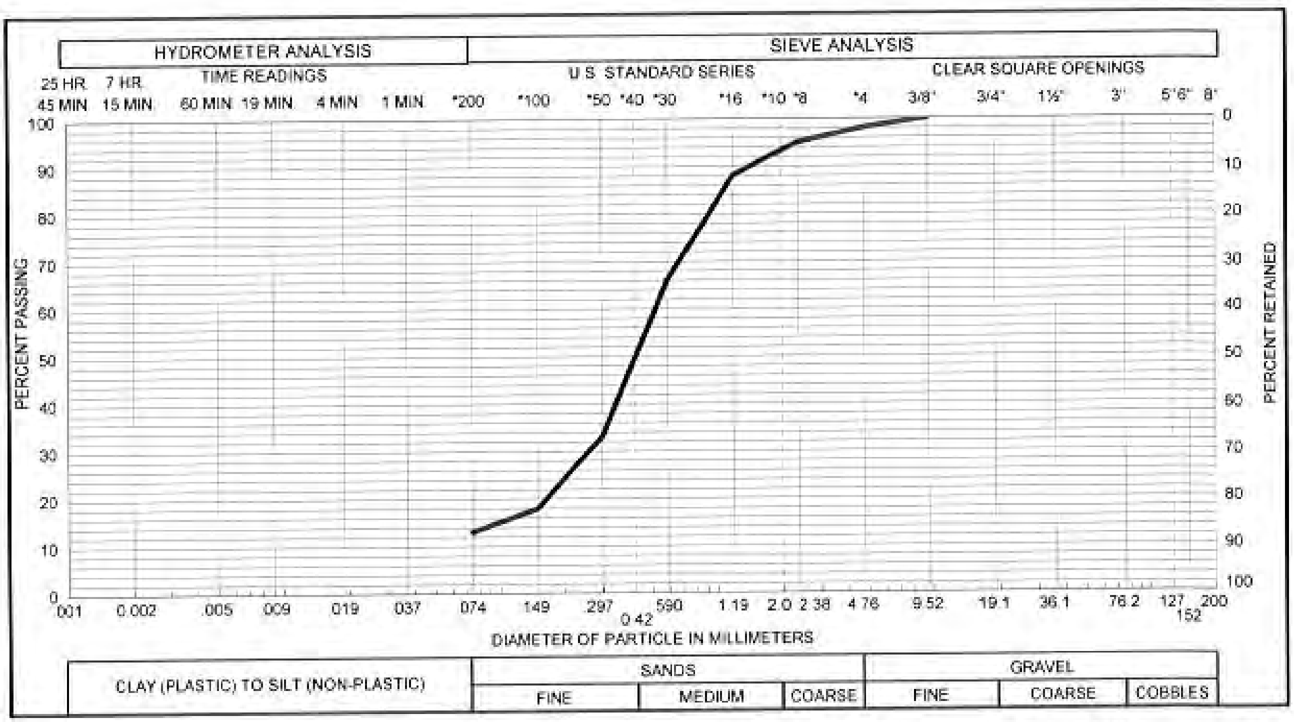
FIG. 6

CH2M HILL, INC
12-MILE PARK CHERRY CREEK STREAM RECLAMATION
PROJECT NO. DN45,052-125
S:\PROJECTS\45000\DN45052.000\125\2 Reports\R1\DN45052-125-R1-X2(GRAD)



Sample of SAND, SLIGHTLY SILTY (SP)
From STREAMBED SAMPLE ADJACENT TO TH-5

GRAVEL	8 %	SAND	91 %
SILT & CLAY	1 %	LIQUID LIMIT	- %
PLASTICITY INDEX			- %

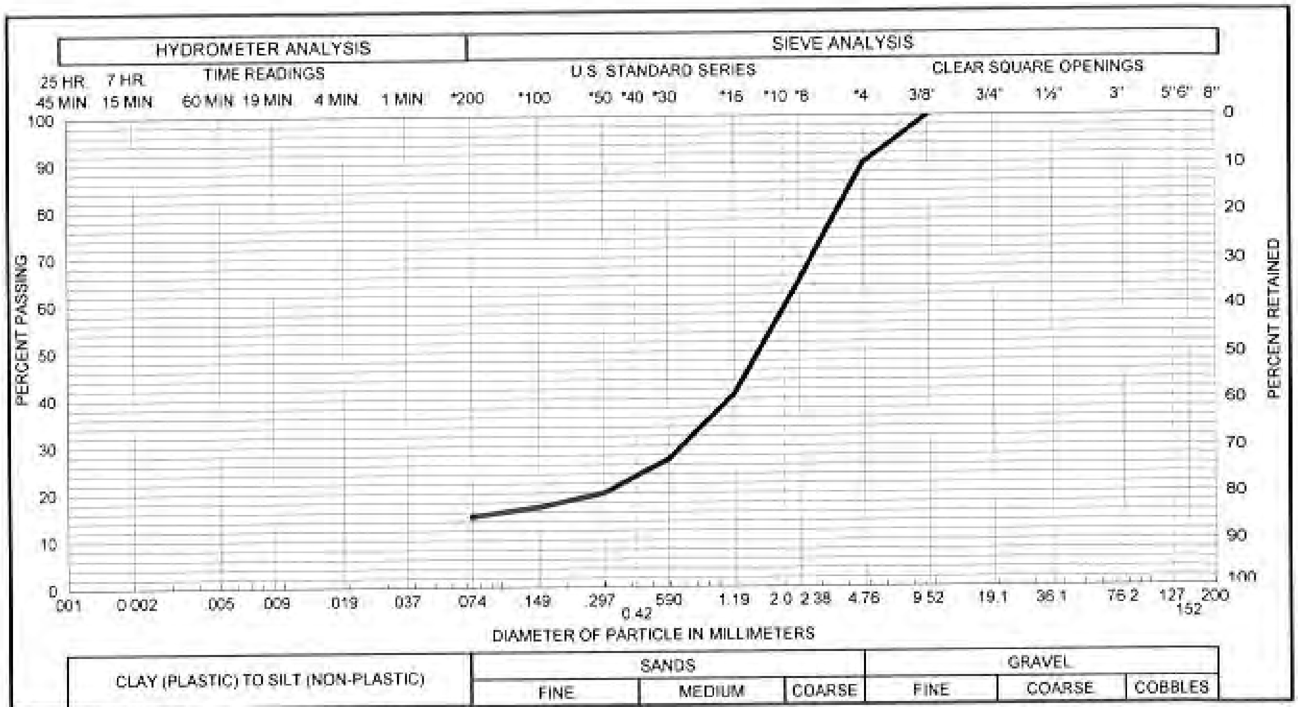


Sample of SAND, SILTY (SM)
From TH - 1 AT 4 FEET

GRAVEL	2 %	SAND	85 %
SILT & CLAY	13 %	LIQUID LIMIT	- %
PLASTICITY INDEX			- %

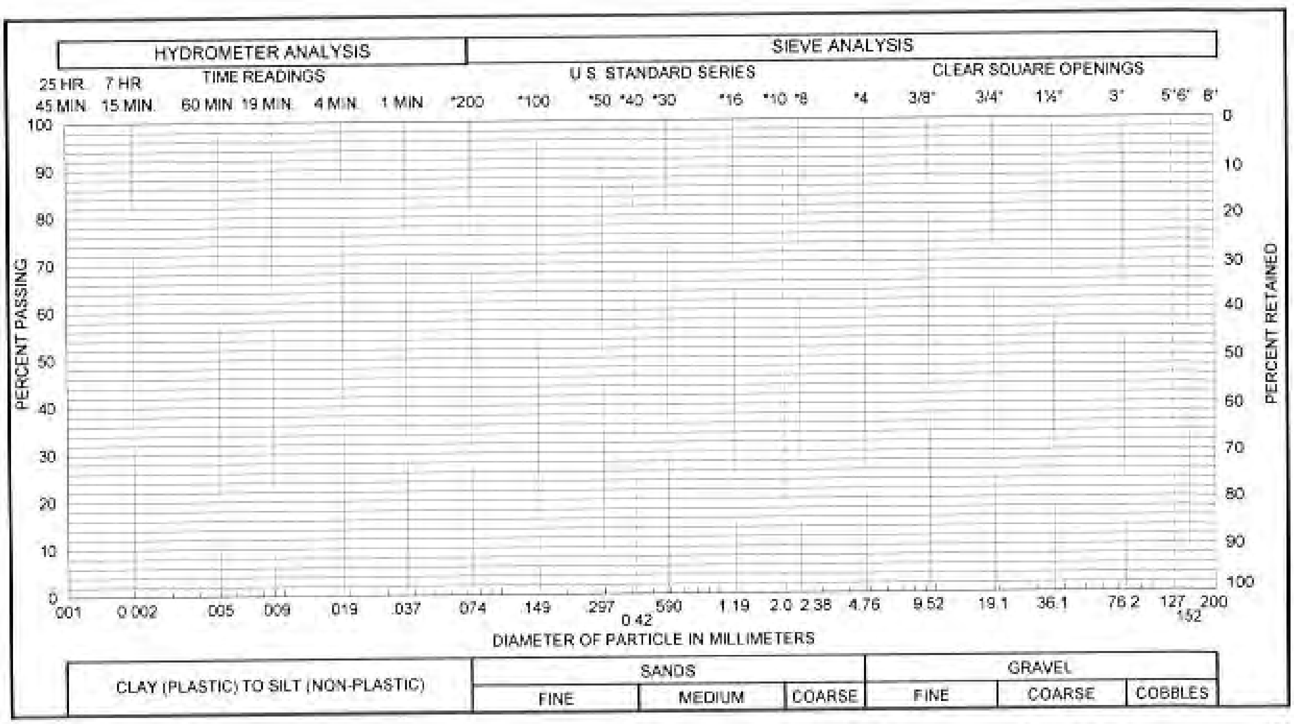
Gradation Test Results

FIG. 7



Sample of SAND, SILTY (SM)
From TH - 2 AT 14 FEET

GRAVEL 10 % SAND 75 %
SILT & CLAY 15 % LIQUID LIMIT - %
PLASTICITY INDEX - %



Sample of
From

GRAVEL % SAND %
SILT & CLAY % LIQUID LIMIT %
PLASTICITY INDEX %

Gradation Test Results

FIG. 8

MEMORANDUM

To: Molly Trujillo, PE
From: George Cotton, PE
Date: March 11, 2011
Subject: Design Flows in the Cherry Creek

The purpose of this memo is to evaluate long-term hydrology of the Cherry Creek in the sedimentation study reach (Pine Lane to the Reservoir). This is a losing reach, according to models that take into consideration water supply operations. It is likely that water diversion from the alluvial aquifer affects flood hydrology and channel forming discharges. Three hydrology studies are reviewed: the SMWSA Master Plan, the Major Drainageway Planning Study, and the CCBWQA phosphorus model.

Analysis of SMWSA Master Plan

In 2007, the South Metro Water Supply Authority published its master plan for water supply development. SMWSA is an umbrella for 13 water providers, most of which are within the Cherry Creek basin. More than 80% of the SMWSA water supply is used within the Cherry Creek basin. Future storage of renewable water supplies by all of the SMWSA water providers occurs at the new Rueter-Hess reservoir, which is also within the Cherry Creek basin.

Figure 2-3 (below) from the SMWSA Master Plan shows the breakdown of water supplies over the planning horizon. Table 1 provides the same information as the graph and also back casts to the year 2000.

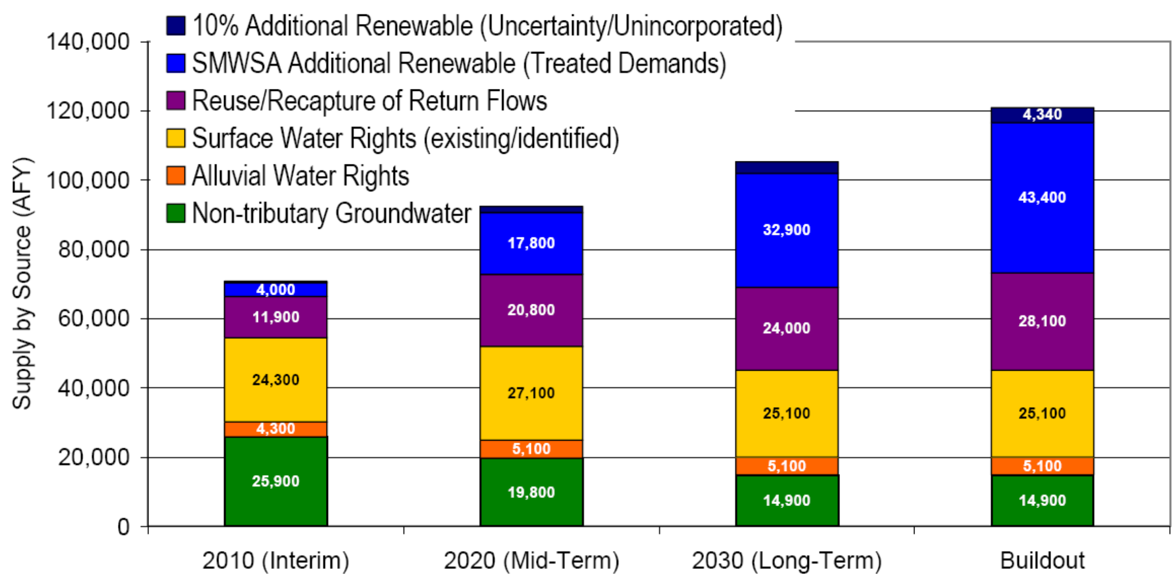


Figure 2-3 Projected Sources of Supply, Aggregated for all 12 SMWSA Water Providers

Figure 1. Taken from SMWSA Master Plan 2007

Table 1. SMWSA Water Sources over planning horizon

Year	Renewable Supply	Surface Supply	Renewable Buffer	Ground Water	Recap / Return	Alluvial (water rights)	Total
2000	0	500	0	42220	3000	3500	49220
2010	4000	24300	400	25900	11900	4300	70800
2020	17800	27100	1780	19800	20800	5100	92380
2030	32900	25100	3290	14900	24000	5100	105290
Buildout	43400	25100	4340	14900	28100	5100	120940

Most of the water supply for the SMWSA water providers comes from imported sources. SMWSA's goal is to shift from a heavy dependence on non-renewable groundwater to renewable water supplies by acquiring surface water rights in other basins and transporting this supply to the SMWSA service area and then to each service provider. This will require the development of existing water rights (called surface supply), then acquiring and developing new water rights (called renewable supply). This will permit ground water use to decline. To account for uncertainty in this process, the master plan includes a renewable buffer that is equal to 10% of the estimated required renewable supply.

A second source of water supply for SMWSA water providers comes from the recapture of flows or return flows. These flows will largely be recovered through alluvial wells. Also, most of the surface water rights on Cherry Creek are diverted through alluvial wells.

So, water supply for SMWSA water providers can be aggregated into two classes: imported supplies (renewable, surface, and groundwater), and alluvial (recapture / return and alluvial water rights). I estimate that on an annual basis about 44% of the total supply will be returned (assuming that 42% of the supply is for domestic use and 58% is for irrigation, with 10% consumption of domestic water and 90% consumption of irrigation). Table 2 provides an estimate of the un-diverted alluvial flow (both flow in the alluvial aquifers and in surface streams), where the un-diverted alluvial flow is equal to 44% of the total supply minus the diverted alluvial flow. These data are shown graphically in Figure 2.

Table 2. Estimate of Un-Diverted Alluvial Flows within SMWSA

Year	Total	Diverted Alluvial	Imported Flows	Un-Diverted Alluvial
2000	49220	6500	42720	14960
2010	70800	16200	54600	14669
2020	92380	25900	66480	14378
2030	105290	29100	76190	16806
Buildout	120940	33200	87740	19530

In 2000, 82% of the SMWSA water providers were associated with the Cherry Creek basin. Using sub-reach 880 in the CCBWQA model (Parker, CO) as a point of reference the SMWSA master plan estimates that 12,300 ac-ft of un-diverted alluvial flow occurred at this point in the Cherry Creek. This compares with 11,700 ac-ft estimated by the CCBWQA model. In addition, the CCBWQA model estimates a reach flow loss of 2,500 ac-ft compared to SMWSA estimate of 5,300 ac-ft.

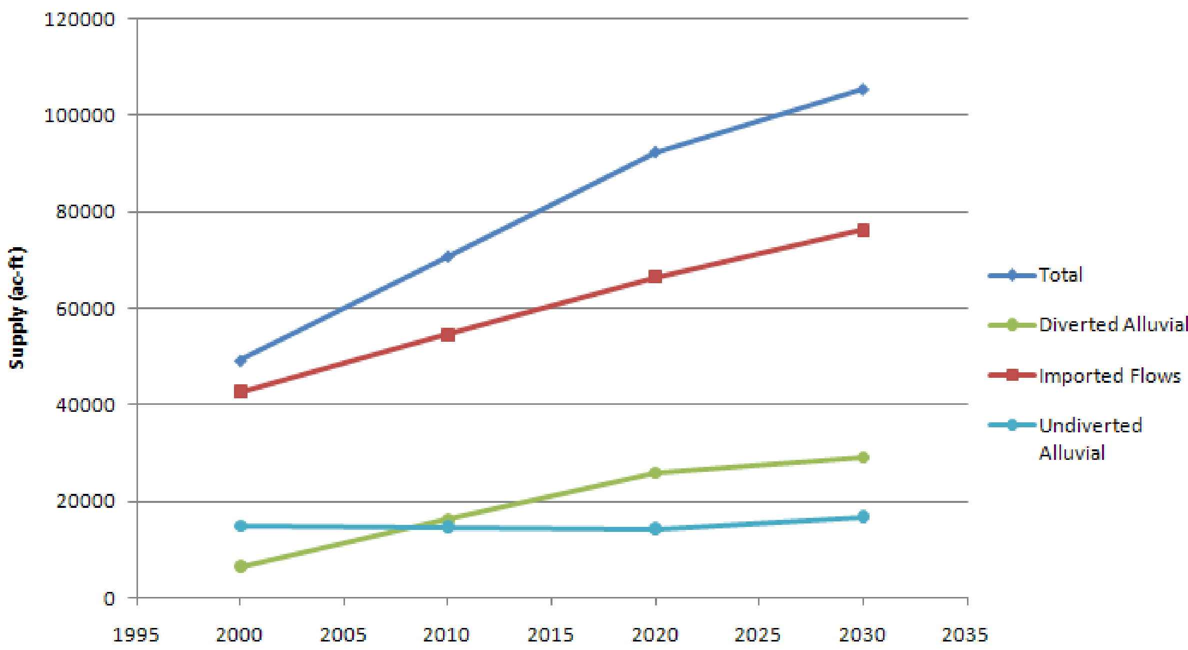


Figure 2. SMWSA Master Plan Water Supply Breakdown

Recovery of flows will increase steadily, which will increase the total diverted alluvial flow in the Cherry Creek. In 2000, only about 6.1% of the total supply was recovered. SMWSA estimates that in 2010, 16.8% was recovered and that by 2020 22.5% will be recovered, which will be close to the maximum expected recovery that will be achieved at build out (23.2%). The result is that un-diverted alluvial flows remain essentially unchanged even as water supply is dramatically increased to the Cherry Creek basin. Of all of the sources of water supply for water providers in SMWSA, recovered flows are probably one of the least difficult to acquire administratively and the least costly to deliver.

Analysis of Major Drainageway Master Plan

The “Cherry Creek Major Drainageway Planning Study” was prepared in 2002 and provides an estimate of the flood hydrology for existing and future conditions in the basin. This hydrology deals directly with the main effect of rural to urban land use change, which is the increase in impervious area and the resulting increase in runoff volume. This is a condition that is not addressed by the SMWSA master plan for the reason that stormwater runoff is considered a minor and unreliable source of water. This may not be entirely true. From 1985 to 2010, basin imperviousness has increased for 13% to 23% and will continue to increase at the rate of 1% for every 11,600 housing units built in the basin. Runoff from these impervious areas ultimately connects to the Cherry Creek, where it may be diverted for water supply as long as overall basin yield from Cherry Creek tends to maintain the historical average.

Urban runoff enters the Cherry Creek via storm drainage outfalls and tributary drainageways. It appears that alluvial pumping very quickly captures minor runoff. So CCBWQA estimates of base flow, which comport with SMWSA planning, indicate that the “Cherry Creek Major Drainageway Planning Study” probably over estimates frequent floods such as the 2-year.

Estimates of less frequent floods are intended to be conservative and are intended to provide a prudent means of delineating flood hazards. All of the jurisdictions in the Cherry Creek carefully administer floodplain regulations and development standards that should ensure that the future floods are less severe than are predicted by the planning study. Tables 3 and 4 summarize flood hydrology data from the "Cherry Creek Major Drainageway Planning Study".

Table 3. Peak Flow Summary - Sedimentation Study Reach / Existing Conditions

	EXISTING CONDITIONS (CFS)					
Sub-Rch	Q002	Q005	Q010	Q025	Q050	Q100
880	1555	4441	8100	16039	24040	39785
878	1564	4454	8115	16072	24058	39835
873	1552	4423	8087	16000	23968	39636
869	1557	4431	8092	16028	23975	39622
867	1563	4438	8102	16056	23980	39630
868	1562	4430	8095	16042	23948	39557
819	1791	5021	8954	17866	27045	43625
816	1764	4980	8915	17772	26832	43272
821	1759	4971	8906	17751	26777	43170
813	1767	4984	8921	17795	26814	43213
812	1769	4986	8921	17798	26812	43217
811	1769	4986	8921	17798	26811	43217

Table 4. Peak Flow Summary - Sedimentation Study Reach / Future Conditions

	FUTURE CONDITIONS (CFS)					
Sub-Rch	Q002	Q005	Q010	Q025	Q050	Q100
880	3294	7000	10939	19599	28168	43246
878	3341	7097	11026	19705	28303	43338
873	3330	7121	11033	19702	28238	43215
869	3347	7170	11083	19762	28272	43263
867	3361	7218	11128	19824	28310	43301
868	3360	7221	11136	19820	28287	43244
819	3949	8389	12825	22573	32353	48250
816	3882	8298	12731	22409	32042	47891
821	3894	8324	12784	22485	32036	47864
813	3915	8356	12829	22570	32100	47897
812	3919	8361	12836	22590	32097	47876
811	3919	8361	12836	22590	32095	47872

One approach to using the planning study flood hydrology would be to scale the existing 2-year flood peaks for sub-reaches by flow volume ratios (sub-reach volume divided by sub-reach 880 volume) as computed by the CCBWQA model (see Table 5). Using this approach, the 2-year existing and future conditions would be as shown in Table 6.

Table 5. Sub-Reach Flow Scaling following based on volume (CCBWQA model)

Sub-Reach	880	878	873	869	867	868
Volume (ac-ft)	76,368	74,567	72,358	67,681	65,061	65,718
Flow Scaling	100.0%	97.6%	94.7%	88.6%	85.2%	86.1%
Sub-Reach	819	816	821	813	812	811
Volume (ac-ft)	70,918	61,328	62,880	59,287	56,555	52,232
Flow Scaling	92.9%	80.3%	82.3%	77.6%	74.1%	68.4%

Table 6. "Cherry Creek Major Drainageway Planning Study" Scaled 2-year flows

	Scaling	Existing Conditions			Future Conditions		
Sub-Rch	Factor	Original	Scaled	Ratio	Original	Scaled	Ratio
880	100.0%	1555	1555	100.0%	3294	3294	100.0%
878	97.6%	1564	1518	97.0%	3341	3215	96.2%
873	94.7%	1552	1473	94.9%	3330	3119	93.7%
869	88.6%	1557	1378	88.5%	3347	2918	87.2%
867	85.2%	1563	1325	84.8%	3361	2806	83.5%
868	86.1%	1562	1339	85.7%	3360	2836	84.4%
819	92.9%	1791	1445	80.7%	3949	3060	77.5%
816	80.3%	1764	1249	70.8%	3882	2645	68.1%
821	82.3%	1759	1280	72.8%	3894	2711	69.6%
813	77.6%	1767	1207	68.3%	3915	2556	65.3%
812	74.1%	1769	1152	65.1%	3919	2441	62.3%
811	68.4%	1769	1064	60.1%	3919	2253	57.5%

CCBWQA Dominant Discharge

The dominant discharge for a stream reach is the product of the probability of a stream discharge multiplied by the sediment load in the reach. This probability approach places a higher weighting on frequent stream flows and lower weighting of rare stream flows. The discharge associated with the maximum weighted sediment loading is referred to as the dominant discharge. This method was used to identify the dominant discharge in the sub-reaches of the study reach over the eight year CCBWQA model simulation. Figure 3 shows the calculation results graphically.

Table 7. Sub-Reach dominant discharges (CCBWQA model)

Sub-Reach	880	878	873	869	867	868
Dominant Q (ac-ft/mo)	1080	880	960	550	500	800
Sub-Reach	819	816	821	813	812	811
Dominant Q (ac-ft/mo)	550	550	500	600	500	n/c

The weighting of more frequent sediment loads follows a normal pattern, which rises steadily to a peak value. While there is a distinct peak in weighted sediment loads for each sub-reach, the less frequent sediment loads don't decline and can reach values that equal or exceed the first peak. This may be a product of the short period of simulation or the complex way that water is routed and diverted from the Cherry Creek.

Recommended Flows

While scaling of flows based on volume is admittedly a very approximate approach it has the advantage of comporting to major drainageway planning and to the losing nature of reach as shown in the CCBWQA model and SMWSA master planning. In the long run, we recommend that the UDSWM model that was used for major drainageway planning be converted to EPA-SWMM. In this way, additional modeling elements found in the CCBWQA modeling elements could be included. EPA-SWMM has similar routines to those developed for the CCBWQA model (for example, alluvial groundwater flow simulation), so the conversion could draw on data and calibration work already conducted by CCBWQA.

For the time being, using scaled 2-year existing-conditions flows from the major drainageway planning study is recommended (green highlighted column in Table 6). Use of future flows is not recommended because the SMWSA planning does not show a future increase in un-diverted alluvial flows.

References

Brown and Caldwell, 2008, "Cherry Creek Basin Watershed Phosphorus Model Documentation" prepared for the Cherry Creek Basin Water Quality Authority

CDM, 2007, "South Metro Water Supply Authority Regional Water Master Plan" prepared for South Metro Water Supply Authority

URS, 2002, "Cherry Creek Corridor – Reservoir to Scott Road / Major Drainageway Planning Study" prepared for Arapahoe County, Douglas County, City of Aurora, City of Centennial, Town of Parker, Urban Drainage and Flood Control District

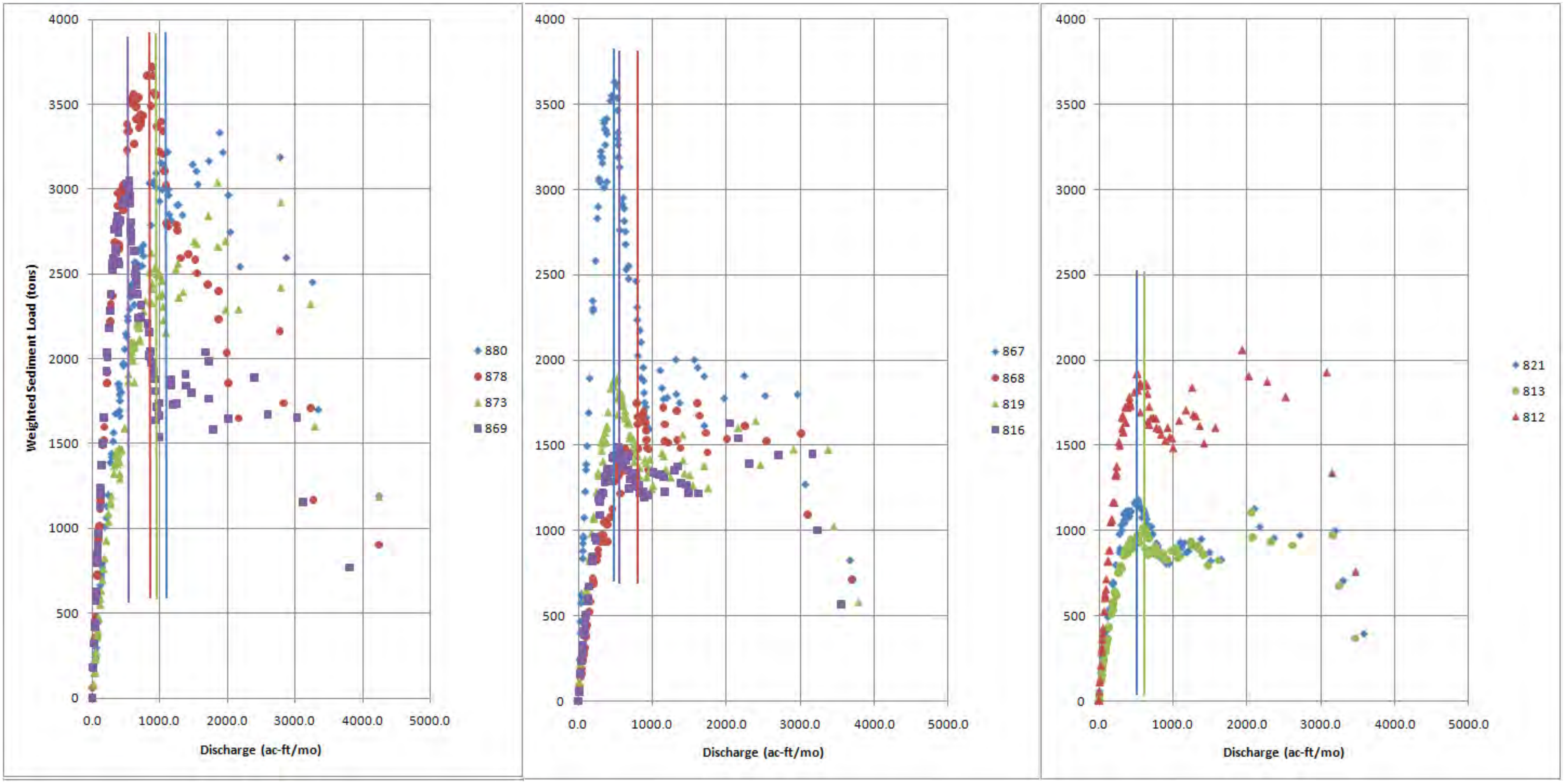


Figure 3 Shows plots of dominant discharge calculation as computed by sub-reach for the CCBWQA simulation. The vertical lines show the approximate location of the first peak in weighted sediment loading, i.e. the dominant discharge for the sub-reach (ac-ft/month). The vertical axis is the probability weighted sediment transport in tons.

MEMORANDUM

To: Molly Trujillo, PE

From: George Cotton

Date: December 20, 2010

Subject: Regression form of the Engelund and Hansen Sediment Transport Capacity Approach

Engelund and Hansen's Approach

Engelund and Hansen (1967) proposed a method for determining total sediment load in streams with dune-covered beds. The relationships are as follows:

$$f\phi = 0.1\ \theta^{1.5} \qquad \text{.......Equation 1.0.0}$$

where:

$$\phi = \frac{g_b}{\sqrt{S_s'\, g\, d_{50}^3}} \qquad \text{.......Equation 1.1.0}$$

$$f = \frac{2U_*^2}{U^2} \qquad \text{.......Equation 1.2.0}$$

$$\frac{U_*}{U} = 0.6 + 2.5\ \ln\left(\frac{y_o'}{k}\right) \qquad \text{.......Equation 1.2.1}$$

where: $k \cong 2.5\ d_f$

$$y_o' = \frac{\theta'}{\theta}\ y_o \qquad \text{.......Equation 1.3.1}$$

$$\theta = \frac{\tau_o}{\gamma_s'} \qquad \text{.......Equation 1.3.2}$$

$$\theta' = 0.06 + 0.4\ \theta^2 \qquad \text{.......Equation 1.3.2}$$

With the value of y'_o the mean velocity, U, can be calculated. The sediment load can then be expressed as:

$$g_b = 0.05\ U^2 \sqrt{\frac{d_{50}}{g\, S_s'}} \left(\frac{\tau_o}{\gamma'_s d_{50}}\right)^{3/2} \qquad \text{.......Equation 2.0.0}$$

Variable definitions and the associated units are provided in Appendix A.

Engelund (1973) also proposed a method for calculation of sediment transport when the bed material is graded. It assumed that particles finer than a certain size will all enter into suspension while larger grains will move as bed load. The criterion for critical size is based on the empirical value of $2.5\ {}^{w}/_{U_*} \cong 2$.

E-H Sediment transport capacity from HEC-RAS 4

While the Engelund and Hansen is not a particularly complex sediment transport formula, there are several aspects of the approach that require detailed knowledge to implement in HEC-RAS 4. So as not to presume the approach taken by HEC, a set of sediment transport data was generated directly from HEC-RAS 4.

Inputs consisted of a wide rectangular channel (50 feet) with a uniform n-value of 0.025 for the geometry. Increments of channel slope varied as 0.0020, 0.0040 and 0.0060 ft/ft. The gradation of the bed material was varied from d_{50} of 0.9 mm to 1.9 mm with gradation coefficients of 2.2 and 3.2 for the 1.9 mm size. Unit discharge was varied from 1.0 cfs/ft to 200 cfs/ft.

Table 1 summarizes the input increments for the Engelund and Hansen sediment transport calculations using HEC-RAS 4. The generated data set is given in Appendix B.

Table 1. HEC-RAS 4 Input Cases

<table>
<tr><th>Case</th><th>Slope, S (ft/ft)</th><th>d_{50} (mm)</th><th>G</th><th>Unit discharge, q, increments (cfs/ft)</th></tr>
<tr><td>1</td><td>0.0020</td><td rowspan="3">0.9</td><td rowspan="9">2.2</td><td rowspan="12">1, 2, 5, 10, 20, 50, 100, 200</td></tr>
<tr><td>2</td><td>0.0040</td></tr>
<tr><td>3</td><td>0.0060</td></tr>
<tr><td>4</td><td>0.0020</td><td rowspan="3">1.2</td></tr>
<tr><td>5</td><td>0.0040</td></tr>
<tr><td>6</td><td>0.0060</td></tr>
<tr><td>7</td><td>0.0020</td><td rowspan="3">1.6</td></tr>
<tr><td>8</td><td>0.0040</td></tr>
<tr><td>9</td><td>0.0060</td></tr>
<tr><td>10</td><td>0.0020</td><td rowspan="3">1.9</td><td rowspan="3">3.2</td></tr>
<tr><td>11</td><td>0.0040</td></tr>
<tr><td>12</td><td>0.0060</td></tr>
</table>

E-H Sediment transport capacity Regression Equation

A sediment transport capacity regression equation was computed by transforming the data set (total bed load, mean velocity, depth, and mean sediment size) to natural log values and then linearly regressing the transformed data set using Excel's LINEST regression function. Since the data set is without error and derived from a fairly simple function it was expected that regression error should be minimal. The r^2 value for the equations was in fact 1.0. The resulting power function formula is

$$g_b = b\, V^{5.0}\, D^{-0.50}$$ ....Equation 3.0.0

where: $b = 0.1118\, G^{0.37}\, d_{50}^{-0.69}$

The coefficient, b, is constant for a known sediment gradation. For example, current bed-material in the Cherry Creek has the following properties: d_{50} = 1.2 and G = 2.2, which give a coefficient of b = 0.132. Up-valley the bed-material coarsens to d_{50} = 1.9 and G = 3.2, which give a coefficient of b = 0.110 (about a 20% reduction).

Of interest in equation 3 are the two exponents. The velocity exponent of 5.0 can be predicted from equation 2, since $\tau_o \propto U^2$. This indicates that the formula has a very high sensitivity to velocity. The flow depth exponent shows a common behavior of sediment transport, which is a reduction in transport capacity with increasing flow depth.

Range of Applicability

As with any regression equation, the use of the Engelund-Hansen regression equation should not exceed the range of data from which it was developed. This is particularly true for the properties of the sediment gradation (G and d_{50}). Likewise, when using this regression equation to estimate sediment transport in the active channel of the Cherry Creek, the active channel roughness should be approximately 0.025 to be consistent with the active-channel roughness that was used to develop this data set.

The ranges are applicable to the hydraulic properties of the active channel of the Cherry Creek and do not necessarily apply to portions of the channel that are outside that boundary where sediment transport is not being calculated.

Variable	**Range**
Velocity, V (ft/s)	1.8 to 20.8
Depth, D (ft)	0.4 to 13.3
Froude No., Fr	0.4 to 1.2
Unit discharge, q (cfs/ft)	1 to 200
Slope, S (ft/ft)	0.0020 to 0.0060
Sediment size, d_{50} (mm)	0.6 to 1.9
Gradation Coefficient, G	2.2 to 3.2

References:

Engelund, F., 1973, "Steady transport on moderately graded sediment," Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark, Progress Report 21

Engelund, F. and E. Hansen, 1967, "A Monograph on Sediment Transport in Alluvial Streams", Teknisk Forlag, Copenhagen

HEC-RAS Version 4.0, March 2008, "River Analysis System Application Guide" U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA

Microsoft Office Excel 2007, Microsoft Corporation

Appendix A. Variable Definitions

d_{50}	mean sediment particle size, mm
d_f	equivalent particle size based on fall velocity, mm
g_b	unit sediment transport capacity, tons/day/ft
g	acceleration of gravity, ft/s^2
k	equivalent roughness size, ft
S'_s	submerged specific gravity of sediment, dimensionless
S	Slope, ft/ft
U_*	shear velocity, ft/s
U, V	mean velocity, ft/s
w	fall velocity, ft/s
y'_o	effective flow depth, ft
γ'_s	submerged unit weight of sediment, lb/ft^3
τ_o	bed shear stress, lb/ft^2

Appendix B. HEC-RAS 4 Data Set

Case	G	d_{50} (mm)	S (ft/ft)	q (cfs/ft)	g_b (tons/day/ft)	V (ft/s)	D (ft)
1	2.2	0.6	0.002	1	5.3	1.8	0.56
				2	17.3	2.37	0.84
				5	82.1	3.42	1.46
				10	267.0	4.51	2.21
				20	868.4	5.96	3.35
				50	4118	8.59	5.81
				100	13350	11.33	8.8
				200	43320	14.95	13.34
2	2.2	1.2	0.002	1	3.3	1.8	0.56
				2	10.8	2.37	0.84
				5	51.3	3.42	1.46
				10	166.8	4.51	2.21
				20	542.6	5.96	3.35
				50	2574	8.59	5.81
				100	8344	11.33	8.8
				200	27060	14.95	13.34
3	2.2	1.6	0.002	1	2.7	1.8	0.56
				2	8.7	2.37	0.84
				5	41.4	3.42	1.46
				10	134.6	4.51	2.21
				20	438	5.96	3.35
				50	2076	8.59	5.81
				100	6734	11.33	8.8
				200	21840	14.95	13.34
4	2.2	0.6	0.004	1	16.9	2.21	0.45
				2	54.7	2.92	0.69
				5	258.8	4.21	1.19
				10	839	5.56	1.8
				20	2724	7.33	2.73
				50	12928	10.58	4.72
				100	41940	13.96	7.15
				200	136240	18.41	10.83
5	2.2	1.2	0.004	1	10.6	2.21	0.45
				2	34.2	2.92	0.69
				5	161.7	4.21	1.19
				10	524.2	5.56	1.8
				20	1702.2	7.33	2.73
				50	8080	10.58	4.72
				100	26200	13.96	7.15
				200	85140	18.41	10.83

(continued)

Case	G	d_{50} (mm)	S (ft/ft)	q (cfs/ft)	g_b (tons/day/ft)	V (ft/s)	D (ft)
6	2.2	1.6	0.004	1	8.5	2.21	0.45
				2	27.6	2.92	0.69
				5	130.5	4.21	1.19
				10	423.2	5.56	1.8
				20	1373.8	7.33	2.73
				50	6520	10.58	4.72
				100	21160	13.96	7.15
				200	68720	18.41	10.83
7	2.2	0.6	0.006	1	33.2	2.5	0.4
				2	103.6	3.3	0.61
				5	503	4.76	1.05
				10	1638.8	6.28	1.59
				20	5318	8.28	2.41
				50	25240	11.95	4.18
				100	81880	15.71	6.35
				200	266000	20.78	9.6
8	2.2	1.2	0.006	1	20.7	2.5	0.4
				2	64.8	3.3	0.61
				5	314.4	4.76	1.05
				10	1024.2	6.28	1.59
				20	3324	8.28	2.41
				50	15772	11.95	4.18
				100	51180	15.71	6.35
				200	166240	20.78	9.6
9	2.2	1.6	0.006	1	16.7	2.5	0.4
				2	52.3	3.3	0.61
				5	253.8	4.76	1.05
				10	826.6	6.28	1.59
				20	2682	8.28	2.41
				50	12730	11.95	4.18
				100	41300	15.71	6.35
				200	134180	20.78	9.6

(continued)

Case	G	d50 (mm)	S (ft/ft)	q (cfs/ft)	gb (tons/day/ft)	V (ft/s)	D (ft)
10	3.2	1.9	0.002	1	2.8	1.80	0.56
				2	9.0	2.37	0.84
				5	42.7	3.42	1.46
				10	138.9	4.51	2.21
				20	451.8	5.96	3.35
				50	2142	8.59	5.81
				100	6946	11.33	8.8
				200	22540	14.95	13.34
11	3.2	1.9	0.004	1	8.8	2.21	0.45
				2	28.5	2.92	0.69
				5	134.6	4.21	1.19
				10	436.6	5.56	1.8
				20	1417.2	7.33	2.73
				50	6726	10.58	4.72
				100	21820	13.96	7.15
				200	70900	18.41	10.83
12	3.2	1.9	0.006	1	17.3	2.5	0.4
				2	53.9	3.3	0.61
				5	261.8	4.76	1.05
				10	852.8	6.28	1.59
				20	2768	8.28	2.41
				50	13132	11.95	4.18
				100	42600	15.71	6.35
				200	138420	20.78	9.6

Cherry Creek Sedimentation Study
Reservoir to Pine Lane
Sediment Transport Equation Calibration

January 2010 2011

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CHERRY CREEK SEDIMENTATION STUDY

SEDIMENT TRANSPORT EQUATION CALIBRATION

Table of Contents

INTRODUCTION

This paper describes the selection and calibration of a sediment transport equation for the Cherry Creek. Calibration is based on data that was collected for the basin and in the reach of the Cherry Creek above Cherry Creek Lake. Sediment transport equations were selected from those that are available in HEC-RAS 4. The equations were then solved for hydraulic and sediment conditions found in the study reach. The best transport equation was determined by comparison to recorded sedimentation in the Cherry Creek reservoir.

Equations were solved using HEC-RAS 4 hydraulic design tools for sediment transport capacity. For the selected equation, a power function was developed that relates the unit sediment transport rate to stream velocity and depth. The power function is suitable for sediments currently found in the Cherry Creek.

DISCUSSION OF HEC-RAS 4 SEDIMENT TRANSPORT TOOLS

HEC-RAS 4 has integrated sediment modeling tools that permit the analysis of rivers with moveable stream beds. Originally developed as separate programs, these models can now be run with the aid of user interface tools that are now widely used in hydraulic engineering practice. There are many other sediment models, and HEC-RAS 4 can be considered to have basic capabilities that are suitable for rivers with a single active channel that is not subject to significant width variation. For example, the USACE makes extensive use of the program in planning navigation channels dredging.

Sediment moves as a mass wave and unlike water waves there is no need to account for the momentum of the wave. This permits the motion of sediment waves to be described by the continuity equation alone. The HEC-RAS sediment routines solve the sediment continuity equation (also known at the Exner equation):

$$\left(1-\lambda_p\right)\gamma_s\, B\ \frac{\delta z}{\delta t} = -\frac{\delta G_s}{\delta x} \quad \text{Equation 1}$$

where: B is the channel width; z is the channel elevation; λ_p is the active layer porosity; γ_s is the dry unit weight of sediment; t is time; x is distance; and, G_s is the transported sediment load.

This equation states that the change of sediment mass during an increment of time (the left side of the equation) is equal to the difference between the incoming and outgoing sediment load (right side of the equation). In HEC-RAS 4, change in elevation is confined to a portion of the channel width that is considered to be active. The active width is defined by the user and typically consists of the portion of the channel cross section that is not densely vegetated and is confined within alluvial features such as a stream bank. HEC-RAS 4 assumes that all scour occurs uniformly within the active width of the channel. The user has the option of letting deposition occur over the entire channel width. Thus the control volume for the solution of the continuity equation consists of the active channel width and the depth of sediment from the stream bed to a non-erodible layer.

When the incoming sediment load and the sediment transport capacity of a stream segment are equal ($\frac{\delta Q_s}{\delta x} = 0$), then the stream segment will neither scour nor aggrade. Identification of stream segments that are in a stable state over time is useful in the calibration when a known volume of deposition has occurred in a downstream sink (i.e. a reservoir or delta). A more difficult approach is to calibrate the model by matching changes in bed profile. Such changes are usually due to relatively small changes in transport capacity and can be masked by the sensitivities of selected transport equations. In either case, a sensitivity analysis should be conducted in order to understand the affect of errors of estimate variables on computed values of sediment transport of bed elevation change.

All segments of the study reach have either been altered due to new construction or have experienced significant erosion. However, prior 1993 segments of the Cherry Creek can be observed to have maintained a stable section. The stream segment at Site #1 is of particular interest because of its proximity to the Melvin Gage gate and the reservoir.

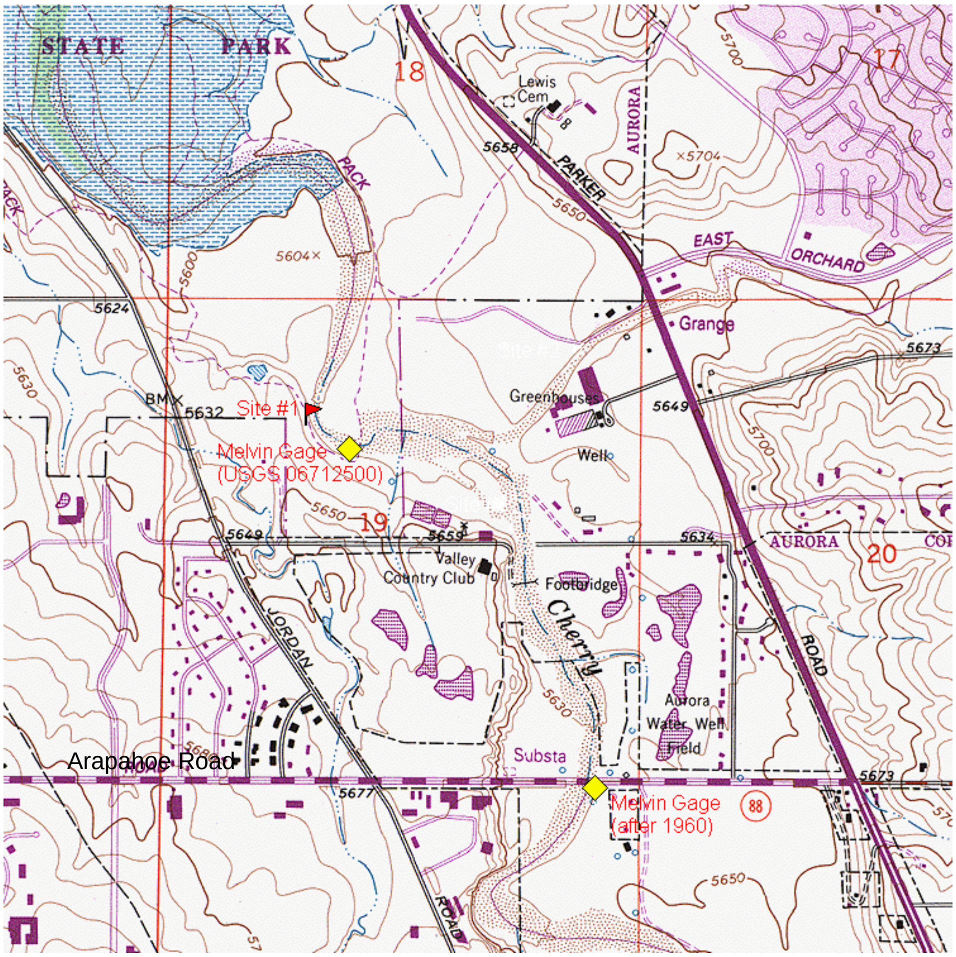

Figure 1. Location of sediment sampling site 1 and the Melvin Gage locations

GOOGLE EARTH AERIAL HISTORY

A photo history of Site #1 is available through Google Earth that is presented in Figures 2 – 7 for December 1937, December 1955, June 1993, September 1999, July 2005, and June 2010. Each photo shows a trace of the 1955 alignment of the stream, the 1955 stream width (80 feet) and the location of Site #1 in November 2010.From 1937 to 1993, the stream alignment and width remained similar with the main change being a shift in the alignment of the channel upstream of the bendway toward the north. Between 1993 and 1999 the channel narrows and begins to move laterally toward the left (west) bank. Cross section data also shows that the channel entrenched about 2 feet during this time.

Figure 2. January 1937, Aerial Photograph of Site #1

Figure 3. January 1955, Aerial Photograph of Site #1

Figure 4. June 1993, Aerial Photograph of Site #1

Figure 5. September 1999, Aerial Photograph of Site #1

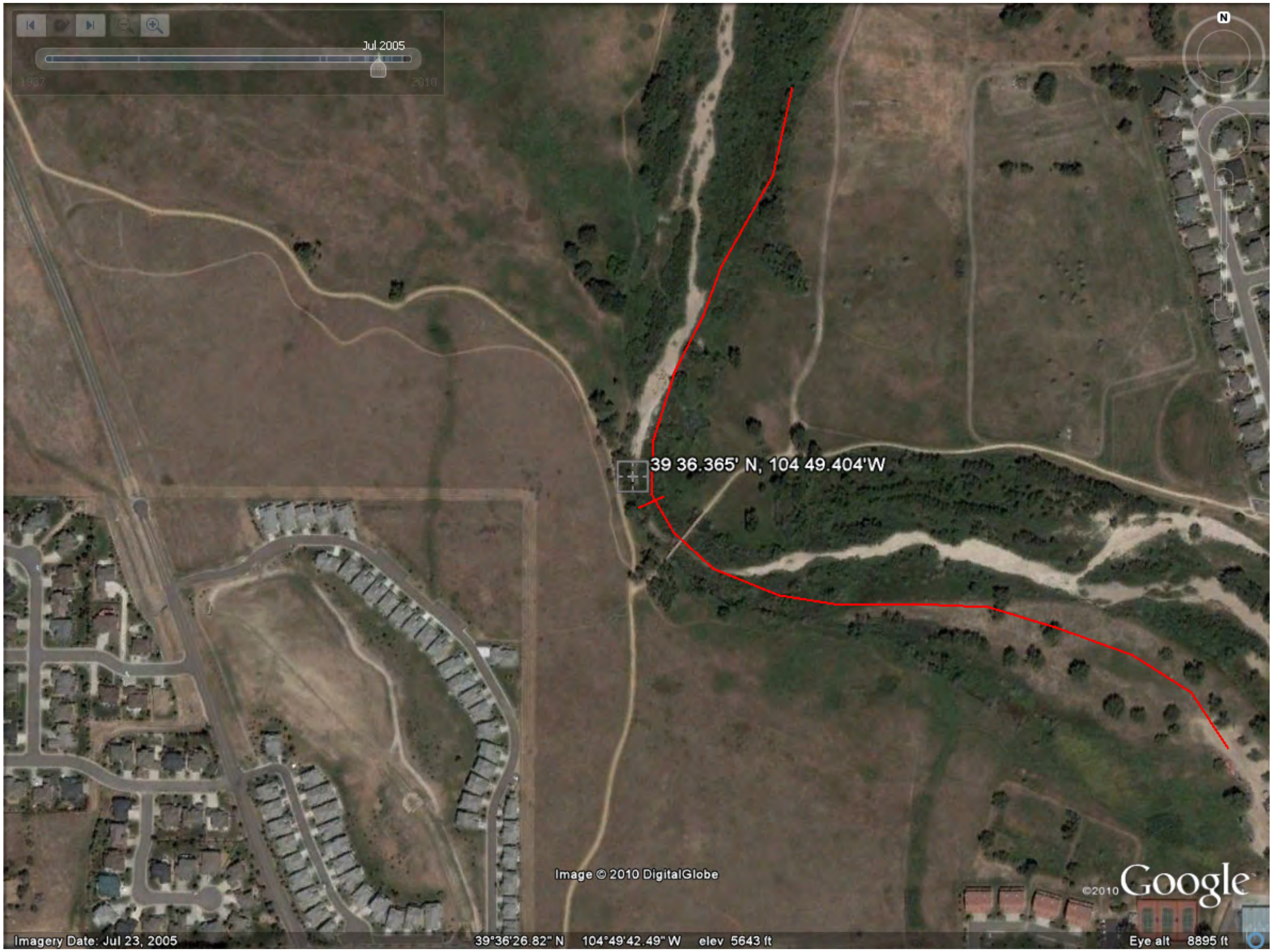

Figure 6. July 2005, Aerial Photograph of Site #1

Figure 7. June 2010, Aerial Photograph of Site #1

MELVIN GAGE HISTORY

During the 30 year history of the Melvin gage, the rating curve was shifted 16 times (see Figure 8). These rating shifts accommodated movement in the stream bed that altered the discharge rating for the stream. Indirectly, these shifts also document the pattern of aggradation and degradation the occurred in that same time frame.

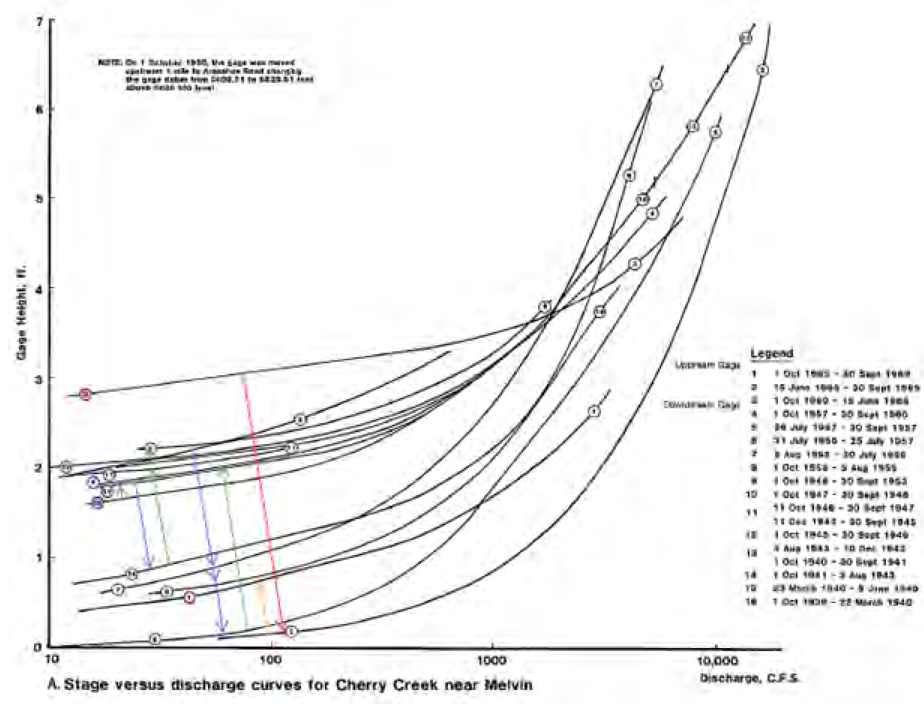

Figure 8. Melvin Gage Discharge Rating Curve Shifts

When the shift is plotted over time (Figure 9) it provides a picture of the transient behavior of sediment waves that move through the channel and their frequency. A cycle of about 14 years (crest to crest of trough to trough) can be seen in the shift history. A brief period of scour is followed by a longer period of aggradation. After the gage was relocated in 1960, there was a period of aggradation that abruptly ended with scour during the 1965 flood.

In the Google Earth aerials the 1937 channel appears to be full of sediment; while in 1955 district cut banks can be seen. This agrees with the gage shift record which shows scour approaching 2 feet in 1955.

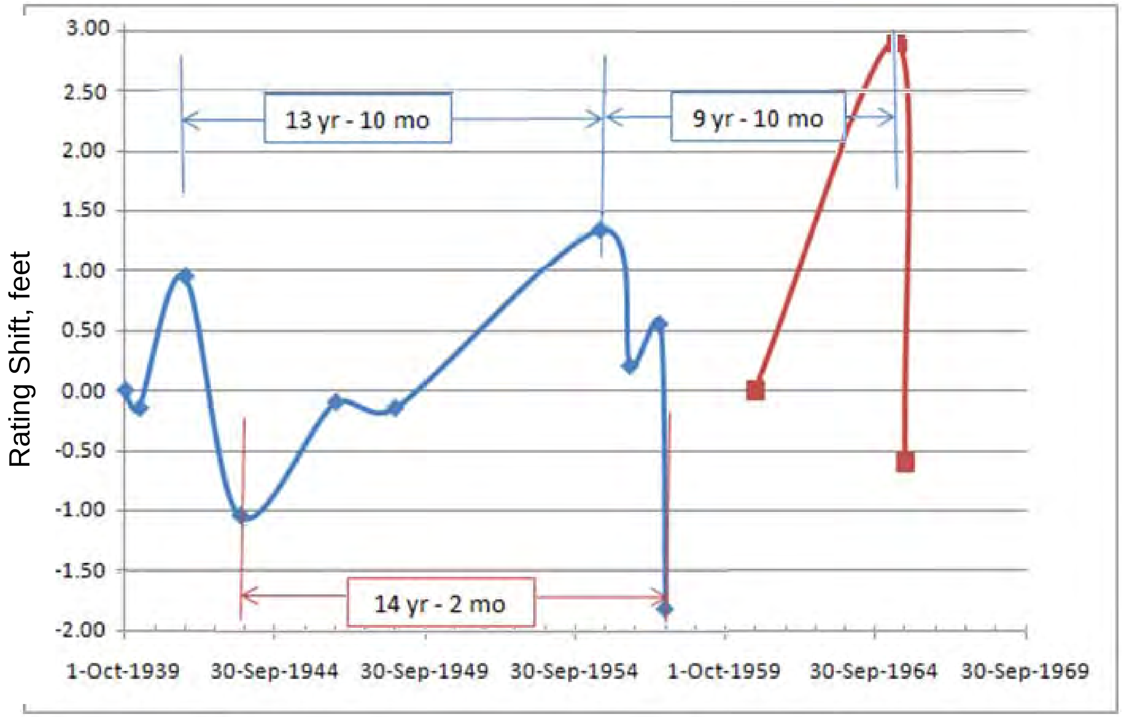

Figure 9. Melvin Gage History

CHANNEL SECTION

Aerial Lidar (Arapahoe County, 2008) was used to cut a cross section near Site #1. The 1940 to 1993 sections was estimated using the measured channel width observed from the 1955 Google Earth and field observation of channel scour and the shift history of the Melvin Gage. Figure 10 shows the original lidar section, the simplified HEC-RAS section and the estimated historic 1937 to 1993 cross section.

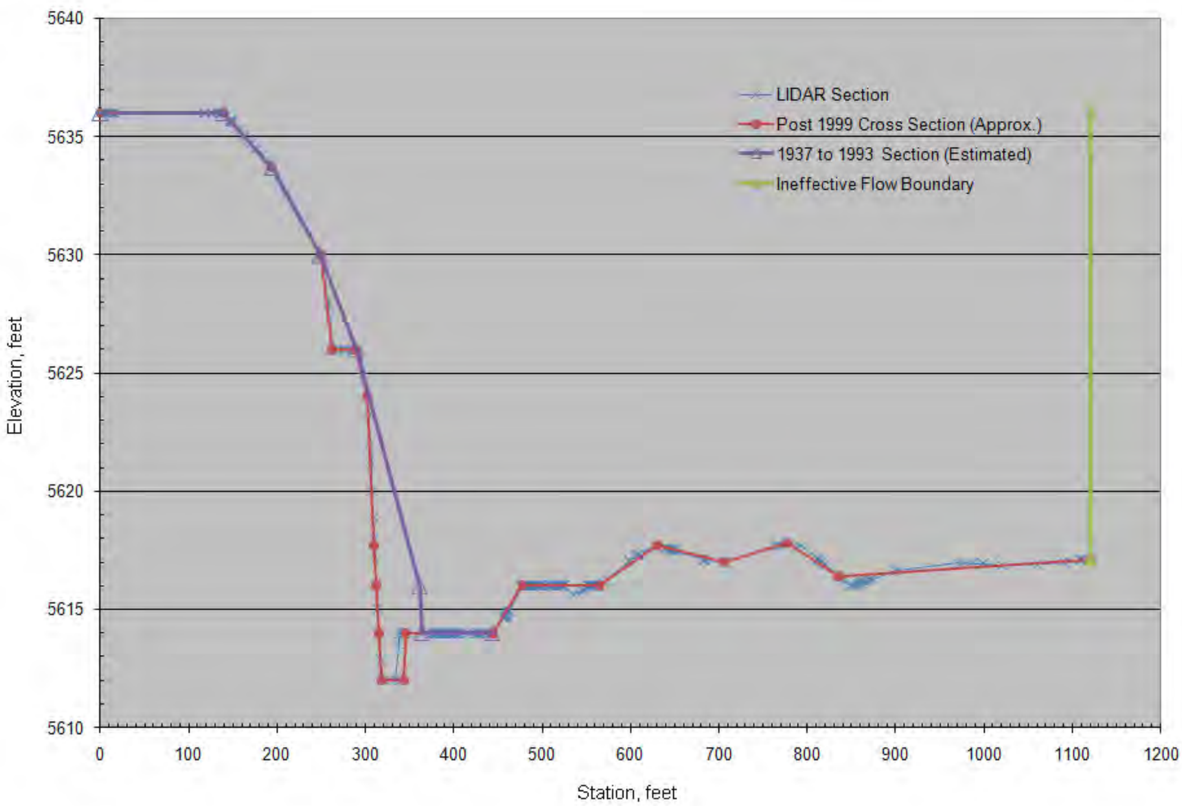

Figure 10. Site #1 Cross Section

SEDIMENT GRADATION

Prior to 1993, sediment gradation in the Cherry Creek consisted of finer particle sizes with a mean, d_{50} particle size of 0.6 mm (BRW-WRC, 1985; CH2M Hill, 2010). Since both sedimentation surveys used for calibration occurred prior to 1993, the finer bed-material gradation was used for calibration. HEC-RAS 4 uses predefined bins for sediment gradation input. The HEC-RAS 4 input for sediment gradation is listed in Table 1.

Table 1. Site #1 Bed-Material Gradation (pre-1993)

Size, mm	% Finer
0.25	15.1
0.50	41.5
1.00	72.7
2.00	92.2
4.00	98.7
8.00	99.9
16.00	100.0

CHANNEL ROUGHNESS

From the aerial photographs it is observed that the active channel was unvegetated from 1937 to 1993 and that overbanks were vegetated with grasses, shrubs and a sparse number of cottonwood trees. The sand-bed channel has a low resistance characteristic of dunes or anti-dunes. An n-value of 0.025 was used for the active channel.

The overbanks have flexible vegetation that is very rough at shallow flow but deflect and become smoother as flow depth increases on the overbank. FHWA HEC-15 routines for vegetated channels were used to estimate overbank roughness. The overbank n-values were input to vary vertically. The tabular values used in HEC-RAS 4 are listed in Table 2. The overbank roughness values are shown graphically in Figure 11.

Table 2. Site #1 Channel Overbank n-values

Overbank Depth (ft)	Overbank Left	Overbank Right
0.6	0.311	0.336
1.6	0.311	0.166
2.7	0.146	0.091
4.5	0.076	0.068
5.8	0.064	0.061
7.5	0.057	0.056
10.6	0.049	0.048

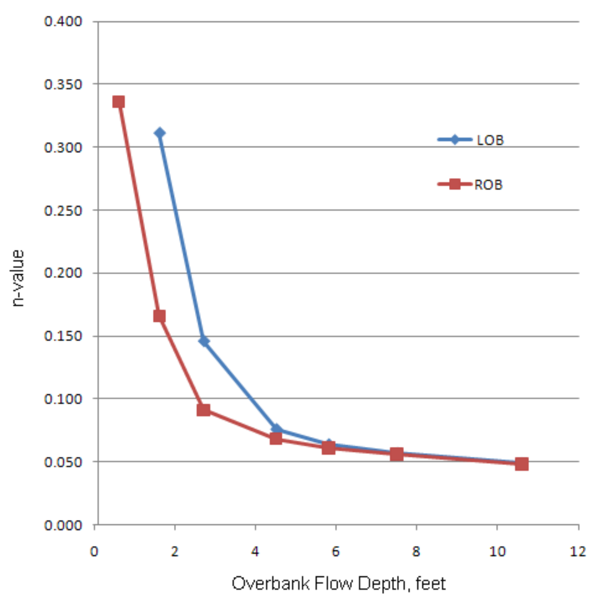

Figure 11. Overbank n-value

SEDIMENT TRANSPORT CAPACITY RATING CURVES

The HEC-RAS 4 hydraulic design tools were used to compute sediment rating curves (sediment transport capacity versus discharge) for six transport relationships available in HEC-RAS 4. For the input channel section, roughness and a range of discharges (from 100 cfs to 50,000 cfs) sediment transport capacity was determined. Sediment inflow was set to equal the transport capacity of the section with a bed slope of 0.0045 ft/ft. Uniform flow hydraulic conditions were computed and each transport equation solved for the same hydraulic conditions.

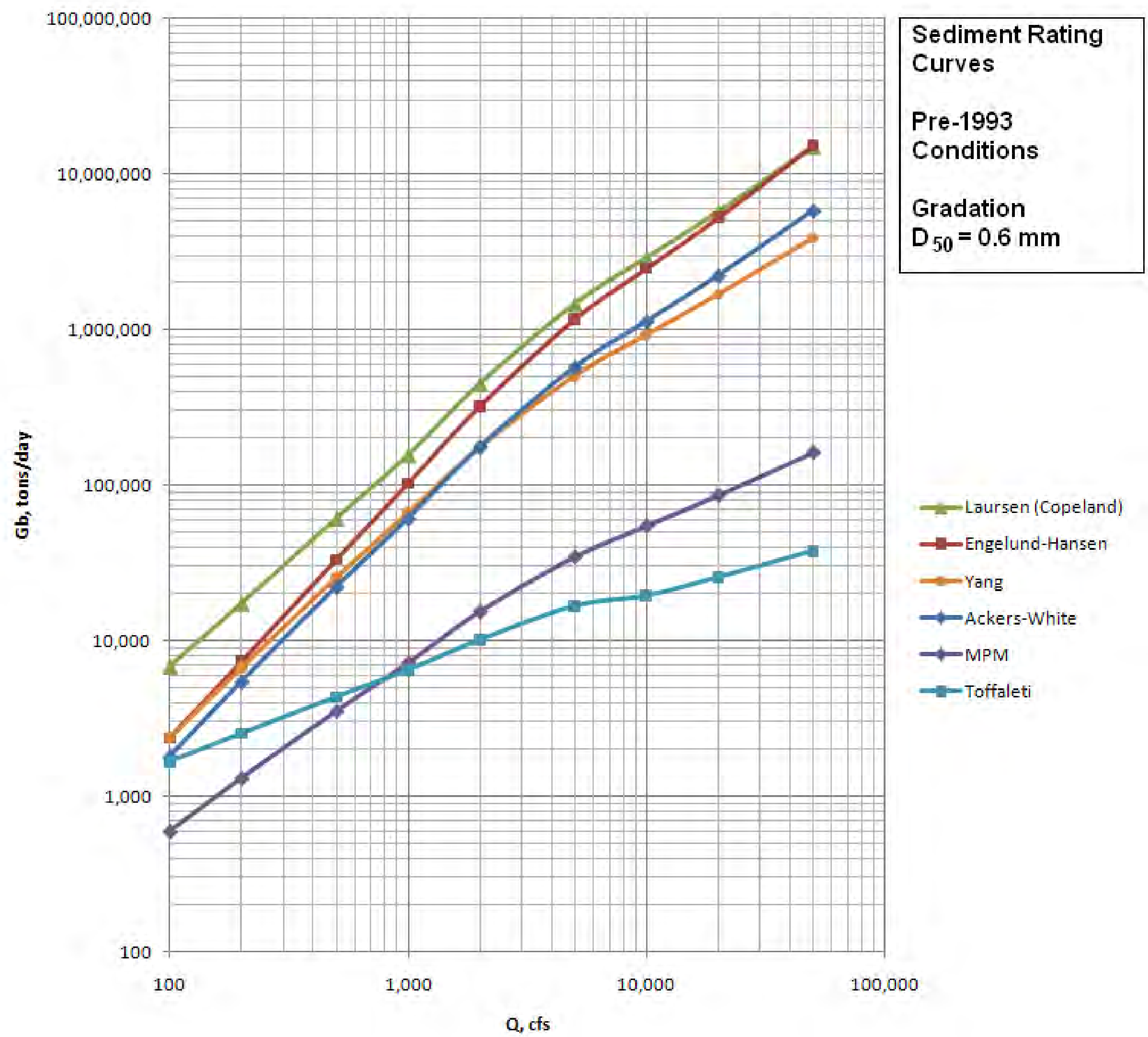

Figure 12. HEC-RAS derived sediment transport capacity rating curves

The resulting rating curves show a wide range of possible sediment transport. At the low end are the Meyer-Peter Muller (MPM) and Toffaleti equations; MPM is a suitable sand bed transport equation but does not account for the suspended portion of the sediment load. Toffaleti is considered a "large" river transport equation and underestimates transport for smaller streams. On this basis the MPM and Toffaleti equations were eliminated from further consideration.

Four relationships are clustered together and each is a suitable transport equation for conditions on the Cherry Creek. The Yang and Ackers-White equations have very similar performance, but the Yang equation is considered to be quite sensitive to channel velocity. Considering that velocities in the Cherry Creek can change quickly, the Yang equation was eliminated from further consideration.

RATING CURVES AS POWER FUNCTIONS

To simplify the use of the rating relationships in calibration, power functions were fitted to the remaining three relationships. Where roughness is rapidly changing (between 2,000 cfs and 5,000 cfs) a power function was not appropriate. This region of the rating curve can be best estimated by using the average of the power functions for the adjacent regions (<2,000 cfs and >5,000 cfs). The general power function equation is given below and Table 3 summarizes the exponents and coefficients for each transport equation.

$$G_b = a\, Q^b \qquad \text{Equation 2}$$

Table 3. Power functions of Sediment Transport Capacity

Transport Equation	a	b
Laursen (Copeland) (<2000 cfs)	11.04	1.3897
Laursen (Copeland) (>5000 cfs)	262.19	1.0111
Engelund-Hansen (<2000 cfs)	1.2357	1.6401
Engelund-Hansen (>5000 cfs)	86.235	1.1149
Ackers-White (<2000 cfs)	1.6184	1.5269
Ackers-White (>5000 cfs)	106.76	1.0065

These transport relationships are specifically for the channel geometry and bed-material conditions at Site #1 for the period from 1937 to 1993.

INFLOW TIME SERIES

The calibration of sediment transport equations was based on measured sediment deposition in Cherry Creek reservoir for two survey periods (1950 to 1961, 1961 to 1965), and the mean daily inflow at the Melvin stream gage for the same periods. The second survey period contains the largest flood of record for the Cherry Creek. At the time of this flood, the Melvin gage had been moved upstream to Arapahoe Road and did not measure the entire inflow to the reservoir. In 1977, the USACE Omaha District published a reconstructed 1965 flood inflow hydrograph to Cherry Creek reservoir that was based on the known extent of the storm in the basin and the change in reservoir volume during the storm. For this calibration, the 1965 flood hydrograph was digitized into 15 minute time intervals (see Figure 13).

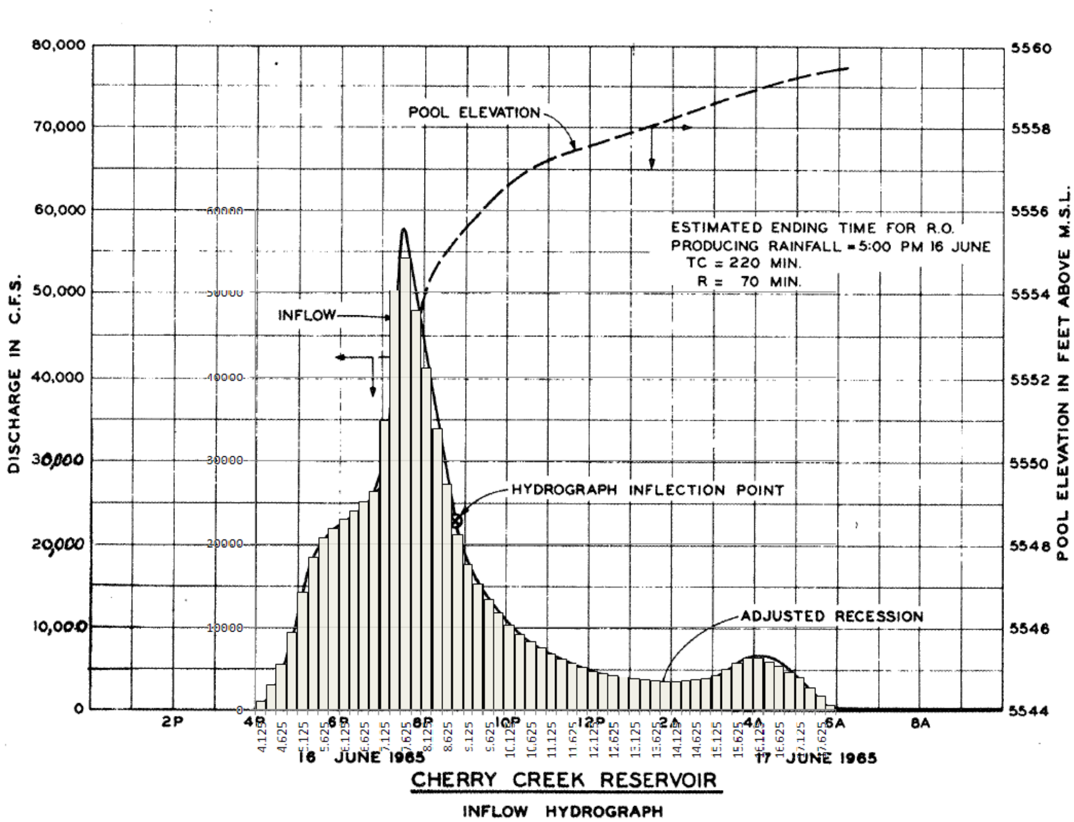

Figure 13. Digitized 1965 Flood Hydrograph at Cherry Creek Reservoir

CALIBRATION TO MEASURED RESERVOIR SEDIMENTATION

The power function form of each sediment transport equation was used to compute sediment load for each sedimentation survey. With the exception of June 16 and 17, 1965 there are no days with mean discharges greater than 2,000 cfs in these periods. This being the case the 1965 flood event was computed separately and added to the 1961 to 1965 sedimentation period. Total sediment loading for each sedimentation survey period was computed by summing daily sediment loads over the period. The loading was calibrated by adding a discharge adjustment factor to mean daily flows that were less than 2,000 cfs. No scaling factor was used for the 1965 flood inflow discharges. Table 4 summarizes the results of the calibration.

Table 4. Comparison of Sediment Transport Calibrations

Transport Equation	Q_e/Q_m < 2,000 cfs	Sediment Loading (tons) 1950 to1961	% of Measured Loading	Sediment Loading (tons) 1961 to1965	% of Measured Loading	Sediment Loading (tons) 1950 to1965	% of Measured Loading
Laursen (Copeland)	1.00	2,476,748	139%	2,617,152	90%	5,093,900	109%
Engelund-Hansen	1.47	2,339,252	131%	2,353,849	81%	4,692,718	100%
Ackers-White	1.55	1,595,454	89%	1,103,421	38%	2,698,875	58%
Measured Loading		**1,783,564**		**2,909,155**		**4,692,719**	

	Q_e/Q_m >5,000 cfs		Mean Inflow (cfs-day)	1965 Flood Sediment Loading (tons)	% of 1961 to 1965 Loading
Laursen (Copeland)	1.08	6/16/1965	6,452	2,181,586	75%
Engelund-Hansen	1.17	6/17/1965	1,029	2,022,750	70%
Ackers-White	1.00			854,723	29%

Ackers-White equation underestimates sediment loading to Cherry Creek reservoir by 42%. The discharge scaling factor was increased to the largest possible value without exceeding the estimated loading for the 1965 flood (see note below). Both Lausen (Copeland) and Engelund-Hansen over estimate sediment loading for the first sedimentation period and under estimate loading for the second period. Taking the two periods together Laursen (Copeland) over estimates by 9% while Engelund-Hansen can be calibrated to match total loading for both periods.

The Larsen equation indicates that there is no scaling factor for mean daily discharge of less than 2,000 cfs. However, the Laursen (Copeland) equation indicates that a discharge-increase of only 65% would double sediment transport, while a 120% discharge increase would triple sediment transport. So it seems unlikely given the normal fluctuations and the sensitivity of the equation to discharge that there would be no scaling factor on mean discharge.

The scaling factor developed for the Engelund-Hansen equation is an indication that the effective discharge would occur in about 12 hours and average about twice the mean value. Since much of the inflow in the period from 1950 to 1965 was from high intensity storm runoff this scaling seems realistic.

Note: The 1965 flood volume recorded at the Melvin gage was 4850 cfs-day, while the USACE storm reconstruction and reservoir stage reading measured the total reservoir inflow at 7,481 cfs-day. Using the USACE estimates of mean daily flow, both the Laursen (Copeland) and the Engelund-Hansen power functions for discharges greater than 5,000 cfs needed a scaling factor in order to match the detailed calculation based on the discretized inflow hydrograph. However, the Ackers-White did not require a discharge scaling factor for discharges of over 5,000 cfs.

RECOMMENDED TRANSPORT EQUATION

The Engelund-Hansen sediment transport equation is recommended for use on the Cherry Creek. Reasons for selecting the equation include:

1. The ability to accurately estimate sediment loading to Cherry Creek reservoir over two sedimentation survey periods.

2. Provides a reasonable value for the mean daily discharge scaling factor, which is consistent with the historic storm runoff character of inflows at the Melvin gage over the two sedimentation survey periods.

3. The equation provides a reasonable estimate of sediment loading during the 1965 flood, while also being able to provide a reasonable estimate of sediment loading from lower flows. The rating curve for the equation shows increased transport for high discharges that approach transport rates for Laursen (Copeland) but are between the rating for Laursen (Copeland) and Ackers-White.

Based on the range of sediment loading estimates for the two sedimentation periods, it is expected that use of the Engelund-Hansen equation may result in sediment loading estimates that are with $\pm$ 25% of measured values. The estimation error is more balanced compared to the other two equations that tend to err on either the high or low end of the range. This indicates that the Engelund-Hansen equation may have less bias.

Yang (1996) describes the Engelund-Hansen equation as based on Bagnold's stream power concept. It is applicable to streams with flows with dune beds, which is similar to hydraulic conditions on the Cherry Creek. Research by Engelund and Hansen (1972) found that the equation could be applied to dune bed and upper regime flow with particle sizes greater than 0.15 mm.

HEC-RAS 4 documentation describes the Engelund-Hansen equation as a total load (bed load and suspended bed-load) equation that was developed from flume data (0.19 mm to 0.93 mm sand sizes were used). It is a function of channel velocity, bed shear, and the d_{50} of the material. The documentation advises that the equation be restricted to sand bed channels. The documentation notes the relative simplicity of the equation is an attraction.

APPLICATION TO CURRENT CONDITIONS AT SITE #1

Since 1993, the Site #1 channel geometry has change slightly and the bed material gradation has coarsened. As shown in Figure 10, the channel has migrated laterally and incised about 2 feet. As a result, the low-flow channel has narrowed from 80 feet to 25 feet. Channel bed material has coarsened from a d_{50} of about a 0.6 mm to 1.2 mm. Riparian vegetation appears to be slightly more dense at the section and is certainly more abundant in this stream segment overall.

Factoring these changes into the sediment transport capacity, a new rating curve was developed (Figure 14). The revised power functions for Site # 1 are given in Table 5.

Table 5. Power functions of Sediment Transport Capacity – 2010 Conditions

Engelund-Hansen		a	b	Qe/Qm
less than	500 cfs	2.41	1.6431	1.25
greater than	2000 cfs	132.14	0.9909	1.17

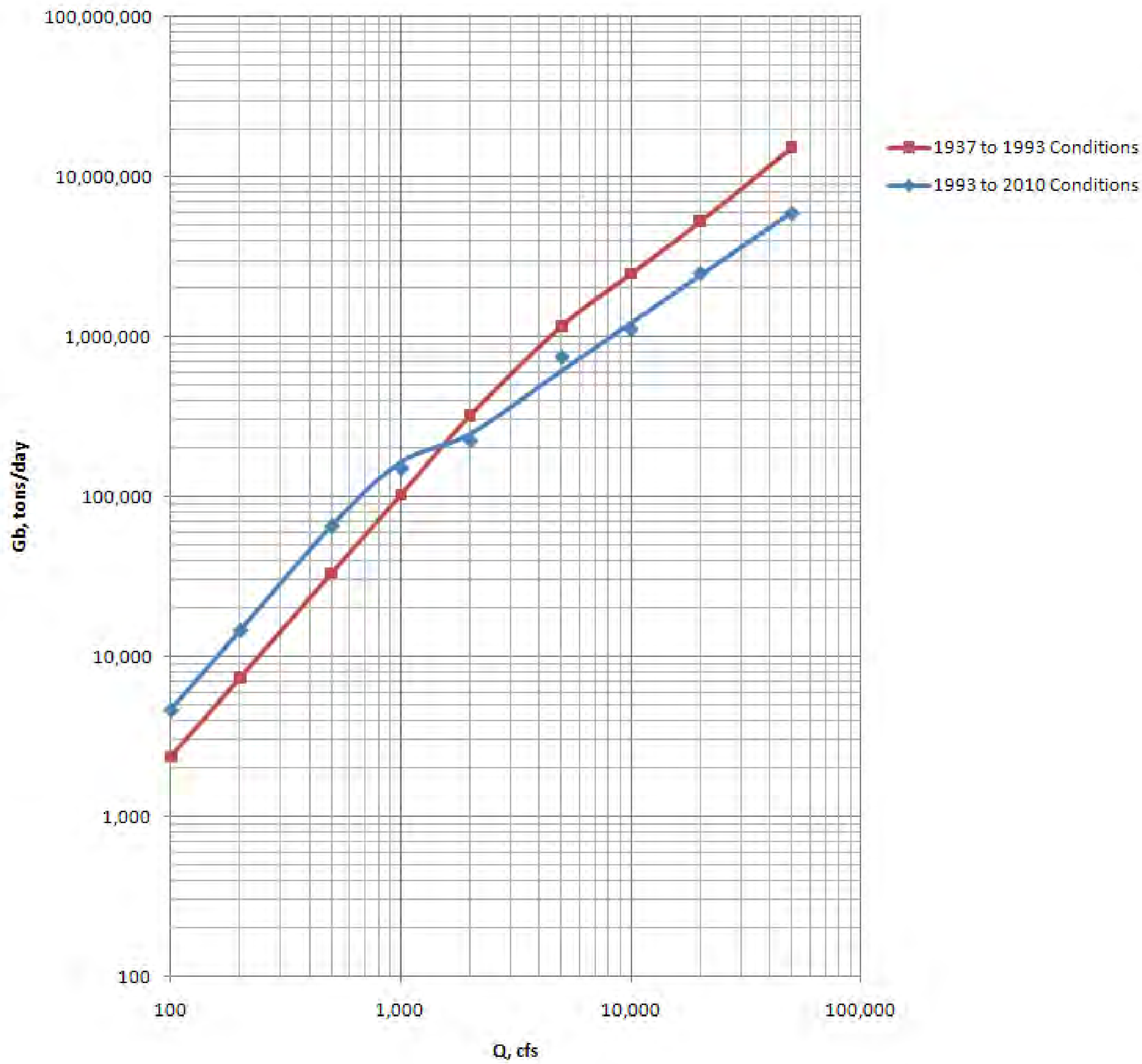

Figure 14. Revised Site #1 Sediment Rating Curve

Mean daily flow data from the C-10 gage (January 1992 to December 2009) was used compare the sediment loading for current conditions and conditions before 1993. During this time period, mean daily inflow to the reservoir did not exceed 352 cfs and so sediment transport capacity is described by the lower power function of the sediment rating curve. The discharge scaling factor was set at 1.25 for both rating curves to account for increased based flow.

Total water inflow in this 18 year time period was 135,908 ac-ft. Using the pre-1993 rating curve, the estimated sediment loading to the reservoir is 1,087,117 tons (525 ac-ft). By comparison, the current 2010 rating results in an estimated sediment loading to the reservoir of 2,146,485 tons (1,037 ac-ft) or approximately twice the sediment load. The current rating is not therefore a stable one and shows that the stream section is now in transition to a new equilibrium. This site should no longer be used as a boundary condition for estimating sediment loading conditions to the reservoir.

A simplified sediment transport capacity formula was developed from synthetic HEC-RAS 4 data set (see Appendix A). The resulting power function (Equation A.3) for a given bed-material gradation has a constant coefficient and is a function of mean velocity and flow depth only. This equation is useful for calculations such as channel equilibrium, sediment wave speed, and sediment load boundary conditions.

$$g_b = b\, V^{5.0}\, D^{-0.50} \quad \text{Equation A.3}$$

$$\text{where: } b = 0.1118\, G^{0.37}\, d_{50}^{-0.69}$$

g_b unit sediment transport capacity, tons/day/ft
d_{50} mean sediment particle size, mm
G gradation coefficient
V mean velocity, ft/s
D flow depth, ft

SENSITIVITY ANALYSIS

The simplified transport equation also provides insight into the sensitivity of the Engelund-Hansen approach to errors of estimate for variables of that affect the computation of velocity and flow depth. Table 6 summarizes the sensitivity of sediment transport capacity due to errors in key variables.

Table 6. Sediment Transport Sensitivity Analysis

Variable	Reference value	Variable Range		Sediment Transport Capacity Error Range	
Slope (ft/ft)	0.0040	0.0035	0.0045	-20%	+21%
d_{50} (mm)	1.2	0.6	1.8	61%	-24%
Gradation Coef.	2.7	2.2	3.2	-7%	6%
n-value	0.025	0.022	0.030	52%	-45%

As can be seen in the above table, fairly large errors can occur in channel slope and bed-material gradation without introducing a seriously error into the estimate of sediment transport capacity. Mean bed-material size is more sensitive but large errors in this variable should be less likely since it is an average. Underestimating the mean sediment size results in a greater error compared to overestimating the mean sediment size. The sensitivity analysis shows the importance of always using the reference n-value for the active channel. Substantial errors in transport capacity (on the order of $\pm$50%) will result if the n-value is changed from the reference value.

A reference n-value of 0.025 for the active channel is required for all sediment transport modeling in the Cherry Creek and its tributaries in order to be consistent with the calibration of the Engelund-Hansen equation.

SUMMARY OF RESULTS

From study field reconnaissance, and review of Google Earth images (from 1937 to 2010) it was determined that the stream segment of the Cherry Creek near Site #1 had a relatively stable cross section between 1937 to 1993. Using a cross section at Site #1 derived from 2008 aerial lidar data and adjusting for lateral erosion and scour that had occurred since 1993, the historic stream cross section was reconstructed. Historic sediment gradation was estimated from 1985 and 2010 samples of the Cherry Creek stream bed. The channel roughness was estimated based on the observed unvegetated width of channel and estimated vegetation coverage. The channel hydraulic conditions were computed over a range of discharges using a vertical change in roughness to simulated the affected of vegetation on the overbank.

Using HEC-RAS 4's hydraulic design tools, six sediment transport capacity rating curves were developed for the historic conditions. Of these three equations were selected for further evaluation: Laursen (Copeland), Engelund-Hansen, and Ackers-White. For more convenient computation, the rating curves were converted to power functions.

The sediment transport equations were compared to measured sediment deposition in Cherry Creek reservoir for two periods (1950 to 1961, 1961 to 1965). Sediment load was estimated for the sedimentation periods using the inflow time series at the Melvin stream gage and the 1965 June flood inflow hydrograph. Based on this analysis the Engelund-Hansen equation was found to most closely estimate the sedimentation history from 1950 to 1965.

A simplified version of the Engelund-Hansen sediment transport equation was developed as a power function. A sensitivity analysis was conducted using the power function version of the Engelund-Hansen sediment transport equation that shows the potential affect on sediment transport capacity estimations caused by errors in key hydraulic variables. Other potential uses of the simplified equation include: equilibrium analysis, estimation of sediment wave speed, and estimation of boundary conditions.

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ENGELUND AND HANSEN'S APPROACH

Engelund and Hansen (1967) proposed a method for determining total sediment load in streams with dune-covered beds. The relationships are as follows:

$$f\phi = 0.1\ \theta^{1.5}$$ ..... Equation A.1

where:

$$\phi = \frac{g_b}{\sqrt{S_s'\, g\, d_{50}^3}}$$ ..... Equation A.1.1

$$f = \frac{2U_*^2}{U^2}$$ ..... Equation A.1.2

$$\frac{U_*}{U} = 0.6 + 2.5 \ln\left(\frac{y_o'}{k}\right)$$ ..... Equation A.1.2.1

where: $k \cong 2.5\ d_f$

$$y_o' = \frac{\theta'}{\theta}\ y_o$$ ..... Equation A.1.3.1

$$\theta = \frac{\tau_o}{\gamma_s'}$$ ..... Equation A.1.3.2

$$\theta' = 0.06 + 0.4\ \theta^2$$ ..... Equation A.1.3.2

With the value of y'_o the mean velocity, U, can be calculated. The sediment load can then be expressed as:

$$g_b = 0.05\ U^2 \sqrt{\frac{d_{50}}{g\, S_s'}} \left(\frac{\tau_o}{\gamma'_s d_{50}}\right)^{3/2}$$ ..... Equation A.2

where:

d_{50}	mean sediment particle size, mm
d_f	equivalent particle size based on fall velocity, mm
g_b	unit sediment transport capacity, tons/day/ft
g	acceleration of gravity, ft/s^2
k	equivalent roughness size, ft
S'_s	submerged specific gravity of sediment, dimensionless
S	Slope, ft/ft
U_*	shear velocity, ft/s
U, V	mean velocity, ft/s
w	fall velocity, ft/s
y'_o	effective flow depth, ft
γ'_s	submerged unit weight of sediment, lb/ft^3
τ_o	bed shear stress, lb/ft^2

Engelund (1973) also proposed a method for calculation of sediment transport when the bed material is graded. It assumed that particles finer than a certain size will all enter into suspension while larger grains will move as bed load. The criterion for critical size is based on the empirical value of $2.5\ {}^{w}/_{U_*} \cong 2$.

E-H SEDIMENT TRANSPORT CAPACITY FROM HEC-RAS 4

While the Engelund and Hansen is not a particularly complex sediment transport formula, there are several aspects of the approach that require detailed knowledge to implement in HEC-RAS 4. So as not to presume the approach taken by HEC, a set of sediment transport capacity data was generated directly from HEC-RAS 4.

Input consisted of a wide rectangular channel (50 feet) with a uniform n-value of 0.025 for the geometry. Increments of channel slope varied as 0.0020, 0.0040 and 0.0060 ft/ft. The gradation of the bed material was varied from d_{50} of 0.6 mm to 1.9 mm with gradation coefficients of 2.2 and 3.2 for the 1.9 mm size. Unit discharge was varied from 1.0 cfs/ft to 200 cfs/ft.

Table A.1 summarizes the input increments for the Engelund and Hansen sediment transport calculations using HEC-RAS 4. The generated data set is given at the end of this Appendix.

Table A.1. HEC-RAS 4 Input Cases

<table>
<tr><th>Case</th><th>Slope, S (ft/ft)</th><th>d_{50} (mm)</th><th>G</th><th>Unit discharge, q, increments (cfs/ft)</th></tr>
<tr><td>1</td><td>0.0020</td><td rowspan="3">0.6</td><td rowspan="9">2.2</td><td rowspan="12">1, 2, 5, 10, 20, 50, 100, 200</td></tr>
<tr><td>2</td><td>0.0040</td></tr>
<tr><td>3</td><td>0.0060</td></tr>
<tr><td>4</td><td>0.0020</td><td rowspan="3">1.2</td></tr>
<tr><td>5</td><td>0.0040</td></tr>
<tr><td>6</td><td>0.0060</td></tr>
<tr><td>7</td><td>0.0020</td><td rowspan="3">1.6</td></tr>
<tr><td>8</td><td>0.0040</td></tr>
<tr><td>9</td><td>0.0060</td></tr>
<tr><td>10</td><td>0.0020</td><td rowspan="3">1.9</td><td rowspan="3">3.2</td></tr>
<tr><td>11</td><td>0.0040</td></tr>
<tr><td>12</td><td>0.0060</td></tr>
</table>

E-H SEDIMENT TRANSPORT CAPACITY REGRESSION EQUATION

A sediment transport capacity regression equation was computed by transforming the data set (total bed load, mean velocity, depth, and mean sediment size) to natural log values and then linearly regressing the transformed data set using Excel's LINEST regression function. Since the data set is without error and derived from a fairly simple function it was expected that regression error should be minimal. The r^2 value for the equations was in fact 1.0. The resulting power function formula is

$$g_b = b\, V^{5.0}\, D^{-0.50} \qquad \text{Equation A.3}$$

$$\text{where: } b = 0.1118\, G^{0.37}\, d_{50}^{-0.69}$$

The coefficient, b, is constant for a known sediment gradation. For example, current bed-material in the Cherry Creek has the following properties: d_{50} = 1.2 and G = 2.2, which give a coefficient of b = 0.132. Up-valley the bed-material coarsens to d_{50} = 1.9 and G = 3.2, which give a coefficient of b = 0.110 (about a 20% reduction).

Of interest in equation 3 are the two exponents. The velocity exponent of 5.0 can be predicted from equation 2, since $\tau_o \propto U^2$. This indicates that the formula has a very high sensitivity to velocity. The flow depth exponent shows a common behavior of sediment transport, which is a reduction in transport capacity with increasing flow depth.

RANGE OF APPLICABILITY

As with any regression equation, the use of the Engelund-Hansen regression equation should not exceed the range of data from which it was developed. This is particularly true for the properties of the sediment gradation (G and d_{50}). Likewise, when using this regression equation to estimate sediment transport in the active channel of the Cherry Creek, the active channel roughness should always be 0.025 to be consistent with the active-channel roughness that was used to develop this data set.

The ranges are applicable to the hydraulic properties of the active channel of the Cherry Creek and do not necessarily apply to portions of the channel that are outside that boundary where sediment transport is not being calculated.

Variable	**Range**
Sediment size, d_{50} (mm)	0.6 to 1.9
Gradation Coefficient, G	2.2 to 3.2
Velocity, V (ft/s)	1.8 to 20.8
Depth, D (ft)	0.4 to 13.3
Froude No., Fr	0.4 to 1.2
Unit discharge, q (cfs/ft)	1 to 200
Slope, S (ft/ft)	0.0020 to 0.0060

HEC-RAS 4 DATA SET

Case	G	d_{50} (mm)	S (ft/ft)	q (cfs/ft)	g_b (tons/day/ft)	V (ft/s)	D (ft)
1	2.2	0.6	0.002	1	5.3	1.8	0.56
				2	17.3	2.37	0.84
				5	82.1	3.42	1.46
				10	267.0	4.51	2.21
				20	868.4	5.96	3.35
				50	4118	8.59	5.81
				100	13350	11.33	8.8
				200	43320	14.95	13.34
2	2.2	1.2	0.002	1	3.3	1.8	0.56
				2	10.8	2.37	0.84
				5	51.3	3.42	1.46
				10	166.8	4.51	2.21
				20	542.6	5.96	3.35
				50	2574	8.59	5.81
				100	8344	11.33	8.8
				200	27060	14.95	13.34
3	2.2	1.6	0.002	1	2.7	1.8	0.56
				2	8.7	2.37	0.84
				5	41.4	3.42	1.46
				10	134.6	4.51	2.21
				20	438	5.96	3.35
				50	2076	8.59	5.81
				100	6734	11.33	8.8
				200	21840	14.95	13.34
4	2.2	0.6	0.004	1	16.9	2.21	0.45
				2	54.7	2.92	0.69
				5	258.8	4.21	1.19
				10	839	5.56	1.8
				20	2724	7.33	2.73
				50	12928	10.58	4.72
				100	41940	13.96	7.15
				200	136240	18.41	10.83
5	2.2	1.2	0.004	1	10.6	2.21	0.45
				2	34.2	2.92	0.69
				5	161.7	4.21	1.19
				10	524.2	5.56	1.8
				20	1702.2	7.33	2.73
				50	8080	10.58	4.72
				100	26200	13.96	7.15
				200	85140	18.41	10.83

(continued)

Case	G	d_{50} (mm)	S (ft/ft)	q (cfs/ft)	g_b (tons/day/ft)	V (ft/s)	D (ft)
6	2.2	1.6	0.004	1	8.5	2.21	0.45
				2	27.6	2.92	0.69
				5	130.5	4.21	1.19
				10	423.2	5.56	1.8
				20	1373.8	7.33	2.73
				50	6520	10.58	4.72
				100	21160	13.96	7.15
				200	68720	18.41	10.83
7	2.2	0.6	0.006	1	33.2	2.5	0.4
				2	103.6	3.3	0.61
				5	503	4.76	1.05
				10	1638.8	6.28	1.59
				20	5318	8.28	2.41
				50	25240	11.95	4.18
				100	81880	15.71	6.35
				200	266000	20.78	9.6
8	2.2	1.2	0.006	1	20.7	2.5	0.4
				2	64.8	3.3	0.61
				5	314.4	4.76	1.05
				10	1024.2	6.28	1.59
				20	3324	8.28	2.41
				50	15772	11.95	4.18
				100	51180	15.71	6.35
				200	166240	20.78	9.6
9	2.2	1.6	0.006	1	16.7	2.5	0.4
				2	52.3	3.3	0.61
				5	253.8	4.76	1.05
				10	826.6	6.28	1.59
				20	2682	8.28	2.41
				50	12730	11.95	4.18
				100	41300	15.71	6.35
				200	134180	20.78	9.6

(continued)

Case	G	d50 (mm)	S (ft/ft)	q (cfs/ft)	gb (tons/day/ft)	V (ft/s)	D (ft)
10	3.2	1.9	0.002	1	2.8	1.80	0.56
				2	9.0	2.37	0.84
				5	42.7	3.42	1.46
				10	138.9	4.51	2.21
				20	451.8	5.96	3.35
				50	2142	8.59	5.81
				100	6946	11.33	8.8
				200	22540	14.95	13.34
11	3.2	1.9	0.004	1	8.8	2.21	0.45
				2	28.5	2.92	0.69
				5	134.6	4.21	1.19
				10	436.6	5.56	1.8
				20	1417.2	7.33	2.73
				50	6726	10.58	4.72
				100	21820	13.96	7.15
				200	70900	18.41	10.83
12	3.2	1.9	0.006	1	17.3	2.5	0.4
				2	53.9	3.3	0.61
				5	261.8	4.76	1.05
				10	852.8	6.28	1.59
				20	2768	8.28	2.41
				50	13132	11.95	4.18
				100	42600	15.71	6.35
				200	138420	20.78	9.6

Cherry Creek Sedimentation Study
Reservoir to Pine Lane
Sediment Budget

March 2011

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CHERRY CREEK SEDIMENTATION STUDY

Sediment Budget

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INTRODUCTION

This paper discusses the sediment budget of the Cherry Creek from near the confluence of Baldwin Gulch (Pine Lane bridge over the Cherry Creek) to the Piney Creek confluence (southern boundary of Cherry Creek State Park). The discussion focuses on the period from 1992 to 2002 for which there is a calibrated simulation of water operations in the Cherry Creek (2008, Brown & Caldwell) that was developed by the Cherry Creek Basin Water Quality Authority (CCBWQA). The simulation provides mean monthly time series for 11 stream sub-reaches, which provides a more detailed stream hydrology than can be provide by existing gages that are located at Parker and within Cherry Creek reservoir.

Sediment inflow is estimated at the upper sub-reach. This rating is expected to be stable given the recent observations of channel behavior and stream stabilization measures that have been constructed in this stream segment. Sediment transport capacity for sub-reaches is based on channel gradients and characteristic channel sections. Channel sections were derived from 2008 LiDaR topography. Some adjustments were made to sections, when needed to make the section more representative. For example, some channel sections have temporarily scoured but now have been or will shortly be repaired. Sediment transport capacity ratings for the sub-reaches were developed using HEC-RAS 4 design tools with the Engelund-Hansen formula.

Sediment budget was calculated on a monthly basis for each sub-reach and the potential volume of reach aggradation / scour computed. A discharge-scaling term was estimated from daily and monthly flow records at the Parker stream gage and then applied to the monthly time series simulation for estimation of mean monthly sediment transport capacity.

It was found that the study reach looses stream flow at the rate of about 6.3% per mile relative to inflow at the confluence of Baldwin Gulch (near Parker, CO). Over the simulation period, 32% of inflow is diverted by water suppliers as well as inflows from stormwater runoff and return flows. These diversions occur from the alluvial aquifer of the Cherry Creek valley via well fields that are operated by water providers. As a result, 67% of the sediment supply that enters the study reach is deposited within the study reach. Most of the study sub-reaches are depositional with the exception of the sub-reach below the confluence of Happy Canyon Wash, which is scour prone.

DESCRIPTION OF WATER OPERATIONS

The current pattern of stream flow in the Cherry Creek above the reservoir is complex and continuously changing as water supply providers expand to meet the demand of new development in the watershed. Both the surface flows and flows in the alluvium of the channel are affected by this water development. The alluvial aquifer plays an important role in water operations as the means of diverting decreed alluvial water and in recovering re-useable return flows. Alluvial groundwater is captured by an extensive array of shallow wells along the valley floor. So, unlike many stream in Colorado where surface diversion structures are common, diversions from the Cherry Creek are predominantly made by well fields.

As a result, stream flow in the Cherry Creek cannot be well understood by the measurement of surface stream flow alone. As water demand increases in the basin, it is projected (South Metro Water Supply Authority Regional Master Plan) that use of non-tributary groundwater will decrease and will be replaced by renewable imported water and recaptured flows. Water from the basin itself will be fully used such that most flow that will be carried in the stream will originate from storm runoff and return flows. Since return flows are derived from water imported to the basin (either from non-tributary groundwater or imported renewable water rights), these flows can be reused completely by the water provider and are not subject to calls from downstream water users. The ability to recover return flow is important to meeting future water demand.

Since the early 1990s, stream flow in the Cherry Creek above the reservoir has increased and groundwater elevations in the alluvial aquifer are higher. The result has been increased riparian vegetation and a general improved quality of stream ecology compared to the dry stream bed that existed for the prior century or longer. Modeling by CCBWQA shows that alluvial aquifer levels will remain at a healthy elevation in the Cherry Creek, although the pattern of base stream flow will not be particularly natural.

It is unlikely that water development will cause the stream to dry up for several reasons. First, although the Cherry Creek alluvium plays an important role in recovering return flow, it does not have a substantial amount of water storage capacity (perhaps around 5,000 ac-ft between Parker and the southern boundary of the reservoir). Second, CCBWQA modeling shows relatively constant down valley flow in the alluvium, indicating that it is being used primarily as a means of collecting flows and not as a water supply. In drought years, depletion of alluvial groundwater would be of marginal benefit and would probably make it more difficult to recover return flows.

Sustained groundwater elevations in the alluvium will be important to the riparian plant community. So while surface flows may vary significantly, groundwater elevations should ensure that larger riparian plants weather drought conditions in the watershed.

CCBWQA MODEL STRUCTURE

The CCBWQA model derives its spatial topology from the UDFCD UDSWM model that was developed for stormwater master planning and flood hazard delineation (Figure 1 below shows the portion of the UDSWM model schematic for the study reach). The CCBWQA model simulates frequent runoff, flow in alluvium, and contaminant (phosphorus) loading that were not part of the original UDSWM model. The CCBWQA model does not simulate flood hydrology. The master plan model ended above the Piney Creek confluence, so the CCBWQA adds in tributaries that confluence within the state park or drain directly to the reservoir.

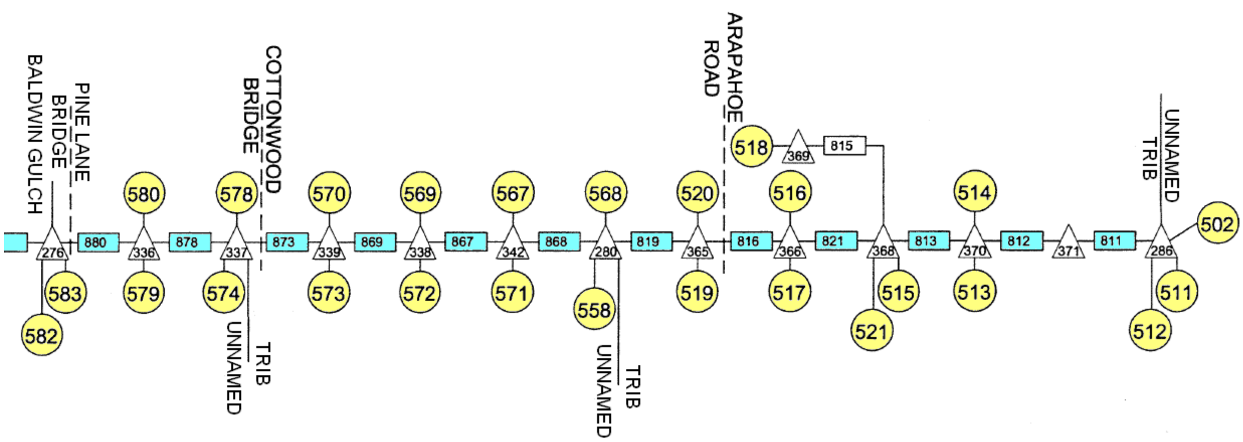


Figure 1. CCBWQA model structure for the study reaches

FLOW PATTERN

Gage data between the Parker and CC-10 gage show that the study reach looses flow. The CCBWQA model shows (Figure 2) this loss process in more detail. As discussed previously, the loosing reach behavior is the result of pumping from alluvial wells and is part of water supply operations by water providers. Figure 2, shows an underlying loss rate of about 6.3% per mile (red line) that results in 32% depletion of stream flow between Parker and Valley Country Club (relative to upstream inflow). This general pattern is interrupted by larger tributary inflows including Happy Canyon Wash and three unnamed tributaries below Chenango.

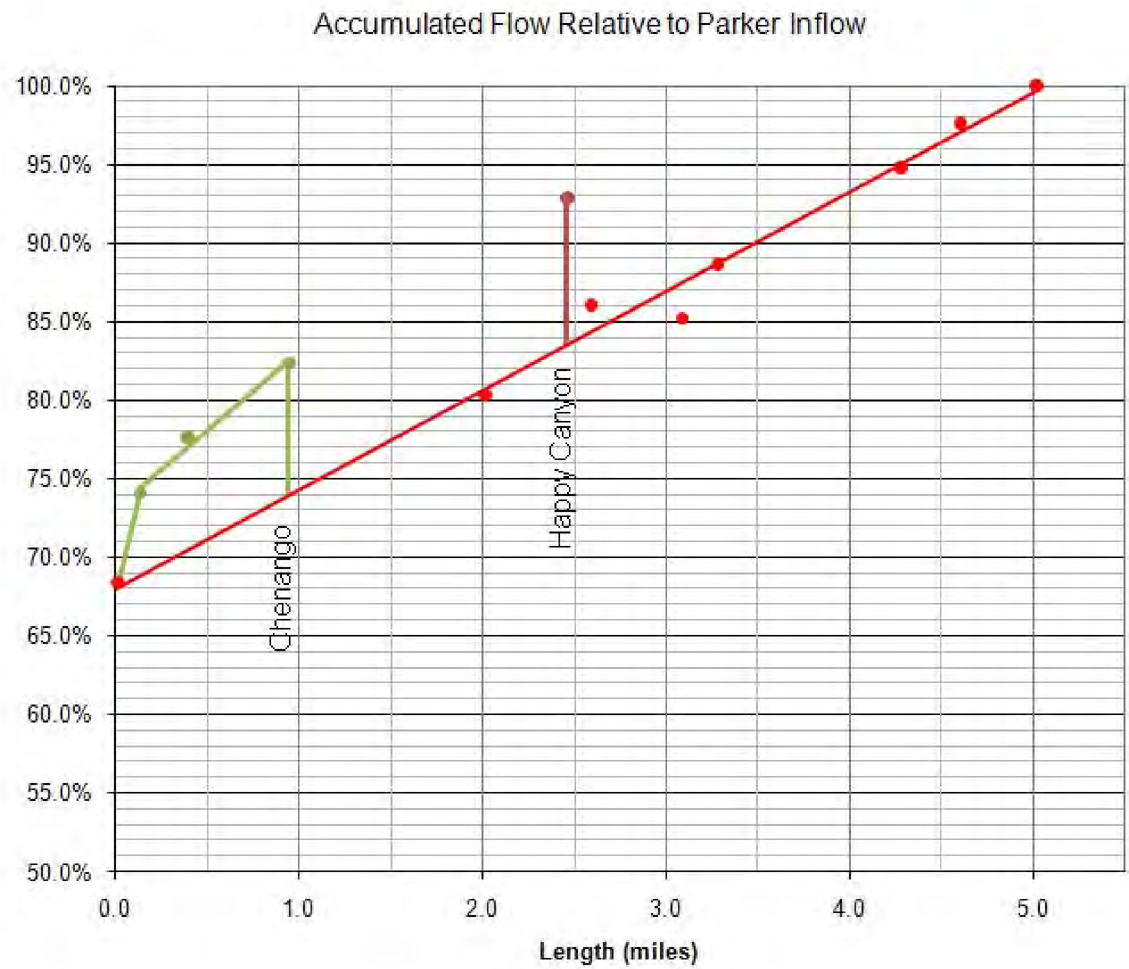


Figure 2. Loosing reach behavior for the Cherry Creek below Parker, CO

SUB-REACH CHARACTERISTICS

Characteristics of each sub-reach included stream slope, reach length, channel cross section, un-vegetated active channel width, active channel width, and fall at structures (see Table 1). With the exception of reach length, which was obtained from the master plan, all these data were measured for this study either in the field (un-vegetated active channel width), 2008 LiDaR topography (channel cross section, stream slope, active channel width, invert elevation). There is a 12 foot difference between elevation change due to stream slope between the master plan and this study. The smaller changes are within the LiDaR accuracy (+ 1.0 foot), while larger changes are due to the construction of drop structures and other grade controls since 2002.

Stream slopes measured for this study were found to be in a narrower range than was reported in the Master Plan, averaging 0.0395 $\pm$0.00043 ft/ft compared to 0.00444 $\pm$0.0007. Outside of the un-vegetated active channel, roughness was varied vertically to account for the change in roughness of flexible riparian vegetation as flow depth increases (Table 2). Bedload gradation was varied between the un-vegetated active channel width (coarser gradation) and the remainder of the cross section (Table 3). Channel cross sections are plotted and tabulated in Appendix A.

Table 1. Sub-Reach Characteristics

Sub-Reach	Invert Elev	Study Slope (ft/ft)	MP Slope (ft/ft)	MP Fall (ft)	Reach Length (ft)	Un-Veg ActWid (ft)	Slope Fall (ft)	MP-Stdy Fall Diff. (ft)
880	5750.0	0.00379	0.00450	9.5	2180	15	8.0	1.5
878	5746.0	0.00457	0.00500	8.7	1715	35	8.0	0.7
873	5720.0	0.00472	0.00440	28.0	5270	35	30.0	-2.0
869	5704.0	0.00383	0.00440	4.6	1032	35	4.0	0.6
867	5700.0	0.00438	0.00470	3.0	2615	35	2.8	0.2
868	5694.0	0.00400	0.00380	9.3	696	35	14.0	-4.7
819	5676.0	0.00358	0.00280	9.4	2353	39	12.0	0.0
816	5654.0	0.00350	0.00500	35.0	5657	25	24.5	10.0
821	5638.0	0.00345	0.00450	18.9	2903	25	14.5	4.4
813	5628.0	0.00332	0.00520	7.2	1378	25	4.6	2.6
812	5624.0	0.00388	0.00520	3.2	627	25	2.4	0.8

Table 2. Vertical variation in roughness with flow depth

Depth (ft)	n-value Left	Main	Right
0.0	0.311	0.025	0.311
1.0	0.311	0.025	0.311
2.0	0.146	0.025	0.146
4.0	0.076	0.025	0.076
5.0	0.064	0.025	0.064
7.0	0.057	0.025	0.057
10.0	0.049	0.025	0.049

Table 3. Bed material gradation properties

Grain size (mm)	% Finer Left	Main	Right
0.25	15.1	2.5	15.1
0.5	41.5	14.0	41.5
1.0	72.7	42.1	72.7
2.0	92.2	75.2	92.2
4.0	98.7	94.1	98.7
8.0	99.9	99.3	99.9
16.0	100.0	100.0	100.0

HEC-RAS RESULTS

Rating curves were developed for each sub-reach by using the HEC-RAS 4 hydraulic design tool for sediment transport capacity. A set of increasing discharges from 10 cfs to 10,000 cfs was input as the flow range. A simple three cross section reach was created by repeating the sub-reach cross section at 100 foot intervals and offsetting section by the sub-reach stream slope. Hydraulic design output for each sub-reach is listed in Appendix B.

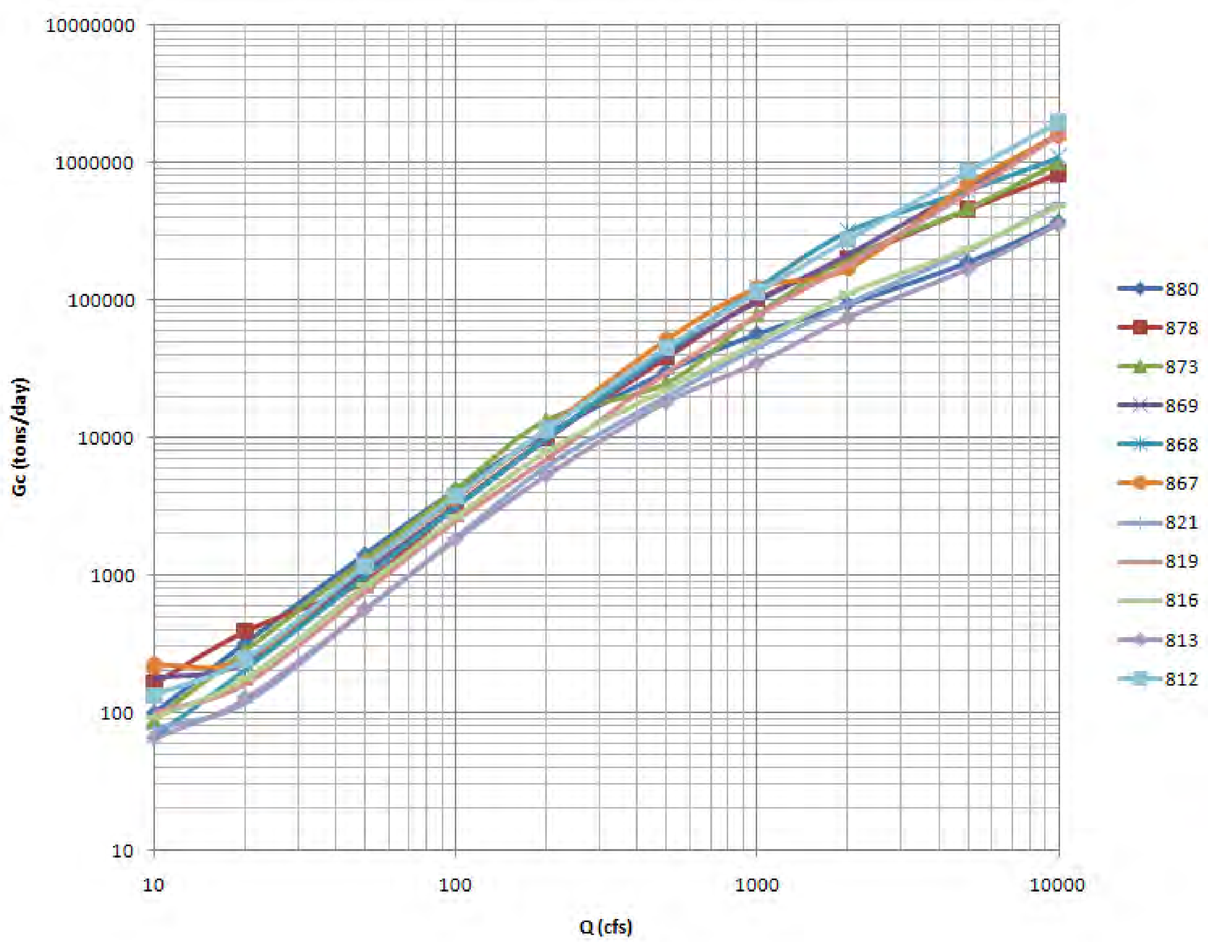


Figure 3. Sub-Reach Sediment Transport Rating Curves

The sediment ratings show similar pattern particularly in the lower range of flow (less than 500 cfs) but still differ from each other by as much as a factor of three times. The rating for sub-reach 813 is the lowest of all rating. This sub-reach includes the Arapahoe Road bridge and Valley Country Club, which have had a history of aggradation. The ratings were not simplified by curve fitting and were used in sediment budgeting analysis with the Excel table lookup function. Log interpolation was used for discharges greater than 10 cfs and linear interpolation was used for discharges between 0 and 10 cfs.

TIME STEP SCALING

The sediment budget analysis was conducted at monthly time steps; however, the sediment transport function is an instantaneous measurement. To account for the variations in flow within a monthly time step, a scaling analysis was conducted using the Parker gage (USGS 393109104464500 CHERRY CREEK NEAR PARKER, CO).

The sediment rating for the sub-reaches was computed from mean-daily discharges by first multiplying the daily discharges by 1.25 (in accordance with the sediment transport calibration of the Engelund-Hansen equation). Next, the mean-monthly discharges were scaled by a factor, such that the total monthly volume of sediment closely matched the volume computed for sum of the daily sediment volumes for a month. The result was a scaling factor of 1.352. The sediment volume computed using a monthly time step was within 0.4% of the volume computed using a daily time step. For the period from 1995 to 2002, scatter was also low with an R2 value of 0.9878. Figure 4 shows the relationship between daily and monthly time step scaling.

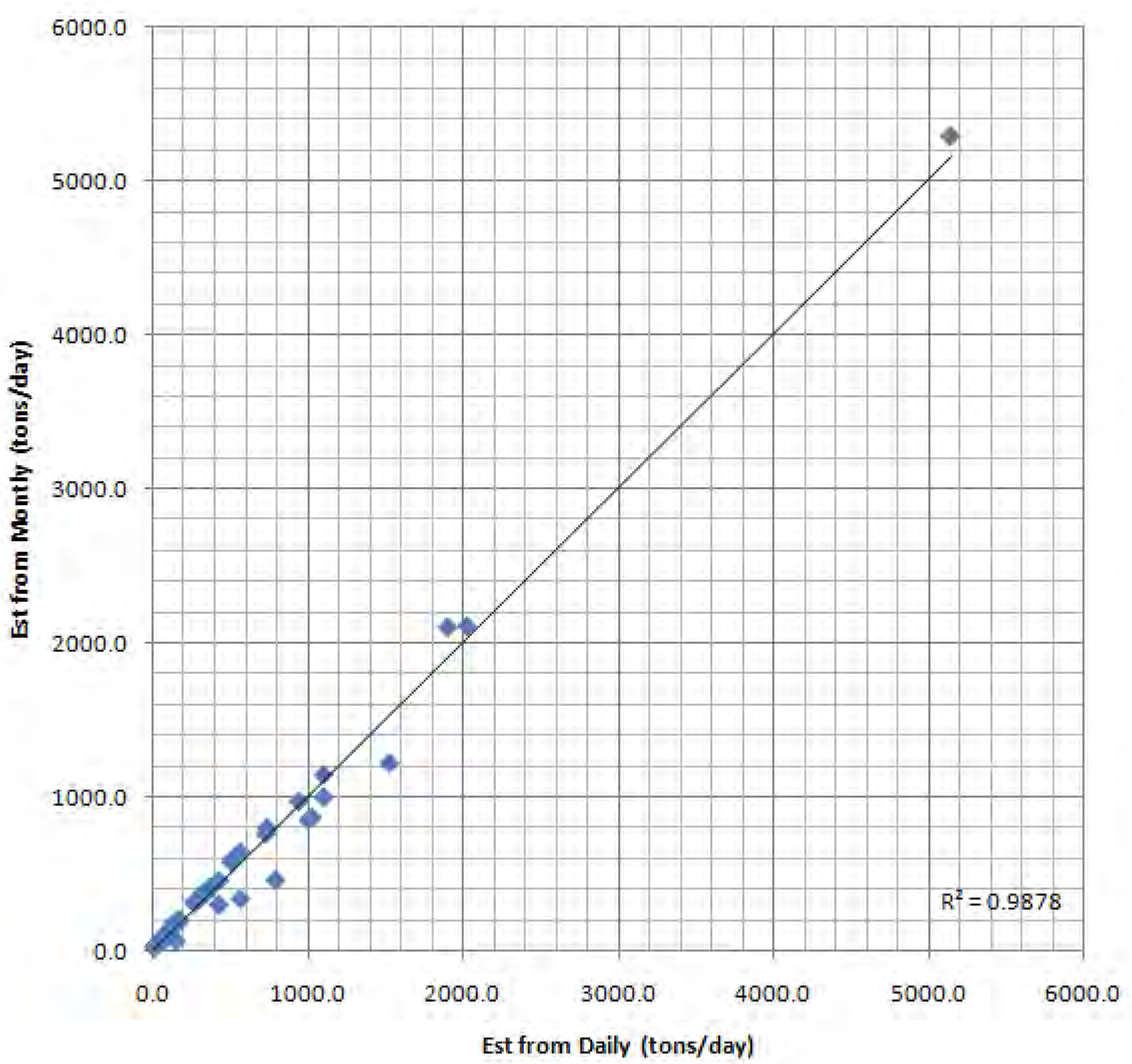


Figure 4. Estimates of sediment volume using daily and scaled monthly time steps

SUPPLY REACH

The upper most sub-reach is 880, which is located at the Pine Lane bridge over the Cherry Creek. As with other areas of the Cherry Creek, the active channel has changed significantly since the early 1990's becoming significantly more vegetated (Figure 5). As the un-vegetated narrowed and base flows increased, this reach developed minor scour problems in the low-flow channel. With the construction of the new bridge, small checks were constructed in the low-flow channel and the scour has been repaired (Figure 6).

The 2008 topographic data reflects a stable condition that can be used to characterize upstream sediment supply to the study reach. This sub-reach has a stream gradient and active channel width that are close to the averages for the overall reach. The unvegetated portion of the active channel width is narrower compared to the other downstream sub-reaches.

The history of sediment loading for this reach is shown in Figure 7 for the simulation period. The pattern of sediment transport follows that of stream flow and so periods of low sediment transport correspond to periods of low stream flow. Histograms of monthly water and sediment loading (Figures 8 and 9) show this pattern. For the eight year simulation period, total sediment transport from this reach is 1.11 million tons (538 ac-ft).

Figure 5. Sub-reach 880 c. 1994

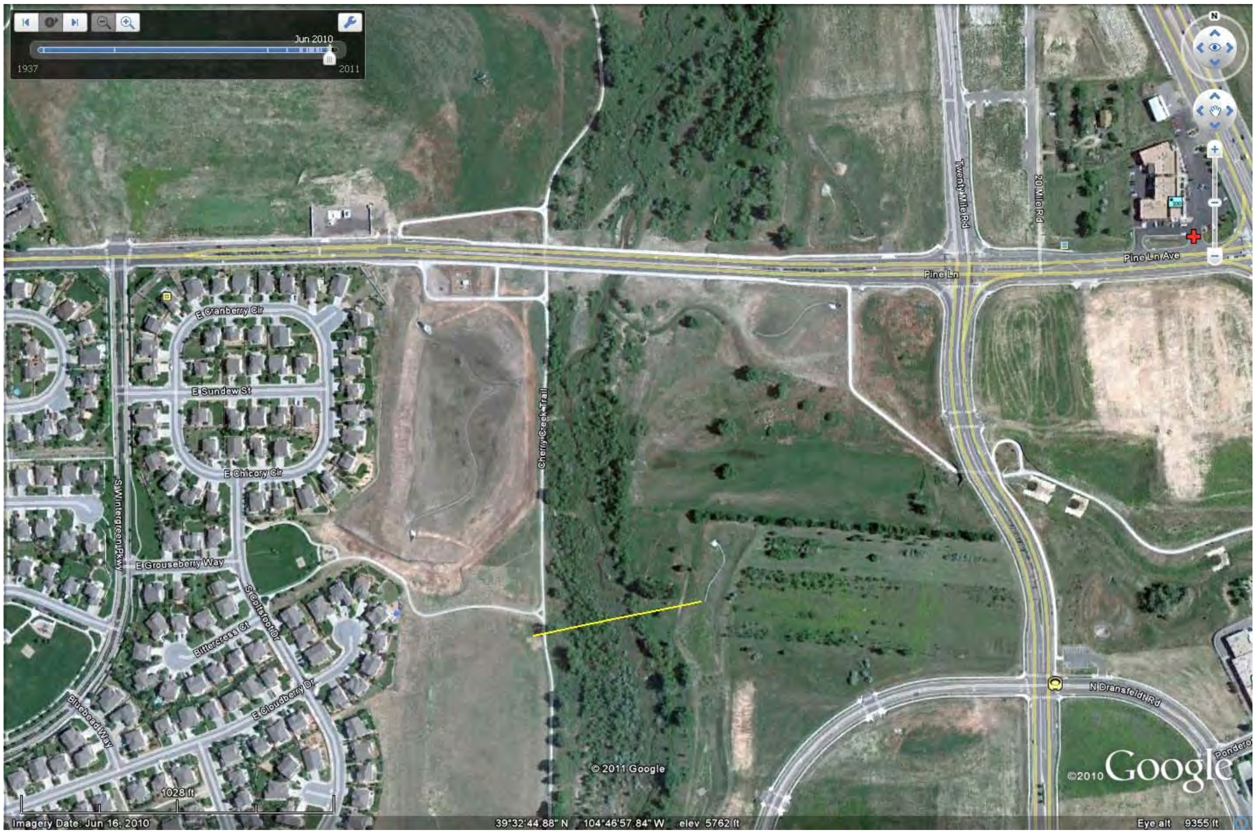


Figure 6. Sub-reach 880 c. 2010

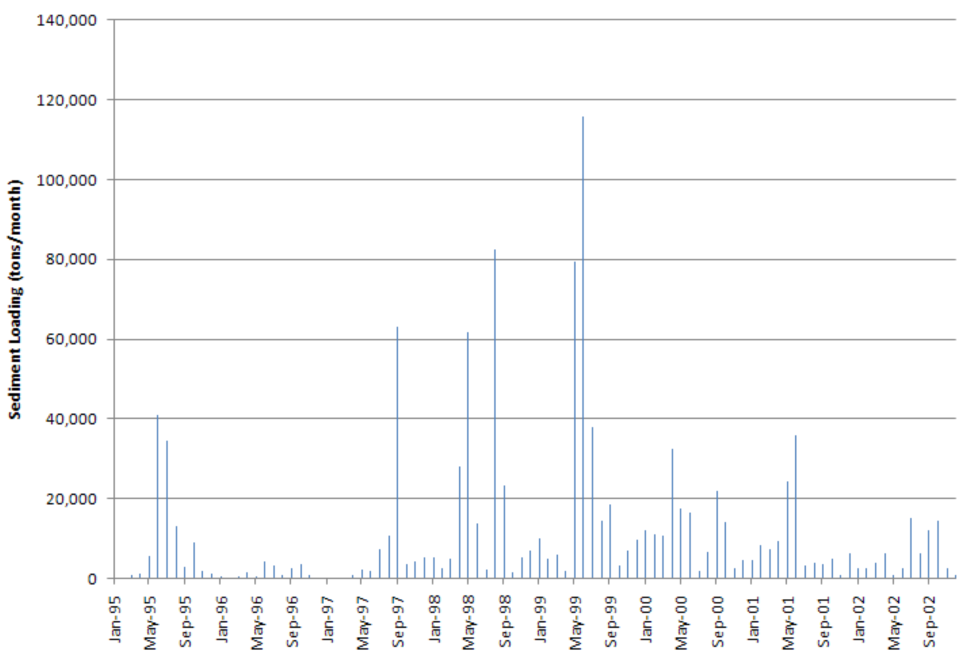


Figure 7. Sediment transport from sub-reach 880

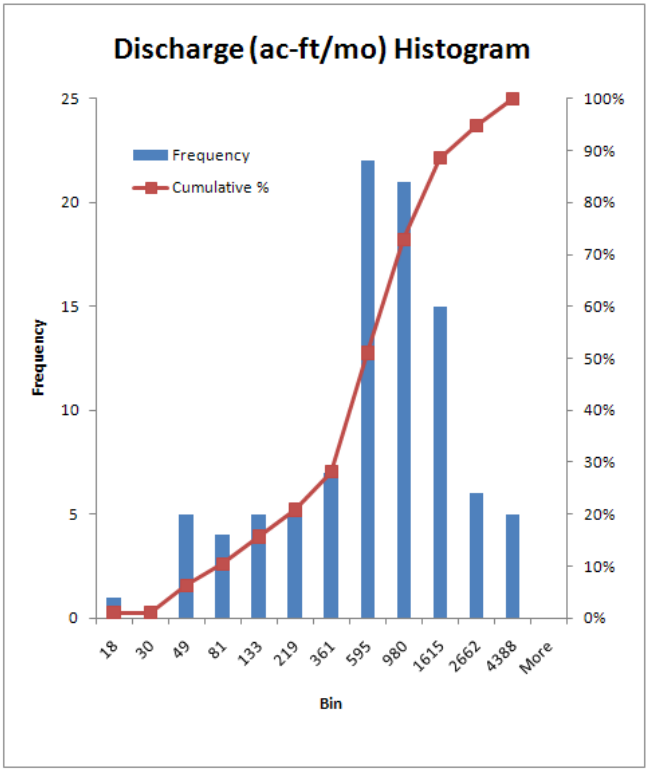


Figure 8. Discharge Histogram for sub-reach 880

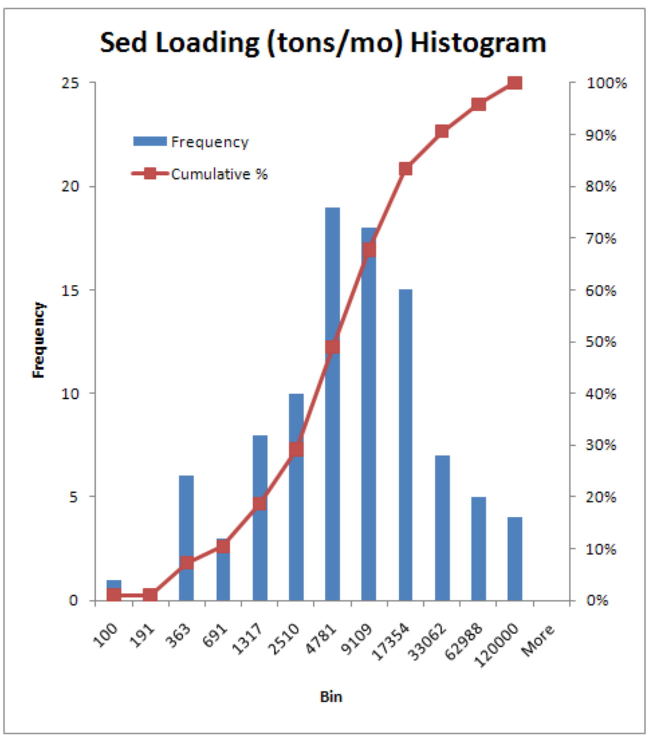


Figure 9. Sediment Loading Histogram for sub-reach 880

SEDIMENT BUDGET BY SUB-REACH

Sediment transport capacity in the study reach steadily decreases in the downstream direction (Figure 10). This creates the potential for aggradation for most sub-reaches. Sub-reach 867, which is located below the Happy Canyon confluence, is the exception to this trend. Sub-reach 812 is a short contracted reach of the Cherry Creek upstream of Caley Avenue that has a locally higher transport capacity and a strong potential to scour. While there has been scour in the stream segment below Happy Canyon, the 812 sub-reach does not show scour. The approach of using uniform flow for the 812 sub-reach is probably not accurate since it does not account for the backwater created by the Caley Avenue constriction of the stream channel.

Figure 10 shows the cumulative transport of sediment for the eight year study period. On an annual basis, there is an average of 2.1 tons (1.6 cubic yards) of sediment depositing per foot of stream length per year within the active channel of the Cherry Creek. Relative to the transport capacity of the Cherry Creek at Parker, only 33% of that capacity remains at the most sub-reach 813.

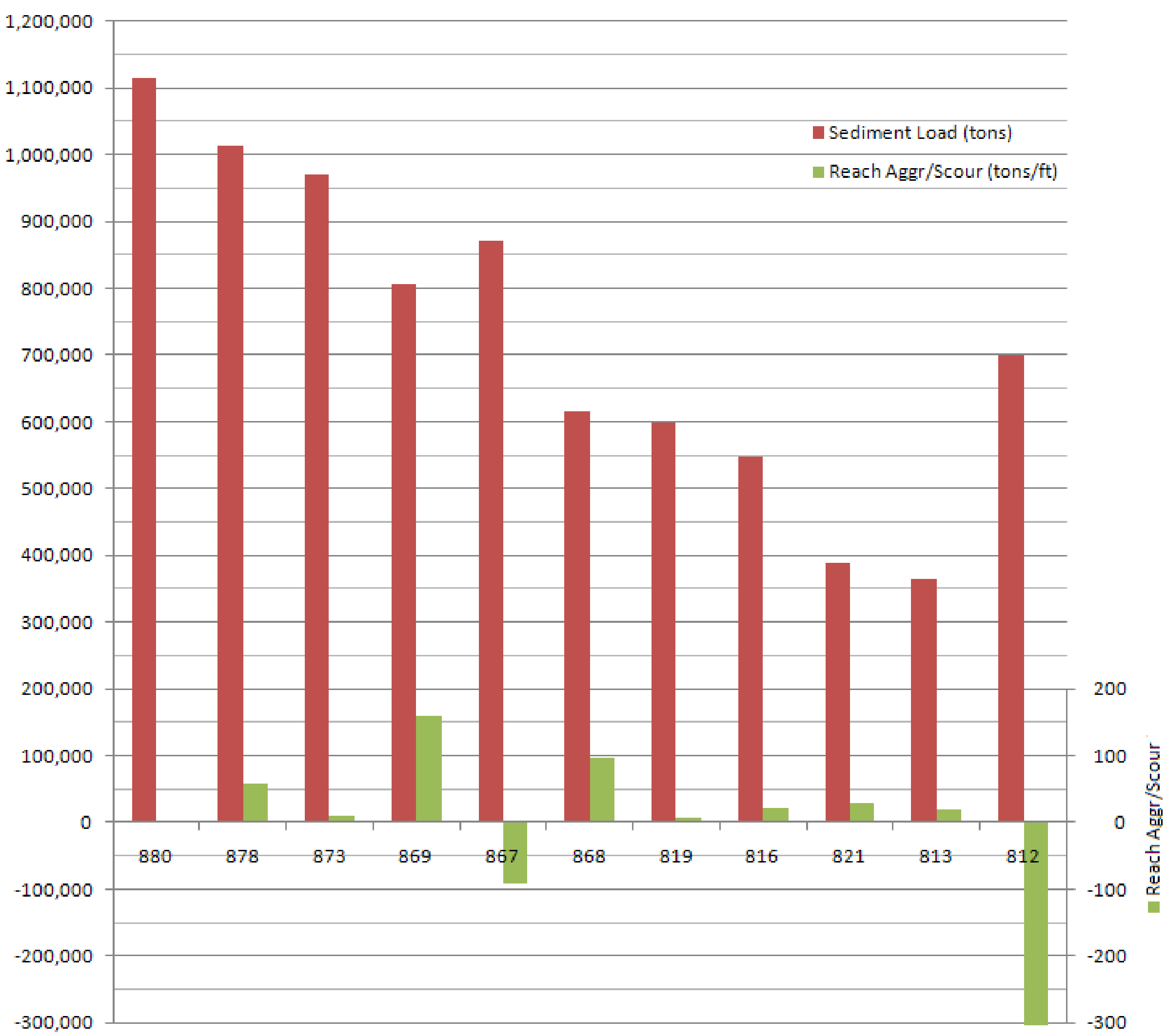


Figure 10. Sediment Budget by Sub-Reach and Potential Aggradation/Scour

As an example of the detailed aggradation/degradation behavior of a sub-reach, reach 867 and 813 are shown in Figure 11. These time series show that while a sub-reach tends to be predominantly aggradational or degradational, there are never-the-less periods where the trend reverses (highlighted in yellow). While a lack of sediment supply to a reach results in channel erosion, erosion still occurs in aggrading reaches as the stream reworks the excess sediment load. Large deposits of sediment in a reach often cause a shift in stream pattern, which can trigger erosion.

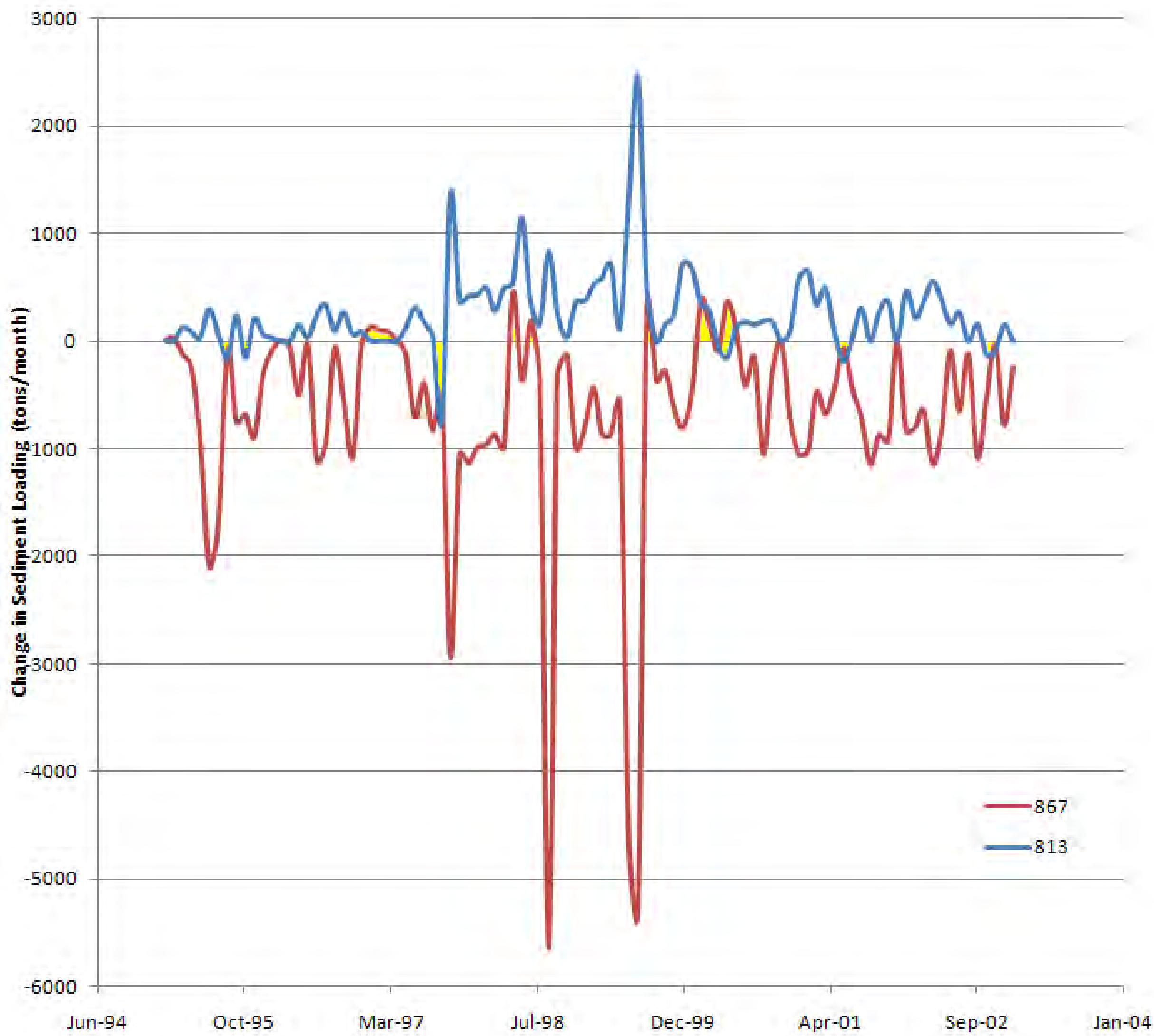


Figure 11. Aggradation / Degradation Time Series for selected sub-reaches (867 and 813), yellow highlights show periods of scour in a predominantly aggrading reach or periods of aggradation in a predominantly scouring reach.

SUMMARY AND FINDINGS

1. The CCBWQA hydrology simulation provided eight years of flow data for the study reach. In addition, the simulation provides detailed routing for 11 sub-reaches following the routing topology that was developed for floodplain master planning (URS, 2002).

2. The hydrology simulation shows that the study reach looses flow to water diversion at the rate of 6.3% per mile. Tributary inflow are quickly diverted and as a result have a fairly localize affect on the water balance.

5. Channel cross-section, stream gradient, and cross section properties (sediment gradations and roughness) were developed for each of the 11 sub-reaches of the study reach.

3. Mean monthly discharge was scaled by a factor of 1.352 for estimation of mean-monthly sediment load. This allowed the use of CCBWQA mean-monthly flow data.

4. The upper sub-reach of the study area (sub-reach 880) was found to be stable and it is recommended as a reliable reach for the estimation of incoming sediment supply to the study reach.

6. The sediment budget for the study sub-reaches shows that transport capacity steadily decreases in the downstream direction. This is directly attributable to the reduction in flow in the Cherry Creek. Only the sub-reach below Happy Canyon showed a potential for scour.

REFERENCES

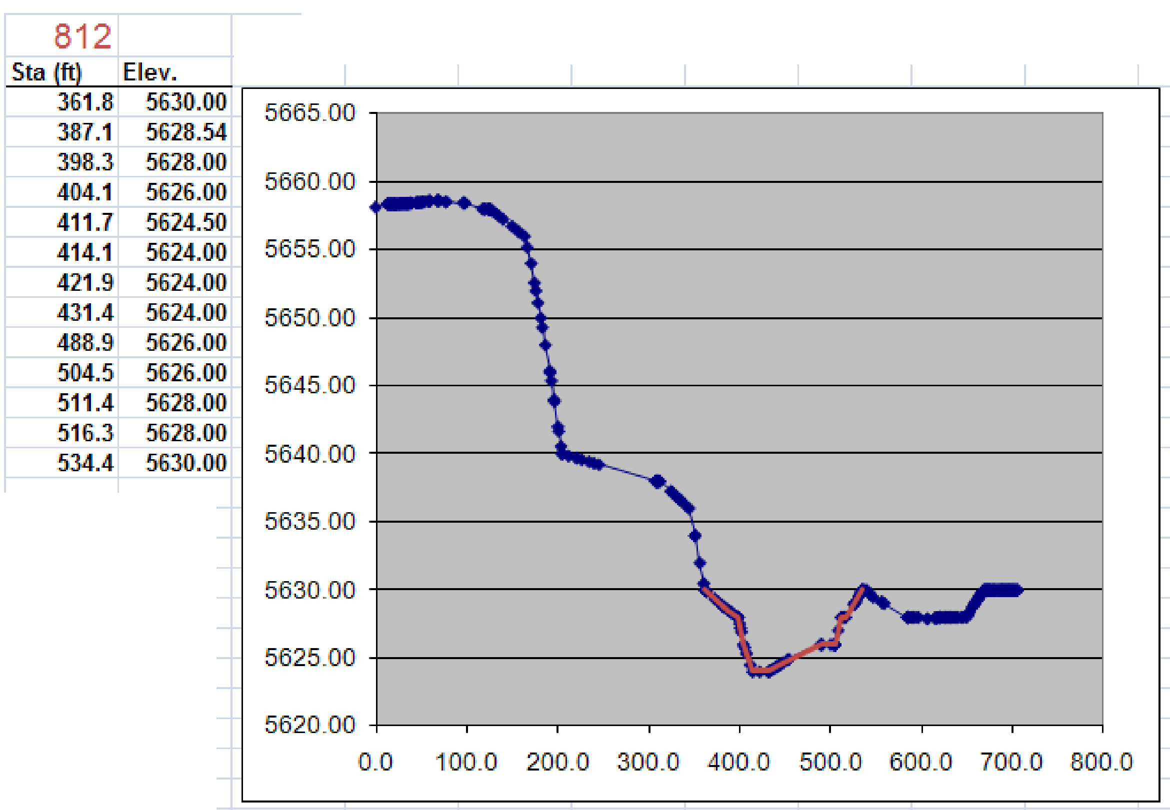
CDM, 2007, "South Metro Water Supply Authority Regional Water Master Plan" prepared for South Metro Water Supply Authority

Brown and Caldwell, 2008, "Cherry Creek Basin Watershed Phosphorus Model Documentation" prepared for the Cherry Creek Basin Water Quality Authority

Table 4. Cross section topwidth (blue values are the approximate width of the active channel)

Depth (ft)	880	878	873	869	867	868	819
0.0	15	107	35	13	57	23	31
2.0	265	274	479	115	256	79	166
4.0	583	901	504	356	288	704	177
6.0	619	1071	610	388	319	736	187
8.0		1227	859			898	198

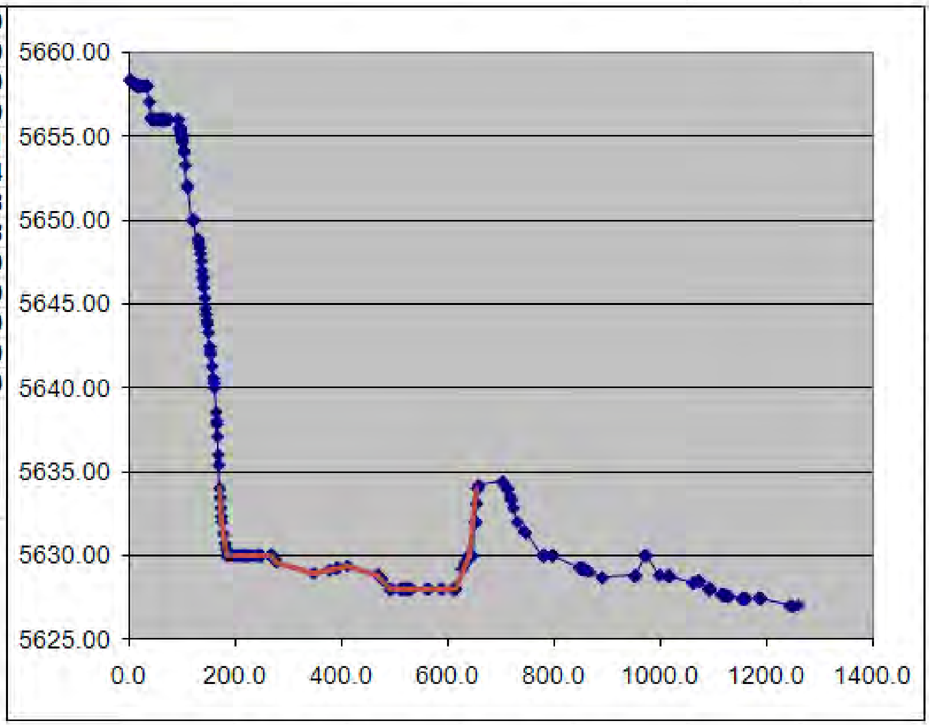
Depth (ft)	816	821	813	812	Low	Avg	High
0.0	41	123	123	17	30	67	135
2.0	106	371	371	100	113	237	340
4.0	407	429	474	113	268	450	601
6.0	628	488	485	173	310	539	729
8.0	720	937			459	807	1021



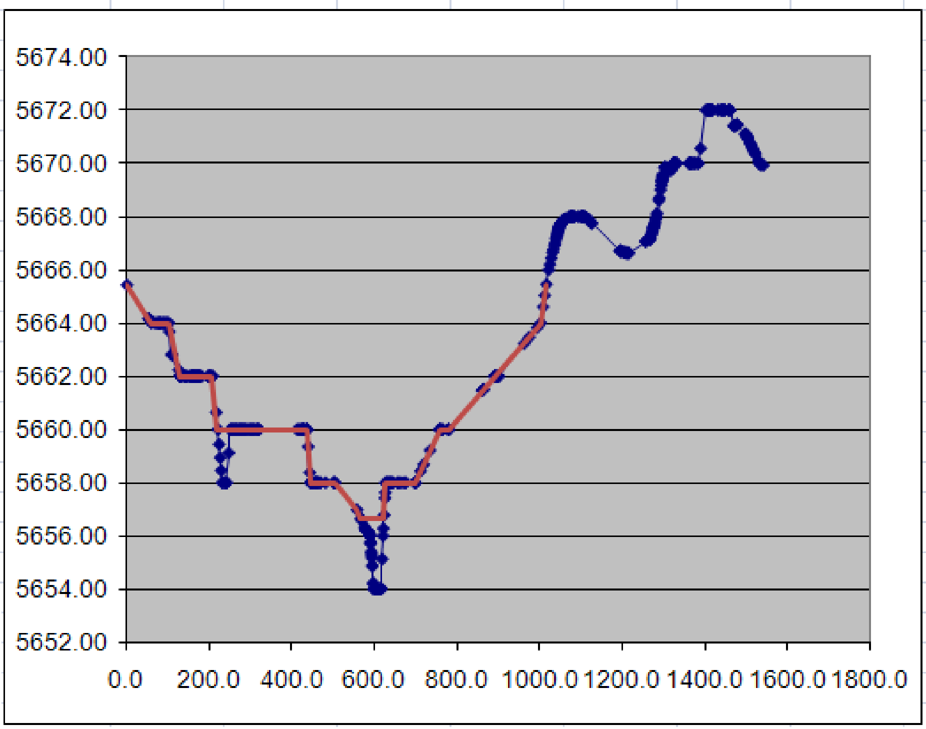
812

Sta (ft)	Elev.
361.8	5630.00
387.1	5628.54
398.3	5628.00
404.1	5626.00
411.7	5624.50
414.1	5624.00
421.9	5624.00
431.4	5624.00
488.9	5626.00
504.5	5626.00
511.4	5628.00
516.3	5628.00
534.4	5630.00

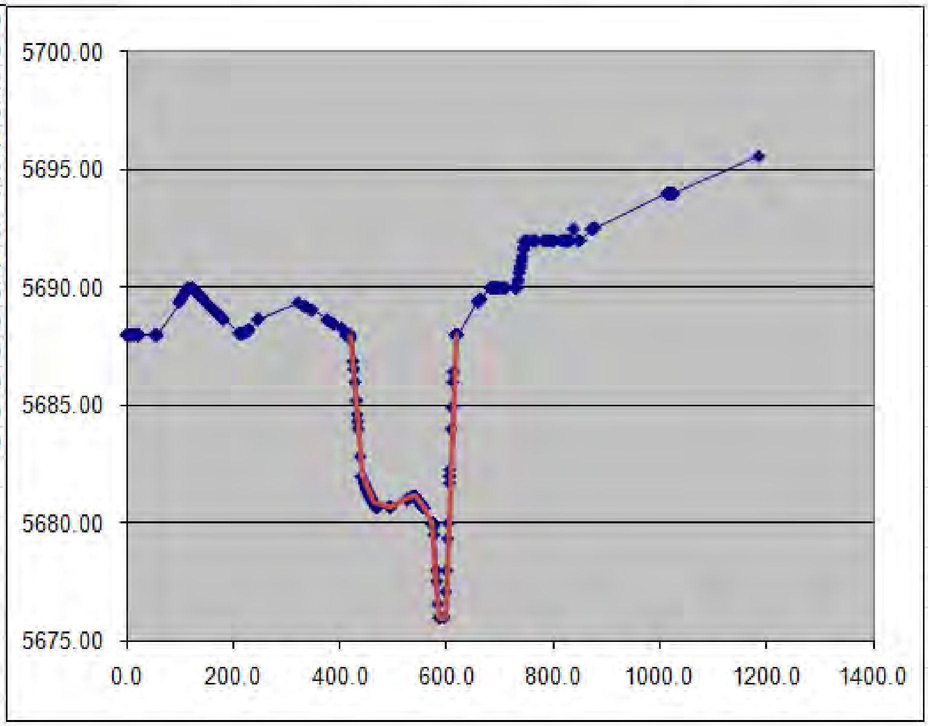
813	
Sta (ft)	Elev.
169.3	5634.00
173.2	5632.00
183.2	5630.00
267.8	5630.00
276.1	5629.61
346.0	5628.94
410.7	5629.38
467.1	5628.88
489.2	5628.00
550.7	5628.00
612.2	5628.00
638.9	5630.00
654.7	5634.00



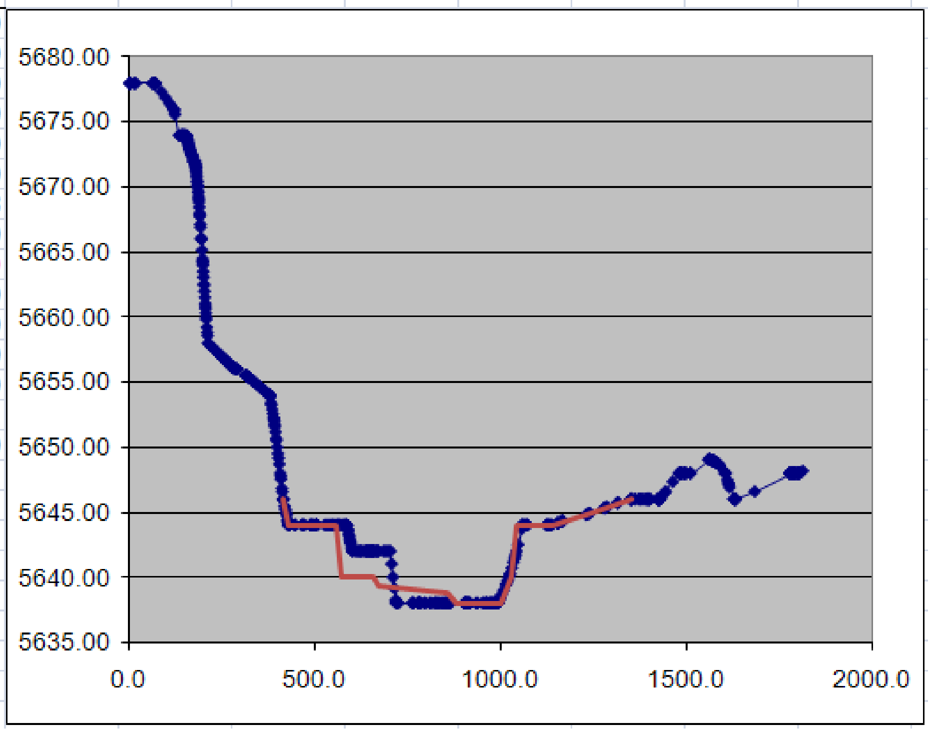
816	
Sta (ft)	Elev.
0.0	5665.43
59.8	5664.00
101.5	5664.00
128.6	5662.00
207.1	5662.00
220.6	5660.00
436.2	5660.00
444.6	5658.00
504.1	5658.00
557.3	5656.98
567.0	5656.65
623.1	5656.65
627.4	5658.00
698.4	5658.00
756.6	5660.00
779.8	5660.00
890.5	5662.00
1002.5	5664.00
1016.4	5665.46



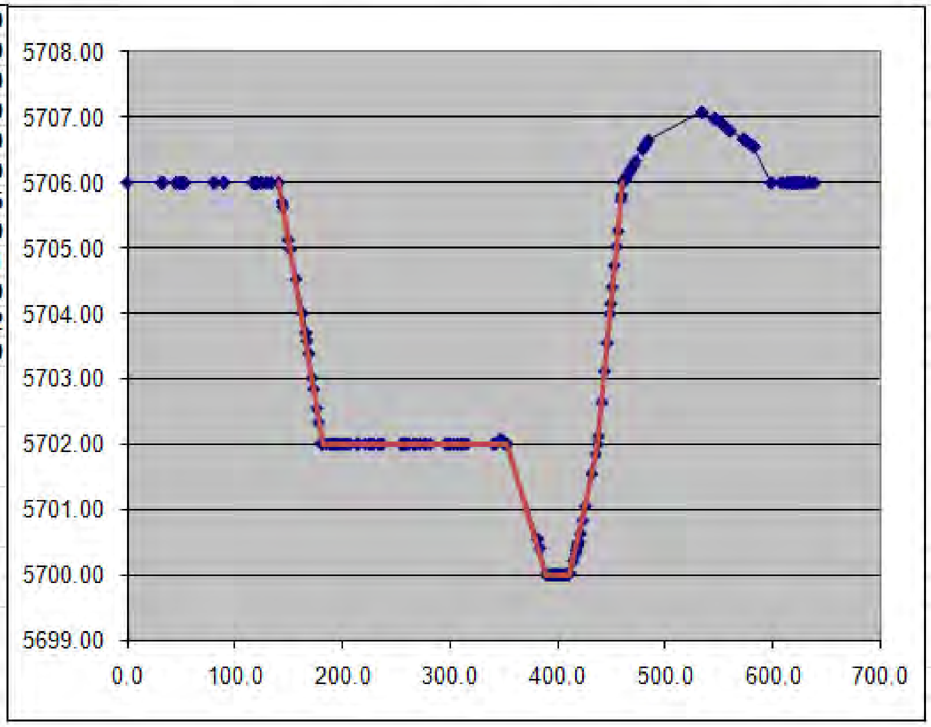
819	
Sta (ft)	Elev.
420.2	5688.00
441.4	5682.00
457.7	5681.12
461.4	5680.95
462.1	5680.94
493.4	5680.72
495.2	5680.67
536.6	5681.16
542.4	5681.14
558.7	5680.65
573.3	5680.00
585.9	5676.00
589.1	5676.00
596.8	5676.00
618.2	5688.00



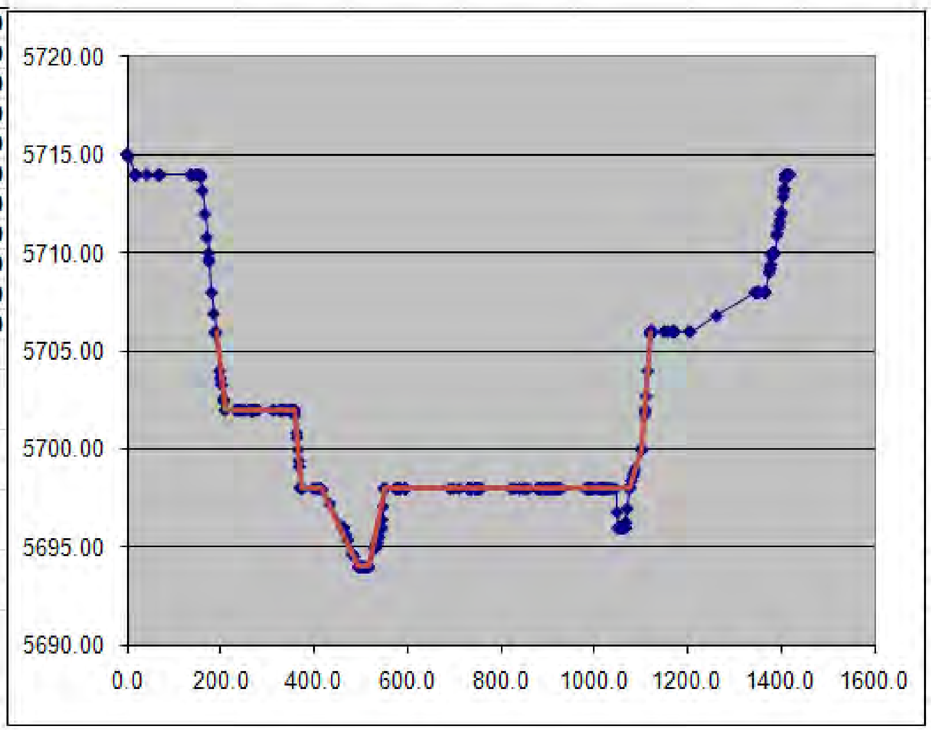
821	
Sta (ft)	Elev.
413.9	5646.00
428.4	5644.00
557.2	5644.00
573.2	5640.00
657.8	5640.00
670.0	5639.40
857.1	5638.88
879.2	5638.00
955.0	5638.00
1002.2	5638.00
1028.9	5640.00
1044.7	5644.00
1138.2	5644.00
1240.6	5644.91
1350.4	5646.00



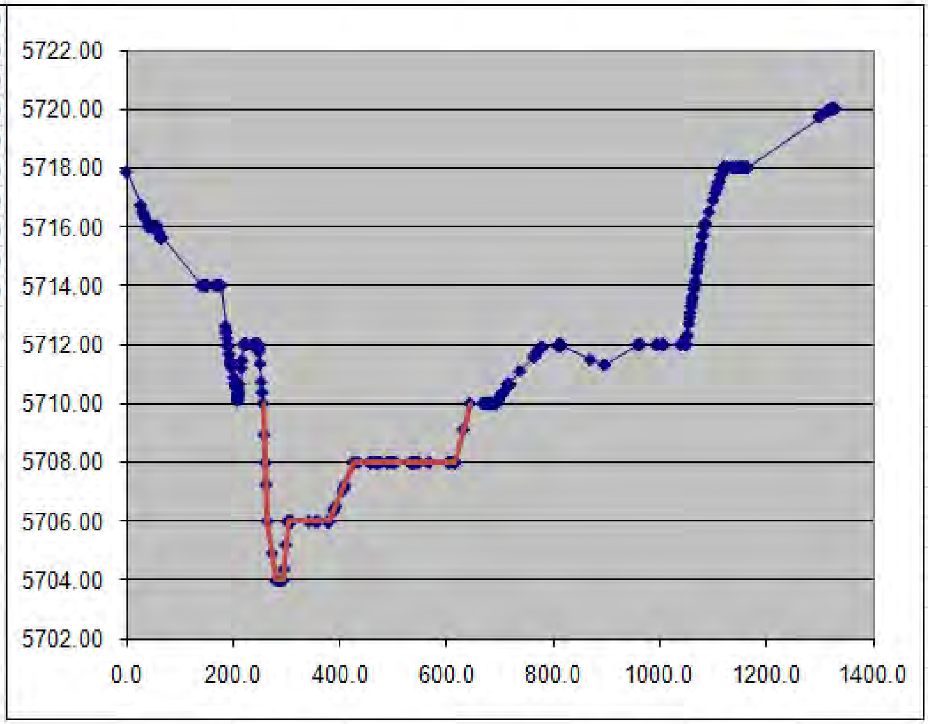
867	
Sta (ft)	Elev.
141.0	5706.00
180.9	5702.00
352.8	5702.00
389.2	5700.00
400.1	5700.00
409.9	5700.00
425.7	5701.05
436.9	5702.00
443.4	5703.11
448.5	5704.00
454.2	5705.02
460.2	5706.00



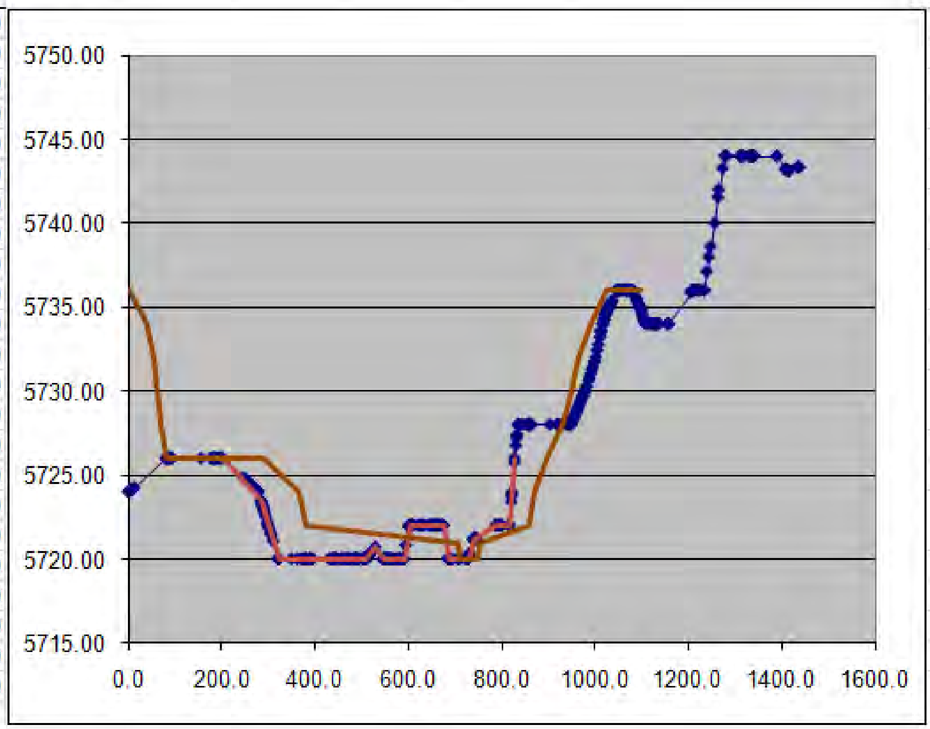
868	
Sta (ft)	Elev.
189.1	5706.00
210.3	5702.00
358.5	5702.00
372.3	5698.00
415.8	5698.00
495.8	5694.00
518.3	5694.00
550.7	5698.00
1075.9	5698.00
1101.8	5700.00
1121.7	5706.00



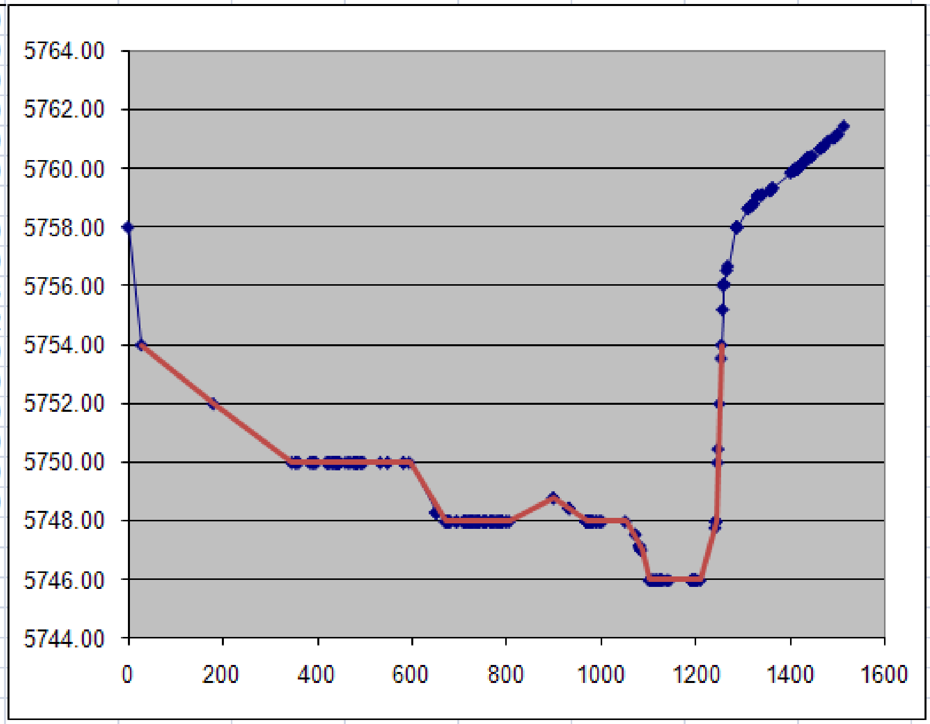
869	
Sta (ft)	Elev.
256.0	5710.00
264.8	5706.00
280.6	5704.00
288.7	5704.00
293.9	5704.00
302.1	5706.00
379.8	5706.00
426.0	5708.00
615.9	5708.00
643.7	5710.00



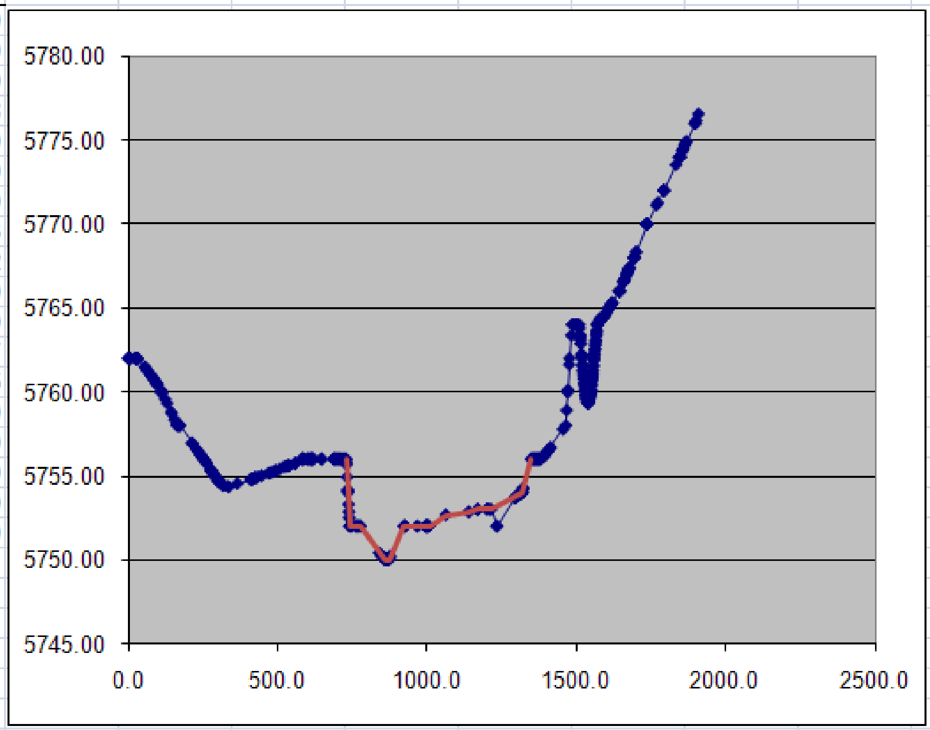
873	
Sta (ft)	Elev.
0	5736.0
38	5734.0
53	5732.0
63	5730.0
71	5728.0
82	5726.0
288	5726.0
364	5724.0
380	5722.0
707	5721.0
711.5	5720.0
731	5720.0
746.5	5720.0
751	5721.0
859	5722.0
868	5724.0
898	5726.0
930	5728.0
949	5730.0
965	5732.0
992	5734.0
1026	5736.0
1099	5736.0



878	
Sta (ft)	Elev.
28.1	5754.00
180.4	5752.00
346.2	5750.00
595.0	5750.00
671.3	5748.00
806.6	5748.00
899.5	5748.81
969.5	5748.00
1051.9	5748.00
1085.3	5747.03
1103.5	5746.02
1156.8	5746.00
1210.1	5746.00
1243.6	5748.00
1247.3	5750.00
1251.3	5752.00
1255.6	5754.00



880	
Sta (ft)	Elev.
730.4	5756.00
742.0	5752.00
777.8	5752.00
857.6	5750.08
861.4	5750.00
865.9	5750.00
872.2	5750.00
872.9	5750.03
877.3	5750.22
923.3	5752.00
1006.8	5752.00
1063.9	5752.67
1140.8	5752.85
1169.8	5753.00
1214.5	5753.00
1315.2	5754.00
1319.2	5754.00
1349.5	5756.00



Tabular summary of Sediment Rating Curves – flow in cfs and transport in tons/day

Flow/Link	880	878	873	869	867	868	819	816
10	100	165	89	178	220	67	99	86
20	321	393	280	231	245	207	161	183
50	1428	916	1305	1059	1178	990	759	811
100	4191	3216	4188	3219	3651	3152	2484	2551
200	10700	10040	13500	9803	11680	10060	7019	7650
500	30290	38510	25040	40910	51720	43100	29820	21660
1000	56710	101500	79210	98910	122600	123600	78020	48230
2000	93280	198300	203300	217500	169600	318400	183300	108300
5000	188800	459600	471200	673300	700500	635000	612400	229800
10000	367900	835900	1019000	1661000	1596000	1102000	1608000	464600

Flow/Link	821	813	812
10	22	127	134
20	100	164	245
50	340	799	1171
100	1095	2510	3739
200	3322	7016	11520
500	10750	21250	45310
1000	24170	46470	114700
2000	58090	95710	276700
5000	177000	226400	862500
10000	474200	496600	1985000

Hydraulic Design Data
Sediment Reach sr812
River: Cherry Creek, Reach: Caley2PineLn
RS: 812.2 to 812
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank	
	Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
	.250	15.1	.250	2.5	.250	15.1
	.500	41.5	.500	14	.500	41.5
	1.00	72.7	1.00	42.1	1.00	72.7
	2.00	92.2	2.00	75.2	2.00	92.2
	4.00	98.7	4.00	94.1	4.00	98.7
	8.00	99.9	8.00	99.3	8.00	99.9
	16.0	100	16.0	100	16.0	100
	d90	1.85		3.44		1.85
	d84	1.49		2.76		1.49
	d50	.604		1.18		.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day) sr_873 873.2
Engelund-Hansen Total All Grains (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sr812	812.2	PF 1	E-H	133.9
2	sr812	812.2	PF 2	E-H	245.2
3	sr812	812.2	PF 3	E-H	1171
4	sr812	812.2	PF 4	E-H	3739
5	sr812	812.2	PF 5	E-H	11520
6	sr812	812.2	PF 6	E-H	45310
7	sr812	812.2	PF 7	E-H	114700
8	sr812	812.2	PF 8	E-H	276700
9	sr812	812.2	PF 9	E-H	862500
10	sr812	812.2	PF 10	E-H	1985000

Hydraulic Design Data
Sediment Reach sr813

River: Cherry Creek, Reach: Caley2PineLn
RS: 813.2 to 813.2
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank	
	Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
	.250	15.1	.250	2.5	.250	15.1
	.500	41.5	.500	14	.500	41.5
	1.00	72.7	1.00	42.1	1.00	72.7
	2.00	92.2	2.00	75.2	2.00	92.2
	4.00	98.7	4.00	94.1	4.00	98.7
	8.00	99.9	8.00	99.3	8.00	99.9
	16.0	100	16.0	100	16.0	100
d90		1.85		3.44		1.85
d84		1.49		2.76		1.49
d50		.604		1.18		.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day) (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sr813	813.2	PF 1	E-H	65.11
2	sr813	813.2	PF 2	E-H	126.6
3	sr813	813.2	PF 3	E-H	563.8
4	sr813	813.2	PF 4	E-H	1813
5	sr813	813.2	PF 5	E-H	5327
6	sr813	813.2	PF 6	E-H	18150
7	sr813	813.2	PF 7	E-H	35070
8	sr813	813.2	PF 8	E-H	74900
9	sr813	813.2	PF 9	E-H	169000
10	sr813	813.2	PF 10	E-H	357300

Hydraulic Design Data
Sediment Reach sr816
River: Cherry Creek, Reach: Caley2PineLn
RS: 816.2 to 816
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank	
	Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
	.250	15.1	.250	2.5	.250	15.1
	.500	41.5	.500	14	.500	41.5
	1.00	72.7	1.00	42.1	1.00	72.7
	2.00	92.2	2.00	75.2	2.00	92.2
	4.00	98.7	4.00	94.1	4.00	98.7
	8.00	99.9	8.00	99.3	8.00	99.9
	16.0	100	16.0	100	16.0	100
d90		1.85		3.44		1.85
d84		1.49		2.76		1.49
d50		.604		1.18		.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day) (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sr816	816.2	PF 1	E-H	92.51
2	sr816	816.2	PF 2	E-H	177.5
3	sr816	816.2	PF 3	E-H	845.5
4	sr816	816.2	PF 4	E-H	2675
5	sr816	816.2	PF 5	E-H	8001
6	sr816	816.2	PF 6	E-H	22770
7	sr816	816.2	PF 7	E-H	50080
8	sr816	816.2	PF 8	E-H	112400
9	sr816	816.2	PF 9	E-H	239400
10	sr816	816.2	PF 10	E-H	487400

Hydraulic Design Data
Sediment Reach sr819

River: Cherry Creek, Reach: Caley2PineLn
RS: 819.2 to 819
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank	
	Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
	.250	15.1	.250	2.5	.250	15.1
	.500	41.5	.500	14	.500	41.5
	1.00	72.7	1.00	42.1	1.00	72.7
	2.00	92.2	2.00	75.2	2.00	92.2
	4.00	98.7	4.00	94.1	4.00	98.7
	8.00	99.9	8.00	99.3	8.00	99.9
	16.0	100	16.0	100	16.0	100
d90		1.85		3.44		1.85
d84		1.49		2.76		1.49
d50		.604		1.18		.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day)   sr_873 873.2
Engelund-Hansen Total All Grains (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sr819	819.2	PF 1	E-H	99.45
2	sr819	819.2	PF 2	E-H	160.5
3	sr819	819.2	PF 3	E-H	758.9
4	sr819	819.2	PF 4	E-H	2484
5	sr819	819.2	PF 5	E-H	7019
6	sr819	819.2	PF 6	E-H	29820
7	sr819	819.2	PF 7	E-H	78020
8	sr819	819.2	PF 8	E-H	183300
9	sr819	819.2	PF 9	E-H	612400
10	sr819	819.2	PF 10	E-H	1608000

Hydraulic Design Data
Sediment Reach sr821
River: Cherry Creek, Reach: Caley2PineLn
RS: 821.2 to 821
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank	
	Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
	.250	15.1	.250	2.5	.250	15.1
	.500	41.5	.500	14	.500	41.5
	1.00	72.7	1.00	42.1	1.00	72.7
	2.00	92.2	2.00	75.2	2.00	92.2
	4.00	98.7	4.00	94.1	4.00	98.7
	8.00	99.9	8.00	99.3	8.00	99.9
	16.0	100	16.0	100	16.0	100
d90		1.85		3.44		1.85
d84		1.49		2.76		1.49
d50		.604		1.18		.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day) (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sr821	821.2	PF 1	E-H	75.20
2	sr821	821.2	PF 2	E-H	116.3
3	sr821	821.2	PF 3	E-H	553.5
4	sr821	821.2	PF 4	E-H	1854
5	sr821	821.2	PF 5	E-H	6125
6	sr821	821.2	PF 6	E-H	19830
7	sr821	821.2	PF 7	E-H	44690
8	sr821	821.2	PF 8	E-H	93610
9	sr821	821.2	PF 9	E-H	227600
10	sr821	821.2	PF 10	E-H	504600

Hydraulic Design Data
Sediment Reach sr_867
River: Cherry Creek, Reach: Caley2PineLn
RS: 867.2 to 867
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank	
	Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
	.250	15.1	.250	2.5	.250	15.1
	.500	41.5	.500	14	.500	41.5
	1.00	72.7	1.00	42.1	1.00	72.7
	2.00	92.2	2.00	75.2	2.00	92.2
	4.00	98.7	4.00	94.1	4.00	98.7
	8.00	99.9	8.00	99.3	8.00	99.9
	16.0	100	16.0	100	16.0	100

	Left	Main	Right
d90	1.85	3.44	1.85
d84	1.49	2.76	1.49
d50	.604	1.18	.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day) sr_873 873.2
Engelund-Hansen Total All Grains (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sr_867	867.2	PF 1	E-H	220.0
2	sr_867	867.2	PF 2	E-H	245.4
3	sr_867	867.2	PF 3	E-H	1178
4	sr_867	867.2	PF 4	E-H	3651
5	sr_867	867.2	PF 5	E-H	11680
6	sr_867	867.2	PF 6	E-H	51720
7	sr_867	867.2	PF 7	E-H	122600
8	sr_867	867.2	PF 8	E-H	169600
9	sr_867	867.2	PF 9	E-H	700500
10	sr_867	867.2	PF 10	E-H	1596000

Hydraulic Design Data
Sediment Reach sr_868
River: Cherry Creek, Reach: Caley2PineLn
RS: 868.2 to 868
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank
Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
.250	15.1	.250	2.5	.250	15.1
.500	41.5	.500	14	.500	41.5
1.00	72.7	1.00	42.1	1.00	72.7
2.00	92.2	2.00	75.2	2.00	92.2
4.00	98.7	4.00	94.1	4.00	98.7
8.00	99.9	8.00	99.3	8.00	99.9
16.0	100	16.0	100	16.0	100

	Left	Main	Right
d90	1.85	3.44	1.85
d84	1.49	2.76	1.49
d50	.604	1.18	.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day) sr_873 873.2
Engelund-Hansen Total All Grains (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sr_868	868.2	PF 1	E-H	66.99
2	sr_868	868.2	PF 2	E-H	207.3
3	sr_868	868.2	PF 3	E-H	990.3
4	sr_868	868.2	PF 4	E-H	3152
5	sr_868	868.2	PF 5	E-H	10060
6	sr_868	868.2	PF 6	E-H	43100
7	sr_868	868.2	PF 7	E-H	123600
8	sr_868	868.2	PF 8	E-H	318400
9	sr_868	868.2	PF 9	E-H	635000
10	sr_868	868.2	PF 10	E-H	1102000

Hydraulic Design Data
Sediment Reach sr_869
River: Cherry Creek, Reach: Caley2PineLn
RS: 867.2 to 867
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank	
	Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
	.250	15.1	.250	2.5	.250	15.1
	.500	41.5	.500	14	.500	41.5
	1.00	72.7	1.00	42.1	1.00	72.7
	2.00	92.2	2.00	75.2	2.00	92.2
	4.00	98.7	4.00	94.1	4.00	98.7
	8.00	99.9	8.00	99.3	8.00	99.9
	16.0	100	16.0	100	16.0	100

	Left	Main	Right
d90	1.85	3.44	1.85
d84	1.49	2.76	1.49
d50	.604	1.18	.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day) sr_869 869.2
Engelund-Hansen Total All Grains (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sr_869	867.2	PF 1	E-H	177.5
2	sr_869	867.2	PF 2	E-H	230.8
3	sr_869	867.2	PF 3	E-H	1059
4	sr_869	867.2	PF 4	E-H	3219
5	sr_869	867.2	PF 5	E-H	9803
6	sr_869	867.2	PF 6	E-H	40910
7	sr_869	867.2	PF 7	E-H	98910
8	sr_869	867.2	PF 8	E-H	217500
9	sr_869	867.2	PF 9	E-H	673300
10	sr_869	867.2	PF 10	E-H	1661000

Hydraulic Design Data
Sediment Reach sr873
River: Cherry Creek, Reach: Caley2PineLn
RS: 873.2 to 873
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank	
	Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
	.250	15.1	.250	2.5	.250	15.1
	.500	41.5	.500	14	.500	41.5
	1.00	72.7	1.00	42.1	1.00	72.7
	2.00	92.2	2.00	75.2	2.00	92.2
	4.00	98.7	4.00	94.1	4.00	98.7
	8.00	99.9	8.00	99.3	8.00	99.9
	16.0	100	16.0	100	16.0	100
d90		1.85		3.44		1.85
d84		1.49		2.76		1.49
d50		.604		1.18		.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day)   sr873 873.2
Engelund-Hansen   Total   All Grains (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sr873	873.2	PF 1	E-H	88.61
2	sr873	873.2	PF 2	E-H	279.8
3	sr873	873.2	PF 3	E-H	1305
4	sr873	873.2	PF 4	E-H	4188
5	sr873	873.2	PF 5	E-H	13500
6	sr873	873.2	PF 6	E-H	25040
7	sr873	873.2	PF 7	E-H	79210
8	sr873	873.2	PF 8	E-H	203300
9	sr873	873.2	PF 9	E-H	471200
10	sr873	873.2	PF 10	E-H	1019000

Hydraulic Design Data
Sediment Reach sr_878

River: Cherry Creek, Reach: Caley2PineLn
RS: 878.2 to 878
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank	
	Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
	.250	15.1	.250	2.5	.250	15.1
	.500	41.5	.500	14	.500	41.5
	1.00	72.7	1.00	42.1	1.00	72.7
	2.00	92.2	2.00	75.2	2.00	92.2
	4.00	98.7	4.00	94.1	4.00	98.7
	8.00	99.9	8.00	99.3	8.00	99.9
	16.0	100	16.0	100	16.0	100
	d90	1.85		3.44		1.85
	d84	1.49		2.76		1.49
	d50	.604		1.18		.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day)   sedRch 880.2
Engelund-Hansen   Total   All Grains (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sr_878	878.2	PF 1	E-H	164.5
2	sr_878	878.2	PF 2	E-H	393.3
3	sr_878	878.2	PF 3	E-H	915.9
4	sr_878	878.2	PF 4	E-H	3216
5	sr_878	878.2	PF 5	E-H	10040
6	sr_878	878.2	PF 6	E-H	38510
7	sr_878	878.2	PF 7	E-H	101500
8	sr_878	878.2	PF 8	E-H	198300
9	sr_878	878.2	PF 9	E-H	459600
10	sr_878	878.2	PF 10	E-H	835900

Hydraulic Design Data
Sediment Reach sedRch

River: Cherry Creek, Reach: Caley2PineLn
RS: 880.2 to 880.2
Sediment Transport Functions: Engelund-Hansen
Temperature: 55
Specific Gravity of Sediment: 2.65
Concentration of Fine Sediment: 0
Fall Velocity Method: Default
Depth/Width Type: Default

Gradation	Left Overbank		Main Channel		Right Overbank	
	Diameter	% Finer	Diameter	% Finer	Diameter	% Finer
	.250	15.1	.250	2.5	.250	15.1
	.500	41.5	.500	14	.500	41.5
	1.00	72.7	1.00	42.1	1.00	72.7
	2.00	92.2	2.00	75.2	2.00	92.2
	4.00	98.7	4.00	94.1	4.00	98.7
	8.00	99.9	8.00	99.3	8.00	99.9
	16.0	100	16.0	100	16.0	100

	Left	Main	Right
d90	1.85	3.44	1.85
d84	1.49	2.76	1.49
d50	.604	1.18	.604

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.000	0.000	0.000
6	.088	0.000	0.000	0.000
7	.177	0.151	0.025	0.151
8	.354	0.264	0.115	0.264
9	.707	0.312	0.281	0.312
10	1.41	0.195	0.331	0.195
11	2.83	0.065	0.189	0.065
12	5.64	0.012	0.052	0.012
13	11.3	0.001	0.007	0.001
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day) sedRch 880.2
Engelund-Hansen Total All Grains (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	sedRch	880.2	PF 1	E-H	100.3
2	sedRch	880.2	PF 2	E-H	321.1
3	sedRch	880.2	PF 3	E-H	1428
4	sedRch	880.2	PF 4	E-H	4191
5	sedRch	880.2	PF 5	E-H	10700
6	sedRch	880.2	PF 6	E-H	30290
7	sedRch	880.2	PF 7	E-H	56710
8	sedRch	880.2	PF 8	E-H	93280
9	sedRch	880.2	PF 9	E-H	188800
10	sedRch	880.2	PF 10	E-H	367900

Sub-Segment Stream Flows (monthly volume - ac-ft)

(Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Inc. Length (ft)	2180	1715	5270	1032	2615	696	2353	5657	2903	1378	627	70
Total Q (ac-ft)	76368	74567	72358	67681	65061	65718	70918	61328	62880	59287	56555	52232
Total L (mi)	5.0	4.6	4.3	3.3	3.1	2.6	2.5	2.0	0.9	0.4	0.1	0.0
Jan-95	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0
Feb-95	41.9	36.0	29.8	41.3	30.9	22.3	1.7	0.0	0.0	0.0	0.0	0.0
Mar-95	136.7	130.9	124.9	122.8	108.4	102.4	104.9	74.9	74.9	64.4	55.8	45.0
Apr-95	198.1	171.7	159.6	157.8	144.0	144.5	155.6	129.5	135.2	134.0	127.2	109.6
May-95	640.1	653.3	664.9	619.3	610.8	632.0	758.7	672.2	706.7	687.2	658.7	594.9
Jun-95	2176.2	2160.6	2159.9	2005.2	1976.2	2010.1	2461.2	2315.1	2373.0	2328.7	2277.3	2146.1
Jul-95	1921.1	1867.9	1848.0	1724.0	1707.8	1746.3	2158.7	2043.8	2108.7	2076.5	2027.7	1903.8
Aug-95	1060.2	1047.4	1027.9	928.5	900.2	914.4	969.6	877.7	902.4	876.1	842.6	772.5
Sep-95	419.6	380.5	314.1	303.0	294.5	303.0	389.7	358.6	376.8	375.5	365.7	336.9
Oct-95	836.5	809.3	777.1	722.9	684.3	695.3	917.0	827.8	851.8	826.2	773.5	687.0
Nov-95	280.4	275.0	264.4	261.8	272.6	271.6	253.1	224.7	230.8	221.0	232.9	239.8
Dec-95	176.3	175.7	172.9	172.2	157.9	159.9	115.2	54.1	57.2	52.3	41.5	28.9
Jan-96	71.1	69.5	71.5	83.7	74.0	67.9	18.4	9.9	9.9	8.4	12.0	11.4
Feb-96	50.8	49.2	46.8	57.9	47.2	38.6	0.0	0.0	0.0	0.0	0.0	0.0
Mar-96	72.8	69.4	65.2	74.8	64.8	58.9	25.1	0.0	0.0	0.0	0.0	0.0
Apr-96	228.2	216.6	199.4	207.9	203.1	208.3	214.0	94.7	104.8	88.6	86.3	77.7
May-96	56.7	41.0	23.5	37.5	32.0	33.0	45.0	28.5	34.7	34.9	35.0	29.0
Jun-96	545.2	515.2	471.7	451.6	436.5	440.8	582.9	550.8	562.2	545.0	529.2	497.0
Jul-96	449.2	423.6	392.7	385.6	373.5	375.9	443.2	429.6	437.9	432.3	422.9	402.8
Aug-96	125.0	113.5	75.6	84.4	73.1	73.5	112.0	93.1	98.3	94.2	87.8	76.9
Sep-96	393.6	359.5	263.8	245.4	235.7	244.3	364.6	330.4	348.9	344.1	333.8	305.6
Oct-96	490.7	455.4	379.6	358.6	361.7	384.5	634.3	605.8	647.0	646.6	635.3	587.2
Nov-96	110.9	93.7	68.2	75.5	63.6	62.5	114.8	104.3	107.5	102.0	97.0	88.3
Dec-96	35.5	0.0	0.0	15.3	5.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0

Sub-Segment Stream Flows (monthly volume - ac-ft)

(Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-97	32.4	4.3	0.0	15.9	5.1	1.9	0.0	0.0	0.0	0.0	0.0	0.0
Feb-97	45.7	44.5	16.3	30.0	19.2	13.7	0.0	0.0	0.0	0.0	0.0	0.0
Mar-97	40.9	40.8	39.1	49.7	40.0	31.9	0.0	0.0	0.0	0.0	0.0	0.0
Apr-97	136.7	127.7	109.3	112.1	98.7	96.9	127.0	92.4	94.4	81.8	72.5	59.0
May-97	336.9	326.8	316.6	292.6	282.6	293.0	405.9	361.8	382.0	372.7	359.0	324.2
Jun-97	283.0	263.0	232.0	224.6	206.9	203.1	215.8	195.8	195.8	184.5	173.3	158.3
Jul-97	749.1	722.8	689.0	659.6	642.0	648.3	770.4	716.3	730.0	706.4	680.3	639.6
Aug-97	934.3	899.8	864.6	861.3	881.2	919.1	1158.7	1150.6	1213.7	1254.4	1262.0	1213.5
Sep-97	2860.5	2826.6	2781.6	2596.0	2532.2	2541.9	2909.0	2708.4	2724.9	2617.2	2526.7	2394.6
Oct-97	472.8	445.3	415.7	393.8	387.6	398.1	493.9	410.8	429.1	409.2	389.8	349.2
Nov-97	559.9	546.7	524.5	481.7	458.2	460.2	539.3	411.5	415.6	383.1	359.3	324.7
Dec-97	621.4	617.2	611.2	569.3	539.6	539.5	603.1	483.2	483.1	446.5	416.1	375.4
Jan-98	622.6	624.0	623.1	577.4	546.1	546.1	588.1	398.4	398.3	351.9	311.6	258.4
Feb-98	401.8	400.8	398.8	404.3	389.8	389.8	335.8	93.3	91.6	31.5	17.6	9.0
Mar-98	581.6	581.6	581.0	561.8	533.8	533.8	496.3	280.7	280.2	210.4	162.3	112.0
Apr-98	1715.7	1710.5	1711.6	1470.3	1374.7	1379.3	1415.9	1173.9	1181.2	1065.8	960.2	819.5
May-98	2767.9	2767.7	2784.6	2390.1	2249.4	2256.7	2396.7	2166.3	2177.8	2057.6	1938.0	1749.5
Jun-98	1115.8	1101.4	1082.1	993.9	944.1	950.9	924.4	694.6	704.7	607.8	557.6	416.7
Jul-98	308.2	275.1	230.7	216.9	199.5	197.8	184.6	142.5	144.6	132.7	119.5	99.6
Aug-98	3331.1	3267.3	3224.6	3113.0	3075.2	3097.8	3375.3	3166.4	3203.8	3158.8	3081.3	2958.7
Sep-98	1531.2	1520.5	1501.2	1377.6	1329.3	1337.0	1437.4	1299.7	1313.2	1237.9	1178.3	1073.2
Oct-98	203.6	158.9	88.8	92.5	82.7	82.2	66.9	43.1	47.2	47.5	46.2	39.6
Nov-98	629.2	612.6	595.1	563.4	539.5	544.0	553.3	385.4	392.5	371.3	328.1	285.2
Dec-98	717.4	717.2	729.3	668.2	640.2	641.9	690.9	566.7	571.8	526.4	509.7	466.8

Sub-Segment Stream Flows (monthly volumes - ac-ft)

(Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-99	905.9	907.3	918.5	869.3	837.2	837.2	806.9	564.4	563.2	480.3	429.9	390.8
Feb-99	613.5	614.2	613.3	589.5	564.7	564.7	533.4	289.9	289.5	193.1	150.2	114.0
Mar-99	654.7	655.3	657.5	644.1	625.1	625.1	585.9	366.4	366.4	269.1	189.8	118.7
Apr-99	302.0	293.9	277.4	276.1	261.3	260.6	211.1	61.9	61.4	38.2	28.2	19.6
May-99	3247.3	3222.6	3288.5	3026.3	2967.9	3016.6	3453.7	3233.9	3311.6	3244.4	3155.8	2952.3
Jun-99	4229.0	4233.6	4238.5	3799.4	3679.2	3698.8	3788.0	3558.3	3589.7	3468.4	3470.1	3429.8
Jul-99	2033.8	2004.5	1965.5	1725.1	1619.1	1633.6	1703.0	1489.7	1512.5	1416.6	1314.9	1140.8
Aug-99	1118.7	1044.4	953.4	900.5	893.8	906.1	969.7	780.7	801.9	760.9	705.7	643.4
Sep-99	1328.3	1305.7	1274.7	1190.5	1155.0	1169.0	1248.2	1099.2	1121.1	1054.0	1004.8	906.5
Oct-99	455.8	418.0	359.2	334.6	309.6	308.9	270.8	182.1	185.1	159.9	134.8	100.9
Nov-99	730.2	714.2	693.0	672.7	652.4	655.2	631.9	397.7	401.9	303.0	239.1	192.5
Dec-99	886.3	883.8	879.1	839.3	785.6	793.3	775.5	539.3	539.3	430.9	323.1	165.0
Jan-00	1013.4	1014.9	1020.5	986.1	923.9	950.5	904.3	779.0	779.0	667.4	587.8	498.6
Feb-00	985.8	985.7	985.4	934.1	852.5	882.7	827.7	764.6	776.0	668.8	662.2	663.6
Mar-00	938.8	939.2	939.2	915.8	852.0	883.6	831.1	772.3	817.6	782.4	779.7	780.7
Apr-00	1877.2	1864.8	1853.7	1677.2	1572.9	1606.5	1549.0	1458.1	1498.6	1472.1	1423.0	1397.9
May-00	1267.6	1255.8	1262.1	1166.1	1111.4	1145.1	1195.8	1115.6	1155.8	1097.8	1086.8	1060.7
Jun-00	1246.3	1236.8	1232.3	1161.2	1135.6	1167.7	1184.9	1063.0	1102.6	1034.3	991.0	917.2
Jul-00	258.0	213.2	141.9	139.0	122.1	120.3	152.4	122.8	122.8	112.2	101.9	87.4
Aug-00	709.3	648.7	577.6	547.0	529.6	536.2	657.5	600.4	613.6	594.4	572.3	529.8
Sep-00	1474.0	1420.2	1338.9	1243.9	1205.5	1213.8	1506.3	1387.4	1402.5	1338.6	1278.5	1189.9
Oct-00	1110.7	1064.4	1000.3	926.1	888.5	888.5	989.3	829.0	828.9	779.1	737.7	677.9
Nov-00	398.2	381.4	354.4	343.2	326.1	326.1	276.7	78.7	78.3	66.0	52.6	40.5
Dec-00	562.8	564.8	575.9	558.0	542.0	547.8	527.9	302.8	339.4	261.6	224.5	197.8

Sub-Segment Stream Flows (monthly volumes - ac-ft)

(Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-01	572.0	570.4	572.6	572.9	563.4	569.7	557.5	468.3	527.9	430.5	327.0	181.6
Feb-01	860.9	864.8	872.5	838.5	809.5	810.1	755.0	690.7	740.6	632.6	558.7	452.2
Mar-01	749.6	750.3	751.8	724.2	684.0	684.0	634.8	576.9	621.1	529.4	524.6	526.0
Apr-01	886.0	882.2	872.5	840.7	802.0	802.0	744.6	677.7	716.5	684.7	682.6	682.7
May-01	1551.7	1545.2	1537.7	1386.7	1324.3	1330.8	1410.5	1348.8	1388.2	1363.8	1363.1	1361.5
Jun-01	2004.6	1983.5	1968.4	1786.0	1708.4	1722.1	1754.3	1624.4	1657.6	1614.9	1577.5	1517.5
Jul-01	454.0	403.3	346.9	330.2	313.3	313.5	340.8	300.7	305.8	288.9	272.7	248.3
Aug-01	515.4	440.4	345.8	338.3	348.8	378.1	607.4	585.1	636.1	652.8	653.0	610.6
Sep-01	502.8	456.6	399.2	384.7	368.5	372.3	383.5	334.2	344.3	332.8	314.6	284.4
Oct-01	586.8	513.9	425.9	410.5	390.5	387.9	472.5	423.2	423.2	402.1	382.7	357.2
Nov-01	126.6	105.6	48.3	58.3	47.4	43.6	16.1	0.0	0.0	0.0	0.0	0.0
Dec-01	687.2	688.7	694.2	652.5	625.0	626.3	663.9	491.4	493.5	448.3	414.8	376.1
Jan-02	376.4	378.2	379.1	371.5	353.2	353.2	315.5	126.3	130.9	100.4	85.2	68.1
Feb-02	396.4	399.2	400.5	379.5	353.3	355.1	382.5	240.0	281.6	231.6	211.9	181.9
Mar-02	518.5	522.8	527.8	505.5	492.3	493.4	482.5	310.4	347.4	282.6	243.6	212.3
Apr-02	695.7	692.3	686.2	625.5	597.3	606.3	697.9	538.7	584.1	522.4	481.7	420.3
May-02	119.5	100.9	71.9	78.8	68.0	64.4	33.9	10.5	35.2	8.2	5.7	2.5
Jun-02	402.1	375.1	336.8	314.9	298.4	301.9	332.1	295.8	314.9	298.6	284.3	257.0
Jul-02	1157.2	1114.3	1048.2	990.6	959.3	959.3	1132.7	1013.8	1017.4	971.4	931.7	876.4
Aug-02	675.1	630.3	564.8	545.1	528.3	530.9	700.7	642.3	650.5	628.7	608.6	572.6
Sep-02	1027.3	956.9	841.5	817.2	801.1	805.4	992.5	943.1	953.9	922.2	897.4	855.5
Oct-02	1128.0	1089.7	1038.2	949.2	916.7	926.3	1011.6	895.2	910.0	863.8	819.0	748.2
Nov-02	391.1	378.2	360.4	343.0	328.8	335.4	317.7	185.8	195.8	189.1	178.1	154.9
Dec-02	118.9	118.4	113.5	119.2	110.8	110.8	68.2	0.0	0.0	0.0	0.0	0.0

Sub-Segment Alluvial Flows (monthly volume, ac-ft) (Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-95	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.2	0.2
Feb-95	184.8	185.7	187.5	198.0	209.5	202.3	239.8	287.0	262.5	221.8	168.6	152.5
Mar-95	170.6	171.4	173.1	182.8	193.5	187.4	220.4	264.2	243.2	208.5	165.4	143.7
Apr-95	188.9	189.8	191.6	202.4	214.8	207.8	243.0	292.2	270.1	235.4	194.2	164.3
May-95	182.8	183.7	185.5	195.9	209.5	201.2	234.4	282.9	261.8	233.4	200.4	167.0
Jun-95	188.9	189.8	191.6	202.4	219.9	208.1	242.7	294.2	270.8	249.4	223.4	186.3
Jul-95	182.8	183.7	185.5	195.9	221.6	201.4	236.7	286.0	261.7	246.0	222.7	191.1
Aug-95	188.9	189.8	191.6	202.4	232.7	207.8	245.4	294.4	269.2	251.2	221.7	195.7
Sep-95	188.9	189.8	191.3	202.4	228.9	207.3	242.8	290.5	267.6	242.6	204.9	184.3
Oct-95	182.8	183.7	185.4	195.9	219.2	200.3	233.2	278.5	257.8	230.3	190.1	171.4
Nov-95	188.9	189.8	191.6	202.4	226.3	207.4	241.7	287.2	266.3	238.8	198.7	177.3
Dec-95	182.8	183.7	185.5	195.9	216.7	201.6	234.6	277.4	258.4	232.9	198.4	173.7
Jan-96	188.9	189.8	191.6	202.4	222.5	209.1	243.6	286.6	267.9	243.8	213.1	184.2
Feb-96	188.9	189.8	191.6	202.4	220.7	210.1	244.2	284.5	268.7	242.2	210.8	182.6
Mar-96	176.7	177.6	179.3	189.3	205.0	197.3	228.5	264.8	252.0	226.9	198.8	171.4
Apr-96	188.9	189.8	191.6	202.4	217.7	211.2	244.0	283.5	269.7	245.4	218.5	187.3
May-96	182.8	183.6	185.4	195.9	209.1	204.3	235.5	275.6	261.0	240.7	216.1	184.7
Jun-96	188.7	189.1	191.2	202.4	214.1	210.5	241.0	282.5	269.2	245.9	217.9	188.2
Jul-96	182.7	183.5	185.3	195.9	207.1	202.8	231.8	272.5	259.3	240.7	216.3	186.8
Aug-96	187.9	187.9	190.7	202.4	212.0	208.1	236.7	279.9	265.9	248.8	224.9	194.6
Sep-96	187.5	186.3	190.4	202.4	210.1	206.4	233.7	275.8	263.6	239.5	206.1	182.5
Oct-96	181.6	179.4	184.7	195.9	202.8	198.5	223.9	264.6	253.3	228.8	194.2	172.0
Nov-96	188.8	185.4	191.1	202.4	209.8	204.6	229.6	272.1	260.9	237.5	204.1	179.3
Dec-96	182.8	181.0	185.0	195.9	203.3	198.0	220.6	261.9	252.5	230.2	199.9	174.1
Jan-95	188.9	189.2	191.0	202.4	210.4	205.0	226.6	269.5	261.3	239.8	212.3	183.4

Sub-Segment Alluvial Flows (monthly volume, ac-ft) (Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-97	188.9	189.8	191.5	202.4	210.7	205.4	225.5	268.4	261.6	241.7	217.6	187.2
Feb-97	170.6	171.4	173.1	182.8	190.6	186.1	204.1	241.4	236.6	219.9	200.5	172.5
Mar-97	188.9	189.8	191.6	202.4	211.2	206.3	225.7	266.4	261.8	245.2	226.2	195.0
Apr-97	182.8	183.7	185.4	195.9	205.3	199.6	218.0	258.0	253.0	240.6	225.7	195.2
May-97	188.8	189.4	191.4	202.4	212.8	206.0	224.5	266.1	260.5	250.3	236.9	206.8
Jun-97	182.7	183.6	185.4	195.9	206.1	198.5	216.8	255.3	250.5	238.3	220.1	196.4
Jul-97	187.9	188.0	190.6	202.4	211.2	203.8	222.1	259.7	256.3	236.6	207.3	189.8
Aug-97	188.9	189.8	191.6	202.4	217.5	202.7	224.9	259.6	253.9	237.4	204.9	189.9
Sep-97	182.8	183.7	185.5	195.9	213.6	195.8	219.3	250.7	244.0	227.2	192.7	179.5
Oct-97	188.9	189.8	191.6	202.4	219.4	202.3	227.7	259.6	251.1	234.2	200.6	184.3
Nov-97	182.8	183.7	185.5	195.9	212.9	196.3	221.9	253.2	243.1	230.5	204.5	184.4
Dec-97	188.9	189.8	191.6	202.4	222.9	203.7	231.6	264.9	251.7	244.2	225.2	201.0
Jan-98	188.9	189.8	191.6	202.4	223.1	204.6	233.3	269.5	252.4	249.8	233.9	207.8
Feb-98	170.6	171.4	173.1	182.8	200.9	185.6	212.1	247.9	228.9	230.0	217.1	192.5
Mar-98	188.9	189.8	191.6	202.4	226.6	206.2	236.7	279.3	254.2	264.2	260.2	228.9
Apr-98	182.8	183.7	185.5	195.9	231.8	200.5	232.1	275.2	246.8	267.4	276.1	247.9
May-98	188.9	189.8	191.6	202.4	251.5	208.5	242.0	289.2	255.6	285.9	303.3	282.1
Jun-98	182.8	183.7	185.4	195.9	246.0	202.9	233.7	281.1	247.3	275.9	288.1	278.7
Jul-98	188.9	189.8	191.6	202.4	247.6	209.8	240.4	288.0	254.3	274.4	275.9	277.2
Aug-98	188.9	189.8	191.6	202.4	249.3	209.9	243.2	288.7	253.2	272.0	268.9	276.2
Sep-98	182.8	183.7	185.4	195.9	235.0	203.4	234.5	276.7	244.4	253.3	241.9	254.3
Oct-98	188.9	189.8	191.6	202.4	236.1	210.5	242.2	286.1	252.5	258.3	245.8	257.4
Nov-98	182.8	183.7	185.5	195.9	227.9	204.5	235.8	278.5	245.4	249.9	238.8	248.1
Dec-98	188.9	189.8	191.6	202.4	233.4	212.3	244.9	290.9	255.2	262.4	254.1	258.3

Sub-Segment Alluvial Flows (monthly volume, ac-ft) (Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-99	188.9	189.8	191.6	202.4	232.5	213.3	246.7	295.7	257.0	269.7	263.7	262.2
Feb-99	170.6	171.4	173.1	182.8	208.9	193.4	224.1	271.3	233.8	250.6	249.9	243.7
Mar-99	188.9	189.8	191.6	202.4	229.0	214.7	249.2	304.1	260.5	281.7	285.7	275.5
Apr-99	182.8	183.7	185.5	195.9	224.1	208.2	243.0	297.1	253.6	277.7	285.7	276.8
May-99	188.9	189.8	191.6	202.4	243.0	215.8	257.0	313.0	263.5	301.4	304.7	301.8
Jun-99	182.8	183.7	185.5	195.9	243.8	209.1	250.9	304.1	255.5	290.0	288.6	291.7
Jul-99	188.9	189.8	191.6	202.4	257.7	215.9	258.5	313.5	263.4	289.2	280.7	291.5
Aug-99	188.9	189.8	191.6	202.4	256.7	215.9	258.7	312.6	262.8	281.6	266.9	282.2
Sep-99	182.8	183.7	185.5	195.9	240.8	208.9	249.2	300.8	254.1	263.5	243.4	260.2
Oct-99	188.9	189.8	191.6	202.4	241.9	216.1	256.9	312.6	263.2	274.4	257.1	267.1
Nov-99	182.8	183.7	185.5	195.9	231.7	209.8	249.2	306.9	256.6	273.9	269.3	270.6
Dec-99	188.9	189.8	191.6	202.4	244.0	217.0	258.7	320.7	267.7	292.0	299.8	298.7
Jan-00	188.9	189.8	191.6	202.4	248.6	217.0	259.4	321.0	270.1	299.8	304.8	301.9
Feb-00	176.7	177.6	179.3	189.3	236.2	203.0	243.4	300.3	253.4	284.3	285.1	282.4
Mar-00	188.9	189.8	191.6	202.4	256.5	217.0	261.1	321.0	270.8	303.9	304.8	301.9
Apr-00	182.8	183.7	185.5	195.9	250.2	210.0	254.0	310.6	262.1	293.9	294.8	292.0
May-00	188.9	189.8	191.6	202.4	258.4	217.0	263.2	321.0	270.8	303.1	303.4	301.4
Jun-00	182.8	183.7	185.2	195.9	242.7	209.9	252.8	309.0	261.9	288.3	286.4	287.2
Jul-00	188.9	189.8	191.6	202.4	241.6	216.1	257.7	317.8	269.8	294.2	292.8	295.0
Aug-00	188.9	189.7	191.2	202.4	234.9	215.0	255.0	315.0	268.8	286.2	278.7	286.0
Sep-00	182.8	183.7	185.5	195.9	226.9	207.3	247.0	304.5	259.8	273.4	263.2	273.0
Oct-00	188.9	189.8	191.6	202.4	231.0	214.0	255.4	314.2	269.2	272.0	253.0	267.3
Nov-00	182.8	183.7	185.5	195.9	222.1	207.6	247.8	307.6	261.9	266.6	252.0	259.5
Dec-00	188.9	189.8	191.6	202.4	227.5	215.2	256.9	320.9	270.8	284.5	279.1	276.6

Sub-Segment Alluvial Flows (monthly volume, ac-ft) (Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-01	188.9	189.8	191.6	202.4	225.8	215.7	257.6	321.0	270.8	293.3	300.4	297.6
Feb-01	170.6	171.4	173.1	182.8	205.5	195.3	233.5	289.9	244.6	271.9	275.3	272.7
Mar-01	188.9	189.8	191.6	202.4	231.0	216.6	259.2	321.0	270.8	303.9	304.8	301.9
Apr-01	182.8	183.7	185.5	195.9	226.0	209.9	252.0	310.6	262.1	294.1	294.9	292.2
May-01	188.9	189.8	191.6	202.4	242.0	217.0	262.0	320.9	270.8	302.6	302.5	301.2
Jun-01	182.8	183.7	185.3	195.9	232.6	209.7	252.3	307.3	261.9	278.8	266.4	275.1
Jul-01	188.8	189.5	191.2	202.4	232.5	215.5	257.0	311.8	269.6	271.1	243.2	260.0
Aug-01	188.8	189.2	191.2	202.4	227.3	214.1	254.0	307.9	268.4	260.1	224.3	242.1
Sep-01	182.8	182.9	185.0	195.9	215.3	206.0	242.9	294.5	259.0	243.9	204.6	219.7
Oct-01	188.9	189.8	191.5	202.4	218.2	212.1	248.2	301.5	267.5	248.0	207.4	217.5
Nov-01	182.8	183.7	185.5	195.9	210.2	205.2	240.6	292.6	260.0	242.4	209.0	210.4
Dec-01	188.9	189.8	191.6	202.4	218.8	212.2	250.0	305.8	270.2	256.9	228.5	221.9
Jan-02	188.9	189.8	191.6	202.4	219.1	212.5	251.0	308.6	270.8	261.7	237.1	225.5
Feb-02	170.6	171.4	173.1	182.8	198.7	192.2	227.6	281.0	244.6	242.2	223.7	208.7
Mar-02	188.9	189.8	191.6	202.4	222.4	213.0	253.1	314.4	270.8	276.0	262.0	240.6
Apr-02	182.8	183.7	185.4	195.9	214.7	206.2	245.3	304.4	262.1	268.6	255.6	235.8
May-02	188.9	189.7	191.5	202.4	219.3	212.7	251.6	309.5	270.8	264.8	237.4	226.5
Jun-02	182.8	183.7	185.4	195.9	212.1	205.1	242.3	296.1	261.8	247.6	212.5	206.3
Jul-02	188.9	189.6	191.4	202.4	218.0	210.4	248.8	302.8	269.3	246.7	202.1	198.8
Aug-02	188.8	188.5	190.5	202.4	214.0	208.6	245.1	298.3	267.7	237.6	186.2	183.1
Sep-02	182.8	183.7	185.5	195.9	207.8	200.5	236.6	286.9	258.1	228.8	179.3	172.1
Oct-02	188.9	189.8	191.6	202.4	215.2	206.4	244.9	296.1	266.5	233.6	181.3	171.0
Nov-02	149.5	150.3	151.7	160.2	170.0	163.3	194.2	233.6	211.5	180.9	137.2	127.9

Sediment Transport Capacity by Sub-Reach (tons/month)

	880	878	873	869	867	868	819	816	821	813	812
Inc. Length (ft)	2,180	1,715	5,270	1,032	2,615	696	2,353	5,657	2,903	1,378	627
Total Sed (tons)	1,114,398	1,014,397	970,610	806,145	870,066	615,726	597,878	547,001	388,284	363,510	700,714
Total L (mi)	5.0	4.6	4.3	3.3	3.1	2.6	2.5	2.0	0.9	0.4	0.1
Jan-95	0	0	0	0	0	0	0	0	0	0	0
Feb-95	252	364	168	448	420	84	0	0	0	0	0
Mar-95	961	1488	775	1519	1643	465	713	496	403	279	527
Apr-95	1320	1890	960	1890	2130	660	1050	810	690	600	1140
May-95	5704	8246	5332	6231	7161	3658	4433	4216	3100	3069	5828
Jun-95	41130	26670	37050	26610	28710	24870	26910	26970	18480	18180	36360
Jul-95	34689	24087	29481	21390	23095	20212	22227	22568	15593	15531	30814
Aug-95	13175	14136	11005	7626	7719	6696	5735	5425	3689	3844	7223
Sep-95	2820	4200	1860	3600	4350	1350	2610	2220	1890	1650	3300
Oct-95	8928	10788	6882	6603	7285	4278	5208	5115	3503	3658	6696
Nov-95	1890	3030	1560	3120	4020	1230	1680	1410	1170	960	2100
Dec-95	1240	2015	1054	2108	2418	744	806	341	310	248	372
Jan-96	496	806	434	1023	1116	310	124	62	62	31	124
Feb-96	319	522	261	667	667	174	0	0	0	0	0
Mar-96	496	806	403	930	992	279	186	0	0	0	0
Apr-96	1530	2400	1200	2490	3000	930	1440	600	540	390	780
May-96	403	465	155	465	496	155	310	186	186	155	341
Jun-96	4200	5910	2910	5340	6450	1980	3600	3390	2610	2370	4650
Jul-96	3131	4836	2418	4743	5704	1736	3069	2759	2294	1953	3937
Aug-96	868	1302	465	1054	1116	341	775	589	527	434	806
Sep-96	2640	3960	1560	2940	3480	1110	2430	2040	1770	1500	3000
Oct-96	3658	5239	2325	4433	5518	1798	3937	3813	2945	2883	5642
Nov-96	750	1050	420	900	930	270	780	660	540	450	870
Dec-96	248	0	0	186	62	0	0	0	0	0	0

Sediment Transport Capacity by Sub-Reach (tons/month)

	880	878	873	869	867	868	819	816	821	813	812
Jan-97	217	62	0	186	93	0	0	0	0	0	0
Feb-97	280	448	84	336	252	56	0	0	0	0	0
Mar-97	279	465	248	620	620	155	0	0	0	0	0
Apr-97	930	1410	660	1350	1470	450	840	570	480	360	660
May-97	2325	3720	1953	3596	4309	1364	2790	2325	1984	1674	3348
Jun-97	1890	2910	1380	2670	3060	900	1440	1230	990	810	1560
Jul-97	7409	9362	5642	6386	7223	3813	4495	4464	3162	3131	5983
Aug-97	10726	12276	8215	7068	7595	6758	7750	8494	6076	6820	13733
Sep-97	63000	42180	56730	40500	43440	36930	35850	35010	23520	22140	43260
Oct-97	3441	5084	2573	4867	5921	1860	3317	2635	2232	1860	3627
Nov-97	4410	6360	3480	5490	6630	2100	3390	2550	2100	1680	3240
Dec-97	5425	7657	4619	6045	7037	2821	3782	3100	2449	2015	3875
Jan-98	5425	7781	4774	6076	7037	2883	3720	2573	2077	1581	2883
Feb-98	2520	4144	2212	4508	5376	1652	2100	532	420	140	140
Mar-98	4836	7130	4247	6014	7006	2790	3317	1798	1457	961	1519
Apr-98	27930	21510	25080	15870	15420	13080	10530	8490	5610	5070	8340
May-98	61876	41943	58714	36642	37014	31279	26598	24924	16461	15314	28551
Jun-98	13860	14310	11610	8280	8100	6930	5100	4200	3000	2640	4890
Jul-98	2139	3131	1426	2666	3038	930	1271	930	744	589	1116
Aug-98	82491	56668	75144	55986	61628	53103	47740	46872	32240	31403	62341
Sep-98	23190	19290	20100	14250	14550	12390	10800	10110	6720	6480	11820
Oct-98	1426	1829	558	1147	1271	372	465	279	248	217	434
Nov-98	5370	7350	4290	5820	6810	2790	3450	2400	1980	1620	2940
Dec-98	6913	9269	6200	6417	7223	3751	4154	3596	2728	2356	4650

Sediment Transport Capacity by Sub-Reach (tons/month)

	880	878	873	869	867	868	819	816	821	813	812
Jan-99	10199	12369	9114	7099	7533	5797	4650	3565	2697	2170	3999
Feb-99	4788	6888	4200	5516	6384	2744	3136	1680	1372	784	1260
Mar-99	5921	8277	5239	6324	7192	3596	3720	2356	1922	1209	1767
Apr-99	2040	3240	1650	3300	3870	1170	1410	390	300	180	240
May-99	79298	55273	77686	53506	58156	50809	49662	48546	34162	32829	64883
Jun-99	115650	87690	115200	74610	79920	69090	56280	55080	38040	35580	73590
Jul-99	38068	25730	32674	21390	21080	18042	14880	13175	8835	8339	14725
Aug-99	14384	14105	9703	7254	7626	6603	5735	4867	3379	3379	6200
Sep-99	18420	16770	15270	11190	11460	9870	8490	7590	5130	4980	9000
Oct-99	3224	4774	2201	4123	4743	1426	1860	1178	961	713	1240
Nov-99	6870	8910	5520	6210	7020	3750	3780	2460	2040	1320	2160
Dec-99	9827	12028	8463	6975	7471	5301	4526	3441	2635	1953	3007
Jan-00	12245	13733	10850	8432	8060	7161	5084	4836	3317	2976	5270
Feb-00	10933	12499	9570	7221	7076	5916	4408	4437	3074	2784	5481
Mar-00	10819	12772	9455	7471	7564	6324	4743	4805	3410	3472	6758
Apr-00	32340	23280	28680	19770	19410	16950	12270	12300	8430	8580	16290
May-00	17639	16709	15531	11160	11067	9827	8184	8060	5611	5487	10633
Jun-00	16590	15930	14430	10710	11130	9840	7770	7170	5010	4830	8790
Jul-00	1798	2449	868	1705	1860	558	1054	775	651	496	961
Aug-00	6758	8153	4216	5952	7006	2790	4030	3782	2852	2666	5146
Sep-00	21810	18120	16590	12030	12330	10500	11700	11280	7530	7350	13590
Oct-00	14198	14353	10509	7595	7595	6386	5921	5146	3441	3441	6448
Nov-00	2670	4230	2100	4110	4830	1470	1860	480	390	300	480
Dec-00	4588	6851	4185	5983	7037	2914	3472	1953	1767	1178	2077

Sediment Transport Capacity by Sub-Reach (tons/month)

	880	878	873	869	867	868	819	816	821	813	812
Jan-01	4712	6944	4154	6045	7068	3100	3596	3007	2604	1953	3038
Feb-01	8456	10584	7532	6300	6776	4956	4004	3892	2884	2548	4564
Mar-01	7440	9796	6510	6603	7285	4154	3937	3658	2883	2387	4774
Apr-01	9510	11640	8070	6780	7230	5220	4260	4110	3030	2940	5820
May-01	24490	20243	21638	14880	14942	12710	10819	11129	7657	7843	15655
Jun-01	35970	24660	31710	21930	22380	19080	15150	14760	10020	9990	19440
Jul-01	3193	4619	2139	4061	4774	1457	2356	1922	1612	1302	2542
Aug-01	3968	5022	2139	4185	5332	1767	3813	3689	2914	2914	5797
Sep-01	3690	5070	2370	4590	5460	1680	2550	2070	1740	1470	2820
Oct-01	4929	6076	2635	5053	5983	1798	3193	2728	2201	1829	3565
Nov-01	840	1170	300	690	690	210	120	0	0	0	0
Dec-01	6417	8804	5704	6355	7192	3596	4061	3131	2480	2015	3844
Jan-02	2604	4309	2325	4588	5394	1643	2170	806	682	465	806
Feb-02	2492	4116	2240	4228	4872	1484	2380	1400	1316	952	1792
Mar-02	3999	6231	3627	5766	6913	2449	3255	1984	1829	1271	2263
Apr-02	6330	8580	5430	6060	6900	3300	4050	3300	2670	2280	4290
May-02	837	1147	434	961	1054	310	248	62	186	31	62
Jun-02	2700	4140	2010	3750	4410	1350	2220	1830	1590	1320	2550
Jul-02	15190	14973	11377	8494	8618	7254	7440	6851	4495	4495	8184
Aug-02	6231	7874	4061	5921	7006	2759	4216	4030	2945	2790	5456
Sep-02	12120	12570	7620	6690	7230	5250	5760	5850	3900	4020	7410
Oct-02	14570	14663	11191	7936	7967	6851	6138	5518	3720	3813	7037
Nov-02	2640	4170	2160	4080	4860	1500	2130	1170	990	840	1590
Dec-02	837	1364	713	1457	1705	527	465	0	0	0	0

Sediment Load Difference by Sub-Reach (tons/month)

	878	873	869	867	868	819	816	821	813	812
Inc. Length (ft)	2,180	1,715	5,270	1,032	2,615	696	2,353	5,657	2,903	1,378
Total Sed (tons)	100,001	43,787	164,465	-63,921	254,340	17,848	50,877	158,717	24,774	-337,204
Total L (mi)	5.0	4.6	4.3	3.3	3.1	2.6	2.5	2.0	0.9	0.4
Jan-95	0	0	0	0	0	0	0	0	0	0
Feb-95	-112	196	-280	28	336	84	0	0	0	0
Mar-95	-527	713	-744	-124	1178	-248	217	93	124	-248
Apr-95	-570	930	-930	-240	1470	-390	240	120	90	-540
May-95	-2542	2914	-899	-930	3503	-775	217	1116	31	-2759
Jun-95	14460	-10380	10440	-2100	3840	-2040	-60	8490	300	-18180
Jul-95	10602	-5394	8091	-1705	2883	-2015	-341	6975	62	-15283
Aug-95	-961	3131	3379	-93	1023	961	310	1736	-155	-3379
Sep-95	-1380	2340	-1740	-750	3000	-1260	390	330	240	-1650
Oct-95	-1860	3906	279	-682	3007	-930	93	1612	-155	-3038
Nov-95	-1140	1470	-1560	-900	2790	-450	270	240	210	-1140
Dec-95	-775	961	-1054	-310	1674	-62	465	31	62	-124
Jan-96	-310	372	-589	-93	806	186	62	0	31	-93
Feb-96	-203	261	-406	0	493	174	0	0	0	0
Mar-96	-310	403	-527	-62	713	93	186	0	0	0
Apr-96	-870	1200	-1290	-510	2070	-510	840	60	150	-390
May-96	-62	310	-310	-31	341	-155	124	0	31	-186
Jun-96	-1710	3000	-2430	-1110	4470	-1620	210	780	240	-2280
Jul-96	-1705	2418	-2325	-961	3968	-1333	310	465	341	-1984
Aug-96	-434	837	-589	-62	775	-434	186	62	93	-372
Sep-96	-1320	2400	-1380	-540	2370	-1320	390	270	270	-1500
Oct-96	-1581	2914	-2108	-1085	3720	-2139	124	868	62	-2759
Nov-96	-300	630	-480	-30	660	-510	120	120	90	-420
Dec-96	248	0	-186	124	62	0	0	0	0	0

Sediment Load Difference by Sub-Reach (tons/month)

	878	873	869	867	868	819	816	821	813	812
Jan-97	155	62	-186	93	93	0	0	0	0	0
Feb-97	-168	364	-252	84	196	56	0	0	0	0
Mar-97	-186	217	-372	0	465	155	0	0	0	0
Apr-97	-480	750	-690	-120	1020	-390	270	90	120	-300
May-97	-1395	1767	-1643	-713	2945	-1426	465	341	310	-1674
Jun-97	-1020	1530	-1290	-390	2160	-540	210	240	180	-750
Jul-97	-1953	3720	-744	-837	3410	-682	31	1302	31	-2852
Aug-97	-1550	4061	1147	-527	837	-992	-744	2418	-744	-6913
Sep-97	20820	-14550	16230	-2940	6510	1080	840	11490	1380	-21120
Oct-97	-1643	2511	-2294	-1054	4061	-1457	682	403	372	-1767
Nov-97	-1950	2880	-2010	-1140	4530	-1290	840	450	420	-1560
Dec-97	-2232	3038	-1426	-992	4216	-961	682	651	434	-1860
Jan-98	-2356	3007	-1302	-961	4154	-837	1147	496	496	-1302
Feb-98	-1624	1932	-2296	-868	3724	-448	1568	112	280	0
Mar-98	-2294	2883	-1767	-992	4216	-527	1519	341	496	-558
Apr-98	6420	-3570	9210	450	2340	2550	2040	2880	540	-3270
May-98	19933	-16771	22072	-372	5735	4681	1674	8463	1147	-13237
Jun-98	-450	2700	3330	180	1170	1830	900	1200	360	-2250
Jul-98	-992	1705	-1240	-372	2108	-341	341	186	155	-527
Aug-98	25823	-18476	19158	-5642	8525	5363	868	14632	837	-30938
Sep-98	3900	-810	5850	-300	2160	1590	690	3390	240	-5340
Oct-98	-403	1271	-589	-124	899	-93	186	31	31	-217
Nov-98	-1980	3060	-1530	-990	4020	-660	1050	420	360	-1320
Dec-98	-2356	3069	-217	-806	3472	-403	558	868	372	-2294

Sediment Load Difference by Sub-Reach (tons/month)

	878	873	869	867	868	819	816	821	813	812
Jan-99	-2170	3255	2015	-434	1736	1147	1085	868	527	-1829
Feb-99	-2100	2688	-1316	-868	3640	-392	1456	308	588	-476
Mar-99	-2356	3038	-1085	-868	3596	-124	1364	434	713	-558
Apr-99	-1200	1590	-1650	-570	2700	-240	1020	90	120	-60
May-99	24025	-22413	24180	-4650	7347	1147	1116	14384	1333	-32054
Jun-99	27960	-27510	40590	-5310	10830	12810	1200	17040	2460	-38010
Jul-99	12338	-6944	11284	310	3038	3162	1705	4340	496	-6386
Aug-99	279	4402	2449	-372	1023	868	868	1488	0	-2821
Sep-99	1650	1500	4080	-270	1590	1380	900	2460	150	-4020
Oct-99	-1550	2573	-1922	-620	3317	-434	682	217	248	-527
Nov-99	-2040	3390	-690	-810	3270	-30	1320	420	720	-840
Dec-99	-2201	3565	1488	-496	2170	775	1085	806	682	-1054
Jan-00	-1488	2883	2418	372	899	2077	248	1519	341	-2294
Feb-00	-1566	2929	2349	145	1160	1508	-29	1363	290	-2697
Mar-00	-1953	3317	1984	-93	1240	1581	-62	1395	-62	-3286
Apr-00	9060	-5400	8910	360	2460	4680	-30	3870	-150	-7710
May-00	930	1178	4371	93	1240	1643	124	2449	124	-5146
Jun-00	660	1500	3720	-420	1290	2070	600	2160	180	-3960
Jul-00	-651	1581	-837	-155	1302	-496	279	124	155	-465
Aug-00	-1395	3937	-1736	-1054	4216	-1240	248	930	186	-2480
Sep-00	3690	1530	4560	-300	1830	-1200	420	3750	180	-6240
Oct-00	-155	3844	2914	0	1209	465	775	1705	0	-3007
Nov-00	-1560	2130	-2010	-720	3360	-390	1380	90	90	-180
Dec-00	-2263	2666	-1798	-1054	4123	-558	1519	186	589	-899

Sediment Load Difference by Sub-Reach (tons/month)

	878	873	869	867	868	819	816	821	813	812
Jan-01	-2232	2790	-1891	-1023	3968	-496	589	403	651	-1085
Feb-01	-2128	3052	1232	-476	1820	952	112	1008	336	-2016
Mar-01	-2356	3286	-93	-682	3131	217	279	775	496	-2387
Apr-01	-2130	3570	1290	-450	2010	960	150	1080	90	-2880
May-01	4247	-1395	6758	-62	2232	1891	-310	3472	-186	-7812
Jun-01	11310	-7050	9780	-450	3300	3930	390	4740	30	-9450
Jul-01	-1426	2480	-1922	-713	3317	-899	434	310	310	-1240
Aug-01	-1054	2883	-2046	-1147	3565	-2046	124	775	0	-2883
Sep-01	-1380	2700	-2220	-870	3780	-870	480	330	270	-1350
Oct-01	-1147	3441	-2418	-930	4185	-1395	465	527	372	-1736
Nov-01	-330	870	-390	0	480	90	120	0	0	0
Dec-01	-2387	3100	-651	-837	3596	-465	930	651	465	-1829
Jan-02	-1705	1984	-2263	-806	3751	-527	1364	124	217	-341
Feb-02	-1624	1876	-1988	-644	3388	-896	980	84	364	-840
Mar-02	-2232	2604	-2139	-1147	4464	-806	1271	155	558	-992
Apr-02	-2250	3150	-630	-840	3600	-750	750	630	390	-2010
May-02	-310	713	-527	-93	744	62	186	-124	155	-31
Jun-02	-1440	2130	-1740	-660	3060	-870	390	240	270	-1230
Jul-02	217	3596	2883	-124	1364	-186	589	2356	0	-3689
Aug-02	-1643	3813	-1860	-1085	4247	-1457	186	1085	155	-2666
Sep-02	-450	4950	930	-540	1980	-510	-90	1950	-120	-3390
Oct-02	-93	3472	3255	-31	1116	713	620	1798	-93	-3224
Nov-02	-1530	2010	-1920	-780	3360	-630	960	180	150	-750
Dec-02	-527	651	-744	-248	1178	62	465	0	0	0

Cherry Creek Sedimentation Study
Reservoir to Pine Lane
Sediment Budget

March 2011

Prepared for:

Southeast Metropolitan Stormwater Authority
76 Inverness Drive
Englewood, Colorado

Submitted to:

Ms. Molly Trujillo, P.E.

Prepared by:

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CHERRY CREEK SEDIMENTATION STUDY

SEDIMENT BUDGET

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Sub-Segment Stream Flows (monthly volume - ac-ft)

(Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Inc. Length (ft)	2180	1715	5270	1032	2615	696	2353	5657	2903	1378	627	70
Total Q (ac-ft)	76368	74567	72358	67681	65061	65718	70918	61328	62880	59287	56555	52232
Total L (mi)	5.0	4.6	4.3	3.3	3.1	2.6	2.5	2.0	0.9	0.4	0.1	0.0
Jan-95	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0
Feb-95	41.9	36.0	29.8	41.3	30.9	22.3	1.7	0.0	0.0	0.0	0.0	0.0
Mar-95	136.7	130.9	124.9	122.8	108.4	102.4	104.9	74.9	74.9	64.4	55.8	45.0
Apr-95	198.1	171.7	159.6	157.8	144.0	144.5	155.6	129.5	135.2	134.0	127.2	109.6
May-95	640.1	653.3	664.9	619.3	610.8	632.0	758.7	672.2	706.7	687.2	658.7	594.9
Jun-95	2176.2	2160.6	2159.9	2005.2	1976.2	2010.1	2461.2	2315.1	2373.0	2328.7	2277.3	2146.1
Jul-95	1921.1	1867.9	1848.0	1724.0	1707.8	1746.3	2158.7	2043.8	2108.7	2076.5	2027.7	1903.8
Aug-95	1060.2	1047.4	1027.9	928.5	900.2	914.4	969.6	877.7	902.4	876.1	842.6	772.5
Sep-95	419.6	380.5	314.1	303.0	294.5	303.0	389.7	358.6	376.8	375.5	365.7	336.9
Oct-95	836.5	809.3	777.1	722.9	684.3	695.3	917.0	827.8	851.8	826.2	773.5	687.0
Nov-95	280.4	275.0	264.4	261.8	272.6	271.6	253.1	224.7	230.8	221.0	232.9	239.8
Dec-95	176.3	175.7	172.9	172.2	157.9	159.9	115.2	54.1	57.2	52.3	41.5	28.9
Jan-96	71.1	69.5	71.5	83.7	74.0	67.9	18.4	9.9	9.9	8.4	12.0	11.4
Feb-96	50.8	49.2	46.8	57.9	47.2	38.6	0.0	0.0	0.0	0.0	0.0	0.0
Mar-96	72.8	69.4	65.2	74.8	64.8	58.9	25.1	0.0	0.0	0.0	0.0	0.0
Apr-96	228.2	216.6	199.4	207.9	203.1	208.3	214.0	94.7	104.8	88.6	86.3	77.7
May-96	56.7	41.0	23.5	37.5	32.0	33.0	45.0	28.5	34.7	34.9	35.0	29.0
Jun-96	545.2	515.2	471.7	451.6	436.5	440.8	582.9	550.8	562.2	545.0	529.2	497.0
Jul-96	449.2	423.6	392.7	385.6	373.5	375.9	443.2	429.6	437.9	432.3	422.9	402.8
Aug-96	125.0	113.5	75.6	84.4	73.1	73.5	112.0	93.1	98.3	94.2	87.8	76.9
Sep-96	393.6	359.5	263.8	245.4	235.7	244.3	364.6	330.4	348.9	344.1	333.8	305.6
Oct-96	490.7	455.4	379.6	358.6	361.7	384.5	634.3	605.8	647.0	646.6	635.3	587.2
Nov-96	110.9	93.7	68.2	75.5	63.6	62.5	114.8	104.3	107.5	102.0	97.0	88.3
Dec-96	35.5	0.0	0.0	15.3	5.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0

Sub-Segment Stream Flows (monthly volume - ac-ft)

(Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-97	32.4	4.3	0.0	15.9	5.1	1.9	0.0	0.0	0.0	0.0	0.0	0.0
Feb-97	45.7	44.5	16.3	30.0	19.2	13.7	0.0	0.0	0.0	0.0	0.0	0.0
Mar-97	40.9	40.8	39.1	49.7	40.0	31.9	0.0	0.0	0.0	0.0	0.0	0.0
Apr-97	136.7	127.7	109.3	112.1	98.7	96.9	127.0	92.4	94.4	81.8	72.5	59.0
May-97	336.9	326.8	316.6	292.6	282.6	293.0	405.9	361.8	382.0	372.7	359.0	324.2
Jun-97	283.0	263.0	232.0	224.6	206.9	203.1	215.8	195.8	195.8	184.5	173.3	158.3
Jul-97	749.1	722.8	689.0	659.6	642.0	648.3	770.4	716.3	730.0	706.4	680.3	639.6
Aug-97	934.3	899.8	864.6	861.3	881.2	919.1	1158.7	1150.6	1213.7	1254.4	1262.0	1213.5
Sep-97	2860.5	2826.6	2781.6	2596.0	2532.2	2541.9	2909.0	2708.4	2724.9	2617.2	2526.7	2394.6
Oct-97	472.8	445.3	415.7	393.8	387.6	398.1	493.9	410.8	429.1	409.2	389.8	349.2
Nov-97	559.9	546.7	524.5	481.7	458.2	460.2	539.3	411.5	415.6	383.1	359.3	324.7
Dec-97	621.4	617.2	611.2	569.3	539.6	539.5	603.1	483.2	483.1	446.5	416.1	375.4
Jan-98	622.6	624.0	623.1	577.4	546.1	546.1	588.1	398.4	398.3	351.9	311.6	258.4
Feb-98	401.8	400.8	398.8	404.3	389.8	389.8	335.8	93.3	91.6	31.5	17.6	9.0
Mar-98	581.6	581.6	581.0	561.8	533.8	533.8	496.3	280.7	280.2	210.4	162.3	112.0
Apr-98	1715.7	1710.5	1711.6	1470.3	1374.7	1379.3	1415.9	1173.9	1181.2	1065.8	960.2	819.5
May-98	2767.9	2767.7	2784.6	2390.1	2249.4	2256.7	2396.7	2166.3	2177.8	2057.6	1938.0	1749.5
Jun-98	1115.8	1101.4	1082.1	993.9	944.1	950.9	924.4	694.6	704.7	607.8	557.6	416.7
Jul-98	308.2	275.1	230.7	216.9	199.5	197.8	184.6	142.5	144.6	132.7	119.5	99.6
Aug-98	3331.1	3267.3	3224.6	3113.0	3075.2	3097.8	3375.3	3166.4	3203.8	3158.8	3081.3	2958.7
Sep-98	1531.2	1520.5	1501.2	1377.6	1329.3	1337.0	1437.4	1299.7	1313.2	1237.9	1178.3	1073.2
Oct-98	203.6	158.9	88.8	92.5	82.7	82.2	66.9	43.1	47.2	47.5	46.2	39.6
Nov-98	629.2	612.6	595.1	563.4	539.5	544.0	553.3	385.4	392.5	371.3	328.1	285.2
Dec-98	717.4	717.2	729.3	668.2	640.2	641.9	690.9	566.7	571.8	526.4	509.7	466.8

Sub-Segment Stream Flows (monthly volumes - ac-ft)

(Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-99	905.9	907.3	918.5	869.3	837.2	837.2	806.9	564.4	563.2	480.3	429.9	390.8
Feb-99	613.5	614.2	613.3	589.5	564.7	564.7	533.4	289.9	289.5	193.1	150.2	114.0
Mar-99	654.7	655.3	657.5	644.1	625.1	625.1	585.9	366.4	366.4	269.1	189.8	118.7
Apr-99	302.0	293.9	277.4	276.1	261.3	260.6	211.1	61.9	61.4	38.2	28.2	19.6
May-99	3247.3	3222.6	3288.5	3026.3	2967.9	3016.6	3453.7	3233.9	3311.6	3244.4	3155.8	2952.3
Jun-99	4229.0	4233.6	4238.5	3799.4	3679.2	3698.8	3788.0	3558.3	3589.7	3468.4	3470.1	3429.8
Jul-99	2033.8	2004.5	1965.5	1725.1	1619.1	1633.6	1703.0	1489.7	1512.5	1416.6	1314.9	1140.8
Aug-99	1118.7	1044.4	953.4	900.5	893.8	906.1	969.7	780.7	801.9	760.9	705.7	643.4
Sep-99	1328.3	1305.7	1274.7	1190.5	1155.0	1169.0	1248.2	1099.2	1121.1	1054.0	1004.8	906.5
Oct-99	455.8	418.0	359.2	334.6	309.6	308.9	270.8	182.1	185.1	159.9	134.8	100.9
Nov-99	730.2	714.2	693.0	672.7	652.4	655.2	631.9	397.7	401.9	303.0	239.1	192.5
Dec-99	886.3	883.8	879.1	839.3	785.6	793.3	775.5	539.3	539.3	430.9	323.1	165.0
Jan-00	1013.4	1014.9	1020.5	986.1	923.9	950.5	904.3	779.0	779.0	667.4	587.8	498.6
Feb-00	985.8	985.7	985.4	934.1	852.5	882.7	827.7	764.6	776.0	668.8	662.2	663.6
Mar-00	938.8	939.2	939.2	915.8	852.0	883.6	831.1	772.3	817.6	782.4	779.7	780.7
Apr-00	1877.2	1864.8	1853.7	1677.2	1572.9	1606.5	1549.0	1458.1	1498.6	1472.1	1423.0	1397.9
May-00	1267.6	1255.8	1262.1	1166.1	1111.4	1145.1	1195.8	1115.6	1155.8	1097.8	1086.8	1060.7
Jun-00	1246.3	1236.8	1232.3	1161.2	1135.6	1167.7	1184.9	1063.0	1102.6	1034.3	991.0	917.2
Jul-00	258.0	213.2	141.9	139.0	122.1	120.3	152.4	122.8	122.8	112.2	101.9	87.4
Aug-00	709.3	648.7	577.6	547.0	529.6	536.2	657.5	600.4	613.6	594.4	572.3	529.8
Sep-00	1474.0	1420.2	1338.9	1243.9	1205.5	1213.8	1506.3	1387.4	1402.5	1338.6	1278.5	1189.9
Oct-00	1110.7	1064.4	1000.3	926.1	888.5	888.5	989.3	829.0	828.9	779.1	737.7	677.9
Nov-00	398.2	381.4	354.4	343.2	326.1	326.1	276.7	78.7	78.3	66.0	52.6	40.5
Dec-00	562.8	564.8	575.9	558.0	542.0	547.8	527.9	302.8	339.4	261.6	224.5	197.8

Sub-Segment Stream Flows (monthly volumes - ac-ft)

(Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-01	572.0	570.4	572.6	572.9	563.4	569.7	557.5	468.3	527.9	430.5	327.0	181.6
Feb-01	860.9	864.8	872.5	838.5	809.5	810.1	755.0	690.7	740.6	632.6	558.7	452.2
Mar-01	749.6	750.3	751.8	724.2	684.0	684.0	634.8	576.9	621.1	529.4	524.6	526.0
Apr-01	886.0	882.2	872.5	840.7	802.0	802.0	744.6	677.7	716.5	684.7	682.6	682.7
May-01	1551.7	1545.2	1537.7	1386.7	1324.3	1330.8	1410.5	1348.8	1388.2	1363.8	1363.1	1361.5
Jun-01	2004.6	1983.5	1968.4	1786.0	1708.4	1722.1	1754.3	1624.4	1657.6	1614.9	1577.5	1517.5
Jul-01	454.0	403.3	346.9	330.2	313.3	313.5	340.8	300.7	305.8	288.9	272.7	248.3
Aug-01	515.4	440.4	345.8	338.3	348.8	378.1	607.4	585.1	636.1	652.8	653.0	610.6
Sep-01	502.8	456.6	399.2	384.7	368.5	372.3	383.5	334.2	344.3	332.8	314.6	284.4
Oct-01	586.8	513.9	425.9	410.5	390.5	387.9	472.5	423.2	423.2	402.1	382.7	357.2
Nov-01	126.6	105.6	48.3	58.3	47.4	43.6	16.1	0.0	0.0	0.0	0.0	0.0
Dec-01	687.2	688.7	694.2	652.5	625.0	626.3	663.9	491.4	493.5	448.3	414.8	376.1
Jan-02	376.4	378.2	379.1	371.5	353.2	353.2	315.5	126.3	130.9	100.4	85.2	68.1
Feb-02	396.4	399.2	400.5	379.5	353.3	355.1	382.5	240.0	281.6	231.6	211.9	181.9
Mar-02	518.5	522.8	527.8	505.5	492.3	493.4	482.5	310.4	347.4	282.6	243.6	212.3
Apr-02	695.7	692.3	686.2	625.5	597.3	606.3	697.9	538.7	584.1	522.4	481.7	420.3
May-02	119.5	100.9	71.9	78.8	68.0	64.4	33.9	10.5	35.2	8.2	5.7	2.5
Jun-02	402.1	375.1	336.8	314.9	298.4	301.9	332.1	295.8	314.9	298.6	284.3	257.0
Jul-02	1157.2	1114.3	1048.2	990.6	959.3	959.3	1132.7	1013.8	1017.4	971.4	931.7	876.4
Aug-02	675.1	630.3	564.8	545.1	528.3	530.9	700.7	642.3	650.5	628.7	608.6	572.6
Sep-02	1027.3	956.9	841.5	817.2	801.1	805.4	992.5	943.1	953.9	922.2	897.4	855.5
Oct-02	1128.0	1089.7	1038.2	949.2	916.7	926.3	1011.6	895.2	910.0	863.8	819.0	748.2
Nov-02	391.1	378.2	360.4	343.0	328.8	335.4	317.7	185.8	195.8	189.1	178.1	154.9
Dec-02	118.9	118.4	113.5	119.2	110.8	110.8	68.2	0.0	0.0	0.0	0.0	0.0

Sub-Segment Alluvial Flows (monthly volume, ac-ft) (Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-95	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.2	0.2
Feb-95	184.8	185.7	187.5	198.0	209.5	202.3	239.8	287.0	262.5	221.8	168.6	152.5
Mar-95	170.6	171.4	173.1	182.8	193.5	187.4	220.4	264.2	243.2	208.5	165.4	143.7
Apr-95	188.9	189.8	191.6	202.4	214.8	207.8	243.0	292.2	270.1	235.4	194.2	164.3
May-95	182.8	183.7	185.5	195.9	209.5	201.2	234.4	282.9	261.8	233.4	200.4	167.0
Jun-95	188.9	189.8	191.6	202.4	219.9	208.1	242.7	294.2	270.8	249.4	223.4	186.3
Jul-95	182.8	183.7	185.5	195.9	221.6	201.4	236.7	286.0	261.7	246.0	222.7	191.1
Aug-95	188.9	189.8	191.6	202.4	232.7	207.8	245.4	294.4	269.2	251.2	221.7	195.7
Sep-95	188.9	189.8	191.3	202.4	228.9	207.3	242.8	290.5	267.6	242.6	204.9	184.3
Oct-95	182.8	183.7	185.4	195.9	219.2	200.3	233.2	278.5	257.8	230.3	190.1	171.4
Nov-95	188.9	189.8	191.6	202.4	226.3	207.4	241.7	287.2	266.3	238.8	198.7	177.3
Dec-95	182.8	183.7	185.5	195.9	216.7	201.6	234.6	277.4	258.4	232.9	198.4	173.7
Jan-96	188.9	189.8	191.6	202.4	222.5	209.1	243.6	286.6	267.9	243.8	213.1	184.2
Feb-96	188.9	189.8	191.6	202.4	220.7	210.1	244.2	284.5	268.7	242.2	210.8	182.6
Mar-96	176.7	177.6	179.3	189.3	205.0	197.3	228.5	264.8	252.0	226.9	198.8	171.4
Apr-96	188.9	189.8	191.6	202.4	217.7	211.2	244.0	283.5	269.7	245.4	218.5	187.3
May-96	182.8	183.6	185.4	195.9	209.1	204.3	235.5	275.6	261.0	240.7	216.1	184.7
Jun-96	188.7	189.1	191.2	202.4	214.1	210.5	241.0	282.5	269.2	245.9	217.9	188.2
Jul-96	182.7	183.5	185.3	195.9	207.1	202.8	231.8	272.5	259.3	240.7	216.3	186.8
Aug-96	187.9	187.9	190.7	202.4	212.0	208.1	236.7	279.9	265.9	248.8	224.9	194.6
Sep-96	187.5	186.3	190.4	202.4	210.1	206.4	233.7	275.8	263.6	239.5	206.1	182.5
Oct-96	181.6	179.4	184.7	195.9	202.8	198.5	223.9	264.6	253.3	228.8	194.2	172.0
Nov-96	188.8	185.4	191.1	202.4	209.8	204.6	229.6	272.1	260.9	237.5	204.1	179.3
Dec-96	182.8	181.0	185.0	195.9	203.3	198.0	220.6	261.9	252.5	230.2	199.9	174.1
Jan-95	188.9	189.2	191.0	202.4	210.4	205.0	226.6	269.5	261.3	239.8	212.3	183.4

Sub-Segment Alluvial Flows (monthly volume, ac-ft)

(Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-97	188.9	189.8	191.5	202.4	210.7	205.4	225.5	268.4	261.6	241.7	217.6	187.2
Feb-97	170.6	171.4	173.1	182.8	190.6	186.1	204.1	241.4	236.6	219.9	200.5	172.5
Mar-97	188.9	189.8	191.6	202.4	211.2	206.3	225.7	266.4	261.8	245.2	226.2	195.0
Apr-97	182.8	183.7	185.4	195.9	205.3	199.6	218.0	258.0	253.0	240.6	225.7	195.2
May-97	188.8	189.4	191.4	202.4	212.8	206.0	224.5	266.1	260.5	250.3	236.9	206.8
Jun-97	182.7	183.6	185.4	195.9	206.1	198.5	216.8	255.3	250.5	238.3	220.1	196.4
Jul-97	187.9	188.0	190.6	202.4	211.2	203.8	222.1	259.7	256.3	236.6	207.3	189.8
Aug-97	188.9	189.8	191.6	202.4	217.5	202.7	224.9	259.6	253.9	237.4	204.9	189.9
Sep-97	182.8	183.7	185.5	195.9	213.6	195.8	219.3	250.7	244.0	227.2	192.7	179.5
Oct-97	188.9	189.8	191.6	202.4	219.4	202.3	227.7	259.6	251.1	234.2	200.6	184.3
Nov-97	182.8	183.7	185.5	195.9	212.9	196.3	221.9	253.2	243.1	230.5	204.5	184.4
Dec-97	188.9	189.8	191.6	202.4	222.9	203.7	231.6	264.9	251.7	244.2	225.2	201.0
Jan-98	188.9	189.8	191.6	202.4	223.1	204.6	233.3	269.5	252.4	249.8	233.9	207.8
Feb-98	170.6	171.4	173.1	182.8	200.9	185.6	212.1	247.9	228.9	230.0	217.1	192.5
Mar-98	188.9	189.8	191.6	202.4	226.6	206.2	236.7	279.3	254.2	264.2	260.2	228.9
Apr-98	182.8	183.7	185.5	195.9	231.8	200.5	232.1	275.2	246.8	267.4	276.1	247.9
May-98	188.9	189.8	191.6	202.4	251.5	208.5	242.0	289.2	255.6	285.9	303.3	282.1
Jun-98	182.8	183.7	185.4	195.9	246.0	202.9	233.7	281.1	247.3	275.9	288.1	278.7
Jul-98	188.9	189.8	191.6	202.4	247.6	209.8	240.4	288.0	254.3	274.4	275.9	277.2
Aug-98	188.9	189.8	191.6	202.4	249.3	209.9	243.2	288.7	253.2	272.0	268.9	276.2
Sep-98	182.8	183.7	185.4	195.9	235.0	203.4	234.5	276.7	244.4	253.3	241.9	254.3
Oct-98	188.9	189.8	191.6	202.4	236.1	210.5	242.2	286.1	252.5	258.3	245.8	257.4
Nov-98	182.8	183.7	185.5	195.9	227.9	204.5	235.8	278.5	245.4	249.9	238.8	248.1
Dec-98	188.9	189.8	191.6	202.4	233.4	212.3	244.9	290.9	255.2	262.4	254.1	258.3

Sub-Segment Alluvial Flows (monthly volume, ac-ft) (Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-99	188.9	189.8	191.6	202.4	232.5	213.3	246.7	295.7	257.0	269.7	263.7	262.2
Feb-99	170.6	171.4	173.1	182.8	208.9	193.4	224.1	271.3	233.8	250.6	249.9	243.7
Mar-99	188.9	189.8	191.6	202.4	229.0	214.7	249.2	304.1	260.5	281.7	285.7	275.5
Apr-99	182.8	183.7	185.5	195.9	224.1	208.2	243.0	297.1	253.6	277.7	285.7	276.8
May-99	188.9	189.8	191.6	202.4	243.0	215.8	257.0	313.0	263.5	301.4	304.7	301.8
Jun-99	182.8	183.7	185.5	195.9	243.8	209.1	250.9	304.1	255.5	290.0	288.6	291.7
Jul-99	188.9	189.8	191.6	202.4	257.7	215.9	258.5	313.5	263.4	289.2	280.7	291.5
Aug-99	188.9	189.8	191.6	202.4	256.7	215.9	258.7	312.6	262.8	281.6	266.9	282.2
Sep-99	182.8	183.7	185.5	195.9	240.8	208.9	249.2	300.8	254.1	263.5	243.4	260.2
Oct-99	188.9	189.8	191.6	202.4	241.9	216.1	256.9	312.6	263.2	274.4	257.1	267.1
Nov-99	182.8	183.7	185.5	195.9	231.7	209.8	249.2	306.9	256.6	273.9	269.3	270.6
Dec-99	188.9	189.8	191.6	202.4	244.0	217.0	258.7	320.7	267.7	292.0	299.8	298.7
Jan-00	188.9	189.8	191.6	202.4	248.6	217.0	259.4	321.0	270.1	299.8	304.8	301.9
Feb-00	176.7	177.6	179.3	189.3	236.2	203.0	243.4	300.3	253.4	284.3	285.1	282.4
Mar-00	188.9	189.8	191.6	202.4	256.5	217.0	261.1	321.0	270.8	303.9	304.8	301.9
Apr-00	182.8	183.7	185.5	195.9	250.2	210.0	254.0	310.6	262.1	293.9	294.8	292.0
May-00	188.9	189.8	191.6	202.4	258.4	217.0	263.2	321.0	270.8	303.1	303.4	301.4
Jun-00	182.8	183.7	185.2	195.9	242.7	209.9	252.8	309.0	261.9	288.3	286.4	287.2
Jul-00	188.9	189.8	191.6	202.4	241.6	216.1	257.7	317.8	269.8	294.2	292.8	295.0
Aug-00	188.9	189.7	191.2	202.4	234.9	215.0	255.0	315.0	268.8	286.2	278.7	286.0
Sep-00	182.8	183.7	185.5	195.9	226.9	207.3	247.0	304.5	259.8	273.4	263.2	273.0
Oct-00	188.9	189.8	191.6	202.4	231.0	214.0	255.4	314.2	269.2	272.0	253.0	267.3
Nov-00	182.8	183.7	185.5	195.9	222.1	207.6	247.8	307.6	261.9	266.6	252.0	259.5
Dec-00	188.9	189.8	191.6	202.4	227.5	215.2	256.9	320.9	270.8	284.5	279.1	276.6

Sub-Segment Alluvial Flows (monthly volume, ac-ft) (Third period of CCBWQA model)

	880	878	873	869	867	868	819	816	821	813	812	811
Jan-01	188.9	189.8	191.6	202.4	225.8	215.7	257.6	321.0	270.8	293.3	300.4	297.6
Feb-01	170.6	171.4	173.1	182.8	205.5	195.3	233.5	289.9	244.6	271.9	275.3	272.7
Mar-01	188.9	189.8	191.6	202.4	231.0	216.6	259.2	321.0	270.8	303.9	304.8	301.9
Apr-01	182.8	183.7	185.5	195.9	226.0	209.9	252.0	310.6	262.1	294.1	294.9	292.2
May-01	188.9	189.8	191.6	202.4	242.0	217.0	262.0	320.9	270.8	302.6	302.5	301.2
Jun-01	182.8	183.7	185.3	195.9	232.6	209.7	252.3	307.3	261.9	278.8	266.4	275.1
Jul-01	188.8	189.5	191.2	202.4	232.5	215.5	257.0	311.8	269.6	271.1	243.2	260.0
Aug-01	188.8	189.2	191.2	202.4	227.3	214.1	254.0	307.9	268.4	260.1	224.3	242.1
Sep-01	182.8	182.9	185.0	195.9	215.3	206.0	242.9	294.5	259.0	243.9	204.6	219.7
Oct-01	188.9	189.8	191.5	202.4	218.2	212.1	248.2	301.5	267.5	248.0	207.4	217.5
Nov-01	182.8	183.7	185.5	195.9	210.2	205.2	240.6	292.6	260.0	242.4	209.0	210.4
Dec-01	188.9	189.8	191.6	202.4	218.8	212.2	250.0	305.8	270.2	256.9	228.5	221.9
Jan-02	188.9	189.8	191.6	202.4	219.1	212.5	251.0	308.6	270.8	261.7	237.1	225.5
Feb-02	170.6	171.4	173.1	182.8	198.7	192.2	227.6	281.0	244.6	242.2	223.7	208.7
Mar-02	188.9	189.8	191.6	202.4	222.4	213.0	253.1	314.4	270.8	276.0	262.0	240.6
Apr-02	182.8	183.7	185.4	195.9	214.7	206.2	245.3	304.4	262.1	268.6	255.6	235.8
May-02	188.9	189.7	191.5	202.4	219.3	212.7	251.6	309.5	270.8	264.8	237.4	226.5
Jun-02	182.8	183.7	185.4	195.9	212.1	205.1	242.3	296.1	261.8	247.6	212.5	206.3
Jul-02	188.9	189.6	191.4	202.4	218.0	210.4	248.8	302.8	269.3	246.7	202.1	198.8
Aug-02	188.8	188.5	190.5	202.4	214.0	208.6	245.1	298.3	267.7	237.6	186.2	183.1
Sep-02	182.8	183.7	185.5	195.9	207.8	200.5	236.6	286.9	258.1	228.8	179.3	172.1
Oct-02	188.9	189.8	191.6	202.4	215.2	206.4	244.9	296.1	266.5	233.6	181.3	171.0
Nov-02	149.5	150.3	151.7	160.2	170.0	163.3	194.2	233.6	211.5	180.9	137.2	127.9

Sediment Transport Capacity by Sub-Reach (tons/month)

	880	878	873	869	867	868	819	816	821	813	812
Inc. Length (ft)	2,180	1,715	5,270	1,032	2,615	696	2,353	5,657	2,903	1,378	627
Total Sed (tons)	1,114,398	1,014,397	970,610	806,145	870,066	615,726	597,878	547,001	388,284	363,510	700,714
Total L (mi)	5.0	4.6	4.3	3.3	3.1	2.6	2.5	2.0	0.9	0.4	0.1
Jan-95	0	0	0	0	0	0	0	0	0	0	0
Feb-95	252	364	168	448	420	84	0	0	0	0	0
Mar-95	961	1488	775	1519	1643	465	713	496	403	279	527
Apr-95	1320	1890	960	1890	2130	660	1050	810	690	600	1140
May-95	5704	8246	5332	6231	7161	3658	4433	4216	3100	3069	5828
Jun-95	41130	26670	37050	26610	28710	24870	26910	26970	18480	18180	36360
Jul-95	34689	24087	29481	21390	23095	20212	22227	22568	15593	15531	30814
Aug-95	13175	14136	11005	7626	7719	6696	5735	5425	3689	3844	7223
Sep-95	2820	4200	1860	3600	4350	1350	2610	2220	1890	1650	3300
Oct-95	8928	10788	6882	6603	7285	4278	5208	5115	3503	3658	6696
Nov-95	1890	3030	1560	3120	4020	1230	1680	1410	1170	960	2100
Dec-95	1240	2015	1054	2108	2418	744	806	341	310	248	372
Jan-96	496	806	434	1023	1116	310	124	62	62	31	124
Feb-96	319	522	261	667	667	174	0	0	0	0	0
Mar-96	496	806	403	930	992	279	186	0	0	0	0
Apr-96	1530	2400	1200	2490	3000	930	1440	600	540	390	780
May-96	403	465	155	465	496	155	310	186	186	155	341
Jun-96	4200	5910	2910	5340	6450	1980	3600	3390	2610	2370	4650
Jul-96	3131	4836	2418	4743	5704	1736	3069	2759	2294	1953	3937
Aug-96	868	1302	465	1054	1116	341	775	589	527	434	806
Sep-96	2640	3960	1560	2940	3480	1110	2430	2040	1770	1500	3000
Oct-96	3658	5239	2325	4433	5518	1798	3937	3813	2945	2883	5642
Nov-96	750	1050	420	900	930	270	780	660	540	450	870
Dec-96	248	0	0	186	62	0	0	0	0	0	0

Sediment Transport Capacity by Sub-Reach (tons/month)

	880	878	873	869	867	868	819	816	821	813	812
Jan-97	217	62	0	186	93	0	0	0	0	0	0
Feb-97	280	448	84	336	252	56	0	0	0	0	0
Mar-97	279	465	248	620	620	155	0	0	0	0	0
Apr-97	930	1410	660	1350	1470	450	840	570	480	360	660
May-97	2325	3720	1953	3596	4309	1364	2790	2325	1984	1674	3348
Jun-97	1890	2910	1380	2670	3060	900	1440	1230	990	810	1560
Jul-97	7409	9362	5642	6386	7223	3813	4495	4464	3162	3131	5983
Aug-97	10726	12276	8215	7068	7595	6758	7750	8494	6076	6820	13733
Sep-97	63000	42180	56730	40500	43440	36930	35850	35010	23520	22140	43260
Oct-97	3441	5084	2573	4867	5921	1860	3317	2635	2232	1860	3627
Nov-97	4410	6360	3480	5490	6630	2100	3390	2550	2100	1680	3240
Dec-97	5425	7657	4619	6045	7037	2821	3782	3100	2449	2015	3875
Jan-98	5425	7781	4774	6076	7037	2883	3720	2573	2077	1581	2883
Feb-98	2520	4144	2212	4508	5376	1652	2100	532	420	140	140
Mar-98	4836	7130	4247	6014	7006	2790	3317	1798	1457	961	1519
Apr-98	27930	21510	25080	15870	15420	13080	10530	8490	5610	5070	8340
May-98	61876	41943	58714	36642	37014	31279	26598	24924	16461	15314	28551
Jun-98	13860	14310	11610	8280	8100	6930	5100	4200	3000	2640	4890
Jul-98	2139	3131	1426	2666	3038	930	1271	930	744	589	1116
Aug-98	82491	56668	75144	55986	61628	53103	47740	46872	32240	31403	62341
Sep-98	23190	19290	20100	14250	14550	12390	10800	10110	6720	6480	11820
Oct-98	1426	1829	558	1147	1271	372	465	279	248	217	434
Nov-98	5370	7350	4290	5820	6810	2790	3450	2400	1980	1620	2940
Dec-98	6913	9269	6200	6417	7223	3751	4154	3596	2728	2356	4650

Sediment Transport Capacity by Sub-Reach (tons/month)

	880	878	873	869	867	868	819	816	821	813	812
Jan-99	10199	12369	9114	7099	7533	5797	4650	3565	2697	2170	3999
Feb-99	4788	6888	4200	5516	6384	2744	3136	1680	1372	784	1260
Mar-99	5921	8277	5239	6324	7192	3596	3720	2356	1922	1209	1767
Apr-99	2040	3240	1650	3300	3870	1170	1410	390	300	180	240
May-99	79298	55273	77686	53506	58156	50809	49662	48546	34162	32829	64883
Jun-99	115650	87690	115200	74610	79920	69090	56280	55080	38040	35580	73590
Jul-99	38068	25730	32674	21390	21080	18042	14880	13175	8835	8339	14725
Aug-99	14384	14105	9703	7254	7626	6603	5735	4867	3379	3379	6200
Sep-99	18420	16770	15270	11190	11460	9870	8490	7590	5130	4980	9000
Oct-99	3224	4774	2201	4123	4743	1426	1860	1178	961	713	1240
Nov-99	6870	8910	5520	6210	7020	3750	3780	2460	2040	1320	2160
Dec-99	9827	12028	8463	6975	7471	5301	4526	3441	2635	1953	3007
Jan-00	12245	13733	10850	8432	8060	7161	5084	4836	3317	2976	5270
Feb-00	10933	12499	9570	7221	7076	5916	4408	4437	3074	2784	5481
Mar-00	10819	12772	9455	7471	7564	6324	4743	4805	3410	3472	6758
Apr-00	32340	23280	28680	19770	19410	16950	12270	12300	8430	8580	16290
May-00	17639	16709	15531	11160	11067	9827	8184	8060	5611	5487	10633
Jun-00	16590	15930	14430	10710	11130	9840	7770	7170	5010	4830	8790
Jul-00	1798	2449	868	1705	1860	558	1054	775	651	496	961
Aug-00	6758	8153	4216	5952	7006	2790	4030	3782	2852	2666	5146
Sep-00	21810	18120	16590	12030	12330	10500	11700	11280	7530	7350	13590
Oct-00	14198	14353	10509	7595	7595	6386	5921	5146	3441	3441	6448
Nov-00	2670	4230	2100	4110	4830	1470	1860	480	390	300	480
Dec-00	4588	6851	4185	5983	7037	2914	3472	1953	1767	1178	2077

Sediment Transport Capacity by Sub-Reach (tons/month)

	880	878	873	869	867	868	819	816	821	813	812
Jan-01	4712	6944	4154	6045	7068	3100	3596	3007	2604	1953	3038
Feb-01	8456	10584	7532	6300	6776	4956	4004	3892	2884	2548	4564
Mar-01	7440	9796	6510	6603	7285	4154	3937	3658	2883	2387	4774
Apr-01	9510	11640	8070	6780	7230	5220	4260	4110	3030	2940	5820
May-01	24490	20243	21638	14880	14942	12710	10819	11129	7657	7843	15655
Jun-01	35970	24660	31710	21930	22380	19080	15150	14760	10020	9990	19440
Jul-01	3193	4619	2139	4061	4774	1457	2356	1922	1612	1302	2542
Aug-01	3968	5022	2139	4185	5332	1767	3813	3689	2914	2914	5797
Sep-01	3690	5070	2370	4590	5460	1680	2550	2070	1740	1470	2820
Oct-01	4929	6076	2635	5053	5983	1798	3193	2728	2201	1829	3565
Nov-01	840	1170	300	690	690	210	120	0	0	0	0
Dec-01	6417	8804	5704	6355	7192	3596	4061	3131	2480	2015	3844
Jan-02	2604	4309	2325	4588	5394	1643	2170	806	682	465	806
Feb-02	2492	4116	2240	4228	4872	1484	2380	1400	1316	952	1792
Mar-02	3999	6231	3627	5766	6913	2449	3255	1984	1829	1271	2263
Apr-02	6330	8580	5430	6060	6900	3300	4050	3300	2670	2280	4290
May-02	837	1147	434	961	1054	310	248	62	186	31	62
Jun-02	2700	4140	2010	3750	4410	1350	2220	1830	1590	1320	2550
Jul-02	15190	14973	11377	8494	8618	7254	7440	6851	4495	4495	8184
Aug-02	6231	7874	4061	5921	7006	2759	4216	4030	2945	2790	5456
Sep-02	12120	12570	7620	6690	7230	5250	5760	5850	3900	4020	7410
Oct-02	14570	14663	11191	7936	7967	6851	6138	5518	3720	3813	7037
Nov-02	2640	4170	2160	4080	4860	1500	2130	1170	990	840	1590
Dec-02	837	1364	713	1457	1705	527	465	0	0	0	0

Sediment Load Difference by Sub-Reach (tons/month)

	878	873	869	867	868	819	816	821	813	812
Inc. Length (ft)	2,180	1,715	5,270	1,032	2,615	696	2,353	5,657	2,903	1,378
Total Sed (tons)	100,001	43,787	164,465	-63,921	254,340	17,848	50,877	158,717	24,774	-337,204
Total L (mi)	5.0	4.6	4.3	3.3	3.1	2.6	2.5	2.0	0.9	0.4
Jan-95	0	0	0	0	0	0	0	0	0	0
Feb-95	-112	196	-280	28	336	84	0	0	0	0
Mar-95	-527	713	-744	-124	1178	-248	217	93	124	-248
Apr-95	-570	930	-930	-240	1470	-390	240	120	90	-540
May-95	-2542	2914	-899	-930	3503	-775	217	1116	31	-2759
Jun-95	14460	-10380	10440	-2100	3840	-2040	-60	8490	300	-18180
Jul-95	10602	-5394	8091	-1705	2883	-2015	-341	6975	62	-15283
Aug-95	-961	3131	3379	-93	1023	961	310	1736	-155	-3379
Sep-95	-1380	2340	-1740	-750	3000	-1260	390	330	240	-1650
Oct-95	-1860	3906	279	-682	3007	-930	93	1612	-155	-3038
Nov-95	-1140	1470	-1560	-900	2790	-450	270	240	210	-1140
Dec-95	-775	961	-1054	-310	1674	-62	465	31	62	-124
Jan-96	-310	372	-589	-93	806	186	62	0	31	-93
Feb-96	-203	261	-406	0	493	174	0	0	0	0
Mar-96	-310	403	-527	-62	713	93	186	0	0	0
Apr-96	-870	1200	-1290	-510	2070	-510	840	60	150	-390
May-96	-62	310	-310	-31	341	-155	124	0	31	-186
Jun-96	-1710	3000	-2430	-1110	4470	-1620	210	780	240	-2280
Jul-96	-1705	2418	-2325	-961	3968	-1333	310	465	341	-1984
Aug-96	-434	837	-589	-62	775	-434	186	62	93	-372
Sep-96	-1320	2400	-1380	-540	2370	-1320	390	270	270	-1500
Oct-96	-1581	2914	-2108	-1085	3720	-2139	124	868	62	-2759
Nov-96	-300	630	-480	-30	660	-510	120	120	90	-420
Dec-96	248	0	-186	124	62	0	0	0	0	0

Sediment Load Difference by Sub-Reach (tons/month)

	878	873	869	867	868	819	816	821	813	812
Jan-97	155	62	-186	93	93	0	0	0	0	0
Feb-97	-168	364	-252	84	196	56	0	0	0	0
Mar-97	-186	217	-372	0	465	155	0	0	0	0
Apr-97	-480	750	-690	-120	1020	-390	270	90	120	-300
May-97	-1395	1767	-1643	-713	2945	-1426	465	341	310	-1674
Jun-97	-1020	1530	-1290	-390	2160	-540	210	240	180	-750
Jul-97	-1953	3720	-744	-837	3410	-682	31	1302	31	-2852
Aug-97	-1550	4061	1147	-527	837	-992	-744	2418	-744	-6913
Sep-97	20820	-14550	16230	-2940	6510	1080	840	11490	1380	-21120
Oct-97	-1643	2511	-2294	-1054	4061	-1457	682	403	372	-1767
Nov-97	-1950	2880	-2010	-1140	4530	-1290	840	450	420	-1560
Dec-97	-2232	3038	-1426	-992	4216	-961	682	651	434	-1860
Jan-98	-2356	3007	-1302	-961	4154	-837	1147	496	496	-1302
Feb-98	-1624	1932	-2296	-868	3724	-448	1568	112	280	0
Mar-98	-2294	2883	-1767	-992	4216	-527	1519	341	496	-558
Apr-98	6420	-3570	9210	450	2340	2550	2040	2880	540	-3270
May-98	19933	-16771	22072	-372	5735	4681	1674	8463	1147	-13237
Jun-98	-450	2700	3330	180	1170	1830	900	1200	360	-2250
Jul-98	-992	1705	-1240	-372	2108	-341	341	186	155	-527
Aug-98	25823	-18476	19158	-5642	8525	5363	868	14632	837	-30938
Sep-98	3900	-810	5850	-300	2160	1590	690	3390	240	-5340
Oct-98	-403	1271	-589	-124	899	-93	186	31	31	-217
Nov-98	-1980	3060	-1530	-990	4020	-660	1050	420	360	-1320
Dec-98	-2356	3069	-217	-806	3472	-403	558	868	372	-2294

Sediment Load Difference by Sub-Reach (tons/month)

	878	873	869	867	868	819	816	821	813	812
Jan-99	-2170	3255	2015	-434	1736	1147	1085	868	527	-1829
Feb-99	-2100	2688	-1316	-868	3640	-392	1456	308	588	-476
Mar-99	-2356	3038	-1085	-868	3596	-124	1364	434	713	-558
Apr-99	-1200	1590	-1650	-570	2700	-240	1020	90	120	-60
May-99	24025	-22413	24180	-4650	7347	1147	1116	14384	1333	-32054
Jun-99	27960	-27510	40590	-5310	10830	12810	1200	17040	2460	-38010
Jul-99	12338	-6944	11284	310	3038	3162	1705	4340	496	-6386
Aug-99	279	4402	2449	-372	1023	868	868	1488	0	-2821
Sep-99	1650	1500	4080	-270	1590	1380	900	2460	150	-4020
Oct-99	-1550	2573	-1922	-620	3317	-434	682	217	248	-527
Nov-99	-2040	3390	-690	-810	3270	-30	1320	420	720	-840
Dec-99	-2201	3565	1488	-496	2170	775	1085	806	682	-1054
Jan-00	-1488	2883	2418	372	899	2077	248	1519	341	-2294
Feb-00	-1566	2929	2349	145	1160	1508	-29	1363	290	-2697
Mar-00	-1953	3317	1984	-93	1240	1581	-62	1395	-62	-3286
Apr-00	9060	-5400	8910	360	2460	4680	-30	3870	-150	-7710
May-00	930	1178	4371	93	1240	1643	124	2449	124	-5146
Jun-00	660	1500	3720	-420	1290	2070	600	2160	180	-3960
Jul-00	-651	1581	-837	-155	1302	-496	279	124	155	-465
Aug-00	-1395	3937	-1736	-1054	4216	-1240	248	930	186	-2480
Sep-00	3690	1530	4560	-300	1830	-1200	420	3750	180	-6240
Oct-00	-155	3844	2914	0	1209	465	775	1705	0	-3007
Nov-00	-1560	2130	-2010	-720	3360	-390	1380	90	90	-180
Dec-00	-2263	2666	-1798	-1054	4123	-558	1519	186	589	-899

Sediment Load Difference by Sub-Reach (tons/month)

	878	873	869	867	868	819	816	821	813	812
Jan-01	-2232	2790	-1891	-1023	3968	-496	589	403	651	-1085
Feb-01	-2128	3052	1232	-476	1820	952	112	1008	336	-2016
Mar-01	-2356	3286	-93	-682	3131	217	279	775	496	-2387
Apr-01	-2130	3570	1290	-450	2010	960	150	1080	90	-2880
May-01	4247	-1395	6758	-62	2232	1891	-310	3472	-186	-7812
Jun-01	11310	-7050	9780	-450	3300	3930	390	4740	30	-9450
Jul-01	-1426	2480	-1922	-713	3317	-899	434	310	310	-1240
Aug-01	-1054	2883	-2046	-1147	3565	-2046	124	775	0	-2883
Sep-01	-1380	2700	-2220	-870	3780	-870	480	330	270	-1350
Oct-01	-1147	3441	-2418	-930	4185	-1395	465	527	372	-1736
Nov-01	-330	870	-390	0	480	90	120	0	0	0
Dec-01	-2387	3100	-651	-837	3596	-465	930	651	465	-1829
Jan-02	-1705	1984	-2263	-806	3751	-527	1364	124	217	-341
Feb-02	-1624	1876	-1988	-644	3388	-896	980	84	364	-840
Mar-02	-2232	2604	-2139	-1147	4464	-806	1271	155	558	-992
Apr-02	-2250	3150	-630	-840	3600	-750	750	630	390	-2010
May-02	-310	713	-527	-93	744	62	186	-124	155	-31
Jun-02	-1440	2130	-1740	-660	3060	-870	390	240	270	-1230
Jul-02	217	3596	2883	-124	1364	-186	589	2356	0	-3689
Aug-02	-1643	3813	-1860	-1085	4247	-1457	186	1085	155	-2666
Sep-02	-450	4950	930	-540	1980	-510	-90	1950	-120	-3390
Oct-02	-93	3472	3255	-31	1116	713	620	1798	-93	-3224
Nov-02	-1530	2010	-1920	-780	3360	-630	960	180	150	-750
Dec-02	-527	651	-744	-248	1178	62	465	0	0	0

Cherry Creek Sedimentation Study
Reservoir to Pine Lane
Scenario Development and Evaluation

May 2011

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CHERRY CREEK SEDIMENTATION STUDY

SCENARIO DEVELOPMENT AND EVALUATION

Table of Contents

INTRODUCTION

This paper discusses possible scenarios for channel design that are based on an assessment of equilibrium analysis of the Cherry Creek for a study reach that extends from the confluence of Baldwin Gulch (Pine Lane bridge over the Cherry Creek) to the Piney Creek confluence (southern boundary of Cherry Creek State Park). The analysis uses channel geometry, mean bed material size, and stream gradient data that were compiled for the sedimentation study (see preceding study papers). In this paper, new scaled 2-year flows for sub-reaches of the study reach are developed. The development of these discharges is discussed in some detail and is admittedly approximate but provide sufficient detail for this level of analysis. The hydrology of the Cherry Creek is complex due to importation of a substantial amount of water into the Cherry Creek basin to meet the growth in water demand by developing communities within the basin. The Cherry Creek alluvial aquifers play an important role in recycling the portion of this imported water permitted under Colorado water law.

The losing nature of the Cherry Creek through the study reach is challenging for channel design because it diminishes that capacity of stream to transport the natural supply of sediment that is delivered to the stream by the watershed. The sediment budget (see study paper "Sediment Budget") found that most sub-reaches in the study reach will have sedimentation. However, maintaining sediment transport is desirable because of the maintenance associated with removing sediment deposits and the increased risks due to loss of channel capacity.

The upper sub-reach is estimated to be stable and so serves as the proxy reach for the evaluation of sediment equilibrium in the lower reaches. A method of equilibrium analysis is used which scales the discharge, material size, stream gradient and sediment transport relative to proxy reach. Three scenarios were developed based on the objective of transporting a uniform sediment load through the study reach. Stream reaches with a uniform transport rate through all of the sub-reaches will not be as prone to scour and deposition. The recommended scenario comports with current channel reclamation projects that have already been constructed but does not convey the entire basin sediment load. As a result, sediment deposition appears to be likely near the Arapahoe / Douglas County line (sub-reach 873) further analysis will be required to determine the most likely locations for deposition.

DESIGN FLOWS

The long-term hydrology of the Cherry Creek in the sedimentation study reach (Pine Lane to the Reservoir) is that of a losing reach, according to models that take into consideration water supply operations. It is likely that water diversion from the alluvial aquifer affects more frequent flood hydrology and channel forming discharges. Three hydrology studies are reviewed: the SMWSA Master Plan, the Major Drainageway Planning Study, and the CCBWQA phosphorus model.

ANALYSIS OF SMWSA MASTER PLAN

In 2007, the South Metro Water Supply Authority published its master plan for water supply development. SMWSA is an umbrella for 13 water providers, most of which are within the Cherry Creek basin. More than 80% of the SMWSA water supply is used within the Cherry Creek basin. Future storage of renewable water supplies by all of the SMWSA water providers occurs at the new Rueter-Hess reservoir, which is also within the Cherry Creek basin.

Figure 1 (below) from the SMWSA Master Plan shows the breakdown of water supplies over the planning horizon. Table 1 provides the same information as the graph and also back casts to the year 2000.

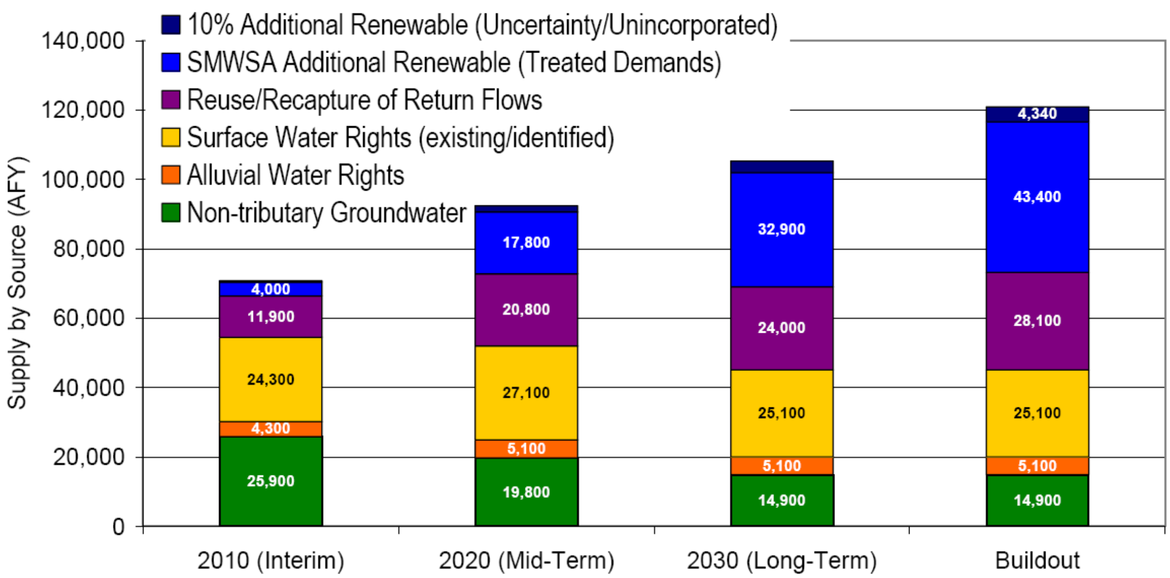

Figure 2-3 Projected Sources of Supply, Aggregated for all 12 SMWSA Water Providers

Figure 1. Taken from SMWSA Master Plan 2007

Table 1. SMWSA Water Sources over planning horizon

Year	Renewable Supply	Surface Supply	Renewable Buffer	Ground Water	Recap / Return	Alluvial (water rights)	Total
2000	0	500	0	42220	3000	3500	49220
2010	4000	24300	400	25900	11900	4300	70800
2020	17800	27100	1780	19800	20800	5100	92380
2030	32900	25100	3290	14900	24000	5100	105290
Buildout	43400	25100	4340	14900	28100	5100	120940

Most of the water supply for the SMWSA water providers comes from imported sources. SMWSA's goal is to shift from a heavy dependence on non-renewable groundwater to renewable water supplies by acquiring surface water rights in other basins and transporting this supply to the SMWSA service area and then to each service provider. This will require the development of existing water rights (called surface supply), then acquiring and developing new water rights (called renewable supply). This will permit ground water use to decline. To account for uncertainty in this process, the master plan includes a renewable buffer that is equal to 10% of the estimated required renewable supply.

A second source of water supply for SMWSA water providers comes from the recapture of flows or return flows. These flows will largely be recovered through alluvial wells. Also, most of the surface water rights on Cherry Creek are diverted through alluvial wells.

So, water supply for SMWSA water providers can be aggregated into two classes: imported supplies (renewable, surface, and groundwater), and alluvial (recapture / return and alluvial water rights). I estimate that on an annual basis about 44% of the total supply will be returned (assuming that 42% of the supply is for domestic use and 58% is for irrigation, with 10% consumption of domestic water and 90% consumption of irrigation). Table 2 provides an estimate of the un-diverted alluvial flow (both flow in the alluvial aquifers and in surface streams), where the un-diverted alluvial flow is equal to 44% of the total supply minus the diverted alluvial flow. These data are shown graphically in Figure 2.

Table 2. Estimate of Un-Diverted Alluvial Flows within SMWSA

Year	Total	Diverted Alluvial	Imported Flows	Un-Diverted Alluvial
2000	49220	6500	42720	14960
2010	70800	16200	54600	14669
2020	92380	25900	66480	14378
2030	105290	29100	76190	16806
Buildout	120940	33200	87740	19530

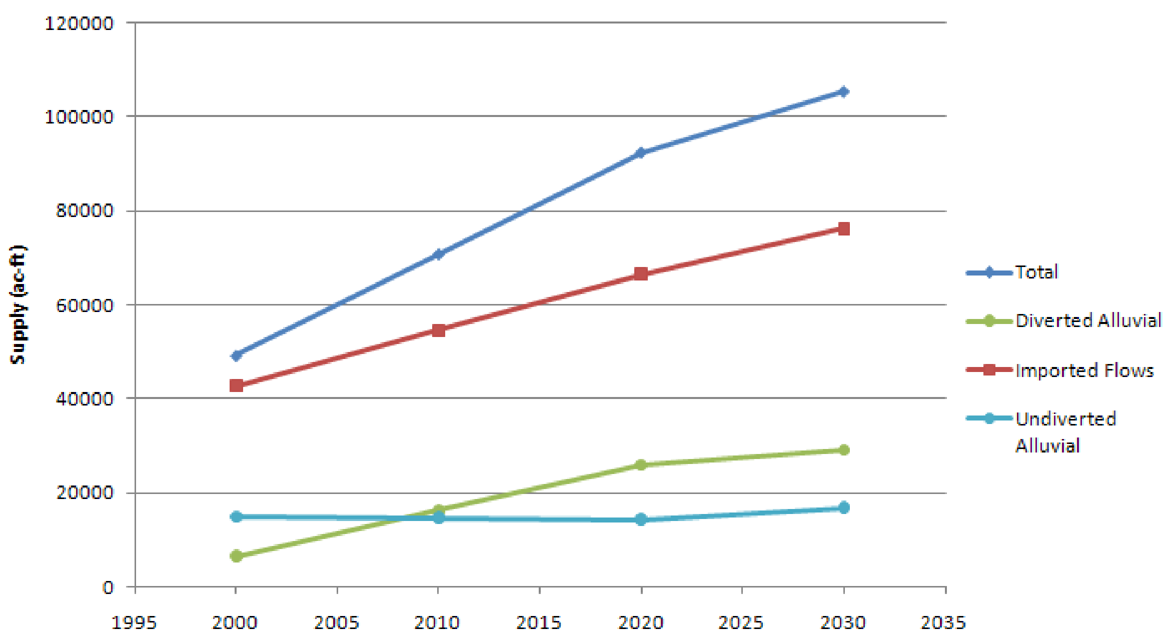

Figure 2. SMWSA Master Plan Water Supply Breakdown

In 2000, 82% of the SMWSA water providers were associated with the Cherry Creek basin. Using sub-reach 880 in the CCBWQA model (Parker, CO) as a point of reference the SMWSA master plan estimates that 12,300 ac-ft of un-diverted alluvial flow occurred at this point in the Cherry Creek. This compares with 11,700 ac-ft estimated by the CCBWQA model. In addition, the CCBWQA model estimates a reach flow loss of 2,500 ac-ft compared to SMWSA estimate of 5,300 ac-ft.

Recovery of flows will increase steadily, which will increase the total diverted alluvial flow in the Cherry Creek. In 2000, only about 6.1% of the total supply was recovered. SMWSA estimates that in 2010, 16.8% was recovered and that by 2020 22.5% will be recovered, which will be close to the maximum expected recovery that will be achieved at build out (23.2%). The result is that un-diverted alluvial flows remain essentially unchanged even as water supply is dramatically increased to the Cherry Creek basin. Of all of the sources of water supply for water providers in SMWSA, recovered flows are probably one of the least difficult to acquire administratively and the least costly to deliver.

ANALYSIS OF MAJOR DRAINAGEWAY MASTER PLAN

The "Cherry Creek Major Drainageway Planning Study" was prepared in 2002 and provides an estimate of the flood hydrology for existing and future conditions in the basin. This hydrology deals directly with the main effect of rural to urban land use change, which is the increase in impervious area and the resulting increase in runoff volume. This is a condition that is not addressed by the SMWSA master plan for the reason that stormwater runoff is considered a minor and unreliable source of water. This may not be entirely true. From 1985 to 2010, basin imperviousness has increased for 13% to 23% and will continue to increase at the rate of 1% for every 11,600 housing units built in the basin. Runoff from these impervious areas ultimately connects to the Cherry Creek, where it may be diverted for water supply as long as overall basin yield from Cherry Creek tends to maintain the historical average.

Urban runoff enters the Cherry Creek via storm drainage outfalls and tributary drainageways. It appears that alluvial pumping very quickly captures minor runoff. So CCBWQA estimates of base flow, which comport with SMWSA planning, indicate that the "Cherry Creek Major Drainageway Planning Study" probably over estimates frequent floods such as the 2-year.

Estimates of less frequent floods are intended to be conservative and are intended to provide a prudent means of delineating flood hazards. All of the jurisdictions in the Cherry Creek carefully administer floodplain regulations and development standards that should ensure that the future floods are less severe than are predicted by the planning study. Tables 3 and 4 summarize flood hydrology data from the "Cherry Creek Major Drainageway Planning Study".

Table 3. Peak Flow Summary - Sedimentation Study Reach / Existing Conditions

	EXISTING CONDITIONS (CFS)					
Sub-Rch	Q002	Q005	Q010	Q025	Q050	Q100
880	1555	4441	8100	16039	24040	39785
878	1564	4454	8115	16072	24058	39835
873	1552	4423	8087	16000	23968	39636
869	1557	4431	8092	16028	23975	39622
867	1563	4438	8102	16056	23980	39630
868	1562	4430	8095	16042	23948	39557
819	1791	5021	8954	17866	27045	43625
816	1764	4980	8915	17772	26832	43272
821	1759	4971	8906	17751	26777	43170
813	1767	4984	8921	17795	26814	43213
812	1769	4986	8921	17798	26812	43217
811	1769	4986	8921	17798	26811	43217

Table 4. Peak Flow Summary - Sedimentation Study Reach / Future Conditions

	FUTURE CONDITIONS (CFS)					
Sub-Rch	Q002	Q005	Q010	Q025	Q050	Q100
880	3294	7000	10939	19599	28168	43246
878	3341	7097	11026	19705	28303	43338
873	3330	7121	11033	19702	28238	43215
869	3347	7170	11083	19762	28272	43263
867	3361	7218	11128	19824	28310	43301
868	3360	7221	11136	19820	28287	43244
819	3949	8389	12825	22573	32353	48250
816	3882	8298	12731	22409	32042	47891
821	3894	8324	12784	22485	32036	47864
813	3915	8356	12829	22570	32100	47897
812	3919	8361	12836	22590	32097	47876
811	3919	8361	12836	22590	32095	47872

One approach to using the planning study flood hydrology would be to scale the existing 2-year flood peak for sub-reach 880 by the flow volume ratios (sub-reach volume divided by sub-reach 880 volume) as computed by the CCBWQA model (Table 5). Using this approach, the 2-year existing and future conditions would be as shown in Table 6.

Table 5. Sub-Reach Flow Scaling following based on volume (CCBWQA model)

Sub-Reach	880	878	873	869	867	868
Volume (ac-ft)	76,368	74,567	72,358	67,681	65,061	65,718
Flow Scaling	100.0%	97.6%	94.7%	88.6%	85.2%	86.1%
Sub-Reach	819	816	821	813	812	811
Volume (ac-ft)	70,918	61,328	62,880	59,287	56,555	52,232
Flow Scaling	92.9%	80.3%	82.3%	77.6%	74.1%	68.4%

Table 6. "Cherry Creek Major Drainageway Planning Study" Scaled 2-year flows

	Scaling	Existing Conditions			Future Conditions		
Sub-Rch	Factor	Original	Scaled	Ratio	Original	Scaled	Ratio
880	100.0%	1555	1555	100.0%	3294	3294	100.0%
878	97.6%	1564	1518	97.0%	3341	3215	96.2%
873	94.7%	1552	1473	94.9%	3330	3119	93.7%
869	88.6%	1557	1378	88.5%	3347	2918	87.2%
867	85.2%	1563	1325	84.8%	3361	2806	83.5%
868	86.1%	1562	1339	85.7%	3360	2836	84.4%
819	92.9%	1791	1445	80.7%	3949	3060	77.5%
816	80.3%	1764	1249	70.8%	3882	2645	68.1%
821	82.3%	1759	1280	72.8%	3894	2711	69.6%
813	77.6%	1767	1207	68.3%	3915	2556	65.3%
812	74.1%	1769	1152	65.1%	3919	2441	62.3%
811	68.4%	1769	1064	60.1%	3919	2253	57.5%

CCBWQA DOMINANT DISCHARGE

The dominant discharge for a stream reach is the product of the probability of a stream discharge multiplied by the sediment load in the reach. This probability approach places a higher weighting on frequent stream flows and lower weighting of rare stream flows. The discharge associated with the maximum weighted sediment loading is referred to as the dominant discharge. This method was used to identify the dominant discharge in the sub-reaches of the study reach over the eight year CCBWQA model simulation. Figure 3 shows the calculation results graphically.

Table 7. Sub-Reach dominant discharges (CCBWQA model)

Sub-Reach	**880**	**878**	**873**	**869**	**867**	**868**
Dominant Q (ac-ft/mo)	**1080**	**880**	**960**	**550**	**500**	**800**
Sub-Reach	**819**	**816**	**821**	**813**	**812**	**811**
Dominant Q (ac-ft/mo)	**550**	**550**	**500**	**600**	**500**	**n/c**

The weighting of more frequent sediment loads follows a normal pattern, which rises steadily to a peak value. While there is a distinct peak in weighted sediment loads for each sub-reach, the less frequent sediment loads don't decline and can reach values that equal or exceed the first peak. This may be a product of the short period of simulation or the complex way that water is routed and diverted from the Cherry Creek.

RECOMMENDED FLOWS

While scaling of flows based on volume is admittedly a very approximate approach it has the advantage of comporting to major drainageway planning and to the losing nature of reach as shown in the CCBWQA model and SMWSA master planning. In the long run, we recommend that the UDSWM model that was used for major drainageway planning be converted to EPA-SWMM. In this way, additional modeling elements found in the CCBWQA analysis could be included. EPA-SWMM has similar routines to those developed for the CCBWQA model (for example, alluvial groundwater flow simulation), so the model conversion could draw on data and calibration work already conducted by CCBWQA.

For the time being, using scaled 2-year existing-conditions flows from the major drainageway planning study is recommended (green highlighted column in Table 6). Use of future flows is not recommended because the SMWSA planning does not show a future increase in un-diverted alluvial flows.

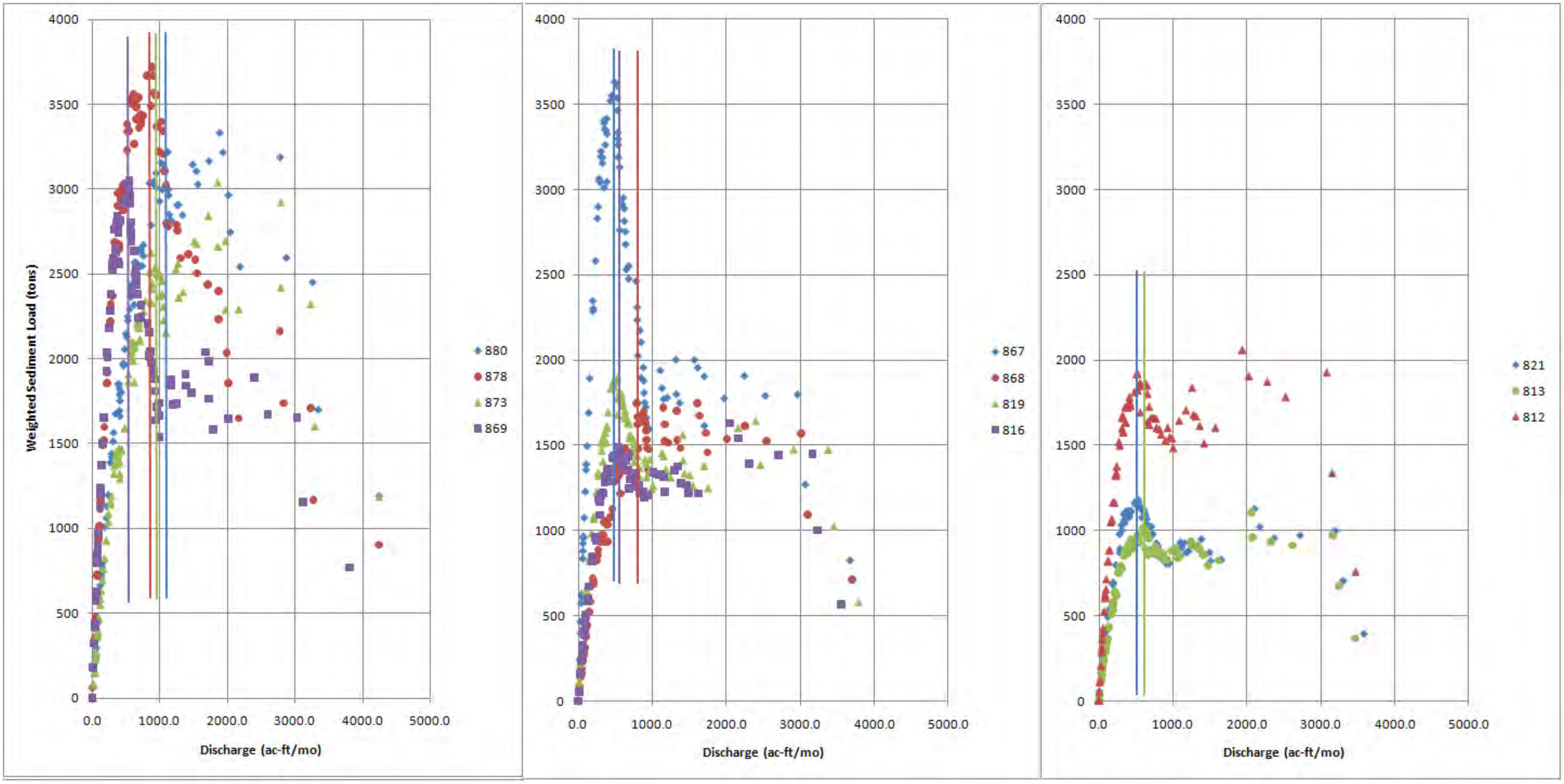

Figure 3 Shows plots of dominant discharge calculation as computed by sub-reach for the CCBWQA simulation. The vertical lines show the approximate location of the first peak in weighted sediment loading, i.e. the dominant discharge for the sub-reach (ac-ft/month). The vertical axis is the probability weighted sediment transport in tons.

CHANNEL DESIGN SCENARIOS

In most streams, water discharge and sediment load gradually increase. In response, channel size tends to increase and channel gradient may slightly decrease. In streams with heavy flow diversion, sediment transport capacity is quickly lost as discharge is lost. This results in sediment deposition and a decrease in channel size. Deposition tends to be a chronic problem and sediment will gradually diminish channel capacity over many years. This will necessitate periodic removal of sediment from the channel. Therefore, it is desirable to maintain sediment transport capacity, if possible, by countering the loss of discharge with increased stream power.

Three scenarios are evaluated here with the objective of maximizing the transport of sediment. The first scenario looks at minimal improvement of existing channel conditions; the second scenario looks at channel improvements similar to the type of stream reclamation projects currently being constructed in the reach; and the third scenario mimics the form of a stable reach of the Cherry Creek. The scenarios are not mutually exclusive but could be combined as needed to take best advantage of opportunities for channel improvement on the Cherry Creek.

EQUILIBRIUM INDEX METHOD

The equilibrium index method is based on fundamental scaling relationships for basic stream cross section properties (i.e., material size, stream discharge, sediment transport and stream gradient) that are widely used in geomorphology, stream assessment and channel restoration design. The method uses Griffith's (2003) derivation of Leopold and Maddock's (1953) empirical equations for stream scaling (see Appendix B). Sediment transport is added in the form of a power function equation that is based on the calibrated Engelund-Hansen equation that was developed for the Cherry Creek.

The resulting equation is referred to as the equilibrium index, I_E, where:

$$I_E = \frac{Q_r^{\,h}\, S_r}{G_{br}\, d_r^{\,g}}$$

What's the difference between Qr and Gbr?

Q_r is the dimensionless steam discharge;
S_r is the dimensionless steam gradient;
G_{br} is the dimensionless steam discharge; and,
d_r is the dimensionless mean sediment size
h and g are scaling exponents that are derived from hydraulic and sediment transport formulas
Note: The subscript "r" refers to the ratio of reach variable to proxy reach variable.

The spreadsheet computes uniform flow in a channel section that is defined by a depth versus topwidth rating. Sediment transport is computed for the active, un-vegetated portion of the channel and the vegetated portions of the active channel and overbanks. The stream discharges are the selected design discharges, the material property is the average sediment size, and reach gradients are taken from topographic maps.

When the equilibrium index is near 1.0 then the stream conditions are balanced between the stream's power (numerator) and the work needed for sediment transport (denominator). The equilibrium equation cannot be solved directly since the each variable interacts with the others. The solution is obtained by trial and error. In the spread sheet, variables that can potentially change have yellow cells, while cells that are computed are shown in light purple and scaling variables are shown in blue. The final results of each scenario calculation are provided in Appendix A.

Reach 880 is downstream of Pine Lane

SELECTED PROXY REACH

The most upstream sub-reach 880 was found to be a stable stream reach of the Cherry Creek. This reach was used as the upstream boundary for the sediment budget analysis. Sub-reach 880 characteristics (geometry, mean sediment size, and stream gradient) that were used for sediment budget analysis were also used as proxy reach characteristics.

higher or lower capacity ?

SCENARIO #1

This scenario develops a uniform rate of sediment transport with minimal modification to the existing stream channel. Uniform sediment transport conditions were obtained by adjusting the stream grade and the stream active channel width until sediment transport capacity equaled that of the upstream proxy reach. The largest difference in sediment transport capacity existing at sub-reach 869 ("17 Mile House"reach), which is an improved reach of the Cherry Creek (completed in 2006), and the two downstream sub-reaches that are above the Happy Canyon Creek confluence (stream reaches managed by the Parker/Jordan Metro District).

It is expected that sub-reach channel gradients would adjust over time to regain transport capacity. Existing sub-reach gradients vary from 0.192% (the as-built profile for sub-reach 869) to 0.40% near Arapahoe Road. The adjusted gradient was computed to be 0.395%. As a result, the active channel width was calculated varies between about 18 feet to 50 feet.

The main problem with this scenario is the low width/depth ratios for the active channel. When a sand bed channel is relatively narrow, there is a strong potential for low-flow incisement. This has been a chronic problem for reaches of the Cherry Creek since the increase base flow that began in the early 1990's. A second problem is the irregularity of active channel width and floodplain width. This may be a secondary cause of low-flow incisement during larger flows because narrow stream reaches have higher active channel velocities.

This scenario shows that it is possible to carry the total sediment load through the lower reaches of the study reach. The reach geometry adjustments appear logical with stream generally increasing in width in the downstream direction. However, the change in width is very irregular due and is strongly influence by encroachment into the floodplain. The un-vegetated active channel width for sub-reach 812 (at Caley Avenue) is exceptionally narrow. During a large flood this sub-reach has would also have significant contraction scour.

SCENARIO #2

This scenario assumes that sub-reach channels below 17 Mile House will continue to be improved following guidance provided by major drainageway planning. As an approximation, scenario #2 assumes that these channel improvements will generally follow the form of the 17-Mile House stream reclamation (based on the project as-built plans).

The grade of the channel in sub-reach 869 was adjusted to match proxy reach sediment transport capacity. This would be an adjustment from a constructed grade of 0.192% to a gradient of 0.263%. This is slightly less than the total grade between riffle drop crests (0.36%), which would slightly affect the capacity of the low-flow channel but would probably not impact that stability of this reach.

The geometry of downstream sub-reaches was varied by adjusting the active channel width and channel grade to maintain a sediment transport capacity equal to that of the proxy reach. The channel banks are 4.0

feet high (topwidth B3 in the equilibrium calculation) and are assumed to maintain their height and slope as stream width increases. The unvegetated portion of the active channel was assumed to be 80% of the active channel width. The active channel width and channel grade were varied to maintain sediment transport capacity equal to that of the proxy reach. The result is an active channel at a nearly uniform gradient of 0.261% and an active width that is fairly uniform that slightly decreases in the downstream direction.

The Caley choke section (sub-reach 812) is relaxed for this scenario. At its 1-foot depth the cross section is about 80 feet wide, compared to the current width of only about 50 feet. The sensitivity of the cross section to encroachment is demonstrated by the need to widen the channel at its 6-foot (topwidth B4) from 173 feet to 486 feet.

The most significant problem with Scenario #2 is the lack of stream power. As a result, this alternative has low equilibrium indices, which are the result of the mild stream gradients. The channel section is fairly wide with a high width/depth ratio, which may result in areas of the cross section that have partial sedimentation (i.e. sand bars). Bars provide areas for the establishment of vegetation that can result in a narrowing of the unvegetated active channel and reduced sediment transport capacity. This would promote further deposition (increasing channel grade) until a balance between sediment transport and stream power is achieved.

As was anticipated by major drainageway planning, the difference in fall between the original channel grade and the improved channel grade would be accommodated by drop structures. Because deposition is likely for this scenario, it is desirable not to accumulate large differences in grade between drop structures, which would create the potential for large deposition areas between drop structures. This would not only affect channel capacity or but could also result in lateral instability.

A good guide to drop spacing is to follow the frequency of a riffle sequence with a small grade change at each riffle location. Riffle sequencing is roughly 2π times the channel width, which in natural stream can vary by nearly a factor of two. Therefore, construction of riffle sequences would only require on average of about 0.6 feet of drop per riffle to accommodate the potential grade difference that might be caused by sediment deposition. This would limit potential deposition to about 1.0 foot.

SCENARIO #3

Scenario #3 is an improved version of Scenario #1 that reduces the irregular variations in active channel width, while also adjusting stream gradient to maintain uniform sediment transport capacity. For this scenario, a small shallow active channel is incised into a wider channel floor. The channel is similar to the channel section of proxy reach near Pine Lane. The resulting channel gradient is similar to the grade computed for Scenario #1 (about 0.400% compared to 0.395%). The active channel is more uniform with an un-vegetated active channel width of about 10 to 12 feet. As with Scenario #1, the result is a small width to depth ratio (about 3), which makes the section vulnerable to low-flow incisement.

This scenario has the advantage of a much wider riparian zone compared to Scenario #2. At its 2-foot depth (topwidth B2), the channel has a riparian fringe (channel width minus the unvegetated active channel width) of about 152 feet compared to about 57 feet for Scenario #2. The active channel also carries less discharge (350 cfs compared to about 950 cfs for Scenario #2), which means that flow will be conveyed more frequently through the riparian zone. This provides a water quality benefit, since vegetated portions of the channel have a lower velocity that promote settling of sediment and allow nutrient exchange to plants.

In order to provide consistent sediment transport capacity, the channel section is more uniform and carries nearly constant topwidth at its 4-foot and 6-foot depths (350 feet and 486 feet, respectively). This would require eliminating floodplain encroachments within approximately a 500 foot width of the Cherry

Creek floodplain. This is not to say that the section needs to be completely prismatic, but the channel benefits from having relatively uniform cross section geometry. A related benefit of a wide vegetated overbank section is that the plant communities have more room to diversify.

This scenario has the advantage of having an equilibrium index that is close to 1.0. While there is still a deficit in stream power it is the lowest of all three scenarios. So it is the most likely scenario to transport the full upstream sediment load without excessive sedimentation during a large flood. The wider channel and steeper stream gradient are characteristic of the natural Cherry Creek stream environment. The low-flow channel would have capacity for current base flows but would require stabilization. Because there is less depth in the low channel there would also be a tendency for lateral migration within the channel overbank. So low-flow channel stabilization would need to include both vertical and lateral control structures.

DISCUSSION OF SCENARIOS #2 AND #3

Scenario #2 comports with most the channel improvements that have been constructed for the Cherry Creek to date. Its largest disadvantage is that it has a significant deficit in stream power relative to sediment transport capacity, and as a result, a potential for aggradation during larger flood events. Sediment balance for the reach indicates that there is enough sediment supplied that such aggradation would be possible. To understand the deposition pattern during larger flood events and determining the extent of problems for low flows will require further analysis that is based on sediment routing calculations. Sediment routing calculations can be conducted using HEC-RAS with sub-reach 880 at the supply reach.

Scenario #2 needs frequent grade control to absorb the difference between the design channel profile and the original stream gradient. Small drops that are based on a riffle sequence are recommended. With a limited drop height of about 0.6 feet and frequent drops of one about every 350 feet would provide consistent control of the channel grade. This approach recognizes that the biggest risk to stream channel stability is potential aggradation. Use of large drop structures risks a larger depth of deposition that would reduce waterway capacity and increase the potential for lateral migration. Smaller drops limit the sediment deposition to smaller depths that pose lower risks.

Scenario #3 is an alternative approach to the Cherry Creek that is closer to equilibrium. The major benefit is the increased size of the riparian zone and the associated water quality benefits of having more flow travel through vegetated areas of the channel. The additional overall channel width required for this scenario may not comport well with the history of encroachment within the study reach and lack of right-of-ways within the stream corridor. The smaller channel size and shallower embedment create the risk that the low-flow channel may shift within the overbank. So, control structures are needed for both vertical and horizontal channel stabilization.

While this analysis has focused on channel form associated with a minor 2-year flood, design must also consider major floods. Sediment loads created by a single large event can easily surpass the sediment load created by many years of transport by smaller flows. As a result, the low-flow channel section is vulnerable to being filled in or being out flanked during a major flood. Investigation is needed for any scenario to determine how likely an incised low-flow channel can survive a major flood. The investigation should address if there is a need for additional lateral stabilization of the active channel. It is recommended that the initial tool for these investigations be the one-dimensional moveable-bed model HEC-RAS.

Finally, it should be noted that Scenario #2 and #3 are not mutually exclusive. Since both scenarios have adequate sediment transport during low flow, they can be used as benefits different sub-reaches. Such mixing for stream cross sections would however make it even more important to evaluate channel behavior at transitions between sub-reaches during major floods using a moveable-bed model.

SUMMARY AND FINDINGS

1. Water supply development in the Cherry Creek basin results in the reach between Parker and Cherry Creek reservoir being a losing reach. It is expected that on average there will be about 32% less stream flow at the lower end of the study reach compared to inflow at the upper end.

2. An interim approach to the estimation of channel forming flows is proposed that scales the 2-year Major Drainageway Planning flow at sub-reach 880 according to the average loss rates calculated by the CCBWQA model for downstream sub-reaches.

3. It is recommended that a better model of minor floods and low-flows be developed that incorporates elements of the CCBWQA model (i.e. water storage in alluvial aquifers, aquifer flows, and pumping operations for water recovery). The new model should upgrade the Major Drainageway Planning hydrology model that is based on UDSWM to EPA-SWMM 4.

4. The upper sub-reach of the study area (sub-reach 880) was found to be stable and it is recommended as a reliable proxy reach for the estimation of incoming sediment supply to the study reach.

5. The equilibrium index method was applied to evaluate three channel design scenarios. It was found that recent improvements to the channel are not in equilibrium between sediment transport and stream power. This results in the potential for sediment deposition within the channel improvements. This aggradation is expected to be minor for 2-year flows and will require further investigation for major floods.

6. Scenarios #2 and #3 developed in this report can be mixed as needed to meet the needs of the corridor. Scenario #2 comports to prior design and major drainageway planning but may be vulnerable to significant aggradation during major floods. Scenario #3 has a cross-section geometry and profile grade that is similar to the original Cherry Creek channel. It has the advantage of creating a larger vegetated channel width, which would provide a significant water quality benefit.

7. It is highly recommended that detailed moveable-bed modeling be conducted for major floods in the study reach to determine the potential damage to downstream channel improvements.

8. A monitoring program for sedimentation and alluvial groundwater elevations should be started so that stream health can be routinely evaluated in light of very rapid changes occurring to the water supply within the basin and the extensive use of the alluvial aquifers as the means of recycling a large portion of that imported water supply as permitted by Colorado water law.

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Previous Papers in the Sedimentation Study:

GK Cotton Consulting, November 2010, "Cherry Creek Sedimentation Study, Reservoir to Pine Lane – Project Data and Evaluation"

GK Cotton Consulting, January 2010, "Cherry Creek Sedimentation Study, Reservoir to Pine Lane – Sediment Transport Equation Calibration"

GK Cotton Consulting, January 2011, "Cherry Creek Sedimentation Study, Reservoir to Pine Lane – Sediment Budget"

APPENDIX A. STREAM CHANNEL STABILITY CALCULATIONS

Stream Channel Stability - REM-SSI

Purpose: **This workbook computes a stability index based on known stable section as a proxy using L-M scaling and sediment transport scaling.**
REM-SSI is a program in the River Environment Modeling (REM) series.

References: Cotton, G.K., PE, 2010, "Stream process scaling and equilibrium index method"
Griffiths, G.A., 2003, "Downstream hydraulic geometry and hydraulic similitude" Water Resources Research, Vol 39, No. 4.
Leopold, L.B. and Maddock, T., 1953, "The hydraulic geometry of stream channels and some physoiographic implications," USGS Prof. Paper 252.

Comments: Comments and questions on this workbook can be sent to:

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Parker, Colorado 80134 email: george.cotton@gkcotton.com

Content:

Reach- Tabulates the geometry, gradient, bed material size and discharge properties for mulitiple reaches.

SSI base- Computes the active channel velocity and sediment transport. The equilibrium index is computed based on an estimated properties of a prototype reach.

SSI Scenarios- Permits the user to adjust reach properties and develop analysis scenarios in a manner that drives the equilibrium index to equilibrium (IE = 1.0).

User Guide: **Yellow** cells indicate required input data for the workbook. **Green** cells indicate previous input values. **Purple** cells are computed dimensional values. **Blue** cells are dimensionless scaling values.

Project Information:

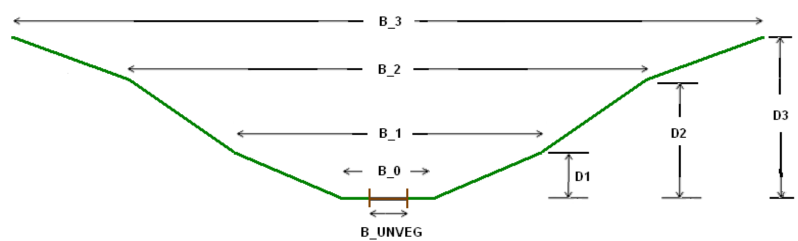
Location:	Cherry Creek / Parker to Valley Country Club
Calc by:	George Cotton, PE
Last Revised:	May 3, 2011

Stream Channel Stability - Reach Data

Location: Cherry Creek / Parker to Valley Country Club
Calc by: George Cotton, PE
Last Revised: May 3, 2011
Printed: May 4, 2011 13:59

Reach	Reach ID	d_{50} (mm)	Q_{2yr} (cfs)	So (ft/ft)	B_{unveg} (ft)	B_0 (ft)	B_1 (ft)	B_2 (ft)	B_3 (ft)	B_4 (ft)
					Topwidth, ft					
1	880	1.9	1555	0.00379	15.0	27.0	80.0	145.5	579.0	619.1
2	878	1.9	1518	0.00457	35.0	106.6	141.0	191.7	652.3	1070.9
3	873	1.9	1473	0.00472	34.0	35.0	44.0	479.0	504.0	610.0
4	869	1.9	1378	0.00383	34.0	35.0	37.0	115.1	355.5	387.7
5	867	1.9	1325	0.00438	34.0	35.0	53.9	84.1	287.5	319.2
6	868	1.9	1339	0.00400	34.0	35.0	50.7	78.8	135.0	736.5
7	819	1.9	1445	0.00358	38.0	39.0	58.7	166.1	176.7	187.3
8	816	1.2	1249	0.00343	25.0	40.8	104.0	275.6	599.8	807.3
9	821	1.2	1280	0.00333	25.0	123.0	201.6	371.1	471.6	487.5
10	813	1.2	1207	0.00403	25.0	123.0	172.2	371.1	473.5	485.4
11	812	1.2	1152	0.00388	24.0	25.0	51.0	84.8	113.1	172.6
12	811	1.2	1064	0.00388						
20										
				Depth, ft	0.0	0.0	1.0	2.0	4.0	6.0
Prototype		1.9	1555	0.00379	15.0	27.0	80.0	145.5	579.0	619.1
				n-value Rating	0.025	0.311	0.311	0.146	0.076	0.061

Channel Geometry:



Gradation Data:

Grain siz (mm)	% Finer Overbank	Active	Up Valley
0.25	15.1	2.5	4.2
0.5	41.5	14.0	12.6
1.0	72.7	42.1	28.9
2.0	92.2	75.2	51.3
4.0	98.7	94.1	73.3
8.0	99.9	99.3	88.7
16.0	100.0	100.0	96.4
G =	2.3	2.2	3.2
d50 =	0.6	1.2	1.9

Transport Equation:

$$g_b = b\,V^{5.0}\,D^{-0.50}$$

$$\text{where: } b = 0.1118\,G^{0.37}\,d_{50}^{-0.69}$$

EH Scaling Factors:

m1	m2		
5.00	-0.50		
e	f	g	h
1.1765	0.0588	0.2353	1.2941

Stream Channel Stability - Scenario #1 Uniform Sediment Transport

Location: Cherry Creek / Parker to Valley Country Club
Calc by: George Cotton, PE
Last Revised: May 3, 2011
Printed: May 4, 2011 13:59

Reach	Q_{2yr} (cfs)	So (ft/ft)	B_{unveg} (ft)	B_0 (ft)	B_1 (ft)	B_2 (ft)	B_3 (ft)	B_4 (ft)	d_{50} (mm)	Y_{2yr} (ft)	Q_{active} (cfs)	G_b (tons/day)	G_{br}	d_r^g	Q_r^h	S_r	I_E
1	1555	0.00379	15.0	27.0	80.0	145.5	579.0	619.1	1.9	3.71	488	45,112	1.00	1.00	1.00	1.00	1.00
2	1518	**0.00395**	**19.4**	106.6	141.0	191.7	652.3	1070.9	1.9	3.27	523	45,112	1.00	1.00	0.97	1.04	1.01
3	1473	**0.00395**	**23.1**	35.0	44.0	479.0	504.0	610.0	1.9	3.08	563	45,112	1.00	1.00	0.93	1.04	0.97
4	1378	**0.00395**	***11.1***	**20.3**	37.0	115.1	355.5	387.7	1.9	3.96	412	45,112	1.00	1.00	0.86	1.04	0.89
5	1325	**0.00395**	***10.3***	**18.8**	53.9	84.1	287.5	319.2	1.9	4.06	399	45,112	1.00	1.00	0.81	1.04	0.85
6	1339	**0.00395**	***7.4***	**13.5**	50.7	78.8	135.0	736.5	1.9	4.53	344	45,112	1.00	1.00	0.82	1.04	0.86
7	1445	**0.00395**	***11.3***	**20.5**	58.7	166.1	176.7	187.3	1.9	3.93	411	45,112	1.00	1.00	0.91	1.04	0.95
8	1249	**0.00395**	***18.7***	**34.0**	104.0	275.6	599.8	807.3	1.2	3.12	464	45,112	1.00	0.90	0.75	1.04	0.87
9	1280	**0.00395**	***27.0***	**49.1**	201.6	371.1	471.6	487.5	1.2	2.74	540	45,112	1.00	0.90	0.78	1.04	0.90
10	1207	**0.00395**	***27.8***	**50.6**	172.2	371.1	473.5	485.4	1.2	2.71	547	45,112	1.00	0.90	0.72	1.04	0.84
11	1152	**0.00395**	***7.0***	**12.8**	51.0	84.8	113.1	172.6	1.2	4.34	303	45,112	1.00	0.90	0.68	1.04	0.79
12	1064	0.00388															
20																	
Prototype	1555	0.00379	15.0	27.0	80.0	145.5	579.0	619.1	1.9	3.71	488	45,112					

Reach	Fr (unitless)	τ_o (lb/ft²)	Q_{over} (cfs)	$V_{ave-active}$ (ft/s)	$V_{ave-over}$ (ft/s)	n-val.$_{over}$ (unitless)	R_{over} (ft)	B_{over} (ft)	Coef. "b" active	G_{b-act} (tons/day)	Coef. "b" over	G_{b-over} (tons/day)
1	0.80	0.877	1067	8.8	1.6	0.086	1.8	371.2	0.110	44523	0.216	588
2	0.80	0.806	995	8.2	1.5	0.102	2.1	308.0	0.110	44741	0.216	371
3	0.79	0.758	910	7.9	1.2	0.108	1.7	453.8	0.110	44915	0.216	197
4	0.83	0.976	966	9.3	1.9	0.077	1.9	268.1	0.110	44160	0.216	952
5	0.83	1.001	926	9.5	2.0	0.076	2.1	212.9	0.110	43981	0.216	1131
6	0.85	1.117	995	10.2	2.5	0.072	2.7	143.2	0.110	43137	0.216	1975
7	0.83	0.968	1034	9.3	2.4	0.078	2.8	156.7	0.110	43625	0.216	1487
8	0.80	0.768	785	8.0	1.3	0.107	1.8	339.1	0.132	44917	0.216	195
9	0.78	0.675	740	7.3	1.2	0.120	1.9	333.3	0.132	44990	0.216	122
10	0.78	0.668	660	7.3	1.1	0.121	1.8	329.3	0.132	45014	0.216	98
11	0.84	1.071	849	9.9	2.8	0.073	3.2	96.5	0.132	43250	0.216	1862
12												
20												
Prototype	0.80	0.877	488	8.8	1.6	0.086	1.8	371.2	0.110	44523	0.216	588

Note: This tab contains the computed output based on scaling relationships that were reported in the REACH tab.
Y_{2yr} is the normal depth for the composite section. Q_{active} and $V_{ave-active}$ are discharge and average velocity for the active portion of the channel (i.e. the portion of the channel with the most sediment transport).
Sediment transport, G_b, is for the width of the channel and consists of transport in the active and over bank segments of the channel.
The scaled values of transport, sediment size, discharge and channel gradient are computed.

The equilibrium index, IE, is given by the following equation: $IE = \dfrac{Q_r^h S_r}{G_{br} d_r^g}$

Scenario #1 - Uniform Sediment Transport

This scenario establishes uniform sediment transport through the study reach at the rate of 45,100 tons/day, even though water discharge is decreasing. The active channel width, Bo, was adjusted (shown in bold type) to create an equilibrium channel form that can transport the incoming sediment load. [Note: It was assumed that the unvegetated portion of the active channel was 55% of the active channel width.] This results in a fairly irregular channel width, since most of the cross section geometry was left unchanged. The active channel is excessively narrow, which indicated the potential for channel erosion by incisement. The problem is worst where floodplain encroachment is highest. The channel is close to equilibrium with a variation in the equilibrium index between 0.84 to 0.97. Because the index is less than 1.0, the channel shows a deficit in stream power and the potential for aggradation.

Stream Channel Stability - Scenario #2 Uniform Sediment Transport w/ 17 Mile House Channel Scaling

Location: Cherry Creek / Parker to Valley Country Club
Calc by: George Cotton, PE
Last Revised: May 3, 2011
Printed: May 4, 2011 13:59

			0.8		38.00	10.00	14.50	<- Geometry Scaling factors									
Reach	Q_{2yr} (cfs)	So (ft/ft)	B_{unveg} (ft)	B_0 (ft)	B_1 (ft)	B_2 (ft)	B_3 (ft)	B_4 (ft)	d_{50} (mm)	Y_{2yr} (ft)	Q_{active} (cfs)	G_b (tons/day)	G_{br}	d_r^g	Q_r^h	S_r	I_E
1	1555	0.00379	15.0	27.0	80.0	145.5	579.0	619.1	1.9	3.71	488	45,112	1.00	1.00	1.00	1.00	1.00
2	1518	0.00392	19.8	106.6	141.0	191.7	652.3	1070.9	1.9	3.27	531	45,112	1.00	1.00	0.97	1.03	1.00
3	1473	0.00408	21.2	35.0	44.0	479.0	504.0	610.0	1.9	3.09	526	45,112	1.00	1.00	0.93	1.08	1.00
4	1378	0.00263	36.2	45.2	83.5	93.5	112.5	387.7	1.9	3.77	1,005	45,112	1.00	1.00	0.86	0.69	0.59
5	1325	0.00269	35.5	44.3	82.3	92.3	106.8	319.2	1.9	3.71	974	45,112	1.00	1.00	0.81	0.71	0.58
6	1339	0.00267	35.6	44.6	82.6	92.6	107.1	736.5	1.9	3.73	983	45,112	1.00	1.00	0.82	0.71	0.58
7	1445	0.00253	37.0	46.3	84.3	94.3	108.8	187.3	1.9	3.86	1,051	45,112	1.00	1.00	0.91	0.67	0.61
8	1249	0.00255	34.4	43.0	81.0	91.0	105.5	807.3	1.2	3.70	914	45,112	1.00	0.90	0.75	0.67	0.56
9	1280	0.00250	34.9	43.6	81.6	91.6	106.1	487.5	1.2	3.74	934	45,112	1.00	0.90	0.78	0.66	0.57
10	1207	0.00261	33.8	42.3	80.3	90.3	104.8	485.4	1.2	3.64	886	45,112	1.00	0.90	0.72	0.69	0.55
11	1152	0.00270	33.1	41.3	79.3	89.3	103.8	486.0	1.2	3.57	850	45,112	1.00	0.90	0.68	0.71	0.54
12	1064	0.00388															
20																	
Prototype	1555	0.00379	15.0	27.0	80.0	145.5	579.0	619.1	1.9	3.71	488	45,112					

Reach	Fr (unitless)	τ_o (lb/ft^2)	Q_{over} (cfs)	$V_{ave\text{-}active}$ (ft/s)	$V_{ave\text{-}over}$ (ft/s)	n-val.$_{over}$ (unitless)	R_{over} (ft)	B_{over} (ft)	Coef. "b" active	$G_{b\text{-}act}$ (tons/day)	Coef. "b" over	$G_{b\text{-}over}$ (tons/day)
1	0.80	0.877	1067	8.8	1.6	0.086	1.8	371.2	0.110	44523	0.216	588
2	0.80	0.799	987	8.2	1.5	0.102	2.1	307.4	0.110	44751	0.216	361
3	0.81	0.785	947	8.0	1.2	0.108	1.7	454.9	0.110	44888	0.216	224
4	0.67	0.618	373	7.4	1.9	0.084	3.0	65.2	0.110	44915	0.216	197
5	0.68	0.624	351	7.4	1.9	0.086	3.0	62.2	0.110	44934	0.216	178
6	0.67	0.622	356	7.4	1.9	0.085	3.0	62.4	0.110	44928	0.216	184
7	0.66	0.610	394	7.4	2.0	0.081	3.1	63.4	0.110	44876	0.216	236
8	0.66	0.588	335	7.2	1.8	0.087	3.0	61.9	0.132	44964	0.216	148
9	0.65	0.584	346	7.2	1.8	0.085	3.0	62.2	0.132	44953	0.216	159
10	0.66	0.593	321	7.2	1.8	0.088	3.0	61.4	0.132	44979	0.216	133
11	0.67	0.601	302	7.2	1.7	0.091	2.9	60.8	0.132	44996	0.216	116
12												
20												
Prototype	0.80	0.877	488	8.8	1.6	0.086	1.8	371.2	0.110	44523	0.216	588

Note: This tab contains the computed output based on scaling relationships that were reported in the REACH tab.
Y_{2yr} is the normal depth for the composite section. Q_{active} and $V_{ave\text{-}active}$ are discharge and average velocity for the active portion of the channel (i.e. the portion of the channel with the most sediment transport).
Sediment transport, G_b, is for the width of the channel and consists of transport in the active and over bank segments of the channel.
The scaled values of transport, sediment size, discharge and channel gradient are computed.

The equilibrium index, IE, is given by the following equation: $IE = \dfrac{Q_r^h S_r}{G_{br} d_r^g}$

Scenario #2 - 17 Mile House Scaling

This scenario establishes uniform sediment transport through the study reach at the rate of 45,100 tons/day, which is greater than the transport capacity of the 17 Mile House reach. It is expected that the 17 Mile House reach will adjust its grade to match the incoming sediment load (0.196% to 0.263%). This is less than the riffle crest to crest grade of the channel (0.356%) and should not result in instability. Channel cross section is patterned after the 17 Mile House reach, which results in a fairly uniform active channel width and width/depth ratio (about 12). The reach grade is adjusted to maintain transport capacity, which results in an average gradient of about 13.8 ft/mile. As flow is lost in the channel, the channel gradient slightly increases and the width gradually decreases. There a substantial an imbalance between stream power and transport capacity in the lower reaches. This will probably result in sediment deposition during large floods.

Stream Channel Stability - Scenario #3 Maximum Uniform Sediment Transport w/ Parabolic Channel Scaling

Location: Cherry Creek / Parker to Valley Country Club
Calc by: George Cotton, PE
Last Revised: May 3, 2011
Printed: May 4, 2011 13:59

0.8 12.00 <-- Geometry Scaling Factors

Reach	Q_{2yr} (cfs)	So (ft/ft)	B_{unveg} (ft)	B_0 (ft)	B_1 (ft)	B_2 (ft)	B_3 (ft)	B_4 (ft)	d_{50} (mm)	Y_{2yr} (ft)	Q_{active} (cfs)	G_b (tons/day)	G_{br}	d_r^g	Q_r^h	S_r	I_E
1	1555	0.00379	15.0	27.0	80.0	145.5	579.0	619.1	1.9	3.71	488	45,112	1.00	1.00	1.00	1.00	1.00
2	1518	0.00392	19.8	106.6	141.0	191.7	652.3	1070.9	1.9	3.27	531	45,112	1.00	1.00	0.97	1.03	1.00
3	1473	0.00408	21.2	35.0	44.0	479.0	504.0	610.0	1.9	3.09	526	45,112	1.00	1.00	0.93	1.08	1.00
4	1378	0.00405	11.6	14.5	26.5	168.0	355.5	486.5	1.9	3.83	410	45,112	1.00	1.00	0.86	1.07	0.91
5	1325	0.00403	12.0	15.0	27.0	164.7	348.6	486.5	1.9	3.79	418	45,112	1.00	1.00	0.81	1.06	0.87
6	1339	0.00404	11.9	14.9	26.9	165.6	350.4	486.5	1.9	3.80	416	45,112	1.00	1.00	0.82	1.07	0.88
7	1445	0.00407	11.1	13.8	25.8	172.0	364.0	486.5	1.9	3.87	399	45,112	1.00	1.00	0.91	1.07	0.98
8	1249	0.00401	10.1	12.6	24.6	159.9	338.5	486.5	1.2	3.80	353	45,112	1.00	0.90	0.75	1.06	0.89
9	1280	0.00402	9.9	12.4	24.4	161.9	342.6	487.5	1.2	3.82	348	45,112	1.00	0.90	0.78	1.06	0.92
10	1207	0.00400	10.4	13.1	25.1	157.2	332.7	485.4	1.2	3.77	359	45,112	1.00	0.90	0.72	1.05	0.85
11	1152	0.00398	10.9	13.7	25.7	153.6	325.0	486.5	1.2	3.73	368	45,112	1.00	0.90	0.68	1.05	0.79
12	1064	0.00388															
20																	
Prototype	1555	0.00379	15.0	27.0	80.0	145.5	579.0	619.1	1.9	3.71	488	45,112					

Reach	Fr (unitless)	τ_o (lb/ft²)	Q_{over} (cfs)	$V_{ave\text{-}active}$ (ft/s)	$V_{ave\text{-}over}$ (ft/s)	n-val.$_{over}$ (unitless)	R_{over} (ft)	B_{over} (ft)	Coef. "b" active	$G_{b\text{-}act}$ (tons/day)	Coef. "b" over	$G_{b\text{-}over}$ (tons/day)
1	0.80	0.877	1067	8.8	1.6	0.086	1.8	371.2	0.110	44523	0.216	588
2	0.80	0.799	987	8.2	1.5	0.102	2.1	307.4	0.110	44751	0.216	361
3	0.81	0.785	947	8.0	1.2	0.108	1.7	454.9	0.110	44888	0.216	224
4	0.83	0.967	968	9.3	1.8	0.082	2.0	273.2	0.110	44301	0.216	811
5	0.83	0.954	907	9.2	1.8	0.083	1.9	264.2	0.110	44409	0.216	703
6	0.83	0.958	923	9.2	1.8	0.083	1.9	266.6	0.110	44382	0.216	730
7	0.84	0.982	1046	9.3	1.9	0.081	2.0	284.1	0.110	44154	0.216	958
8	0.83	0.952	896	9.2	1.8	0.083	2.0	259.1	0.132	44410	0.216	702
9	0.83	0.959	932	9.2	1.8	0.082	2.0	264.3	0.132	44349	0.216	763
10	0.83	0.941	848	9.1	1.7	0.084	1.9	251.8	0.132	44489	0.216	623
11	0.82	0.927	784	9.0	1.7	0.085	1.9	241.9	0.132	44586	0.216	526
12												
20												
Prototype	0.80	0.877	488	8.8	1.6	0.086	1.8	371.2	0.110	44523	0.216	588

Note: This tab contains the computed output based on scaling relationships that were reported in the REACH tab.
Y_{2yr} is the normal depth for the composite section. Q_{active} and $V_{ave\text{-}active}$ are discharge and average velocity for the active portion of the channel (i.e. the portion of the channel with the most sediment transport).
Sediment transport, G_b, is for the width of the channel and consists of transport in the active and over bank segments of the channel.
The scaled values of transport, sediment size, discharge and channel gradient are computed.

The equilibrium index, IE, is given by the following equation: $IE = \dfrac{Q_r^h\, S_r}{G_{br}\, d_r^g}$

Scenario #3 - Shallow Channel Option

This scenario establishes uniform sediment transport through the study reach at the rate of 45,100 tons/day. Channel geometry is adjusted to create a uniform unvegetated channel width of about 10 to 12 feet. The slope and channel width are adjusted to maintain sediment transport. The valley section is approximately parabolic and is scaled to increase in width as the active channel width decreases. This results in a nearly constant discharge within the active channel, even though the reach loses flow. The resulting equilibrium channel form gradually decreases in grade and width as flow is lost from the channel. At a depth of 4 feet (B3 topwidth) the channel is about three times the width of the more incised 17-mile house cross section. There is still a slight imbalance in stream power versus sediment transport (about 10%), The width/depth ratio is low (about 3.5), indicating a stronger tendency to incise the low-flow channel.

APPENDIX B. STABILITY INDEX METHOD

Equilibrium relationships are commonly used in the assessment of stream stability. They have their origins in empirical (Leopold and Maddock, 1953) and qualitative relationships of river process (Lane, 1955). It can be shown that scaling of steady, uniform turbulent flow in a non-prismatic channel with an alluvial boundary provides the basis for these relationships. As a result, an upstream channel section that is in equilibrium can be used to scale downstream channel sections in accordance with the yield of water and sediment.

GRADUALLY VARIED FLOW

The differential equation for one-dimensional gradually varied open-channel flow (Henderson, 1966 see Equation 4-31) can be written as:

$$\frac{dD}{dx}\left(1-\alpha Fr^2\right)=S-S_f \quad (1)$$

where x is the distance in the downstream direction,
D is the flow depth,
α is the energy coefficient (assumed constant),
Fr is the Froude number ($Fr^2=\frac{V^2}{gD}$),
V is the average velocity,
g is the acceleration of gravity, and
S, Sf are the channel gradient and friction slope, respectively.

PROTOTYPE/MODEL SIMILITUDE

The scaling of hydraulic geometry can be explored using similitude methods (Griffiths, 2003). Assuming that the at-station situation is the prototype, equation 1 can be written as:

$$\frac{dD_p}{dx_p}\left(1-\alpha Fr_p^2\right)=S_p-S_{fp} \quad (2)$$

The subscript p denotes the prototype version.

The downstream situation is the model version of equation 1:

$$\frac{dD_m}{dx_m}\left(1-\alpha Fr_m^2\right)=S_m-S_{fm} \quad (3)$$

The subscript m denotes the model version.

Substitution of Dm = Dr Dp and similarly for other variables in equation 3 yields:

$$\frac{1}{S_p}\frac{dD_p}{dx_p}\left(\frac{D_r}{S_r\,x_r}\right)\left(1-\alpha\,Fr_p^2\,\left(Fr_r^2\right)\right)=1-\frac{S_{fp}}{S_p}\left(\frac{S_{fr}}{S_r}\right) \quad (4)$$

The subscript r denotes the ration of model to prototype (i.e. a dimensionless variable).

For dynamic similarity to hold at model and prototype sections equations 2 and 4 must be identical, which implies from equation 4 that:

$$\frac{D_r}{S_r x_r} = 1 \quad (5a)$$

$$\frac{S_{fr}}{S_r} = 1 \quad (5b)$$

$$Fr_r^2 = 1 \quad (5c)$$

From the equation of continuity we have the following scaling relationship.

$$Q_r = V_r B_r D_r \quad (6)$$

where:
Br is the dimensionless channel width,
Qr is the dimensionless discharge,
Vr is the dimensionless velocity, and
xr is the dimensionless reach length.

EFFECT OF ROUGHNESS

Using the Manning formula for fully rough flow the friction slope is:

$$S_f = g\left(\frac{n^2}{D^{1/3}}\right) Fr^2 \quad (7)$$

where g is the acceleration of gravity and n is the Manning roughness coefficient.

In scaling terms equation 7 can be written as:

$$S_{fr} = \left(\frac{n_r^{\;2}}{D_r^{\;1/3}}\right) Fr_r^2 \quad (8)$$

From the Strickler equation (Henderson, 1966 see Equation 4-23) the roughness scaling is a function of a characteristic sediment grain size, d.

$$n_r = d_r^{1/6} \quad (9)$$

where:
dr is the dimensionless particle size.

Equation 8 can then be rewritten as:

$$S_{fr} = \left(\frac{d_r}{D_r}\right)^{1/3} Fr_r^2 \quad (10)$$

SCALING OF SEDIMENT TRANSPORT

Stream form is also dependent on the transport of bed load either in contact with the bed or in suspension. In natural streams where the supply of sediment is not interrupted by excessive deposition or scour (such is caused by a dam), this exchange of bed material maintains a gradation of sediment sizes. Power function versions of sediment transport have been developed for rivers of various sizes and alluvial material. Transport functions may also be derived from sediment transport calculations.

A general power function for unit rate of sediment transport is:

$$g_b = b' V^{m1} D^{m2} \quad (11)$$

where: b', m1, m2 are coefficients of the power function.

The total bed-load sediment transport in a channel is:

$$G_b = B\, g_b \quad (12)$$

where: B is the width of the active channel.

The dimensionless form of equation 12 is:

$$G_{br} = B_r V_r^{m1} D_r^{m2} \quad (13)$$

ALLUVIAL CHANNEL SCALING RELATIONSHIPS

Adopting the active channel width, B, as the longitudinal scale (Br = xr), equation 5 gives the following scaling relationships.

$$S_{fr} = \frac{D_r}{B_r} = \left(\frac{d_r}{D_r}\right)^{1/3} \frac{V_r^2}{D_r} \quad (14a)$$

$$B_r = \frac{D_r^{4/3}}{d_r^{1/3}} \quad (14b)$$

Substituting 14b and 5c into 6 gives:

$$Q_r = \left(\frac{D_r^{4/3}}{d_r^{1/3}}\right) D_r^{1/2} D_r \quad (15a)$$

$$D_r = Q_r^{6/17} d_r^{2/17} \quad (15b)$$

Substituting 15b back into 14b gives:

$$B_r = Q_r^{8/17} d_r^{-3/17} \quad (16)$$

Substituting 15b into 5c gives:

$V_r = D_r^{1/2}$ .... (17a)

$V_r = Q_r^{3/17} d_r^{1/17}$ .... (17b)

Substituting 15b and 16 into 5a gives:

$S_r = \frac{D_r}{B_r}$ .... (18a)

$S_r = Q_r^{-2/17} d_r^{5/17}$ .... (18b)

Substituting 15b, 16 and 17b into 13 gives:

$G_{br} = Q_r^{e} d_r^{f}$ .... (19)

where: e = (8 + 3m1 +6m2)/17; f = (-3 + m1 + 2m2)/17

Summarizing, the theoretically derived scaling relationships for channel geometry are as follows.

$D_r = Q_r^{6/17} d_r^{2/17}$ .... (15)

$B_r = Q_r^{8/17} d_r^{-3/17}$ .... (16)

$V_r = Q_r^{3/17} d_r^{1/17}$ .... (17)

$S_r = Q_r^{-2/17} d_r^{5/17}$ .... (18)

$G_{br} = Q_r^{e} d_r^{f}$ .... (19)

The exponents of Q from the theoretically derived scaling relations are very similar to those from the empirical results of Leopold and Maddock (1953) as summarized in Table 1. The introduction of sediment size, d, by the theoretical derivation gives insight into processes related to channel roughness.

Table 8. Comparison of Empirical and Theoretical Scaling Exponents

Scaling Variable	Empirical* j	Theoretical j'	Theoretical k'
B_r	0.5	0.47	-0.18
D_r	0.4	0.35	0.12
V_r	0.1	0.18	0.06
S_r	-0.1	-0.12	0.29
G_{br}	none	Function of sediment transport relationship	

*Leopold and Maddock (1953)

STABLE CHANNEL ASSESSMENT – EQUILIBRIUM RELATIONSHIPS

LANE RELATIONSHIP - ENHANCED

Lane (1955) describes a general equilibrium relationship among river hydraulic variables, which is often used as the basis for qualitative geomorphic analysis.

$$G_b\, d \propto Q\, S \quad (20)$$

The relationship is applied by assuming that two of the variables remain constant. For example, an increase in bed load +Gb, with no change in sediment size d, or stream discharge Q, will result in an increase in stream slope +S. This is interpreted as a potential for sediment deposition in the existing stream channel. A similar relationship can be derived by dividing equation 18 by equation 19.

$$G_{br}\, d_r^{\,g} = Q_r^{\,h}\, S_r \quad (21)$$

where: $g = 5/17 - f$; and, $h = 2/17 + e$

The theoretically derived equilibrium relationship offers insights into the interplay of alluvial variables that is missing from applying equations 15-19 individually. First, the strong relationship between stream discharge, gradient, and sediment transport is clearly evident. The role of sediment size appears modest, although sediment size can adjust several orders of magnitude due to armoring. The derived equilibrium relationship (21) offers a clear conceptual framework for quantitative analysis. The scaling relationships, which are at-station (prototype) to downstream-station (model), offer a spatial context.

EQUILIBRIUM INDEX APPROACH

Alternatively, the scaling relationships can be formulated as an index, where the index is determined from the properties of the stable prototype cross section relative to other cross sections. The stability index for the prototype reach is 1.0. If other cross sections are also in equilibrium their stability index will also be near 1.0. Index values that are not unity indicate non-equilibrium downstream conditions. Values of IE can then be applied to assessing other downstream cross sections.

Equation 21 can be stated as the following equilibrium index:

$$I_E = \frac{Q_r^{\,h}\, S_r}{G_{br}\, d_r^{\,g}} \quad (22)$$