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Caples Creek Channel Geomorphology Monitoring Report

Sensitive Site Investigation and Mitigation Plan

April 13, 2011

El Dorado Hydroelectric Project No. 184

Prepared For

El Dorado Irrigation District

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CAPLES CREEK CHANNEL GEOMORPHOLOGY MONITORING REPORT

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Prepared for

El Dorado Irrigation District
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Acronyms

cfs	cubic feet per second
EID	El Dorado Irrigation District
FERC	Federal Energy Regulatory Commission
GSA	Girl Scout Access
JSM	Jake Schneider Meadow

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Chapter 1

Introduction

The El Dorado Irrigation District (District) owns and operates the El Dorado Hydroelectric Project (Project 184), which is licensed by the Federal Energy Regulatory Commission (FERC). As a requirement of the FERC Project 184 license[1], the District is required to conduct geomorphic investigations at Caples Creek, Oyster Creek, and the Caples Lake Spillway Channel as described in the Geomorphology Monitoring Plan: Sensitive Site Investigation and Mitigation Plan Development (Monitoring Plan; EID 2008). The primary objective of the Caples Creek component of the Monitoring Plan is to analyze Caples Creek hydraulics and sediment transport to determine an appropriate pulse flow magnitude specific to channel and riparian maintenance needs for Caples Creek. This Monitoring Report provides the results of the Caples Creek component of the Monitoring Plan and makes recommendations regarding the flow regime needed to achieve channel stability and natural resource objectives in Caples Creek. Results of the geomorphic investigations conducted at Oyster Creek and Caples Lake Spillway Channel are reported under separate cover (EID 2009a; EID 2010, respectively).

1.1 Monitoring Plan Study Objectives and Natural Resource Objectives

There are no known past studies performed on Caples Creek to determine the discharge magnitude and frequency required to meet channel maintenance goals. There is also relatively little information on the unimpaired high-flow regime for Caples Creek. The present study analyzes Caples Creek hydraulics and sediment transport to help determine an appropriate pulse flow magnitude specific to channel and riparian maintenance needs for Caples Creek. This report is organized according to the following main study objectives identified in the Monitoring Plan (EID 2008) which include:

1. Conducting a field assessment of geomorphic conditions between the confluence with the spillway channel downstream to Jake Schneider Meadow to document channel stability/instability;

2. Performing hydraulic and sediment transport modeling to evaluate pulse flow requirements for channel and riparian maintenance;

3. Conducting a controlled test flow release to calibrate hydraulic modeling and to conduct *in-situ* field studies to demonstrate flow magnitude needed to transport sediments; and

4. Identifying mitigation measures to meet channel geomorphological objectives.

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[1] Section 7 of the El Dorado Relicensing Settlement Agreement, U.S. Forest Service 4(e) Condition No. 37, and California State Water Resources Control Board Clean Water Act Section 401 Water Quality Certification Condition No. 13

The Monitoring Plan also provides guidance regarding the objectives to consider for the development of pulse flow recommendations:

Pulse flow magnitude and frequency should be dimensioned so as to provide for the following resource objectives as listed in Appendix B of the Settlement Agreement (EID 2003) and the Monitoring Plan (EID 2008):

Fluvial Geomorphology Objective

- Maintain or restore channel integrity.
- Maintain, improve, or restore fluvial processes to provide for balanced sediment transport, channel bed material mobilization and distribution, and channel structural stability that contribute to diverse aquatic habitat and healthy riparian habitat.

Riparian Habitat Objective

- Maintain or restore riparian resources.
- Maintain and restore instream flows sufficient to sustain desired conditions of riparian, aquatic, wetland, and meadow habitats.

Connectivity Objective

- Maintain and restore spatial and temporal connectivity for aquatic and riparian species within and between watersheds to provide physically, chemically, and biologically unobstructed movement for their survival, migration, and reproduction.

Additionally, pulse flows should not be too high as to cause excessive transport, particularly de-stabilizing spawning gravels so that they are depleted from the channel reach and the bed is coarsened.

Chapter 2

Caples Creek Geomorphology

An assessment of geomorphic conditions was performed along 6.5 miles of Caples Creek from the confluence with the Caples Dam Spillway Channel downstream to Jake Schneider Meadow (Figure 2-1). The Monitoring Plan did not call for an assessment upstream of Caples Meadow to Caples Reservoir or downstream of Jake Schneider Meadow to the confluence with the Silver Fork American River, however we have included some information in these sections of Caples Creek to provide a complete understanding of the channel. The assessment included a review of the geomorphic information collected for the relicensing studies, inspection of aerial photography, and a field survey. Information collected in accordance with the Monitoring Plan included characterizing channel planform (sinuosity), channel patterns (single thread, braided, types of depositional features present), gradient, entrenchment, dominant bed particle sizes, channel classification, and describing general channel stability (identifying evidence of channel degradation/aggradation, and bank erosion).

2.1 Reach Delineations and Descriptions

Channel typing using the Rosgen level I and II classification scheme was performed during relicensing studies (ENTRIX 2002). The level I classification was applied to the entire channel, and the Level II classification was applied only to those specific study sites that were considered to be most responsive to changes in the streamflow regime. Figure 2-2 shows the Rosgen (1996) channel classifications. Figure 2-3 is an elevation profile of the Caples Creek channel from the Silver Fork American River confluence to the dam.

Caples Creek is about evenly divided between a non-adjustable bedrock and boulder dominated, steep gradient (8 to 10 percent or more) entrenched A-type channel, alternating between reaches that are alluvial and adjustable channel segments typical of the moderately steep (2 percent) and moderately entrenched B-type channel. Field inspections conducted in 2007 for this Monitoring Report found that the A-type channels are bedrock (A1) and boulder (A2) dominated. The B-type channel segments were mostly dominated by small boulders (B2), although cobble (B3), gravel (B4) and sand dominated (B5) segments were also observed. Much of the channel length follows the jointing pattern in bedrock outcrops. The channel is nearly always a single thread, although there is a prominent channel bifurcation in a bedrock-boulder dominated section about 30,000 feet upstream from the Silver Fork (see Figure 2-3). The A and B channel types showed very few sediment deposits as bar forms, typically having step-pool and cascade bedforms dominated by randomly organized boulders with only small pockets of finer gravel or sand material. The cascade bedform is characteristic of higher gradient mountain channels and are supply limited[2]. The channel pattern over the entire length of Caples Creek has a low sinuousity,

[2] Supply limited channels have a much greater capacity to transport sediments than the available sediment sources, which is often a characteristic of mountain streams (Montgomery and Buffingtion 1997).

1.13 (channel length/valley length), where meanders tend to occur only in the flatter gradient alluvial channel sections and is most prominent in the C channel sections, discussed next.

Other than the A and B type channel classification, there are relatively short lengths of channel defined by low-gradients (0.2 percent), and poorly entrenched with a well developed floodplain. These are the C-type channels, of which the Caples Meadow reach is the largest in association with a wide valley floodplain over a 4,000 foot channel length. Just downstream from the Caples Meadow reach is the Girl Scouts Access (GSA) reach, also a C type channel, which is essentially a continuation of the Meadow reach, but where the valley width is defined by a more narrow floodplain. Both the Caples Meadow and GSA reaches have a pool-riffle bedform with sediment storage in bar forms. The pool-riffle bedforms exhibits a mixture of supply and transport limited characteristics, depending on the degree of bed-surface armoring. In these reaches, armored pool-riffle channels represent supply-limited conditions (Montgomery and Buffington 1997) and gravel is the dominant particle size. The channel reach at the Jake Schneider Meadow (JSM) was classified as an F4 (gravel dominated) channel during relicensing studies. However, based on our field observations and studies for this report, the JSM site within the boundaries of the study area is more moderately entrenched rather than the more highly entrenched section of this reach just downstream from the study sites. The more moderately entrenched channel, with a moderate width-depth ratio is characteristic of the B-channel types. Up and downstream from Jake Schneider Meadow itself, the channel is classified as a B/F channel type over a 12,000-foot long reach.

The channel segments identified as most responsive to EID project operations during relicensing were the Caples Meadow and JSM sites. The geomorphology of the study sites is discussed in more detail in the next section.

2.2 Study Sites

Caples Meadow and Jake Schneider Meadow (see Figure 2-1) are identified in the Monitoring Plan as locations for conducting detailed hydraulic and sediment transport assessments since these locations are likely to be representative of channel types that are most responsive to changes in the watershed. The two study sites are lower gradient, meandering, poorly to moderately entrenched, pool-riffle channel segments, with smaller bed particle sizes than the steeper, moderate to highly entrenched, boulder and bedrock step-pool and cascade channels that comprises most of the length of Caples Creek.

The study sites provide geomorphic conditions valuable for supporting trout spawning and rearing and for the maintenance of riparian habitat. The basic approach articulated in the Monitoring Plan is to evaluate the magnitude of pulse flows based on the capacity to provide channel maintenance in these responsive channel types. Pulse flows should provide periodic transport of the bed material sufficient to prevent excessive deposition of fines in spawning gravels, and to maintain an equilibrium channel form that prevents either aggradation or degradation of the bed, and maintains the channel bankfull dimensions over the long-term.

For both study sites, topographic surveys were performed of the channel cross-section and longitudinal profile, and bed particle size data was collected using pebble counts and bulk sampling. A hydraulic model was developed for the study sites using the cross-section, longitudinal profile, and bed particle size data. The hydraulic model was calibrated based on water surface elevations obtained over several different flows (see Chapter 4). In August 2010, various sediment transport and erosion studies were also performed at both study sites during two controlled flow releases (116 cfs and 220 cfs).

2.2.1 Caples Meadow

The Caples Meadow study site extends from the confluence with the spillway channel to 1,200 feet downstream. Kirkwood Creek joins Caples Creek just downstream from the spillway channel. At the Kirkwood Creek confluence the Caples Creek watershed drainage area is approximately 18.6 square miles with about three-quarters of that drainage area controlled by Caples Lake (13.6 square miles). The study site, showing the location of the cross-sections and longitudinal profile data collection is shown in Figure 2-4.

The measured channel sinuosity (channel length/valley length) is high, 1.55 over the full length of Caples Creek meadow (>1.2 is a moderate sinuosity). There are multiple abandoned channels distributed throughout the meadow floodplain. Point bars, alternate bars, and mid-channel bars are prevalent sediment storage features. The channel gradient is low, 0.0026 foot per foot. Figure 2-5 is a plot of the channel bed and water surface profile over the study reach at low flow.

In the study reach, the bank erosion hazard was rated “high”, and the channel stability was rated “fair” during relicensing study inventories[3]. Field observations of the streambanks for this current study along with photo comparison from the relicensing studies indicate that bank stability erosion hazard has not changed. Bank erosion in the form of slumping of sections of streambank were often observed. Willows are growing on the floodplain, although there are few willows growing directly along the eroding streambank face. The bank erosion hazard on Caples Creek upstream from the Kirkwood Creek confluence was rated “very low” with a “fair” channel stability rating.

Four pebble counts were performed, and one bulk sample was collected from the study reach to characterize bed particle sizes. Wolman (1954) method pebble counts were conducted at multiple cross-sections during low-flow where the conditions permitted using the method, which include flow depths that are not too deep to hand sample particles from the bed and where the predominant particle sizes are coarse enough to distinguish from each other when selecting a particle from the bed (i.e., most particles are coarser than about 8 mm). Table 2-1 shows the pebble count results. The D_i particle sizes represent the cumulative frequency particle size of which *i* percent of the bed surface is finer than. For example, the D_{50} particle size, or median particle size, means that half of the bed surface is finer than the reported value. The geometric mean, like the D_{50} is a measure of the central tendency for a heterogeneous mixture of particle sizes, and is calculated as the square root of the product of the D_{16} and D_{84} particle sizes. The extremes of the particle size distribution have more influence on the geometric mean than the D_{50}. Cumulative particle size distribution plots and frequency histograms for each pebble count sample are provided in Appendix A.

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3 The relicensing study inventories took place in 1999 and 2002, which followed the 1997 wet year during which substantial high flows were experienced throughout the Sierra Nevada.

The dominant particle size (i.e., the size class represented by the greatest frequency) on the bed surface is coarse gravels for each of the sampled transects. Sand makes up a relatively small proportion of the particles sizes sampled. Descriptions of the particle sizes according to the Wentworth scale are presented in Table 2-2. Gravel size particles range from >2 to 64 mm, and sand size material ranges from .06 to 2 mm.

Table 2-1 Caples Meadow Study Site Particle Size Data

	D_{10}	D_{16}	D_{50}	D_{84}	D_{90}	Geometric Mean	Percent Sand	Dominant Size
Pebble Count XS Most Upstr	7.4	9.3	19.4	31.5	36.1	17.7	0%	Coarse gravel
Pebble Count XS A	8.0	11.4	22.6	35.4	41.1	20.1	0%	Coarse gravel
Pebble Count XS A1	8.9	11.6	20.9	36	40.2	19.3	0%	Coarse gravel
Pebble Count XS 1	1.3	2.5	13.6	26.6	30.0	9.0	12.5%	Coarse gravel
Pebble Count XS B	4.0	5.7	13.3	27.3	30.4	11.2	7.3%	Coarse gravel
Bulk Surface XS B	9.0	11.0	24	31.0	34.0	18.4	1.5%	Coarse gravel
Bulk Subsurface XS B	2.1	3.3	12.2	25.9	29.3	9.6	9%	Medium gravel

Table 2-2 Wentworth Particle Size Scale

Particle Size Range	Description
>256 mm	boulder
64–256 mm	cobble
32–64 mm	very coarse gravel
16–32 mm	coarse gravel
8–16 mm	medium gravel
4–8 mm	fine gravel
2–4 mm	very fine gravel
1–2 mm	very coarse sand
0.5–1 mm	coarse sand
0.25–0.5 mm	medium sand
0.125–0.25 mm	fine sand
0.063–0.125 mm	very fine sand
0.0039–0.063 mm	silt
0.00024–0.0039 mm	clay

Bulk sediment samples were also collected on one cross-section deemed most representative of the overall reach at all three study sites. A bottomless 5-gallon bucket was worked into the bed to define a sampling area. The surface and subsurface layers were sampled and analyzed separately to determine the extent of armoring of the channel bed. The bulk subsurface sediment best reflects the gradation of the bedload transported through the reach. The surface layer depth was defined as the depth of the maximum particle size exposed on the bed surface. All material coarser than 16 mm was dried, sieved and weighed in the field, while material finer than 16 mm was taken to a laboratory where it was dried, sieved and weighed. The field and laboratory results were combined to create a single particle size distribution. The bulk sample particle size distribution plots and frequency histograms for Caples Meadow study site are provided in Appendix A. Results of the bulk sediment sampling for Caples Meadow at XS-B are presented in Table 2-1.

The armor ratio, which is calculated as the ratio of the D_{50} surface to D_{50} subsurface is an index characterizing the degree to which the surface particles are larger than the subsurface particles. The higher the ratio, the greater the degree of armoring. Research has shown that streams with a high sediment supply have a low ratio close to 1, streams in which transport capacity exceeds sediment supply the value is approximately 2 (Bunte and Abt 2001). For streams in which sediment supply is nearly eliminated and a coarse lag deposit exists the armor ratio value can be 3 or more. The armor ratio using the bulk surface to subsurface median particle size from XS-B (22.8 mm/12.2 mm) is 1.96. This is consistent for most mountain streams which are typically considered to be supply-limited; that is the transport capacity of the channel is much greater than the available sediment supply.

2.2.2 Jake Schneider Meadow

Jake Schneider Meadow is located about 6.5 miles downstream from Caples Meadow. The drainage area to this study reach is approximately 30 square miles, with about 45 percent of the drainage (13.6 sq mi) controlled by Caples Lake. The study reach is near a long, narrow sloping meadow set-back from and above the stream. Unlike the Caples Meadow study reach where the channel is poorly entrenched and bordered on both banks by a wide floodplain, Jake Schneider Meadow is at least 100 feet and in some areas more than 200 feet from the stream, is located on only the right side of the channel, and the channel is moderately to highly entrenched along most of the study reach.

Relicensing studies stated that there are indicators of lateral instability and evidence of bank erosion probably associated with the 1997 flood (ENTRIX 2003). At the time of the relicensing studies, extensive bank erosion, rooted tree falls resulting in large woody debris jams, and records that a trail bridge crossing downstream washed out, were all indicators of substantial damage due to the 1997 floods. The overall bank erosion hazard rating was “very high” and the overall channel stability was rated “poor”. Field observations of the streambanks for this current study indicate that bank erosion hazard has not changed.

Figure 2-6 shows the location of cross-section and longitudinal profile topographic surveys conducted along the 1,050-foot length of the Jake Schneider Meadow study site. The gradient is lower than Caples Meadow, 0.0014 foot per foot (elevation/distance) (Figure 2-7). The bedform is pool-riffle, and sediment storage is on the bed and in bar formations. The channel is single thread, and with the exception of meander scars close to the existing channel there is no evidence of any remnant or abandoned channels in the meadow. Channel sinuosity is moderately low, 1.15.

Employing the same methods that were utilized for Caples Meadow, two pebble counts were performed, and one bulk sample was collected to characterize bed particle sizes at JSM. Table 2-4 shows the particle size characteristics for each sample, and cumulative particle size distribution plots and frequency histograms for each sample are provided in Appendix B. Two cross-sections were selected with particle sizes coarse enough to measure using the pebble count method. Surface particle sizes at these cross-sections spanned the range from fine gravel to coarse gravel with a small amount of cobble. Most material is in the medium gravel size range (8 to 16 mm). The bulk sample surface fraction was mostly comprised of medium gravel material, although sands were also present, representing about 10 percent of the sample. The bulk sample subsurface material was finer than the surface material and comprised of 33 percent sand, mixed with fine, medium and coarse gravels. The armor ratio is 2.4, indicating a greater relative degree of armoring than Caples Meadow. Field observations found that the majority of the JSM reach has surface particle sizes finer than that indicated by the pebble count data from the two cross-sections. More of the reach consists of bed sediment similar in texture to the bulk subsurface sample that was comprised of fine to coarse gravels mixed with sand. In general, the bulk subsurface particle sizes are the best indicator of the bedload particle size distribution transported into the reach.

Table 2-3 JSM Study Site Particle Size Data

	D_{10}	D_{16}	D_{50}	D_{84}	D_{90}	Geometric Mean	Percent Sand	Dominant Size
Pebble Count XS 1	5.8	6.7	13.3	55.1	71.1	16.3	0%	Medium gravel
Pebble Count XS B	4.5	5.7	11.1	19.1	21.5	10.8	0%	Medium gravel
Bulk Surface XS B	1.9	3.3	11.1	21.1	25.9	8.5	10%	Medium gravel
Bulk Subsurf XS B	0.7	1.0	4.6	12.9	15.4	3.8	33%	Very coarse sand

Chapter 3

Study Site Sediment Transport and Erosion

Direct measurements of sediment transported as suspended load and bedload using field-based empirical methods were made for both the 116 cfs and 220 cfs test flows. The objectives of the sediment sampling were to determine how the rate of sediment transport and the sizes of particles transported vary with flow magnitude. Two additional studies identified in the Monitoring Plan are the installation of erosion pins to track the amount of bank erosion and the use of repeat cross-section surveys to track bed and bank changes over time at both the Caples Meadow and JSM study sites.

The controlled flow releases at Caples Dam were also measured in the Caples Meadow study reach downstream from the Kirkwood Creek confluence, and at the Jake Schneider Meadow study reach. The measured flows at the study sites, which was slightly different than the release at Caples Dam, are used for all of the sediment transport and bed material mobility analyses. The lower controlled flow was 116 cfs and the higher controlled flow was 220 cfs. The controlled flow releases were conducted in August when accretions were anticipated to be minimal. The measured flows at the study sites confirmed that discharge was the same at both Caples Meadow and JSM during the controlled flow releases.

3.1 Suspended Sediment Transport

Suspended sediment transport rates were measured with a depth-integrating hand-held suspended sediment sampler (DH-48) at the Caples Meadow and Jake Schneider Meadow study sites. Samples were collected at two different cross-sections for both the low and high controlled flow releases for a total of four samples at each study site. All samples were collected using the standard USGS equal width interval method (Edwards and Glysson 1999). The sample bottles were sent to a laboratory where they were analyzed for total suspended solids and particle size distribution.

Figure 3-1 is a suspended sediment rating curve (data fitted to an exponential trend line) that shows how the sediment load increases with discharge at the two study sites. JSM had higher suspended sediment loads than Caples Meadow for the same flow release. This may be due to the presence of a finer grained bed surface at JSM compared to Caples Meadow, but could also be due to the fact that the JSM study site is 5 miles further downstream, allowing a greater opportunity for recruitment of fine-grained sediment sources from a larger watershed drainage area than at the higher elevation Caples Meadow site. JSM suspended sediment loads ranged from 12-15 tons/day at 116 cfs and from 19-33 tons/day at 220 cfs. Caples Meadow suspended sediment loads ranged from 4-8 tons/day at 116 cfs and approximately 10 tons/day at 220 cfs. The variability within each study site at a given discharge is within a factor of about two times, which is not uncommon for suspended sediment transport measurements. It is clear from the results of both study sites that suspended sediment transport of fines is already occurring by the time discharge reaches about 116 cfs.

At both sites the median grain diameter increases with increasing discharge as the flow magnitude increases and larger diameter particles are suspended in the water column (Figure 3-2). At Jake Schneider Meadow the D_{50} increases from 0.03 mm (silt) at 116 cfs to about 0.15 mm (fine sand) at 220 cfs, while at Caples Meadow it increases from 0.05 mm (silt) to 0.18 mm (fine sand).

3.2 Bedload Transport

3.2.1 Helley-Smith Sampling

Bedload transport rates were measured with a hand-held Helley-Smith bedload sampler with a 3 inch orifice opening at the Caples Meadow and Jake Schneider study sites. Samples were collected at two different cross-sections at each site for both the low and high controlled flow releases. All samples were collected using the standard USGS equal width interval method (Edwards and Glysson 1999). The sediment collected during the sampling was sent to a laboratory where it was dried, sieved, weighed and then analyzed for total sample mass and particle size distribution.

Figure 3-3 is a bedload rating curve (fit to an exponential trend line) that shows how the sediment load increases with discharge at the two study sites. Caples Meadow shows higher bedload transport rates than Jake Schneider Meadow for about the same flow. This is due to the steeper and therefore higher energy channel at Caples Meadow compared to the less steep channel at Jake Schneider Meadow. From the rating curve, Caples meadow bedload transport rates ranged from 3 to 12 tons/day at 116 cfs and 6-22 tons/day at 220 cfs. Bedload transport rates at the JSM study site ranged from 1-3 tons/day at 116cfs and 4-17 tons day at 220 cfs controlled flows. The variability between bedload data at a given discharge is about four times, which is reasonably close for bedload measurements that can show scatter up to an order of magnitude.

Particle size cumulative frequency curves of all the Helley-Smith bedload samples are displayed in Figure 3-4 for Caples Meadow and Figure 3-5 for Jake Schneider Meadow. A summary table of the results in presented in Table 3-1. At Caples Meadow the D_{50} bedload particle size ranges from 5 mm to 8 mm. Sand comprised from 21 percent to 35 percent of the total bedload in transport, with fine to coarse gravels comprising the majority of the transported material through both the lower and higher controlled flow discharge range that was sampled. The D_{90}, which is a measure of the coarsest particles in transport, ranges from 18 to 25 mm at 116 cfs to 23 to 27 mm at 220 cfs. Photo 3-1 is a series of underwater snapshots clipped from video frames that show bedload in transport during the recession from the 220 cfs flow in Caples Meadow.

Table 3-1 Bedload Particle Size Measured with Helley-Smith Sampler at Caples Meadow and Jake Schneider Meadow Study Sites

	Caples Meadow				Jake Schneider Meadow			
	116 cfs	116 cfs	220 cfs	220 cfs	116 cfs	116 cfs	220 cfs	220 cfs
	XS A	XS 3	XS A	XS 3	XS A	XS C	XS A	XS C
D_{10}	0.8	0.7	0.5	0.6	0.3	0.4	0.3	0.4
D_{16}	1.2	1.3	0.7	0.8	0.4	0.5	0.4	0.5
D_{50}	8.3	7.3	4.5	5.4	0.8	2.9	0.7	2.6
D_{84}	22.1	15.8	16.1	20.5	1.9	8.2	1.7	7.2
D_{90}	24.9	17.9	22.8	27.3	2.7	9.8	2.2	10.2
% Sand	22%	21%	35%	32%	87%	39%	91%	43%

At Jake Schneider Meadow the particle size distribution of the measured bedload varied depending on the sampling site. The flow magnitude over the discharge range sampled did not substantially influence the particle sizes in transport. Sand comprised from 39 percent to 91 percent of the total bedload, with very fine to medium gravels comprising the rest of the bedload material transported. The D_{50} bedload particle size transported at XS A and XS C are consistently about 0.8 mm and 2.8 mm, respectively, regardless of whether it was the lower or higher flow release sampled. The D_{90} bedload particle sizes in transport at JSM range from approximately 2.7 mm at XS A to 10.2 mm at XS C.

3.2.2 Net Frame Bedload Sampling

In addition to the Helley-Smith sampling, bedload traps designed by the U.S. Forest Service (Bunte et al. 2007) were deployed at both the Caples and JSM study sites. Bedload traps are portable samplers that are affixed to the channel bed and are specifically designed to trap gravel and cobble size bedload sediment (4 mm to 180 mm in diameter), but allows sand sized particles to pass through. The traps are net samplers that are secured to the channel bed with a metal plate. The frame of the sampler is 1 foot wide, 8 inches tall, with a 2 foot-long net that collects bedload. Several bedload traps are installed side-by-side to collect a representative proportion of the bedload material transported through the cross-section. The bedload traps are designed with large capacity sampler nets that are intended to allow the traps to be deployed for a long time period (e.g., hours), thus increasing sample time over most other bedload measurement techniques (including Helley-Smith) and enabling more accurate measurements of transport.

Caples Meadow Study Site

Six total bedload traps, three each on XS A (Photo 3-2) and XS 3, were installed at Caples Meadow. The bedload traps were initially deployed on August 3 and were allowed to collect sediment over the approximately 16-hour duration of the targeted 116 cfs flow release. At the end of the sampling period, the sampler bags were emptied so the trapped material could be analyzed. Several challenges were encountered with use of the bedload traps during the monitoring study, with the conclusion that they did not perform as intended and were therefore not an effective method of sampling bedload for this study.

Several of the nets contained large quantities of organic debris (pine needles, pine cones, and other woody organic debris) at the end of the sampling period (Photo 3-3). As the nets filled with organic debris their ability to accurately trap the sediment load in transport diminished substantially. Care was taken to bury the metal base plate of the sampler under the surface sediment to limit potential for hydraulic scour. However, the flow obstruction created by the samplers themselves, when left in place for such a long duration caused the bed to eventually scour below the sampler's bottom plates. This caused the bed and bottom plate of the sampler to sink, leaving the framed-net portion of the sampler perched several inches above the channel bed. This allowed bedload to pass through the gap between the framed net and the bottom metal plate, preventing the trapping of bedload. In addition, two of the three samplers deployed at XS 3 were washed downstream 50 to 75 feet at some time during the 116 cfs release and the third sampler had become partially dislodged from the bed. Prior to the 220 cfs target release the samplers at XS A were re-deployed in the bed in slightly different positions with the hope of achieving better results. The samplers that had washed out at XS 3 were moved upstream to a lower velocity area at XS 2. The results from the 220 cfs release were no better than the previous release. The bed still scoured beneath the samplers and ultimately no useful data was collected with this method.

JSM Study Site

Four bedload traps, two on XS A and two on XS C, were installed at Jake Schneider Meadow using the U.S. Forest Service guidelines (Bunte et al. 2007). All of the bedload traps remained stable and affixed to the bed during the 116 cfs flow. However, a substantial amount of woody debris was captured in the samplers, similar to the Caples Meadow study site. Some sand and a small amount of very fine gravels (up to 8 mm) were captured in the samplers intermixed with the woody debris in all four samplers at both sites (Photo 3-4). Some of this fine material should have passed through the netting as designed, but because the woody debris clogged the net, the fine material was captured. It is not known whether the back-pressure created by the woody debris clogging the net may have caused the samplers to function improperly. Since there was very little sediment captured, and most of what was caught should have passed through the net, and the woody debris may have caused the samplers to function improperly, the samplers were emptied and cleaned, with no useful data collected. The four samplers were redeployed at the same locations for the 220 cfs flow.

Following the 220 cfs controlled flow, the samplers were inspected to see if they were flush to the bed, and that the sampling frame was flush to the bottom metal plate leaving no gaps for bedload to pass through without getting captured in the net. At XS-C the right sampler had a one inch gap under the metal plate, and the left side sampler bottom metal plate was flush to the bed but there was a gap between the net frame itself and the metal plate through which bedload could pass. Both samplers were partially filled with woody debris and sand, no gravel sizes were observed. At XS-A the bottom metal plate on both samplers remained flush to the channel bed, but there was a small ¼-inch (6 mm) gap between the net frame and the bottom metal plate that could let smaller bedload pass through. It is not known to what extent the small ¼-inch gaps might have prevented larger gravel sizes from entering the sampler. There were no gravels or sand captured in either sampler, only woody debris, and ultimately no useful data was collected using this method.

3.2.3 Tracer Gravels

Tracer gravels were installed at the Caples Meadow and JSM study sites to track bedload movement during the two controlled flow releases. Gravels ranging from 19 to 76 mm were collected from the channel, sized, painted, and installed at multiple cross-section locations in a single line at each site. The tracers were worked into the surrounding bed material so that they were embedded in a manner similar to the channel bed material. After each controlled flow release was completed and ramped back to a minimum discharge, the number, size, and distance that any particles moved were recorded. Gravels that could not be found in place or that were not recovered downstream from the transect were recorded as missing, and are presumed to have been mobilized. After completion of the last flow release, the tracer line was checked to make sure that no tracers observed as missing had actually been buried in place. Particles that moved less than 0.5 foot from their transect were not counted as moved. Results for the two study sites are provided and discussed below.

Caples Meadow Study Site

Table 3-2 shows the results of the tracer study for the Caples study site. Eighty-six tracers gravels were placed along three transects prior to the 116 cfs controlled flow. Tracer gravels were mobilized at each of the three cross-sections tested. Table 3-2 shows the results of the tracer study. There was entrainment of every size class tracer, including the 76 mm size class (cobble), the largest tracer used. One-third of the 30 tracers moved at XS-3, nearly one-half of the 25 tracers moved at XS-B, and one-quarter of the 31 tracers moved at XS-A.

115 tracers were installed at four transects prior to the 220 cfs controlled release. Tracer gravels were mobilized at each of the four cross-sections tested, and there was entrainment of every size class tracer including the largest 76 mm size class. 84 percent of the tracers moved at XS-3, 80 percent at XS-B, 30 percent at XS-A, and 67 percent at XS-2. This represents an increase in the total proportion of tracer gravels mobilized at every transect over the 116 cfs flow release. The transported distances also generally appear to be greater.

From the tracer results, bed material transport was occurring by 116 cfs since all grain sizes were entrained at all sites, and particles larger than the D_{50} bed particle size (13.3 mm) and D_{84} (27.3 mm) based on pebble counts were mobilized. The channel bed was in full transport by the 220 cfs flow, with well more than one-half the tracers mobilized at three of the four transects.

JSM Study Site

Table 3-3 shows the results of the tracer study for the JSM study site. Ninety tracers were placed along three transects prior to the 116 cfs flow. The largest particle size entrained was in the 27 mm size class. A small proportion of the total number of tracers placed were mobilized, only 3 percent each at XS-1 and XS-2, and 10 percent at XS-C. Overall, bed mobility increased at the 220 cfs flow, with 0 percent, 17 percent, and 30 percent of the tracers mobilized at XS-1, XS-2, and XS-C, respectively. The largest particle size entrained also increased to the 38 mm size class, although there were only two instances, one at XS-2 and one at XS-C (Photo 3-5).

Table 3-2 Tracer Gravel Results Caples Meadow Study Site

Flow (cfs)	Cross Section	Size (mm)						
		19	27	38	54	76	Total	
116	XS-3	6	6	6	6	6	30	Total No. Tracers
		3	5	3	5	4	20	No. That Did Not Move
							0	No. That Moved
								Distance Downstream of XS (ft)
		3	1	3	1	2	10	No. Missing
		50%	17%	50%	17%	33%	33%	Percentage Moved and Missing
	XS-B	5	5	5	5	5	25	Total No. Tracers
		4	1	3	1	4	13	No. That Did Not Move
		1	4	2	4	1	12	No. That Moved
		1.5'	1.1', 2', 3.1', 4.9'	3.6', 12'	1', 2.1', 2.4', 2.8'	1.9'		Distance Downstream of XS (ft)
							0	No. Missing
		20%	80%	40%	80%	20%	48%	Percentage Moved and Missing
	XS-A	7	6	6	6	6	31	Total No. Tracers
		4	4	6	5	4	23	No. That Did Not Move
		3	2		1	2	8	No. That Moved
		2', 2.4', 7'	0.9', 1.8'		1.1'	1.3', 1.9'		Distance Downstream of XS (ft)
							0	No. Missing
		43%	33%	0%	17%	33%	26%	Percentage Moved and Missing
220	XS-3	5	5	5	5	5	25	Total No. Tracers
		1	1	1		1	4	No. That Did Not Move
		4	4	3	4	3	18	No. That Moved
		13', 16', 19', 22'	11.5', 15', 15', 26'	12', 15.5', 19'	9.5', 12', 13'	10', 16', 26'		Distance Downstream of XS (ft)
		0	0	1	1	1	3	No. Missing
		80%	80%	80%	100%	80%	84%	Percentage Moved and Missing
	XS-B	6	6	6	6	6	30	Total No. Tracers
		2	1	1	1	1	6	No. That Did Not Move
			2	2	3	3	10	No. That Moved
			0.7', 13'	0.5', 6'	5', 12', 20'			Distance Downstream of XS (ft)

Table 3-2 Tracer Gravel Results Caples Meadow Study Site, continued

Flow (cfs)	Cross Section	Size (mm)						
		19	27	38	54	76	Total	
220		4	3	3	2	2	14	No. Missing
		67%	83%	83%	83%	83%	80%	Percentage Moved and Missing
	XS-A	6	6	6	6	6	30	Total No. Tracers
		4	4	5	4	4	21	No. That Did Not Move
			1			1	2	No. That Moved
			2.5'			2'		Distance Downstream of XS (ft)
		2	1	1	2	1	7	No. Missing
		33%	33%	17%	33%	33%	30%	Percentage Moved and Missing
	XS-2	6	6	6	6	6	30	Total No. Tracers
		1	2	2	2	3	10	No. That Did Not Move
		2	2	3	2	3	12	No. That Moved
		0.5', 13'	0.5', 1.2'	1.2', 8', 11'	4', 13'	2.6', 5', 15'		Distance Downstream of XS (ft)
		3	2	1	2	0	8	No. Missing
		83%	67%	67%	67%	50%	67%	Percentage Moved and Missing

Both the 116 cfs and 220 cfs flows entrained particles larger than the D_{50} bed material (11.1 mm) and the D_{84} bed material (19.1 mm) based on pebble counts. However, the proportion of tracer gravels actually mobilized was low indicating that the D_{50} and D_{84} bed material is not transported at flows of 220 cfs or less.

Table 3-3 Tracer Gravel Results JSM Study Site

Flow (cfs)	Cross Section	Size (mm)						
		19	27	38	54	76	Total	
116	XS-1	6	6	6	6	6	30	Total No. Tracers
		6	5	6	6	6	29	No. That Did Not Move
			1				1	No. That Moved
			< 1'					Distance Downstream of XS (ft)
							0	No. Missing
		0%	17%	0%	0%	0%	3%	Percentage Moved and Missing
	XS-C	6	6	6	6	6	30	Total No. Tracers
		5	4	6	6	6	27	No. That Did Not Move
			2				2	No. That Moved
			1', 2'					Distance Downstream of XS (ft)
		1					1	No. Missing
		17%	33%	0%	0%	0%	10%	Percentage Moved and Missing
	XS-2	6	6	6	6	6	30	Total No. Tracers
		6	5	6	6	6	29	No. That Did Not Move
			1				1	No. That Moved
			2'					Distance Downstream of XS (ft)
							0	No. Missing
		0%	17%	0%	0%	0%	3%	Percentage Moved and Missing
220	XS-1	6	6	6	6	6	30	Total No. Tracers
		6	6	6	6	6	30	No. That Did Not Move
							0	No. That Moved
								Distance Downstream of XS (ft)
							0	No. Missing
		0%	0%	0%	0%	0%	0%	Percentage Moved and Missing
	XS-C	5	6	6	6	6	29	Total No. Tracers
		2	5	5	6	6	24	No. That Did Not Move
		1	1	1			3	No. That Moved
		.5'	2	0.5				Distance Downstream of XS (ft)
		2					2	No. Missing
		60%	17%	17%	0%	0%	17%	Percentage Moved and Missing

Table 3-3 Tracer Gravel Results JSM Study Site, continued

Flow (cfs)	Cross Section	Size (mm)						
		19	27	38	54	76	Total	
220	XS-2	6	6	6	6	6	30	Total No. Tracers
		2	2	5	6	6	21	No. That Did Not Move
		4	4	1			9	No. That Moved
		1.5', 4', 4', 10'	.5', 1', 1', 2'	.75'				Distance Downstream of XS (ft)
							0	No. Missing
		67%	67%	17%	0%	0%	30%	Percentage Moved and Missing

3.3 Bank Erosion

At the Caples Meadow and JSM study sites, erosion pins were inserted into the streambank before the controlled flow releases, and then measured before and after each controlled flow release to determine if there was erosion. Bank retreat indicates a loss of bank due to erosion. Accretion indicates a gain in bank material, which can occur if there is sloughing of bank material higher up the bank (than the location of the erosion pin) so that the loosened material comes to rest around the pin, resulting in a net gain of bank material at the pin measurement site. Because the bank itself is not smooth but rather exhibits topographic irregularities, small differences may be due to the measurement technique rather than due to any real changes in the bank surface. It was assumed that differences within 0.5 inch (.04 foot) are outside the accuracy of the measurement technique and should not be interpreted as a real change in the bank. Results of the erosion pin study are presented below.

3.3.1 Caples Meadow Study Site Bank Erosion

Changes in the bank were measured following the 116 cfs and 220 cfs releases. Results are provided in Table 3-4.

Table 3-4 Bank Erosion Data for Caples Meadow Following Controlled Flow Release

Cross-Section	Pin	Description	Height of pin above base flow water surface (ft)	Pin head exposed at installation (ft)	Pin head exposed after 116 cfs release (ft)	Bank retreat (-) / accretion (+) (ft after 116 cfs release	Pin head exposed after 220 cfs flow release (ft)	Bank retreat (-) / accretion (+) after 220 cfs flow release (ft)	Cumulative bank retreat (-) / accretion (+) after 220 cfs flow release (ft)
XS-A	C-1	LB	0.08	0.17	0.25	-0.08	0.13	0.12	0.05
	C-2	LB	0.88	0.17	0.19	-0.02	0.17	0.02	0.00
XS-A1	C-3	LB	0.08	0.17	0.15	0.02	0.15	0.00	0.02
	C-4	LB	0.83	0.17	0.19	-0.02	0.17	0.02	0.00
XS-1	C-5	LB	0.33	0.17	0.13	0.04	0.13	0.00	0.04
	C-6	LB	0.67	0.13	0.13	0.00	0.15	-0.02	-0.02
XS-B	C-7	LB	0.00	0.13	0.13	0.00	0.13	0.00	0.00
	C-8	LB	0.50	0.13	0.10	0.02	0.15	-0.04	-0.02
XS-2	C-9	RB	0.08	0.13	0.13	0.00	0.13	0.00	0.00
	C-10	RB	0.38	0.17	0.15	0.02	0.19	-0.04	-0.02
XS-3	C-11	LB	0.08	0.17	0.17	0.00	0.17	0.00	0.00
	C-12	LB	1.42	0.08	0.10	-0.02	0.10	0.00	-0.02

Overall, there was minimal erosion measured at any of the monitored pin sites for either controlled flow release. Of the 12 erosion pins installed, only one measurement (pin C-1) following the 128 cfs flow release exceeded the minimum threshold of .04 foot, with a bank retreat of .08 foot. Following the second 220 cfs release the same pin was again the only location where there was a measurable change, this time in the opposite direction with a bank accretion of + .12 feet. The cumulative net change after both controlled flows was only significant at the C-1 pin site with a net change of +.05 foot accretion.

The results indicate that overall, at the controlled flow releases tested, direct hydraulic shear force alone against the unsaturated bank in the summer was insufficient to initiate erosion. This indicates that different processes other than high velocity flow or in conjunction with high velocity flow is causing streambank erosion (e.g. bank slumping associated with changes in bank pore pressure during recession from spring runoff, freeze-thaw, and grazing-related erosion).

3.3.2 JSM Study Site Bank Erosion

Bank erosion results are provided in Table 3-5. There was minimal erosion measured at all of the monitored pin sites for either controlled flow release. Of the 11 erosion pins installed, no measurements exceeded the .04-foot threshold following either the 116 cfs flow or the 220 cfs flow. Similar to the results for the Caples Meadow reach, this indicates that at the controlled flow releases tested, direct hydraulic force against the unsaturated bank during the summer was insufficient to initiate erosion.

Table 3-5 Bank Erosion Data for JSM Following Controlled Flow Release

Cross-Section	Pin	Description	Height of pin above base flow water surface (ft)	Pin head exposed at installation (ft)	Pin head exposed after 116 cfs release (ft)	Bank retreat (-) / accretion (+) (ft after 116 cfs release	Pin head exposed after 220 cfs flow release (ft)	Bank retreat (-) / accretion (+) after 220 cfs flow release (ft)	Cumulative bank retreat (-) / accretion (+) after 220 cfs flow release (ft)
XS-A	JS-1	LB	0.75	0.23	0.19	0.04	0.21	-0.02	0.02
	JS-2	LB	1.42	0.29	0.27	0.02	0.27	0.00	0.02
	JS-3	RB	0.67	0.21	0.21	0.00	0.21	0.00	0.00
	JS-4	RB	1.08	0.25	0.23	0.02	0.21	0.02	0.04
XS-1	JS-5	LB	1.75	0.23	0.21	0.02	0.21	0.00	0.02
	JS-6	LB	3.50	0.19	0.17	0.02	0.17	0.00	0.02
	JS-7	RB	1.17	0.17	0.17	0.00	0.17	0.00	0.00
	JS-8	RB	2.00	0.17	0.17	0.00	0.17	0.00	0.00
XS-C	JS-9	LB	0.92	0.17	0.17	0.00	0.19	-0.02	-0.02
	JS-10	LB	1.58	0.17	0.17	0.00	0.17	0.00	0.00
	JS-11	RB	2.50	0.25	0.25	0.00	0.27	-0.02	-0.02

3.4 Time Series of Repeat Cross-Section Surveys

At each of the study sites, cross-sections were surveyed in 2010 and used to develop the channel geometry in the hydraulic models. Since some cross-sections were originally set-up and surveyed for relicensing studies as early as 1999, wherever the original cross-section pins could be found, they were re-occupied and surveyed again in 2007, and also surveyed for a third time in August 2010 just prior to the controlled flow releases at the Caples Meadow and JSM study sites. This provided three sets of cross-sections spanning two time periods 1999 to 2007 and 2007 to 2010. There were also several cross-sections that were first established in 2007 and surveyed again in 2010. This provided two sets of cross-sections that spanned the one time period 2007 to 2010. The time series comparison of the cross-sections provides a means to determine if there has been any channel changes indicating bank erosion or bed mobility between the time periods. The time series of cross-sections are plotted together in Appendix C for the Caples Meadow and JSM study sites.

Since 1999 there have been no spill events[4], so the gaging records for annual peak flows provides an accurate indication of the discharge from the Caples Main Dam (Table 3-6).

[4] Personal communication, Mr. Brian Deason, El Dorado Irrigation District.

However, the natural flow accretions below the dam release point to Caples Meadow and to JSM are not known. Regardless of the lack of data on flow accretion, the cross-section survey data still demonstrate the extent to which project operations prior to the new license provided flows that in combination with natural flow accretions have mobilized bed materials. The maximum annual flow from the Project during the 1999-2007 runoff period was 372 cfs, and during the 2007-2010 runoff period was 402 cfs.

During the controlled flow release in August 2010, the cross-sections were surveyed the day before the controlled flow release, and also following the 116 cfs and 220 cfs test flows. This allowed a comparison of the three cross-section sets to determine if there had been any bank erosion or bed mobility associated with each of the two controlled flow releases. At JSM study site the cross-sections were surveyed only prior to the controlled flow release and after the 220 cfs flow, there was no survey after the 116 cfs release.

Table 3-6 Annual Maximum Flow Releases From Caples Reservoir (USGS 11436999)

Water Year	Date	Streamflow (cfs)
2000	June 15, 2000	168
2001	Nov 9, 2000	88
2002	June 3, 2002	286
2003	May 31, 2003	368
2004	December 4, 2003	170
2005	May 25, 2005	356
2006	May 21, 2006	372
2007	July 2, 2007	94
2008	September 6, 2008	184
2009	July 22, 2009	82
2010	June 11, 2010	402

3.4.1 Caples Meadow Study Site

At the Caples Meadow study site, there was evidence of bed movement and some bank erosion at nearly every cross-section except cross-section B between 1999, 2007, and 2010. This indicates that there must have been some flows during these two time periods that were sufficient to transport sediments and erode banks.

During the 116 cfs and 220 cfs controlled flows there was little net change in the bed or banks. However it should be noted that lack of change in the bed form, particularly after a flow release limited to a less than 24-hour period, does not mean there was no bed movement, only that the final shape of the channel and elevation of the bed and bars show no net change. The channel shape including the bar forms and position and depth of the thalweg can remain relatively consistent even if there has been bed material transport.

A summary description of the changes at each cross-section over the survey periods is provided below.

<u>1999-2007-2010 Cross-section Survey Period</u>

Between 1999 to 2007 XS1 down-cut about 2 feet at the thalweg and about 1 foot across 25 feet of the channel bottom. From 2007 to 2010 there was approximately another .5 foot down-cut near the thalweg, with some channel widening against the lower left and right bank, balanced by deposition on the bar close to the right bank.

XS 2 followed a similar pattern with nearly 2 feet of down-cutting at the thalweg which also migrated toward the right bank between 1999 to 2007. The channel bottom and a portion of the point bar on the left bank side of the channel also down-cut 1 to 2 feet, while there was also .5 to 1.0 foot of sediment accretion near the top of the bar. There was an additional 0.5 foot of down-cut around the thalweg and widening of the low-flow channel from 2007 to 2010, but there was also about 1 foot of sediment accretion across the low part of the bar.

Following a pattern similar to XS1 and XS2, XS3 experienced 1.0 foot of incision at the thalweg which migrated against and eroded the right bank from 1999 to 2007. Erosion exceeded 5 feet against the right bank, accompanied by about 0.5 foot of deposition on a 10-foot wide portion of the lower left-bank bar. However, by 2010 the thalweg had re-aggraded more than a foot, raising the channel invert to the 1999 elevation. About 0.5 to 1.0 foot of new deposition occurred by 2010 near the top of the left-bank bar.

Cross-section A, A1, B, and US were surveyed in 2007 and in 2010, there was no prior survey in 1999. The channel bottom near the right bank of cross-section A aggraded slightly, about 0.5 foot, with about 2 feet of bank erosion from 2007 to 2010. At cross-section A1 the channel migrated against the left bank with 2 to 4 feet of erosion, and the thalweg deepened by 0.5 foot. Cross-section B had virtually no change between 2007 and 2010. Cross-section US shows considerable changes between 2007 and 2010. The channel migrated nearly 10 feet into the right bank, establishing a new, wider low-flow section of channel bottom. The erosion was counterbalanced by aggradation up to 0.5 foot over a 16-foot-wide section of the former channel bottom toward the left bank. There was no net change in the maximum depth of the channel from 2007 to 2010 (i.e., the channel did not incise below its 2007 thalweg depth).

<u>2010 Pre- and Post- 116 cfs and 220 cfs Controlled Flow Releases</u>

The channel at XS1 appears to have narrowed slightly following the 116 cfs flow, and then returned to its original width after the 220 cfs controlled flows. However, the cross-section changes are probably small enough to be within survey measurement error, and therefore may not be indicative of any real change in the channel.

At XS2 there appears to be about 0.5 foot of aggradation toward the left bank of the channel bed following the 116 cfs flow, with a loss of that aggradation and return to the pre- controlled flow release channel elevations following the 220 cfs flow release. However the cross-section changes appear to be small enough to have been within the range of survey measurement error.

At XS3 changes appear to be very small, all within the range of potential measurement accuracy.

3.4.2 JSM Study Site

There was evidence of bed and bank changes between 1999 and 2007, and from 2007 to 2010 at two of the three cross-sections surveyed in each of the two time periods. There was virtually no change at one of the cross-sections since 1999. For the three additional cross-sections surveyed only from 2007 to 2010, there were limited changes at two of the cross-sections, and no changes at the third cross-section. The data indicate that there was sufficient flow, particularly during the 1999 to 2007 period, to mobilize bed material as confirmed by the changes in surveyed channel cross-section. The maximum flow releases from Caples Lake was 372 cfs during the 1999 to 2007 time period and 350 cfs during the 2007 to 2010 time period (Table 3-6).

Following the controlled flow releases (at 116 cfs and 220 cfs), there were only small changes in the cross-sections and these changes were within the expected accuracy of survey measurement techniques associated with coarse-bed channels.

1999-2007-2010 Cross-section Survey Period

At JSM XS1 there appears to be very little change to the channel since the 1999 survey. The less than 0.5 foot of aggradation on the channel bed as of 2010 is likely within topographic survey measurement accuracy for coarse bedded channels.

At JSM XS2, there was from 0.5 foot to more than 1.5 foot of down-cutting across 30 feet of the channel bottom width including deepening at the thalweg from 1999 to 2007. There also appears to be a couple of feet of erosion against the right bank. From 2007 to 2010 there was about a foot of sediment deposition against the toe of the left bank channel bottom, with very little change over the rest of the cross-section.

At JSM XS3, there is about 0.5 to 1.0 foot of incision at the thalweg by 2007, with a small amount of additional thalweg lowering by 2010. There was also up to 1.5 feet of sediment deposition by 2007 across the channel bottom outside of the thalweg, and some deposition over the entire left bank. A small amount of additional deposition on the channel bottom and left bank appears to have occurred by 2010.

Cross-sections A, B, and C were surveyed in 2007 and in 2010, there was no prior survey in 1999. From 2007 to 2010, XS-A experienced a small amount of aggradation on the channel bottom at the toe of the right bank slope and the narrow floodplain (station 61 to 66). At XS B there was very little change, (change in graphic cross-section plot for 2010 shows the large woody debris between stations 42 to 48 close to the right bank). There were no changes at XS C.

2010 Post-116 cfs and 220 cfs Controlled Flow Releases

At JSM XS1 the entire channel bottom is less than 0.5 foot lower following the two controlled flow releases. This apparent lowering is likely an artifact of the survey measurement technique.

For XS2, XSA, XS B (change on graphic plot is associated with survey around large woody debris in channel), XS C, there is no difference between the pre- and post controlled flow of 116 and 220 cfs. At JSM XS3 differences between the pre- and post- controlled flow releases appear to be minor, probably an artifact of the survey measurement technique in coarse bed channels.

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Chapter 4

Hydraulic Modeling

Hydraulic modeling using the one dimensional HEC-RAS software developed by the U.S. Army Corps of Engineers was performed for the study reaches. The modeling effort was undertaken for two primary purposes: 1) to determine the water surface elevation (stage) associated with different magnitude flow events and assess how much flow is needed to inundate the floodplain, and 2) to calculate bed shear stresses that were used to predict the flow magnitude needed to mobilize the bed sediment (incipient motion analysis).

A total station survey was performed in August 2007 at the two study sites to collect the cross-section and channel bed and water surface longitudinal profile topography needed for the HEC-RAS modeling. All of the cross-sections were re-surveyed in August 2010 just prior to and following the controlled flow release study. The most recent 2010 topographic data was used in the modeling. The modeled study reach at Caples Meadow is approximately 1,100 feet, and at JSM study site is approximately 600 feet. Maps showing the locations of the surveyed cross-sections at the modeling reaches are shown in Figures 2-4 and 2-6.

4.1 Model Calibration

In addition to channel topography, the hydraulic model requires specification of the channel roughness in order to simulate water surface elevations. Water surface elevations were measured in the field at the study sites to calibrate the Manning's n roughness values used in the model to ensure that the modeled water surface elevations are in agreement with the measured elevations. Discharge measurements made with a current meter were taken in Caples Meadow during the August 2010 controlled flow releases.

Two staff plates were erected at XS A and XS B in Caples Meadow from which observations of stage were recorded throughout the study. In addition to the staff plate readings, water surface profiles throughout the entire reach were surveyed with a total station during both flow releases. During the July 2009 Dam Spillway Channel controlled flow release study, a flow measurement of 76 cfs was made in the Caples Creek channel and the water surface elevation at all the cross-sections were also surveyed to provide additional calibration data. Another calibration data set is from the water surface elevation profile surveyed during the original August 2007 total station fieldwork when the Caples Creek discharge was at 34 cfs. In summary, water surface elevation calibration data was collected for flows of 34 cfs, 76 cfs, 116 cfs, and 220 cfs at the Caples Meadow study site.

At Jake Schneider Meadow study site the original calibration data was collected during the August 2007 total station survey of the water surface profile when the flow in the channel was near 34 cfs. Water surface elevations were surveyed at all the cross-sections during the August 2010 fieldwork prior to the controlled flow release when discharge was approximately 9 cfs. Two staff plates were erected at XS A and XS 2 for the study from which multiple observations of stage were recorded during the controlled flow releases. The most downstream cross-section in the reach (XS 3) was excluded from the hydraulic modeling because it was located too far away from the other cross-sections to benefit the model. In summary, water surface elevation calibration data was collected for flows of 20 cfs, 45 cfs, 116 cfs, and 220 cfs at Jake Schneider Meadow.

Figures 4-1 and 4-2 depict the water surface and thalweg elevation longitudinal profiles for Caples Meadow and Jake Schneider Meadow study reaches at each of the calibration flows. Note that the elevation datum for the study sites are approximate since they were obtained from a hand-held GPS in the field to get a rough elevation reading.

4.2 Hydraulic Modeling Limitations

HEC-RAS model simulations were performed using the steady state mode for a series of flow magnitudes ranging from low flow up to a high flow that fills or over-tops the channel. Field observations during the controlled flow releases found that at Caples Meadow water begins to overbank at some locations at flows as low as 120 cfs, with more widespread overbanking and inundation over sections of the floodplain by approximately 200 cfs. Once water substantially over-banks onto the floodplain, HEC-RAS does not accurately simulate hydraulics because the model assumes one-dimensional flow paths, but in reality flow over the floodplain is two-dimensional and complex since the flow paths do not necessarily parallel the channel. This was observed when the relic high flow channel that is apparent in the meadow north of the active channel became active. This relic channel, which appears as a swale on the floodplain, was actively conveying flow at the 220 cfs release. Therefore, only flows of 300 cfs or lower were simulated using HEC-RAS for the Caples Meadow study site, since a large percentage of the total flow is out on the floodplain and not accurately accounted for in the model at flows greater than approximately 300 cfs. Discharge at the point of overbanking is further discussed in the next report section.

Flows up to 600 cfs were modeled for Caples Creek at the Jake Schneider Meadow study reach. Once discharge reaches 600 cfs flow exits the channel and floodplain (see Appendix E), spreading out onto the relatively flat forested valley floor where there was no topography for the model.

4.3 Overbanking Results

Cross-section plots showing the modeled water surface elevations and the top of bank are provided in Appendix D and E, for Caples Meadow and JSM, , respectively. The cross-section plots are displayed in 1:1 horizontal to vertical scale to better illustrate the true shape of the channel cross-section.

Top of bank and major breaks in slope were identified along each cross-section, such as the boundary between the channel and active floodplain, prominent bar features, or incipient floodplain features. Flow levels that correspond to geomorphic features, including floodplain and terrace surfaces on the left and right banks of the cross-sections were determined from the modeling. Note that the bank stations do not always correspond to the transition between the channel and floodplain.

We describe a floodplain feature according to the USGS definition (Osterkamp 2008):

> Flood plain is a strip of relatively smooth land bordering a stream incision, built of sediment carried by the stream and dropped in slackwater beyond the influence of the swift current of the channel; the level of the flood plain is generally about the stage of the mean annual flood, and therefore one and only one flood-plain level can occur in a limited reach of bottomland.

Other researches have found a correspondence between the floodplain elevation and the 1.5-year to 2.0-year return interval flow, which is often defined as the bankfull flow (Dunne and Leopold 1978). A terrace is distinguished from a floodplain by its higher elevation on the valley floor and is inundated less frequently than the floodplain by flows of greater magnitude than the mean annual flood.

4.3.1 Overbanking at Caples Meadow Study Site

All of the cross-sections at Caples Meadow are well connected to a floodplain. Field observations during known flow releases and the numerical modeling both show that the flow level at which the channel overtops its banks and begins inundating the floodplain varies from 120 cfs to approximately 350 cfs (at XS 3). Figure 4-3 is the HEC-RAS flood profile for the study reach.

A flow release near or exceeding 350 cfs from Caples Lake Main Dam occurred in four years (2003, 2005, 2006, and 2010) between 1993 and 2010, or about once every 4 years (gage 11436999). This does not include flows from Kirkwood Creek or flow accretion between the dam and the meadow. Earlier flow records (gage 11437000) that combine the flow release from Caples Lake Main Dam with spill flow shows (on an average daily flow basis) show that from 1923 to 1992 there were 8 flows exceeding 350 cfs, which is an average occurrence of once every 8.6 years. This does not include flow accretions downstream of the dam or Kirkwood Creek contributions.

Caples Creek was overbanking at several locations during the 220 cfs controlled flow release. The data in Table 4-1 show overbanking was not uniform throughout the reach. Flow was out of bank at some cross-sections while still contained within the banks at others. Natural topographic variations in channel width and height typically influence the discharge needed to over-bank onto the floodplain. Substantial floodplain flow was observed in the relic channel north of the current channel (Photo 4-1). The flow was entering the floodplain upstream of the Caples Spillway Channel and some of the water was flowing back into the main channel near XS 2. At other locations flow extended about 10 to 50 feet beyond the top of bank and ponded on the floodplain (Photo 4-2).

Table 4-1 Caples Meadow Geomorphic Features and Corresponding Flow Level

XS	Flow (cfs)	LB Feature	Flow (cfs)	RB Feature
Most US	210	floodplain	160	floodplain
A	230	floodplain	170	floodplain
A-1	300	floodplain	250	floodplain
1	300	floodplain	200	floodplain
B	120	floodplain	210	floodplain
2	290	floodplain	120	floodplain
3	310	floodplain	~350	floodplain

Photo 4-3 is an oblique aerial of Caples Meadow taken during a flow of approximately 350 cfs on June 11, 2010. It is evident from the photo that a large portion of the meadow is inundated at 350 cfs. Photos 4-4, 4-5, and Photos 4-6, 4-7 are comparisons of Caples Creek up and downstream of Kirkwood Creek confluence at low flow (less than 10 cfs) and during the approximate 350 cfs flow. All the bars are fully inundated and widespread flooding of the meadow is occurring by 350 cfs.

4.3.2 Overbanking at Jake Schneider Meadow Study Site

Figure 4-4 is the HEC-RAS flood profile for the JSM study reach. Caples Creek at the Jake Schneider Meadow study site does not have a broad floodplain that is inundated by the mean annual flood. Most of the Caples Creek channel length is over 100 feet to more than 250 feet from the main portion of the meadow area, and the meadow is perched several feet higher than the channel. At about 600 cfs flow begins inundating the forest floor adjacent to the channel. There is a 150-foot width of forested land between the right bank of the channel and the main portion of the open meadow. The lowest elevation of the meadow is more than 2 feet higher than the right top of bank. Because of the large topographic difference and distance between the meadow and the channel, and given the presence of well-established coniferous trees between the channel and the meadow, the meadow itself is clearly a terrace feature that is only rarely inundated. This is confirmed by the complete lack of flood debris, or presence of remnant high flow channels, in either the forested section bordering the channel or out on the meadow.

Inset floodplain features on the right bank at XS A and XS B begin inundating at flows of 240 cfs and 260 cfs, respectively (Table 4-2). This is a relatively narrow (about 5 feet wide) geomorphic surface that is located about 2 feet below the forested valley floor and has a build-up of sandy deposits (Photo 4-8). This landform feature appears to be regularly and frequently inundated based on the sandy deposits. Other notable features at Jake Schneider Meadow are distinct breaks in the bank slope. The water surface elevation corresponding to these features range from 220 cfs to 460 cfs. As discussed earlier, flows of approximately 600 cfs begin overbanking onto the forested valley floor (Photo 4-9).

Table 4-2 JSM Study Site Geomorphic Features and Corresponding Flow Level

XS	Flow (cfs)	LB Feature	Flow (cfs)	RB Feature
A	250	break in bank slope	240	inset floodplain
1	350	break in bank slope	460	break in bank slope
B	320	break in bank slope	260	inset floodplain
C	220	break in bank slope	240	break in bank slope
2	415	break in bank slope	230	break in bank slope

Opportunities for woody riparian vegetation development at JSM are very limited. The channel at JSM is bordered by a nearly closed-canopy, well-shaded coniferous forest with both mature well-established trees and very young trees growing quite close to the channel (Photo 4-10). There is little opportunity for woody riparian growth within the closed-canopy shaded margins of the channel. Riparian growth is limited to a narrow strip of land that corresponds to the floodplain elevation between the mature forest floor and the regularly wetted channel.

4.4 Equation-Based Incipient Motion Calculations

In addition to the empirical data obtained from the tracer gravel, Helley-Smith bedload, DH-48 suspended load, and time series of cross-section re-survey studies, the output of the hydraulic modeling coupled with incipient motion equations were used to calculate bed shear stress and determine the flow level necessary to initiate motion of the bed sediment. The equation-based analysis allows evaluation of shear stresses and determination of bed mobility at flow levels too high to empirically measure in the field. Using equations to predict bed mobility requires quality shear stress data and a clear statement of the assumptions since different approaches can lead to substantially different results. This section first summarizes the methods we used to calculate the shear stress exerted on the bed and how these values were used to predict bed mobility. See Appendix F for a more detailed description of how the incipient motion calculations were performed.

4.4.1 Shear Stress Calculation

The following equation (Wilcock 1996), which is derived from Keulegan's (1938) resistance law for rough flow, was used to calculate shear velocity (a measure of the velocity gradient near the bed) in this study:

$$\frac{U}{u*} = \frac{1}{\kappa}\ln\left(\frac{h}{ez_0}\right)$$

where U is flow velocity, h is flow depth, and z_0 (the bed roughness length where flow velocity (u) is 0) is calculated from:

$$z_o = \frac{3D_{84}}{30}$$

where D_{84} is the particle size at which 84 percent of the bed surface is finer.

The equation shows that an increase in velocity for a given depth and grain size will result in a higher shear stress on the bed whereas an increase in depth for a given velocity and grain size will result in lower shear stress. This equation, or variations of it, is commonly used to calculate shear velocity values for use in incipient motion and sediment transport analysis

Local bed shear stress (τ) was calculated from the shear velocity ($u*$) and water density (ρ) as:

$$\tau = u*^2 \rho$$

4.4.2 Shield's Number Selection

Whether or not a particle on the stream bed will be entrained by the flow or remain in place depends on: 1) randomness (grain placement and turbulence), and 2) balance of driving fluid drag (F_D) and resisting gravity forces (F_G)

$$F_D \propto \tau_0 D^2, \text{ and } F_G \propto (\rho_s - \rho) g D^3$$

and

$$\frac{F_D}{F_G} \propto \frac{\tau_0}{(\rho_s - \rho) g D} = \Theta = \tau^*$$

Where D is grain diameter and ρ_s is sediment density. The dimensionless bed shear stress (Θ, commonly called the Shields number, or τ^*) is a measure of sediment mobility. If τ^* is greater than the threshold required for sediment motion (τ^*_c, critical dimensionless bed shear stress), then sediment motion is predicted to occur.

Selection of τ^*_c is not a minor task. Much research continues to be performed in the field of sediment movement initiation. For sediment mixtures of coarse and fine particles, the coarser particles (e.g., gravel) in the mixture will be relatively easier to mobilize than if all the sediment was the same size because the coarser grains protrude higher into the water column where flow velocities are greater, and they have relatively lower pivoting angles. By contrast, the smaller particles in the sediment mixture have higher pivot angles, and are shielded from the higher flow velocities by the larger particles. Therefore, the finer (e.g., sand) particles in a mixture can be relatively harder to mobilize than if all the sediment was the same size.

Additionally, research has shown the importance of the percentage of sand in a sediment mixture on the critical shear stress needed to mobilize both sand and gravel particles (Wilcock 1998; Wilcock and Crowe 2003). Less shear stress is needed to mobilize the gravels in a gravel-sand mixture than in a homogeneous mixture of all gravel. The Wilcock and Crowe (2003) method for calculating the critical shear stress needed to initiate sediment movement for mixed-size sediment was used for this study since it best represents the bed material at the study sites. The method takes into account how particle size variation within the sediment mixture and sand content influence sediment mobility.

4.4.3 Initiation of Motion Results

The modeled hydraulic output for both study sites was used in the calculation of the bed shear stress. The HEC-RAS model option separating the main channel into distinct subsections was utilized. This has the advantage of distinguishing velocities and depths over specific areas of the channel bed pertinent to where bed movement was analyzed rather than using a single cross-section averaged value which does not capture any local variability in the channel hydraulics. The channel was divided into three sub-sections at each cross-section. The subsection with the highest shear stress value of the three total sub-sections was used in the analysis. We used the highest value since because the HEC model doesn't account for random turbulence that results in shear stress spikes on the bed. By using the highest value in HEC we account for the tendency of the model to under-represent these shear stress spikes associated with turbulent flow, since the objective was to determine the largest particle size that could be mobilized at a given discharge.

The local grain shear stress (τ) using the D_{84} of the pebble count and the Wilcock (1996) equation presented above was calculated at each modeling cell using the HEC-RAS output data for the sub-section flow depth and velocity. Therefore, rather than calculating an average boundary shear stress using the average hydraulics of the entire cross-section, a shear stress value was calculated for each of the three subsections across the transect to obtain more accurate results.The shear stress (in units of Pascals) results for all flows modeled at each study site cross-section is presented for the JSM and Caples Meadow study sites in the sub-sections below.

Jake Schneider Meadow

Figure 4-5 shows the critical shear stress (τ_c) required to mobilize the D_{50} and D_{84} particle sizes measured at the respective cross-sections. The critical shear stress values required for initiation of motion were calculated using the Wilcock and Crowe (2003) method and the representative sediment sample collected for each transect. The D_{50} and D_{84} particles are mobilized when the modeled shear stress (τ) exceeds the shear stress required for initiation of motion (τ_c).

Not all of the cross-sections exhibit increases in bed shear stress with increasing flow magnitude. This is expected for two reasons. First, the zones of maximum shear stress change in pools and riffles as the flow increases. The rate of shear stress increase is greater in pool sections compared to riffles as the flow increases. Second, flows greater than approximately 300 cfs begin to flow over a wider channel floodplain surface, which results in increases in wetted perimeter that slow the rate of increase in bed shear stress. Flow increases beyond 350 cfs do not result in larger shear stresses or initiation of motion of larger particle sizes at any of the cross-sections except for a slight increase at XS A. This effect of very small increases in shear stress above 350 cfs is represented in Figure 4-5.

Table 4-3 shows the minimum modeled flow needed to mobilize the D_{50} and the D_{84} particle size (derived from the pebble count and bulk sampling data) at each cross-section. Note that XS A, XS C, and XS 2 use the grain size data from the bulk subsurface samples since the bed was too fine to perform pebble counts and the bulk samples are most representative of the surface sediment at these cross-sections. The D_{50} particle is mobilized at three of the five cross-sections at flows ranging from 116 to 220 cfs. The D_{50} is not mobilized within the maximum flow range modeled, up to 550 cfs, at XS 1 or XS B (Figure 4-5). This appears to be in agreement with the tracer results for XS-1, where only one particle moved at 116 cfs (27 mm) and no particles moved at 220 cfs, although flows higher than 220 cfs were not tested. The D_{84} particle is mobilized only at XS 2 at 220 cfs, and is not mobilized within the modeled flow range (up to 550 cfs) at any of the other four cross-sections. Given that above 550 cfs flows over-top the channel and begin to spread out over the wider forested valley floor, shear stress would not appreciably increase in the channel above the 550 cfs discharge. This is "hydraulic release", that is the shear stress on the channel bed does not increase because the increasing discharge now has a much wider valley cross-section to pass through.

Table 4-3 Modeled Flow Needed to Initiate Motion at JSM

	Flow (cfs)		Particle Size (mm)	
	D_{50}	D_{84}	D_{50}	D_{84}
XS A	220	-	5	13
XS 1	-	-	13	55
XS B	-	-	11	19
XS C	220	-	5	13
XS 2	116	220	5	13

Note: the symbol " - " indicates there was no flow (up to 600 cfs modeled) within the cross-sectional channel geometry that would generate the shear stress needed to mobilize the referenced particle size.

Caples Meadow Study Site

Similar to Jake Schneider Meadow, the pool and riffle morphology of Caples Creek at Caples Meadow results in a complex pattern of shear stress increases and decreases with flow magnitude depending upon the location of the cross-section within the reach. Table 4-4 and Figure 4-6 show the flow needed to initiate motion of the D_{50} and D_{84} particle sizes.

At four of the seven cross-sections that are located on riffle/runs or pool tails (XS Most US, XS A, XS B, and XS 3) the combination of high velocity relative to flow depth at the 76 cfs flow results in higher shear stress values with a greater potential to mobilize sediment than flows greater than 76 cfs. These modeled results support field observations that showed high bedload transport rates on the receding limb of the controlled flow releases as sediment was being transported through the riffles with relatively steep water surface profiles and swift velocities and depositing into the deep and slower velocity pools. As flow levels rise the water surface profile flattens over riffles (see Figure 4-3) and becomes steeper over pools which exhibit a faster rate of bed shear stress increase as the flow approaches bankfull. The D_{50} is mobilized at four of the riffle cross-sections at the 76 cfs flow, but the D_{50} is not mobilized at three cross-sections (XS A-1, XS 1, and XS 2). The D_{84} is mobilized at 76 cfs at XS A and XS 3

Additional detailed bed mobility calculations were performed at the Caples Meadow study site using depths and velocities measured in the field during flows of 76 cfs, 116 cfs, and 220 cfs at XS A and 116 cfs and 220 cfs at XS 3. A bed shear stress calculation was made at closely spaced intervals along the cross-section at every station where velocity and depths were measured. In this manner at least a dozen or more point-specific shear stress calculations could be made along the transect for each flow analyzed. Figure 4-7 and 4-8 shows the calculated shear stress at each point along the two cross-sections. The shear stress required to mobilize the D_{50} and D_{84} particle diameters (from the pebble count data) are shown as horizontal lines on the graphs. Bed shear stress data points that plot above the horizontal dashed lines indicate the shear stress is great enough to mobilize the D_{50} or D_{84} sediment.

At XS A all three flows ranging from 76 cfs to 220 cfs are great enough to mobilize the D_{50} particle on a portion of the cross-section. Although the D_{84} particle is mobilized by the 76 cfs and 116 cfs flows, notably the higher 220 cfs flow would not mobilize the D_{84}. At XS 3 both the D_{50} and D_{84} particles are mobilized by the 116 cfs and 220 cfs flows. The high range in bed shear stress with values of 0 Pa to over 17 Pa highlights how variable shear stress is across the channel and why it is common to see bedload moving in patches or narrow bands down the channel and not uniformly in motion across the entire channel bottom.

Table 4-4 Modeled Flow Needed to Initiate Motion at Caples Meadow

	Flow (cfs)		Particle Size (mm)	
	D_{50}	D_{84}	D_{50}	D_{84}
XS Most US	76	-	19	31
XS A	76	76	23	35
XS A-1	-	-	21	36
XS 1	-	-	14	27
XS B	76	-	13	27
XS 2	-	-	18	31
XS 3	76	76	18	31

Note: the symbol " - " indicates that there was no flow within the cross-sectional channel geometry that would generate the shear stress needed to mobilize the referenced particle size.

4.4.4 Discussion of Bed Mobilization Studies

Four different methods have been presented related to bed mobility analysis. The Helley-Smith bedload sampling and tracer gravel deployment methods both directly measure the size of particles transported by Caples Creek at varying flows. The time series repeat cross-section surveys also help to determine if there has been bedload movement (and bank erosion) over-time since the surveys were first performed in 1999, but the method is limited because it is difficult to know just what specific flows may have initiated bed motion. Unfortunately, the fixed net frame samplers did not function properly and therefore did not yield reliable information on bed mobility.

The fourth method, modeling relies on measurements of bed particle sizes and equation analysis of depths and velocities to calculate the bed shear stress and predict whether or not the bed particles will be mobilized by a given flow. Calibrated HEC-RAS modeling of channel hydraulics was used to calculate shear stresses at the three study sites, and is valuable for predicting at what flow magnitudes there is sufficient shear stress to initiate motion of bed sediments. A variation of the modeling method was also used for Caples Meadow based on actual field measurements of depths and velocities for several flows at two cross-sections from which bed shear stresses and bed mobility calculations were performed.

Of the various methods the tracer gravels and Helley-Smith sampling are most valuable for evaluating bed mobility since they provide direct evidence of sediment motion under field conditions. Of the equation based methods, the data based on measured depths and velocities at Caples Meadow is more robust than the HEC-RAS model based data since field measurements are more accurate than modeling at quantifying local variations in depths and velocities across a cross-section.

Table 4-5 is a comparison of the largest particle sizes trapped in the Helley-Smith sampler versus the largest tracer gravel mobilized. At Jake Schneider Meadow the lower controlled flow release mobilized particle sizes 7 to 13 mm and the higher flow release mobilized particles 7 to 18 mm based on the Helley-Smith sampling. By comparison, the maximum tracer gravel size mobilized at each of the controlled flows was larger, 27 mm at the lower flow and 38 mm at the higher flow. Based on the bulk sediment data the D_{50} (5 mm) and D_{84} (13 mm) were mobilized. It is important to note here that for the tracer gravels, not all of the 27 mm and 38 mm rocks installed actually moved; in fact only a few in each of these two size classes moved. This indicates that although the flow was sufficient to initiate motion for some of the bed material (exceeding the D_{50} and D_{84} sizes) in some portions of the channel, flow was not sufficient to cause complete mobility of the entire bed. Partial transport of bed material does appear to have been initiated based on the tracer and Helly-Smith sampling.

Table 4-5 Comparison of largest particle size mobilized from Helley-Smith bedload and tracer gravel studies at Jake Schneider Meadow and Caples Meadow

Discharge	Helley-Smith Bedload D_{max}		Tracer Gravels D_{max}			
Jake Schneider Meadow						
	XS A	XS C	XS 1	XS C	XS 2	
116 cfs	7 mm	13 mm	27 mm	27 mm	27 mm	
220 cfs	7 mm	18 mm	-	38 mm	38 mm	
Caples Meadow						
	XS A	XS 3	XS A	XS B	XS 2	XS 3
116 cfs	27 mm	27 mm	76 mm	76 mm	a	76mm (b)
220 cfs	27 mm	36 mm	76 mm	76 mm	76 mm	76 mm

Notes

a – No tracer gravels deployed at XS 2 during 116 cfs.

b – Two of the 76 mm tracer gravels at XS 3 were not found after the 116 cfs flow. They were likely buried in the pool downstream.

Similar to Jake Schneider Meadow, maximum particle sizes in transport at Caples Meadow were greater based on the tracer gravel results than the Helley-Smith bedload sampling. The particle sizes mobilized were larger at the Caples Meadow study site than at the Jake Schneider Meadow study site. Cobble size material (>64 mm) up to 76 mm moved with the lower 116 cfs controlled flow release at two of the cross-sections monitored, and at all of the monitored cross-sections at the higher 220 cfs release. In general, a greater proportion of the installed tracer gravels in every size class were mobile at Caples Meadow than at JSM. Maximum bedload particle size captured with the Helley-Smith sampling was 27 mm at the lower flow release and 36 mm at the higher

220 cfs flow. Thus, both the D_{50} (23 mm) and D_{84} (35 mm) surface particle sizes were in motion at 220 cfs.

Overall, results from the tracer gravel, Helley-Smith sampling, and equation based calculations using measured depths and velocities at Caples Meadow show greater bed mobility compared to the HEC-RAS model method. The HEC-RAS model does not account for random fluid turbulence on the bed in which velocities can spike appreciably above the time averaged value, and this will influence sediment mobility (Bridge 2005). Turbulence is a major reason why partial transport conditions exist in which a particle of a given size is observed in motion yet a particle of the same size resting next to it on the bed is immobile. Any turbulent fluctuations in fluid drag and lift on the bed are not accounted for in the modeling, whereas the Helley-Smith and tracer gravel methods are affected by fluid turbulence and thus their results show greater sediment mobility. The method based on measured depths and velocities does a better job of accounting for fluid turbulence than the HEC-RAS modeling since it is specific to measured locations on the transect, yet still much of the spikes in velocities are masked in the time period over which instantaneous velocities are averaged with the current meter.

The analysis for Caples Meadow supports the conclusion that the bed sediment is mobilized frequently enough that a persistent armor layer has not developed (armor ratio is less than 3), nor is there an over-abundance of fine sediment on the bed surface that could indicate lack of transport capacity. The sediment motion analysis shows that particles up to 76 mm in diameter can be mobilized at flows as low as 76 cfs, which is approximately twice the size of the D_{90} measured from pebble counts at the Caples Meadow cross-sections. Importantly, comparison of the cross-sections surveyed in August 2010 with the cross-sections surveyed in August 2007 and 1999 shows a dynamic channel in which the bed surface freely adjusts to changes in flow. The dimensions of the cross-sections have changed over the 3-year period as the channel has undergone episodes of scour and fill that have developed new bar surfaces and scoured new depressions. There is no evidence of sedimentation in pools leading to loss of channel complexity. Our repeat cross-section surveys show that Caples Creek at Caples Meadow is an active channel that has the ability to maintain a pool and riffle morphology under the recent past and most current flow regimes.

Most of the channel bed surface at the JSM study reach was observed to have a D_{50} of approximately very fine to fine gravel size material (2 to 8 mm). Two of the transects (XS 1 and XS B) were purposely located in the section of the reach where coarser size gravels are visible on the bed surface, and the D_{50} is 11mm to 13mm. Tracer gravel results at one of the two gravel cross-sections (XS 1) show movement of a 27 mm particle at 116 cfs, which is approximately the D_{70} particle size based on the XS 1 pebble count.

Although no tracer gravels were installed at XS B at the JSM study site, it is likely that the results would have been similar to XS 1 since the modeled shear stresses are quite similar at the two cross-sections. Tracer gravels deployed at XS C and XS 2 represent transport conditions for most of the study reach which is characterized by finer gravel material than at XS 1 and XS B. The results show that 38 mm particles were mobilized at 220 cfs on both transects. No pebble count data was collected for these cross-sections, but 38 mm is the D_{90} for both the bulk surface and subsurface material that has been used to characterize the sediment for XS A, XS C, and XS 2. The bed mobility results suggest that the channel bed at Jake Schneider Meadow is not armored and there is sufficient shear stress under the current flow regime to transport the dominant particle sizes. There was evidence of bed and bank changes between 1999 and 2007, and from 2007 to 2010 at two of the three cross-sections surveyed in each of the two surveyed time periods. There was virtually no change at one of the cross-sections since 1999. For the three additional cross-sections surveyed only from 2007 to 2010, there were limited changes at two of the cross-sections, and no changes at the third cross-section. The data indicate that there was sufficient flow, particularly during the 1999 to 2007 period, to mobilize bed material. Sand and finer size sediments only compose 10 percent of the bulk surface layer which indicates that buildup of fines is not an issue in the reach (see Table 2-3).

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Chapter 5

Conclusions and Recommendations

Chapter 5 summarizes the conclusions drawn from the Monitoring Plan studies, and provides recommendations for the pulse flow magnitude and frequency that will provide channel and riparian maintenance functions. Section 5.1 reviews the geomorphic and riparian maintenance objectives, that were identified during relicensing of Project 184. The overall study approach summarized in Section 5.2, and Section 5.3 develops the conclusions drawn from the study results related to maintenance of channel geomorphology. Section 5.4 provides the conclusions related to floodplain inundation and riparian maintenance at Caples Meadow. Section 5.5 sets forward the pulse flow recommendations.

5.1 Geomorphic and Riparian Maintenance Objectives

The Monitoring Plan describes geomorphic and riparian maintenance objectives which were identified during the relicensing process for the Caples Creek channel:

> "Peak flows required for performing geomorphic channel maintenance (maintenance of a stable channel form and fluvial processes by transporting the sediment load recruited to the channel) have been altered by flow regulation."

Attenuation of the natural Caples Creek spring runoff has resulted in "a high level of fine stream bed material, little movement of the material with spring runoff events, and affected the channel profile with a suggestion of aggradation of stream bed material " (USFS 2003(b). A lack of willow recruitment was also identified at the Caples Creek meadow by Harris and Lindquist (2000(a) and 2000(b). Furthermore, the the USFS Riparian Conservation Analysis (USFS 2003(b) and USFS Rationale for 4(e) Conditions Report (USFS 2003(c) state that "The intent of introducing pulse flow events to the main channel is to: (a) more closely mimic the timing and duration of peak flows that would occur under an unimpaired hydrograph; (b) initiate transport of bedload material, which would assist in improving habitat conditions for aquatic species; (c) facilitate flooding of the stream side riparian community at the appropriate time of the year; and (d) aide in control of spills into the spillway channel."

The Monitoring Plan provides guidance regarding objectives for pulse flow recommendations. Pulse flow magnitude and frequency should be dimensioned so as to provide for the following resource objectives as listed in Appendix B of the Settlement Agreement (EID 2003):

Fluvial Geomorphology Objectives

- Maintain or restore channel integrity
- Maintain, improve, or restore fluvial processes to provide for balanced sediment transport, channel bed material mobilization and distribution, and channel structural stability that contribute to diverse aquatic habitat and healthy riparian habitat

Riparian Habitat Objectives

- Maintain or restore riparian resources
- Maintain and restore instream flows sufficient to sustain desired conditions of riparian, aquatic, wetland, and meadow habitats

Connectivity Objective

- Maintain and restore spatial and temporal connectivity for aquatic and riparian species within and between watersheds to provide physically, chemically, and biologically unobstructed movement for their survival, migration, and reproduction.

Conversely, pulse flows should not be too high as to cause excessive transport, particularly de-stabilizing spawning gravels so that they are depleted from the channel reach and the bed is coarsened.

5.2 Study Approach

Incipient motion of the bed material is often used as a minimum requirement for channel maintenance flow prescriptions (McBain and Trush 1995). Mitigation of post-dam shifts in channel morphology are frequently addressed by prescription of a channel maintenance flow. The objective is to periodically mobilize the channel bed material and to transport fine sediments from the bed material, particularly where fish spawning areas are of concern. Maintenance of an equilibrium channel morphology requires transporting the bedload supply, periodically scouring the riparian community to discourage channel encroachment, and providing a hydrologic connection to floodplains for recruitment and growth of riparian vegetation. The magnitude, duration, and frequency of the maintenance flow prescription should not, however, excessively transport the bedload supply, depleting spawning gravel material from a reach, or excessively scouring the bed and banks. Determining the bed mobility threshold provides an approximation of the flow magnitude needed to maintain the fluvial processes that support the equilibrium channel form.

The basic approach was to conduct studies that determined mobility and transport of the dominant bed material in the most responsive, alluvial reaches of the Caples Creek channel. A considerable portion of Caples Creek is a non-alluvial, steep bedrock and boulder stream type, where the channel has limited capacity to respond to changes in the flow regime. The Monitoring Plan focused on developing a channel-riparian maintenance flow based on the needs of the most responsive stream reaches in Caples Meadow and at Jake Schneider Meadow.

The study used several different methodological approaches to evaluate sediment transport and bed material incipient motion, including:

- Comparison of repeat cross-section surveys since 1999 through 2010
- Suspended load measurements during test flow releases
- Bedload measurements during test flow releases, using
  - Bedload traps
  - Helly-Smith samplers

  - Tracer gravels
- Hydraulic modeling of shear stress for initiation of bedload transport

As previously discussed (section 3.2.2), the bedload traps did not function as expected, and therefore no incipient motion data could be collected using this method. The suspended and bedload measurements were collected during controlled flow releases from Caples Lake that provided a discharge of 116 cfs and 220 cfs at each study site. The repeat cross-section surveys took advantage of re-measuring several cross-sections at each study site that had been first established in 1999. By re-surveying the cross-sections in 2007 and again in 2010, the surveys provide an indication as to whether or not there have been recent past flows adequate to move bed material or erode bank materials since 1999.

The studies measuring bedload transport from Helly-Smith sampling and tracer gravel movement provide empirical data under field conditions that are useful for estimating the discharge that initiates motion and transports the channel bed material. The channel maintenance flow should be able to mobilize the D_{50} bed material, and we also consider the shear force needed to move the D_{84} in this study. All of the study results, both field based data collection and hydraulic modeling are considered in the following sections in order to draw conclusions.

The study plan also called for monitoring of the stage-discharge relationship during the controlled flow releases, particularly the point at which over-bank flows begin to inundate the Caples Creek Meadow floodplain. Topographic survey of the water surface elevation at different flows, in conjunction with field observations and photographic documentation, and calibrated hydraulic modeling were used to define the stage-discharge relationship and flow over-banking onto the floodplain. Determining the discharge that periodically inundates the floodplain defines the portion of the flow regime that maintains the riparian community.

5.3 Channel Geomorphic Maintenance Conclusions

5.3.1 Comparison of Repeat Cross-section Surveys

The time-series of repeat cross-section surveys provide an indication as to whether or not there have been flows since the first surveys in 1999 adequate to move bed and/or bank material. Since 1999 there have been no spill events, so the gaging records for annual peak flows provide an accurate indication of the discharge from Caples Dam, although the natural flow accretions (including localized runoff and tributary streams such as Kirkwood Creek) below the dam release point to Caples Meadow and to JSM are not known. The cross-section survey data demonstrate the extent to which project operations prior to the new license provided flows that in combination with natural flow accretions have mobilized bed materials. The maximum annual flow from the Project during the 1999-2007 runoff period was 372 cfs, and during the 2007-2010 runoff period was 402 cfs.

It should be recognized that a lack of change in bed topography does not mean there was no bed movement. A flow that is adequate to mobilize bed material may result in no net change in the cross-section. This is because the channel features (for example depth of the thalweg, bar position and elevation, etc.) may reform during the passing of an annual peak flow event so that the channel dimensions and geomorphic features do not exhibit a net change. Only a net change in the channel topography between survey periods, whether it is deposition or scour, is a definitive indicator of bed material movement.

5.3.1.3 Caples Meadow

The time series of repeat cross-section surveys demonstrate that there was bedload movement, including channel thalweg down-cutting, and lateral channel migration during the 1999-2007 runoff seasons. Bedload movement including bar-building and lateral channel migration is also evident during the 2007-2010 runoff period, although the magnitude of the bed topography changes as depicted by the cross-sections is more subtle than during the 1999-2007 period. Overall, the cross-section surveys demonstrate that project operations since 1999 have not eliminated bed material transport or lateral channel migration.

5.3.1.4 JSM

Similar to the conclusions for Caples Meadow, regardless of the unknown magnitude of natural flow accretions to JSM in any of the survey periods, it is clear that past operations did provide bed material transport in the 1999-2007 period and also caused lateral channel migration. The cross-section survey data does not indicate any bed movement or lateral channel migration during the 2007-2010 period.

5.3.2 Suspended Sediment Load

A channel maintenance flow is dependent on transporting a portion of the coarser bed material sizes as bedload movement, not just on transporting the finer particles as suspended sediment. However, suspended sediment transport will occur in conjunction with a channel maintenance flow designed to induce bedload transport since the flow needed for coarse material bedload transport is greater than that needed to transport finer sediments. Suspended sediment concentration depends on the available sediment supply as well as discharge.

The field study results show that fine grained sand was transported as suspended sediment with the 116 cfs test discharge at both study sites, and suspended sediment load increased at both study sites when the test flow was increased to 220 cfs. This is to be expected, as flow increases and the coarser bed material is disrupted, finer sediments are entrained some as suspended load and some as bedload.

5.3.3 Bedload Transport Field Studies

This section addresses the findings of initiating bedload transport based on the empirical field studies using tracer gravels and Helley-Smith sampling. The hydraulic modeling conclusions related to bed material mobilization is addressed in the next section 5.3.4.

There are often two phases of bedload transport in steep mountain channels. Phase 1 is described as movement of surface deposits of sand sized particles or fine gravels in pools, channel margins, and in the lee of larger bed elements. Phase 1 transport signals the initial mobilization and transport of fine bedload over a coarser channel bed surface. Various researchers have found that Phase 1 transport begins in the range of 0.3 to 0.5 of the bankfull discharge (Schmidt and Potyondy 2004).

Phase 2 transport is associated with the initial coarse sediment movement from the coarse surface layer and underlying channel bed. As flow increases bedload becomes progressively coarser as a greater proportion of the material is mobilized intermittently and non-uniformly. The channel maintenance flow must initiate the Phase 2 transport that is responsible for mobilizing the bedload and performing the work that maintains the channel morphology. In the geomorphic literature researchers have found that Phase 2 transport occurs over a varying range of discharges, from 0.5 of the bankfull discharge to the full bankfull discharge (Schmidt and Potyondy 2004). Using a slightly different approach, Andrews and Nankervis (1995) found channel maintenance flows, which should transport the long-term mean bed material load, ranges from 0.8 to 1.6 times bankfull discharge. The bankfull discharge is further considered in relation to the results of the field studies and our conclusions and recommendations in the following report sections.

Interpreting and drawing conclusions from the tracer gravel studies is challenging. This is because bed particles of a given size do not all uniformly mobilize at a given flow threshold. Rather, bed mobilization is sporadic and somewhat random under conditions of turbulent flow and owing to mirco-variability in channel shear stress and inter-relationships acting between the heterogeneous bed particle sizes. We considered the complete range of tracer particle sizes moved and not moved, the proportion of tracers moved relative to the particle size of interest (for this study as represented by the D_{50} and D_{84} size material naturally occurring on the bed), in order to draw pertinent conclusions.

5.3.3.1 Caples Meadow

The D_{50} median bed particle size ranged from 13-23mm and the D_{84} particle size ranged from 27-36mm. Both the tracer gravel and Helley-Smith study methods clearly indicate bedload transport of the D_{50} and D_{84} particle size is occurring at 116 cfs. About one-third of all emplaced tracer gravels were moved, not only including within the range of the D_{50} and D_{84} particle sizes, but up to the maximum tracer size used (76mm) at every transect set-up during the 116 cfs flow. This strongly suggests that a flow less than 116 cfs would be adequate to initiate motion through the D_{84} size bed material. This is also in general agreement with the hydraulic modeling results, discussed below in the next sections. The Helley-Smith bedload sampling data confirms the tracer gravel results that bedload material was in transport at 116 cfs, with 27mm the largest particle size captured, which is greater than the D_{50} and just within the lower range of the D_{84} bed material size represented in the Caples Meadow reach.

Based on both the tracer gravel and Helley-Smith results, an even greater proportion of the bed material, including the largest particle sizes, were in transport as flows were increased up to the 220 cfs discharge. At several of the tracer study transects up to 80 percent of the 76mm size (cobble) tracers moved. The Helley-Smith data also indicates a greater total bedload in transport at 220 cfs, and the maximum particle sizes captured at one of the study transects increased to 36mm compared with the 116 cfs test release.

The difference between the largest particle sizes mobilized comparing the tracers to the Helley-Smith sampling is a function of the different study methodologies. The Helley-Smith sampling is more likely to miss the larger sizes in transport because the bedload tends to move sporadically in bursts and less frequently, and therefore may not be caught in the sampler during the relatively short sampling time compared with the tracer gravels (Ashiq and Bathurst,1999). The Helley-

Smith sampling is on the order of ½ hour for the total composited sample at a study transect, while the tracers were in place for approximately 16 hours. Additionally, the tracer gravels are explicitly addressing initiation of motion, whereas the Helley-Smith sampling is more likely to be trapping material set in motion at some upstream location, so it represents material which is in full transport mode, but may miss particles just at the initiation of motion. As such the Helley-Smith sampler is likely to under-estimate the maximum size that begins motion with a given discharge (Ashiq and Bathurst 1999).

Underwater video taken when flow was receding from the 220 cfs discharge support the bedload transport results from the tracer and Helley-Smith studies. The video clearly demonstrates that a wide range of bed material particle sizes were in motion.

5.3.3.2 JSM

The D_{50} bed material (11-13 mm) and the D_{84} bed material (19-55 mm) is based on pebble counts at the two coarsest transects in the JSM because bed material in most locations was too fine to perform pebble counts. Field observations found that the majority of the Jake Schneider Meadow reach has surface particle sizes finer than that indicated by the pebble count data from the two cross-sections, with most of the reach consisting of bed sediment similar in texture to the bulk subsurface sample D_{50} (5mm) and D_{84} (13mm).

The largest tracer particle entrained at the 116 cfs flow was 27mm (4 tracer particles), but there was only 1 tracer particle in the smallest size class, 19mm, that moved and only 3 percent of the toal 90 tracers emplaced moved. This is probably insufficient to represent initiation of motion of either the D_{50} or D_{84} bed material based on the tracer gravels results. However, we note here that the smallest tracer gravel size used, 19mm, is greater than the median size of the bed material. It is not practical to use tracer gravels much smaller than 19mm because they are too difficult to paint, install, and track their movements.

Comparison with the Helley-Smith sampling indicates that the largest size in transport was 13mm (at one of the two sampling locations, see Table 4-5), within the D_{50} range and within the D_{84} range as represented by the bulk subsurface sample, though not based on the pebble counts at the coarser study transects. Based on both the Helley-Smith and tracer studies, a 116 cfs discharge is probably insufficient to provide initiation of motion of the D_{50} and D_{84} bed material.

At 220 cfs a greater proportion of all the emplaced tracers moved, (16 percent) and the largest particle size entrained increased to 38mm, although there was only 1 tracer particle in this size class. There was no movement of tracers at one of the three study transects (see Table 3-3), at one transect 17 percent of the tracers moved, and at the third transect 30 percent of the tracers moved. The bedload transport rate also increased (at 220 cfs) based on the Helley-Smith sampling and the largest particle size captured increased to 18mm, though this was at just one of the two sampling transects, the maximum particle size did not change at the other sampling transect (see Table 4-5). A large proportion of the bedload material captured during the Helly-Smith sampling is in the sand size category (68 percent <2mm), with 22 percent of the bed material larger than sand, in the fine gravel size range (see Figure 3-5).

The increase to 220 cfs was providing a greater amount of total bedload transport and slightly larger bed material sizes were mobilized than at 116 cfs. But, given the relatively low proportion of total tracer gravel movement, and the fact that the majority of the bedload particle sizes in transport based on the Helley Smith sampling was in the sand size range, there was likely insufficient discharge to initiate motion of the D_{84} and it does not appear that there was adequate discharge to initiate motion of the D_{50} bed material over most of the study reach. We consider next the results of the hydraulic modeling.

5.3.4 Bedload Transport Hydraulic Model

5.3.4.1 Caples Meadow

Key hydraulic modeling results are:

- Flows as low as 76 cfs will transport the D_{50} and D_{84} at four transects. This was generally supported by results of tracer gravel and Helley-Smith sampling.
- There would be a declining capacity to transport bed material as flow increased above 76 cfs at several transects. This was not generally supported by results of tracer gravel and Helley-Smith sampling, which showed increased bed transport
- There is no flow that would mobilize either the D_{50} or D_{84} at three transects, but this did not hold up based on tracer gravel results
- Modelling under-predicts bed movement based on tracer gravel and Helley-Smith results

Hydraulic modeling suggests that flows as low as 76 cfs will provide transport of the median bed particle size and D_{84}, (at four study transects), and that higher flows would provide less shear force, insufficient to mobilize either the D_{50} or D_{84} (see Figure 4-6). The modeling also predicted that at three study transects there was no discharge that would move either the D_{50} or D_{84}. Since there were no field studies set up at two of these modeled transects (XSA-1 and XS 1), there is no other data from which to confirm this inability to move the D_{50} or D_{84} at any discharge. However at the third study transect (XS 2) tracers were deployed for the 220 cfs release. The tracer data showed considerable movement of both the D_{50} and D_{84} particle sizes. This indicates that the model is under-predicting the shear force available to initiate bed material motion.

The tracer gravel and Helley-Smith sampling results generally supported the modeling results in that both field-based studies showed that there was bedload transport occurring at the test flow releases (for XS 3, XS B, and XS A). In fact, a sizable proportion of the D_{50} and D_{84} particle sizes were moved at every transect with tracer gravels during the 116 cfs flow, suggesting that the overall the modeling is correct for these study locations, that a lower flow (76 cfs) could be adequate to initiate bed material transport of either the D_{50} or D_{84}. The tracer studies did not however confirm the model prediction that there would be a declining capacity to transport bed material as discharge increased at all three of these study transects. Rather there were more tracer particles in motion as flows increased up to the 220 cfs test discharge. The Helley-Smith sampling also agreed with the tracer study and did not agree with the modeling that more bed material of larger particle sizes were captured in transport when flow was increased to 220 cfs, although the increase in particle size at the higher discharge was a rather weak trend (see Table

4-5). Overall, the modeling appears to under-predict bed mobility, particularly at the test flows above 76 cfs[5].

Considering together the results of the tracer gravels, Helley-Smith sampling and the hydraulic modeling, all suggest that initiation of motion for the D_{50} and D_{84} bed material size might occur at flows as low as 76 cfs. Further, the model results predicting no movment of bed material at three transects at any discharge are not supported by the empirical field studies which show considerable bed material transport. The magnitude of an appropriate channel maintenance flow based on relationship to bankfull discharge is considered next.

As discussed earlier (see section 5.3.3.3), motion of bed particles can begin at a discharge as small as 50 percent of the bankfull value, and on average flows that range from 0.8 to 1.6 times bankfull discharge transport the long-term mean bed-material load (Andrews and Nankervis 1995). The bankfull channel at Caples Meadow is equivalent to the top of the point bars (which are approximately 1-2 feet below the top of the bank) up to the physical top-of-bank, just below the floodplain elevation. The discharge to the physical top of bank at the floodplain elevation is shown in Table 4-1, and these values likely represent a high estimate for bankfull discharge. Using the discharge at the top-of-bank at floodplain elevation as a very conservative estimate for bankfull flow (ie, the bankfull flow is most likely a lower discharge corresponding to the top of bars), the discharge that transports the long-term mean bed material load can be assessed. Cross-section A (see Appendix C) probably best represents a transect that is between the highest and lowest discharges to the floodplain elevation. The flow to the left bank floodplain is 230 cfs and to the right bank floodplain is 170 cfs, with 200 cfs as an average (between right and left banks). Fifty percent of the 200 cfs bankfull flow to initiate bed motion could be as low as 100 cfs. This is only slightly higher than a 76 cfs flow predicted by the modeling to initiate motion of the mean bed particle size, and is lower than the 116 cfs test flow which demonstrated motion of both the D_{50} and D_{84}.

Using 200 cfs as bankfull flow, the 0.8 to 1.6 range to move the mean bed material load is 160 cfs to 320 cfs, with 240 cfs in the middle of this range. This suggests that a flow of approximately 240 cfs would move the mean annual bed material load and would function as a channel maintenance flow through the Caples Meadow reach. This provides a reasonable estimate for a channel maintenance discharge. The field based data strongly support that a flow of 240 cfs is adequate to transport the full range of bed material sizes represented in Caples Meadow.

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5 It is noted here that the tracer gravel results linked to the 116 cfs and 220 cfs flows first required the test flow release to pass through the 76 cfs discharge as flows ramped up. Therefore, it is possible that most of the tracer gravel movement occurred as the flow reached 76 cfs, rather than when it reached the final target release. However the fact that the higher 220 cfs discharge moved more of the tracer gravels than the lower 116 cfs discharge strongly suggests that it was not the brief period of time during ramp up through the 76 cfs discharge that could be solely linked to bed movement. The more detailed modeling results (based on field measured depths and velocities) further complicates the interpretation of results, in that there are site specific locations at cross-sections A and 3 where there is sufficient shear stress to move the D_{50} and D_{84} that is not predicted by the less detailed modeling results.

5.3.4.2 JSM

There are five key hydraulic modeling results:

- There is not very much difference in the shear stress generated over the entire modeled flow range from 220 cfs to 550 cfs. This is due to the shape of the channel, consistently widening out as flows increase so that depth does not substantially change (see Figure 4-3)
- At 600 cfs flow leaves the channel and inundates the surrounding coniferous forest
- There is no discharge based on the modeling will move the D_{50} at two of the five study transects or move the D_{84} at four of the five study transects (see Table 4-3)
- A discharge of 220 cfs initiates motion of the D_{50} at three of the five transects studied
- Modelling appears to under-predict bed movement based on tracer gravel and Helley-Smith results

When compared to the tracer gravel results, the hydraulic modeling appears to perform better at JSM than at the Caples Meadow site, but still under-predicts bed movement. The tracer gravel results confirmed the modeling results at study XS 1; there was virtually no movement of tracers at either test flow (1 tracer moved at 116 cfs). At study XS C the model predicted movement of the D_{50} starting at 220 cfs, but no movement of the D_{84}. The tracers showed movement of both the D_{50} and D_{84} at 116 cfs, though just a few tracers moved, with a few more moving at 220 cfs. Bed material up to 10mm was in transport at both the 116 cfs and 120 cfs flow based on the Helley-Smith sampling at this study transect, so this is somewhat in agreement with the tracers, although the maximum particle sizes in transport were smaller than the largest tracers that moved. Here again the model tended to under-predict movement. The model did a reasonably good job of predicting for study XS 2 sufficient shear force at 116 cfs to move the D_{50} and at 220 cfs to move the D_{84}, with which the tracers mostly agreed; there was more tracer movement at this study transect with larger particles entrained at the higher test flow. For study transect XS A the model predicted movement of the D_{50} starting at 220 cfs, and no discharge that would move the D_{84}. There were no tracers set up here, but the Helley-Smith sampling shows that bed particles up to 7mm were in transport at the 116 cfs flow, although the vast majority of sediment in transport was sand sized, so that the model slightly underpredicted movement. Results were not different based on the Helly-Smith sampling at XS A at the 220 cfs flow than at 116 cfs, so the model prediction that the D_{84} (13mm based on subsurface sample, but larger based on pebble counts at the coarsest cross-sections) would not move was supported.

Indicators for a bankfull elevation at JSM are a prominent flat, sandy depositional bench just below the rooted elevation of the coniferous forest, which is most visible at XS A. A 250 cfs discharge just begins to reach this elevation and 300 cfs fully inundates the bankfull bench. Using 300 cfs as the estimated bankfull flow at JSM and applying the guideline that motion of bed particles can begin at a discharge as small as 50 percent of the bankfull value, then bed entrainment could begin at flows as low as 150 cfs. The field study results show that there was some bedload transport occurring at both the 116 cfs release and at 220 cfs, but it was not clear whether the median size was in motion over a sufficient area of the channel bed (most of the tracer gravels did not move) at either of these flows.

An approximation for the channel maintenance flow using the estimation that from 0.8 to 1.6 times bankfull discharge transports the long-term mean bed-material load (Andrews and Nankervis 1995), then the channel maintenance flow would range from 240 cfs to 480 cfs. The average for this range is 360 cfs.

Our conclusion is that a higher flow than 220 cfs is likely needed to ensure that the incipient motion threshold is reached for the D_{50}. The conservative approach is to rely on a 360 cfs discharge as a reasonable target for a channel maintenance flow that will transport the mean bed-material load. We are mindful that the hydraulic modeling does not indicate shear stress increases at flows above 220 cfs, but considering that the model has generally under-represented shear force, then there could be more shear as the discharge increases to 360 cfs than the model has predicted. This would likely ensure transport of the coarser bed material represented in the reach.

5.4 Floodplain Inundation and Riparian Maintenance

Successful willow establishment and distribution patterns are closely tied to the annual seasonal hydrograph and variability of high and low events between years. Willows release seeds during a fairly short time period in the spring and early summer, coinciding with the receding limb of the snowmelt hydrograph. High scouring flows are necessary to remove existing vegetation, deposit fresh alluvium, and prepare seed beds. As spring high flows recede, bare alluvial surfaces are exposed on bars where seeds, often transported by the water, are deposited. Bare, moist mineral soils are ideal seedbeds for willows, and some willow species have been observed to only establish on open surfaces and not on vegetated banks (e.g., Sacchi and Price 1992). The spring flows that result in successful willow recruitment may occur the same year as the larger scouring flows, or during subsequent years while the surfaces are still bare. In addition, willow seeds are only viable for a short period of time (a couple of weeks) (Anderson 2006).

Willow seedling survival is dependent, in part, on the magnitude of subsequent flows and moisture availability. The elevation at which the seedlings establish must be high enough to not be scoured during winter and spring flows, but not too high to limit moisture availability during the late summer as water tables drop. Young vegetation that establishes on low-lying surfaces where soil moisture is sufficient throughout the germinant and initial growing season may be scoured by winter and spring flows (Mahoney and Rood 1998; California Energy Commission 2008; Merritt et al. 2009). As a result, establishment success is generally lower on surfaces that are relatively frequently inundated and scoured (e.g., low elevation of bars).

Caples Meadow is dominated by various sedges and grasses, with patches of willows (*Salix lemmonii*) (EID 2009). Portions of the meadow are also co-dominated by various forbs. The dominant sedges are *Carex utriculata* and *C. nebrascensis*. *C. microptera* was also present in some areas within the meadow. *C. utriculate and C. nebrascensis* grow in wet meadows, while *C. microptera* is generally found in drier meadows (Castelli et al. 2000; Dwire et al. 2006; USDA-NRCS 2011). Previous studies indicated that there was a somewhat higher proportion of graminoids (i.e. grasses) in Caples Meadow compared to other unregulated meadows in the general vicinity (Harris and Lindquist 2000a). Harris and Lindquist (2000a) suggested that this may be indicative of a lower ground water table in Caples Meadow compared to the other locations. Some areas of the meadow however, are wet at least throughout the late growing season as *C. nebrascensis* is not usually found in meadows where the water table is more than approximately 3 feet below the root zone at this time (USDA-NRCS 2011). In addition, the meadow is under snow throughout the winter and through the spring. Local snowmelt runoff and lateral inflow to the meadow from the surrounding hillslopes likely play a strong role in maintaining moist soils throughout the growing season. The distribution patterns of the sedges, grasses, and forbs probably reflect elevational differences in depth to the groundwater table (Castelli et al. 2000; Dwire et al. 2006; Loheide and Gorelick 2007).

In Caples Meadow, the willow community is generally mature, with a few patches of younger willows that likely established after recent high flows. A few willow seedlings were observed on low-lying bar surfaces during recent surveys (EID 2009b). Harris and Lindquist (2000a and 200b) also found that Caples Meadow supported fewer willows compared to other meadows in the general vicinity. Harris and Lindquist (2000b) concluded that in addition to changes in the frequency and duration of flows that would inundate the meadow at Caples Creek, past grazing and recent horse and beaver activity may have been adversely affecting riparian recruitment in Caples Meadow. With increased distance from the creek, the willows in Caples Meadow tend to be more scattered and older. Primarily older willows were also established along the relict high flow channels within the meadow. Willows often successfully establish along these high flow channels as they tend to be slightly lower elevation than the surrounding floodplain, holding moisture longer through the growing season and summer (and providing root growth access to the groundwater table), and are not likely to be scoured during spring runoff. Providing a flow magnitude that activates high flow channels on the floodplain may increase their soil moisture and improve willow regeneration.

Over-bank flows onto the floodplain begin as low as 120 cfs (see Table 4-1). During the 220 cfs test release, there was flow over the floodplain in various locations and high flow channels were activated (see Photos 4-1 and 4-2). From observations of the 350 cfs pulse flow during this past spring (2010), a considerable area of the meadow both upstream and downstream from the Kirkwood Creek confluence was inundated (see Photo 4-3). It is estimated that the contribution from Kirkwood Creek at the time of the photos was approximately 50 cfs (pers. comm., Brian Deason), which would result in a total flow of about 400 cfs to the lower Caples Meadow reach.

Considering that there is relatively little riparian vegetation growing along the channel at both study sites today, riparian maintenance flows for purposes of scouring vegetation encroaching on the channel is unnecessary. At Jake Schneider Meadow, no riparian maintenance flow objective is necessary for the meadow itself, which is a terrace feature located well above the channel and not influenced by a hydrologic connection related to over-bank flows. The channel at JSM is bordered by a nearly closed-canopy, well-shaded coniferous forest with mature trees growing close to the low-flow channel. There is little opportunity for woody riparian growth within the shaded margins of the channel. As such, flows that correspond with the elevation of the narrow floodplain below the rooted elevation of the mature trees, where fine sediment deposition and scour of young tree seedlings could occur, is the only area where riparian vegetation can establish. This floodplain elevation already has existing fine sediment deposits, and this is coincident with the channel maintenance flow elevation, so that the discharge for channel and riparian maintenance is approximately the same.

5.5 Recommendations

5.5.1 FERC License Requirements

The FERC license requires a pulse flow release from Caples Lake Dam according to the designated water year types, as follows:

Critically Dry	Dry	Below Normal	Above Normal	Wet
0 cfs	150 cfs	210 cfs	300 cfs	345 cfs

The pulse flow is to be released over a 5-day continuous period, timed to correspond to the annual spring peak runoff. The anticipated frequency of occurrence for each year type based on analysis of the period 1935 to 2010 is shown in Table 5-1. Thus, it can be expected that under the 2006 license, pulse flows in wet and above normal years will occur 30.3 percent and 18.4 percent of the time, respectively.

Table 5-1 Frequency of Water Year Types for Project 184 for the period 1935 - 2010

Water Year Type	Count	Frequency %
Wet	23	30.3
Above Normal	14	18.4
Below Normal	13	17.1
Dry	15	19.7
Critically Dry	11	14.5

The frequency of occurrence for pulse flows under the 2006 license requirement in comparison to the historic frequency of high flows is shown in Table 5-2. For this comparison only high flows (average daily) occurring during the months of May, June, and July are considered. This is the time of year most pertinent to the germination of seeds and the growing season, and is therefore most relevant to the period of time influencing riparian growth. The 2006 license pulse flow will occur with greater frequency than high flows in the past.

Table 5-2 Comparison of Historic High Flow and 2006 License Pulse Flow Frequency in May, June, and July

	Historic High Flow Frequency[a,b]	2006 Pulse Flow License Frequency[a]
>345 cfs	13.8%	30.3%
>300 cfs	22.4%	48.7%
>210 cfs	44.8%	65.8%
>150 cfs	63.8%	85.5%

Notes: (a) Historic high flows and 2006 license pulse flow frequency is calculated only for the months of May, June, July using average daily flow from USGS gaging record. (b) Historic frequency determined from period of record 1935-1992, gaging records included spill flows.

The FERC license further states:

> "The licensee shall, after 5 years of implementation of the new license, and based on monitoring results from the Geomorphology monitoring elements described in Condition No. 37, subsections 6 and 7, increase pulse flows up to a maximum of 600 cfs, based on water year type, or change the duration of the existing pulse flow to a maximum of 10 days in Caples Creek if initial pulse flows are not effectively mitigating sediment/bedload transport or other fluvial processes problem caused by the Project. If monitoring indicates that the pulse flows are resulting in damage to the Caples Creek channel or if monitoring indicates that reduced pulse flows are effective in meeting the fluvial geomorphology objective described in Appendix B, Section 1, of the El Dorado Relicensing Settlement agreement, the FS may decrease the magnitude of the pulse flows. The FS shall, after consultation with the ERC and SWRCB, make the final determination as to whether the pulse flow shall be increased, decreased, or whether the duration shall be lengthened."

5.5.2 Pulse Flow Recommendations

Increasing the pulse flow up to 600 cfs is well-above any estimate of either a channel or riparian maintenance flow appropriate to the Caples Meadow reach or the Jake Schneider Meadow reach and is therefore not warranted. 600 cfs is about 50 percent more flow than is needed to inundate Caples Meadow to provide a hydrologic connection between the channel and the meadow for riparian maintenance, and that is without any flow accretion after the release point at the dam from either localized runoff or tributary streams. It is also about 2.5 times the flow needed to accomplish bedload transport for channel maintenance requirements in Caples Meadow reach and 1.7 times the flow needed for channel and riparian maintenance in the Jake Schneider Meadow reach. The following sections describe the pulse flows that are recommended by water year type for channel and riparian maintenance purposes as appropriate for each study location. These are the minimum flows needed to meet maintenance objectives in Caples Creek. These recommendations are summarized by location and resource objective in Table 5-3.

Table 5-3 Pulse Flow Recommendation for Caples Creek by Resource Objective and Location

	Water Year Type				
Resource Objective/Location	Critically Dry (cfs)	Dry (cfs)	Below Normal (cfs)	Above Normal (cfs)	Wet (cfs)
Channel Maintenance Lower Caples Meadow (below Kirkwood Ck)	0	0 [b]	0 [b]	240	240[a]
Riparian Maintenance Lower Caples Meadow (below Kirkwood Ck)	0	0 [b]	0 [b]	240	400 [c]
Channel and Riparian Maintenance Jake Schneider Meadow	0	0 [b]	0 [b]	360	360

[a] Since 400 cfs flow for riparian maintenance is recommended for wet year types, the channel maintenance flow of 240 cfs in wet years is fully covered

(b) no pulse flows recommended, only license minimum instream flow requirements. (c) or maximum outlet capacity at time of pulse flow per pulse flow determination procedure

The current license requirement for pulse flows in below normal and dry years should be amended. Providing the 2006 license pulse flow requirements in dry and below normal years would mean bedload transport occurs through Caples Meadow in 85 percent of years. Most of the water required for channel maintenance occurs during just a few days per year during high runoff years (Schmidt and Potoyondy 2004). During typical low runoff years, none of the annual water yield is needed for channel maintenance because flows exceeding the 0.8 of bankfull flow fail to occur in dry years (Schmidt and Potoyondy 2004).

5.5.2.3 Pulse Flow Recommendations for Channel Maintenance Resource Objective

For the Caples Meadow reach, the recommendation is to provide bedload transport about every other year (50 percent annual frequency), by providing channel maintenance flows in wet and above normal years. This is in accord with the frequency of channel maintenance flows in unregulated streams, occurring about every 1.5 to 2.0 years.

A channel maintenance flow of 240 cfs has been demonstrated to show that the full range of bed particle sizes and all areas of the channel through Caples Meadow would be mobilized. It will also provide some overbanking flows onto the floodplain with associated sediment deposition, scour of bars, and activation of high flow channels, providing a riparian maintenance function. During wet years, the 400 cfs flow is designated for riparian maintenance purposes, but it will also provide (and exceed) the 240 cfs channel maintenance flow need.

In JSM reach, a flow of 360 cfs is recommended to provide channel maintenance. The channel maintenance flow should occur in both wet and above normal year types, which occurs about every other year, over the long-term. This is consistent with the frequency of bankfull flows on most unregulated alluvial channels, occurring about every 1.5 to 2.0 years.

Flow accretions below Caples Dam are anticipated to provide additional flow to lower Caples Meadow and to JSM in wet and above normal years so that the actual release at Caples Dam will be less than that shown in Table 5-3. Flow accretion is discussed in section 5.5.2.3 and 5.5.2.4

5.5.2.4 Pulse Flow Recommendations for Riparian Maintenance Resource Objective

For Caples Meadow reach, the proposed riparian maintenance flow regime will enhance willow recruitment by providing a greater frequency of higher peak magnitudes compared to historical regulated conditions, enhancing soil moisture conditions. The flows in wet water years are sufficient to inundate the meadow by overbanking and are likely to create new bare alluvial sites with fine sediment deposition for potential riparian establishment. The magnitude of the flows in above normal water years will activate high flow channels within the meadow, improving the potential for establishment along these channels. As shown in Table 5-2 the annual frequency with which high flows will occur under the proposed pulse flows recommended for the wet and above normal years that are most pertinent to riparian maintenance will be similar to that currently defined under the 2006 license, and greater than the past historic high flows.

For the riparian maintenance flow, nearly full inundation of the meadow occurs at about 400 cfs as applied to the lower meadow reach below Kirkwood Creek. Therefore 400 cfs is recommended as the discharge for riparian maintenance purposes through lower Caples Meadow. The frequency of the 400 cfs pulse flow for riparian maintenance should be tied to the wet year types, which occurs about 30 percent of the time. This will saturate most of the Caples Meadow area, activate high flow channels, scour and deposit sediments, providing new opportunities for seed dispersal and germination.

As discussed above (section 5.4), riparian maintenance at JSM does not require a connection with the meadow itself, and does not require flows to scour riparian vegetation to prevent encroachment since the riparian corridor is limited in density and extent along the channel. Further, there is little area for woody riparian growth that is not already occupied by mature forest that is established very close to the channel (a source of large woody debris when there is bank under-cutting). As such, flows that correspond with the elevation of the narrow floodplain below the rooted elevation of the mature trees, where fine sediment deposition and scour of young tree seedlings could occur, is the area where riparian vegetation has established. This is coincident with the floodplain elevation that already has existing fine sediment deposits, and is the stage corresponding to a channel maintenance flow, so that the discharge for channel maintenance and any riparian maintenance is approximately the same. Therefore, channel and riparian maintenance flows are not distinguished further for purposes of pulse flow recommendations in this section.

5.5.2.5 Accretions Downstream of Caples Lake Main Dam to Caples Meadow

There is limited gaging data from which to derive flow accretions between the Caples Main Dam to lower Caples Meadow. There is 4.5 mi^2 of unregulated drainage area contribution below the dam release point, of which 3.6 mi^2 is contributed by Kirkwood Creek. There are 11 years of peak flow data on Kirkwood Creek (Appendix G) that provides some flow information. Considering only the years during which peak flows occurred in April-July, peak flow accretion from Kirkwood Creek has ranged from 77 cfs to 195 cfs, with most flows at or just above 100 cfs. Since these are peak streamflows, we would not expect that flows on Kirkwood Creek would remain this high for 5 continuous days. Assuming that an average 5-day flow that included the annual peak was about one-fourth a typical 100 cfs peak, then about 25 cfs would be a reasonable estimate for an average daily flow accretion rate over a continuous 5-day period. Since there is only a very limited number of years of peak flow data for Kirkwood Creek, it is not possible to distinguish flow accretions rates for wet, above normal, or below normal water years.

Assuming 25 cfs accretion from Kirkwood Creek during the pulse flow release period for wet and above normal years, then a 375 cfs release at the main dam in wet years would provide about 400 cfs to lower Caples Meadow. This does not include about one square mile of watershed between the main dam and Kirkwood Creek that would also provide additional flow accretion. Thus with natural accretion, a 375 cfs release at the dam could be assumed to achieve the 400 cfs pulse flow compliance for riparian maintenance in Caples Meadow in wet years (Table 5-4). A 215 cfs release at the main dam with 25 cfs accretion could be assumed to provide 240 cfs in lower Caples Meadow for above normal years. However, Table 5-4 provides a higher recommended pulse flow defined at the Caples Main Dam release point for above normal years in order to satisfy the 360 cfs needed at JSM. The data, assumptions, and calculations for flow accretion to JSM are discussed in the next secton.

Table 5-4 Recommended Pulse Flow Release at Caples Main Dam and expected Accretion Flows to Caples Meadow and JSM

Reach	Water Year Type				
	Critically Dry (cfs)	Dry (cfs)	Below Normal (cfs)	Above Normal (cfs)	Wet (cfs)
Caples Creek Channel Below Caples Lake Main Dam	0	0	0	250	375
Kirkwood Creek plus 1 mi^2 additional watershed below dam	–	–	–	+25	+25
Resultant flows at Caples Meadow	–	–	–	275	400
Accretions downstream of Caples Meadow [a]	–	–	–	+85	+85
Resultant flows at JSM	–	–	–	360	485

[a] The calculated average accretion from Caples Dam to JSM is 110 cfs, less the estimated 25 cfs inflow from Kirkwood Creek, which is 85 cfs accretion in Caples Creek below the meadow confluence with Kirkwood Creek.

5.5.2.6 Accretions Downstream of Caples Dam to JSM

A project operations flow release that achieves 400 cfs in the lower Caples Meadow reach will provide a flow greater than 400 cfs downstream at Jake Schneider Meadow due to natural flow accretion. There is an additional 12.5 mi^2 of unregulated watershed contributing to Caples Creek below lower Caples Meadow (16.9 mi^2 of unregulated flow contribution beginning at the main dam release point). Therefore, by default the 400 cfs riparian maintenance flow in wet years for Caples Meadow reach will “control” the flow at JSM in wet years, easily exceeding the 360 cfs flow proposed as the channel and riparian maintenance. To achieve a 360 cfs channel and riparian maintenance flow at JSM every other year, a flow release from Caples Lake must occur in both above normal and wet years that meet the 360 cfs flow threshold for JSM.

Hydrographs showing the measured accretion between the Caples Main Dam and JSM collected by EID in 2000 (BN), 2002 (Dry), and 2003 (BN) are provided in Appendix G. These are the only known gaging records at JSM. The accretions were calculated by comparing discharge at the Caples Lake Main Dam and Caples Creek at JSM. Inspection of the hydrographs show that there is at least 75 cfs flow accretion over a continuous five day period during the peak runoff period for each of these years, and it appears that even greater accretion amounts occur.

Temperature and flow data for 2000, 2001, and 2002 was used to determine the pulse flow initiation date in each year using the peak flow determination procedure. For each of the three years the flow data for the five-day period following the trigger date to begin pulse flows was used to calculate the average amount of flow accretion. The average five-day flow accretion calculated for what would have been the pulse flow period in these three years was 110 cfs. Since the only available flow accretion data are for below normal and dry years, it is can be expected that the accretion rate will be greater for the above normal and wet years. However, we applied a conservative approach and assumed that the below normal and dry year accretion flows would be typical for above normal and wet years. Thus, for the above normal and wet years a flow release at Caples Dam would gain at least 110 cfs in natural accretion at JSM (85 cfs accretion below the Kirkwood confluence since Kirkwood Creek is estimated to provide 25 cfs).

As shown in Table 5-4, a 250 cfs release at Caples Dam in above normal years would provide 275 cfs in Caples Meadow accounting for the 25 cfs accretion from Kirkwood Creek. This is greater than the 240 cfs needed for channel maintenance through Caples Meadow. With the additional accretion of 85 cfs below Caples Meadow to JSM, the flow will be 360 cfs. Thus, to satisfy the 360 cfs channel maintenance flow in JSM in above normal years the release from Caples Dam should be 250 cfs.

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Chapter 6

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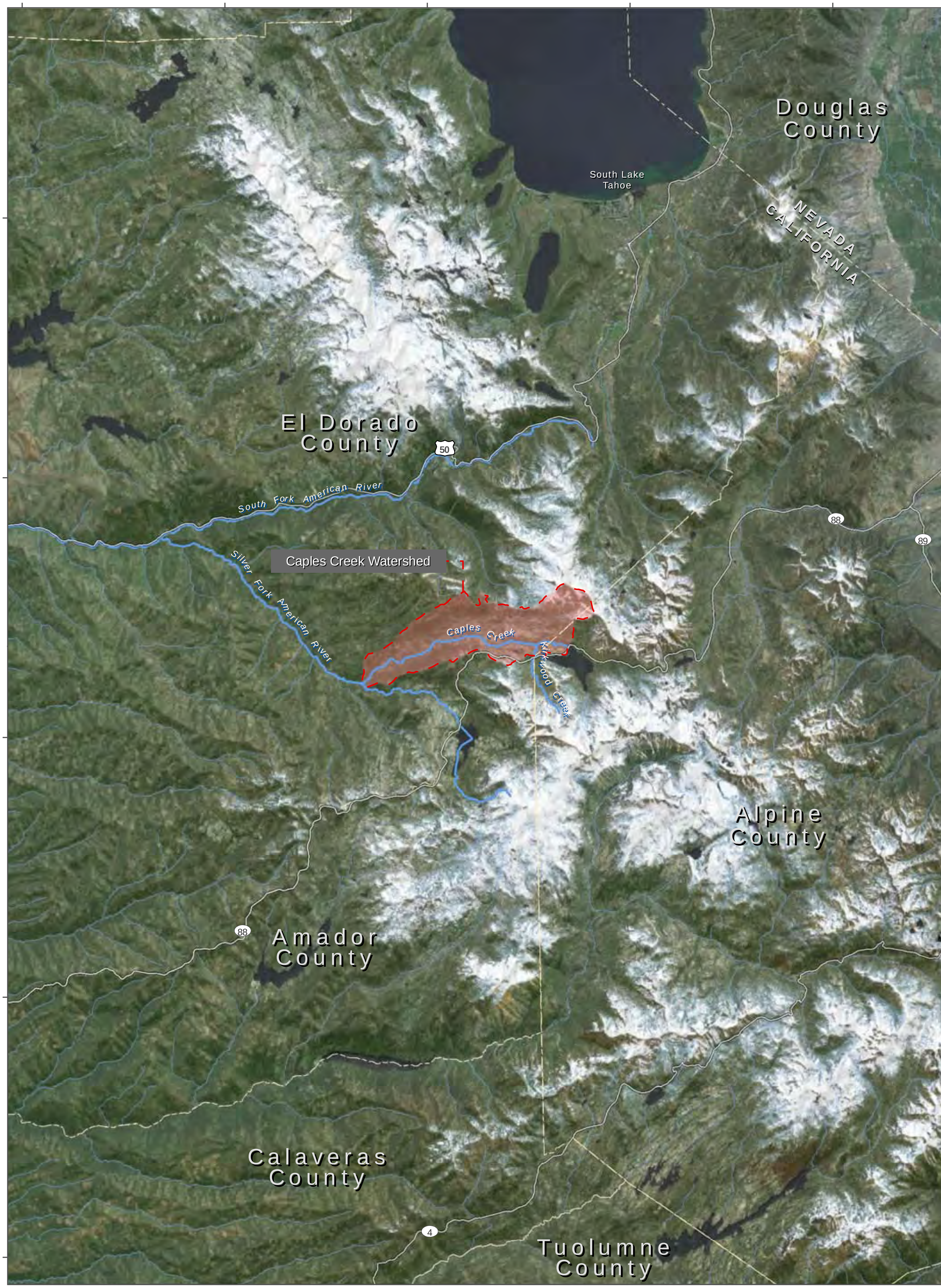
Figures



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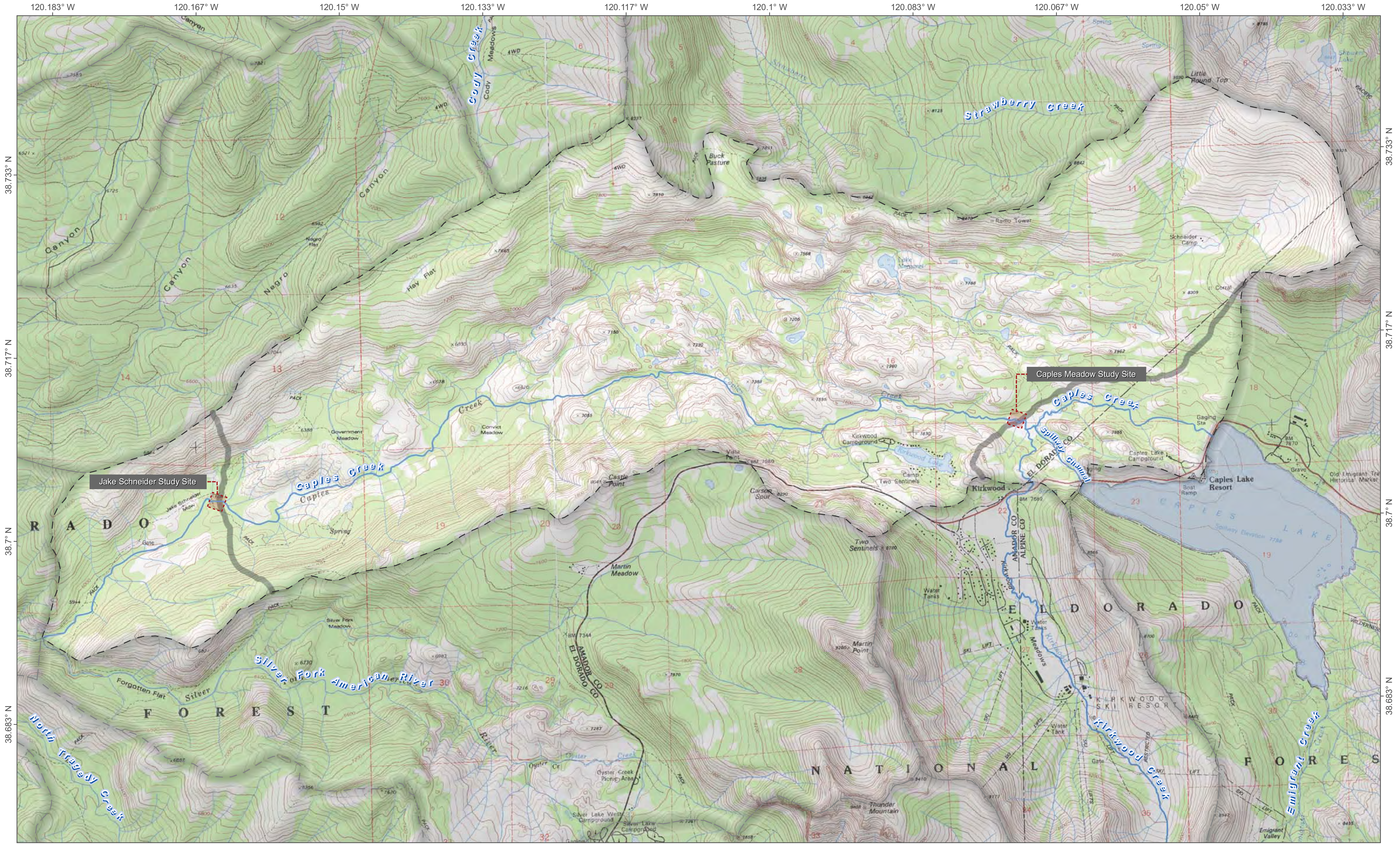
0 1.25 2.5 5

Scale in Miles

Sensitive Site Investigation and Mitigation Plan

Figure 1-1

Vicinity Map



WATERSHED INFORMATION

Hydrologic Region Name (HR):	Sacramento River
Regional Water Quality Control Board Name (RB):	Central Valley
Hydrologic Basin Planning Area Name (HBPA):	Sacramento Basin
Hydrologic Unit Name (HU):	American River
Hydrologic Area Name (HA):	South Fork American
Hydrologic Sub-Area Name (HSA):	Silver Fork
Super Planning Watershed Name (SPWS):	Kirkwood
Planning Watershed Name (PWS):	Caples Creek
Planning Watershed Acres:	9,209.27 Acres

N

0 0.25 0.5 1

Scale in Miles

Legend

- Study Sites
- Watershed Boundary
- Stream | River
- Local Drainage Areas

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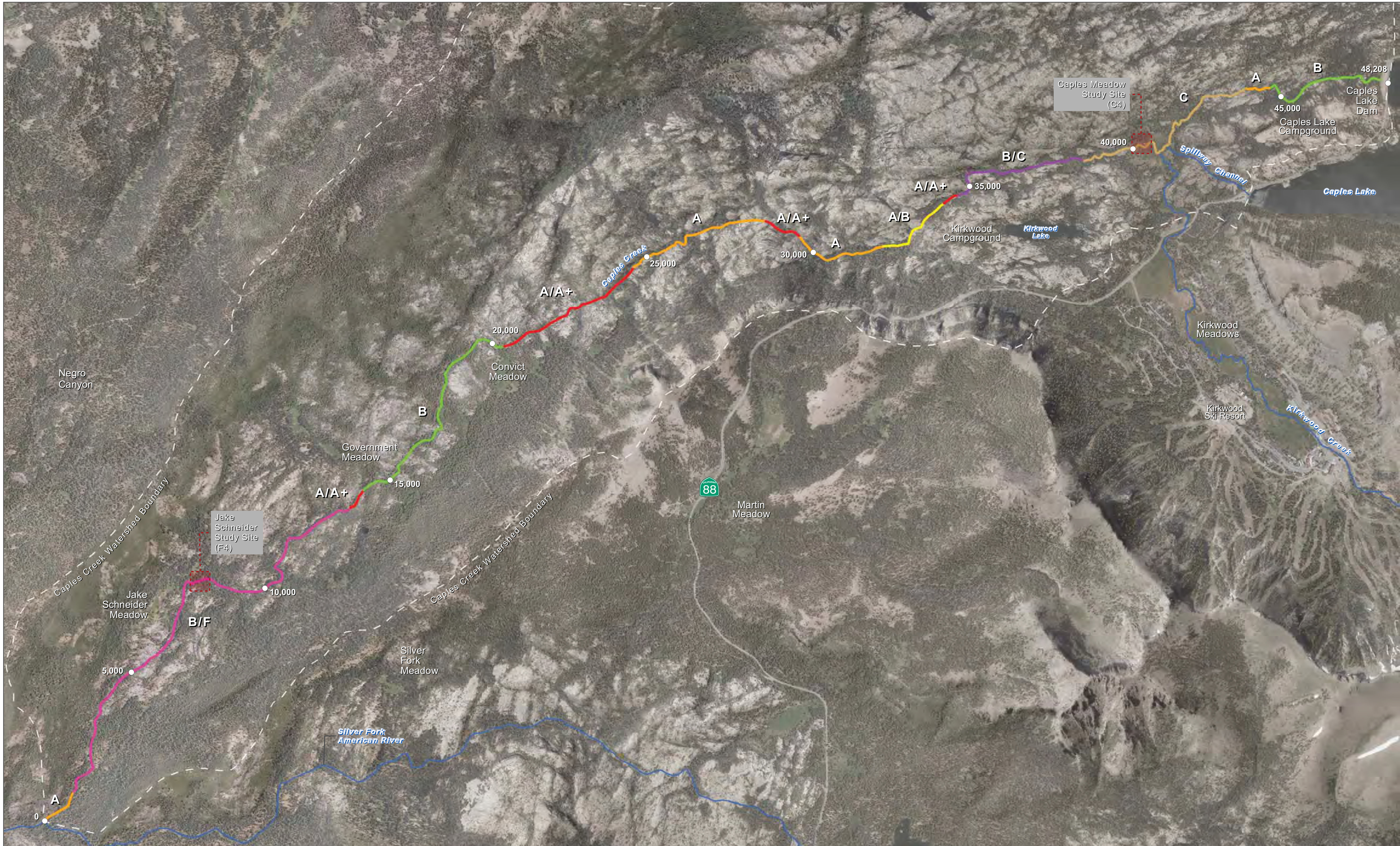
Sensitive Site Investigation and Mitigation Plan

Figure 2-1

Caples Creek Watershed



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Aerial Imagery from U.S. Department of Agriculture, National Agricultural Imagery Program (NAIP), El Dorado County, 2010.

Channel Elevations based on a USGS 10 meter DEM, and Rosgen Level 1 Classification from Doug Parkinson & Associates, 1999.

N

0 0.25 0.5 1
Scale in Miles

Rosgen Level 1 Channel Classifications

- A/A+
- A
- A/B
- B
- B/C
- B/F
- C

Sensitive Site Investigation and Mitigation Plan

Figure 2-2
Caples Creek Rosgen Level I and II Channel Classification

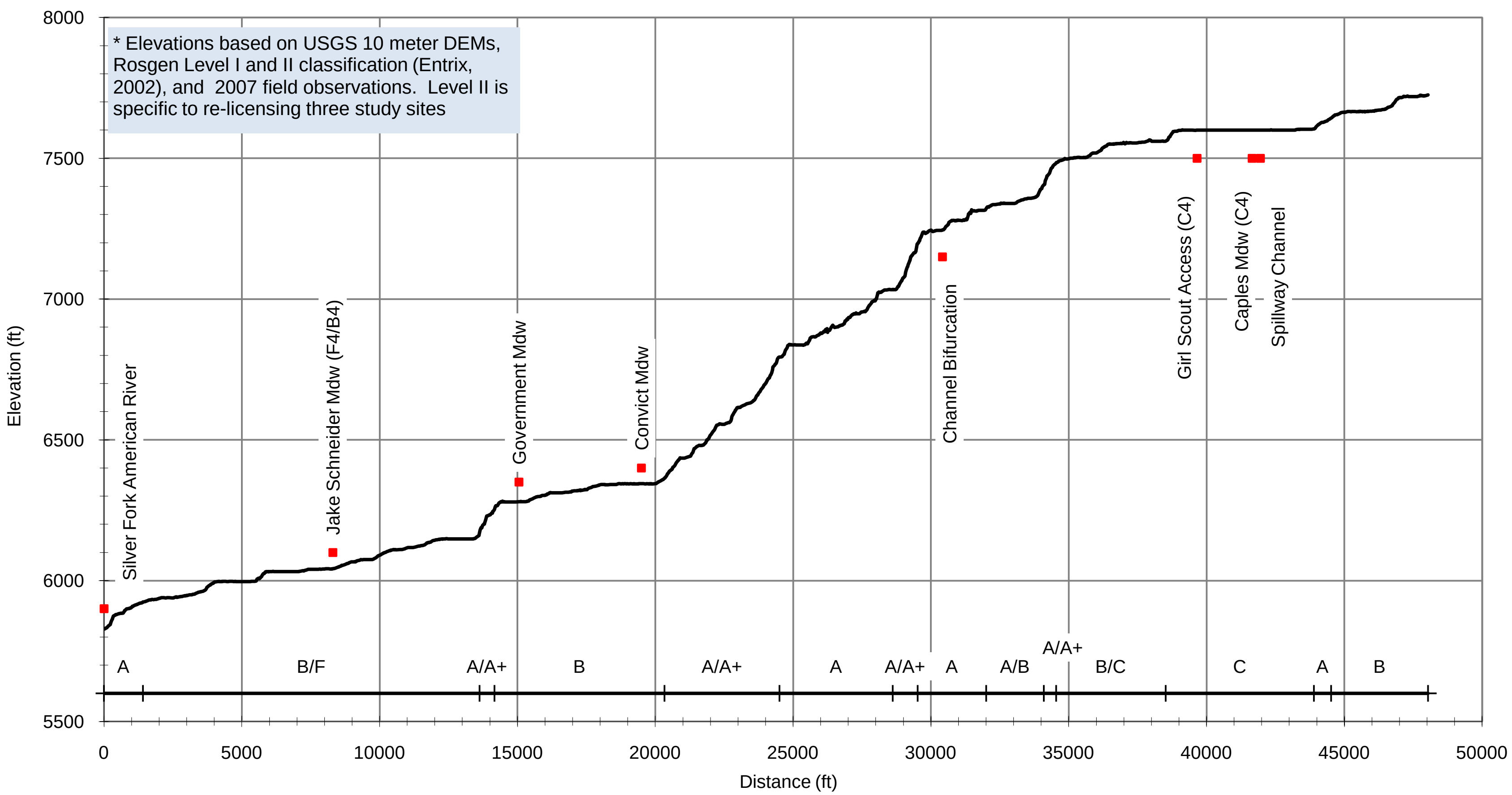

Figure 2-3 Caples Creek Channel Elevation Profile and Rosgen Level I and II Classification

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Cross Section

Thalweg Profile

Sensitive Site Investigation and Mitigation Plan

Figure 2-4

Surveyed Cross Sections and Long Profile

Caples Meadow Study Site

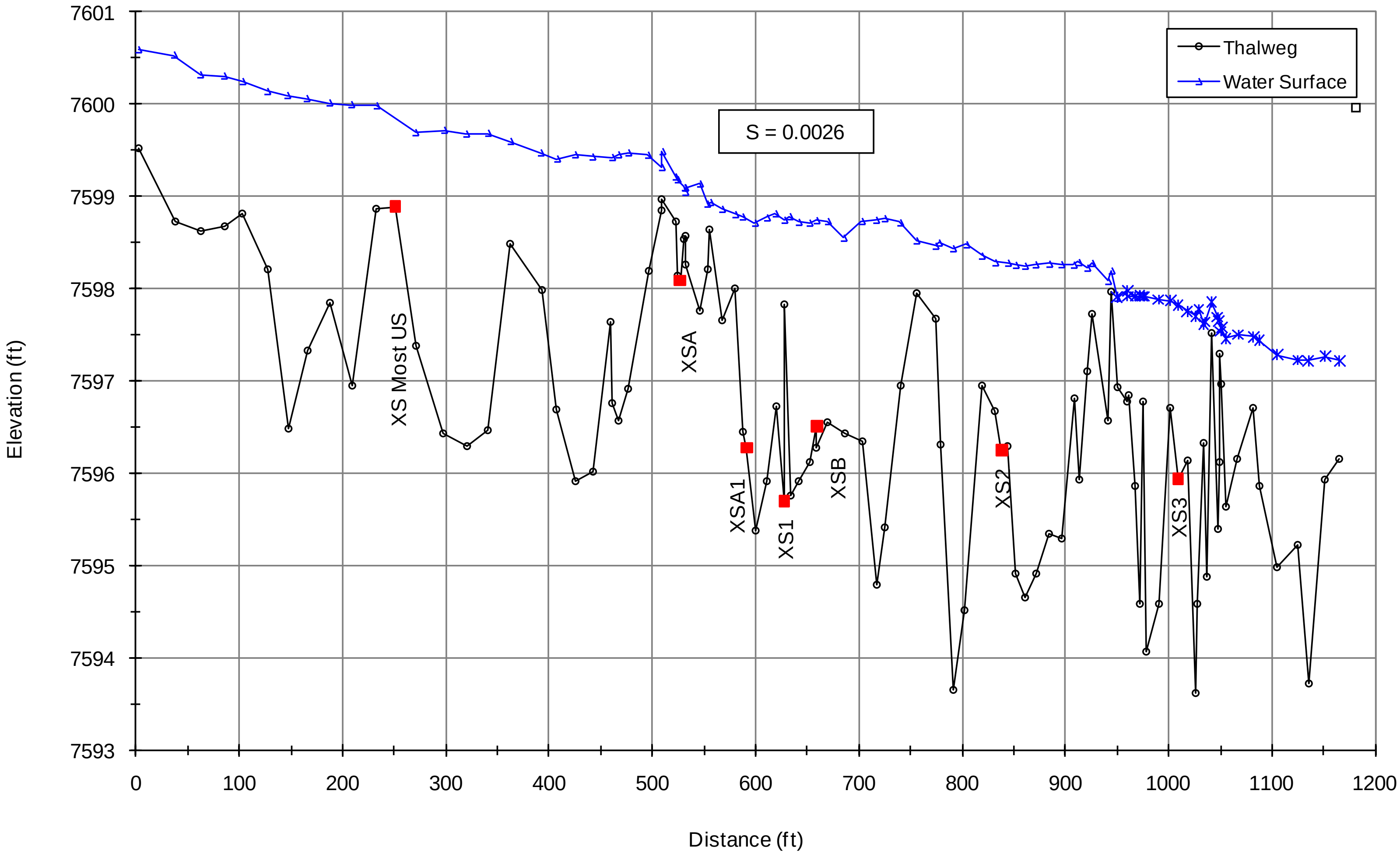

Figure 2-5 Caples Meadow Study Site Thalweg and Longitudinal Profile

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Cross Section
Thalweg Profile

Figure 2-6
Surveyed Cross Sections and Long Profile
Jake Schneider Study Site

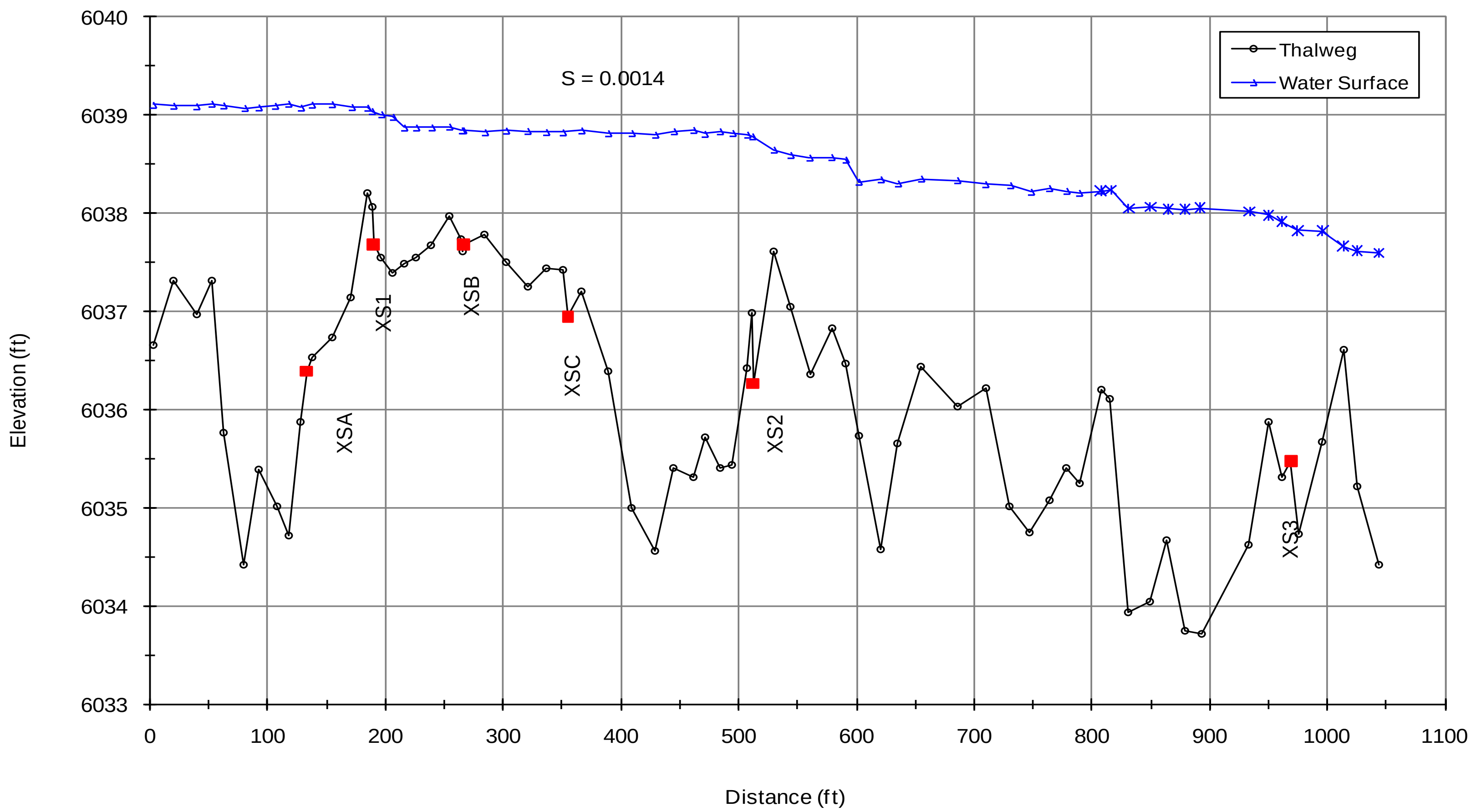


Figure 2-7 Jake Schneider Meadow Study Site Thalweg and Longitudinal Profile

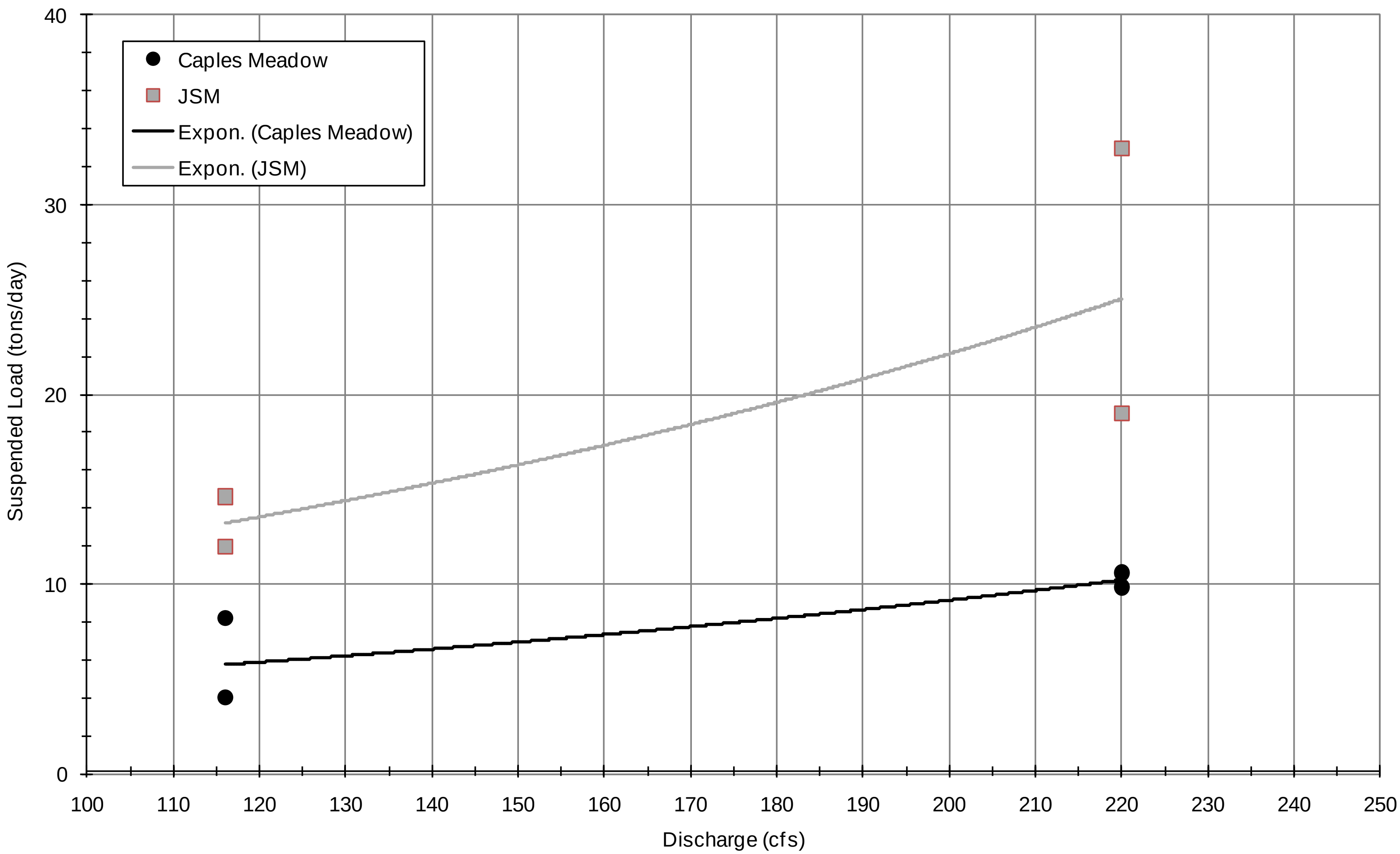


Figure 3-1 Suspended Sediment Load Transport Rates Measured at Caples Meadow and Jake Schneider Meadow

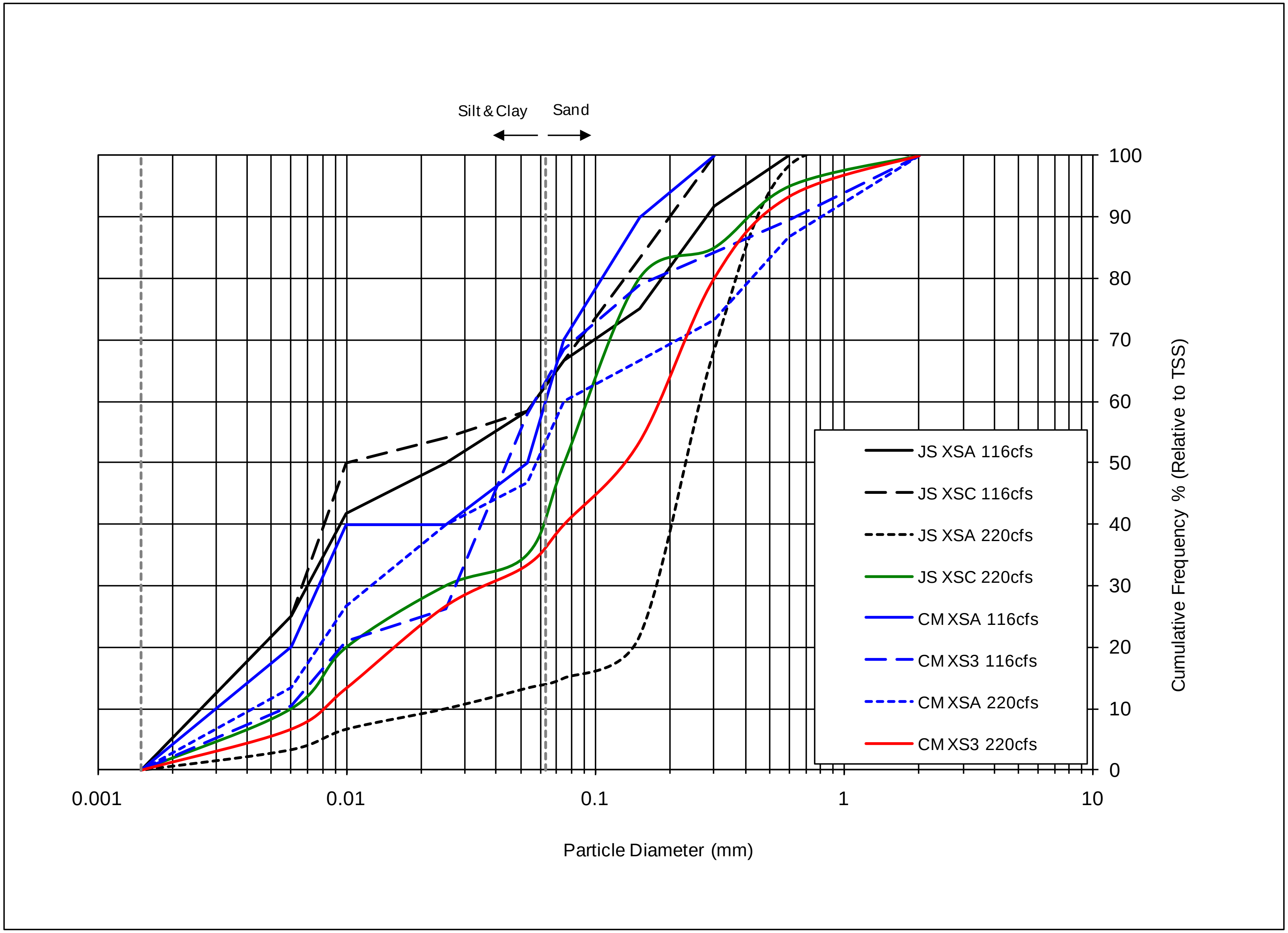


Figure 3-2 Suspended Sediment Grain Size Distributions Measured at Caples Meadow and Jake Schneider Meadow

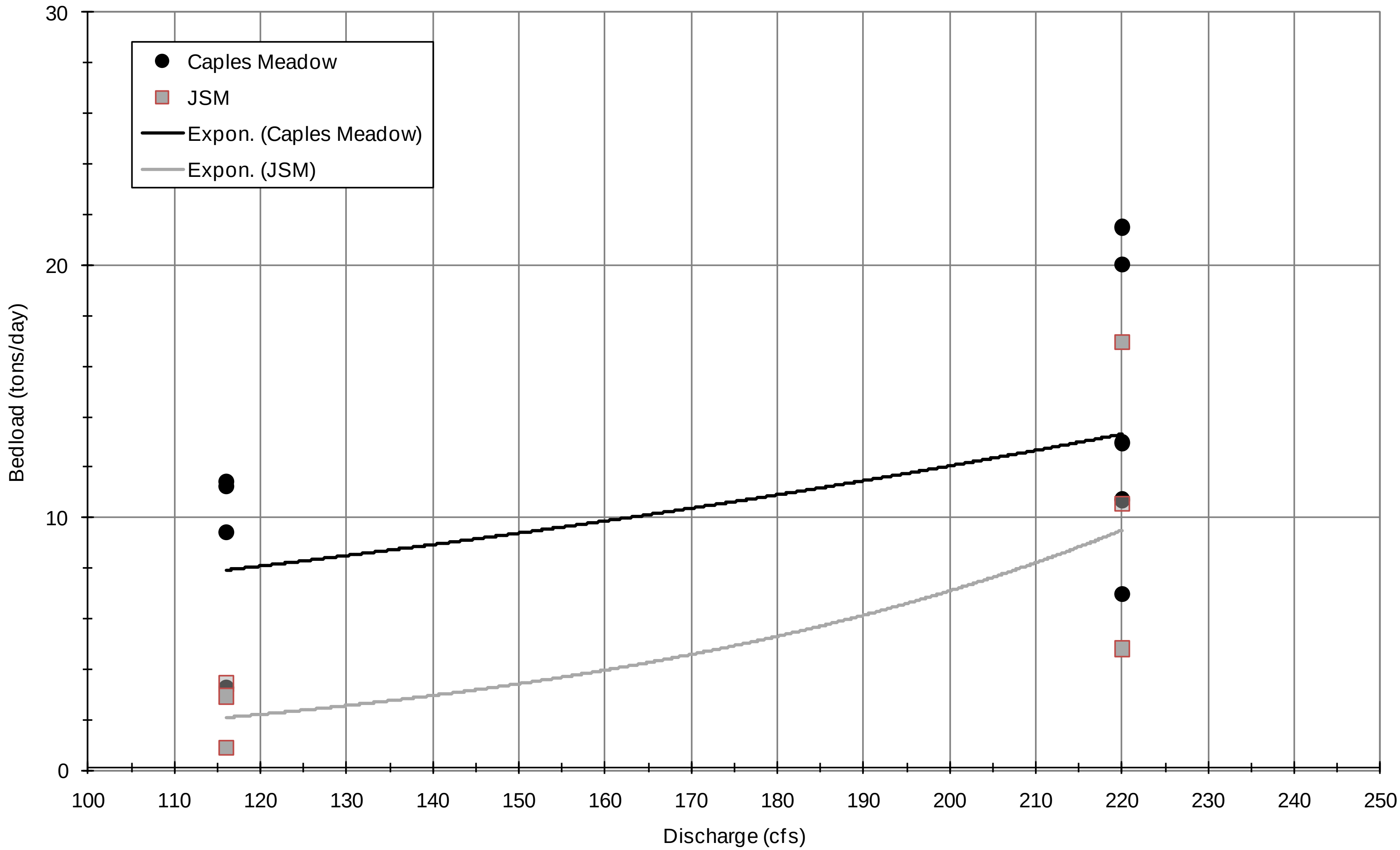


Figure 3-3 Bedload Transport Rates Measured with Helley-Smith Sampler at Caples Meadow and Jake Schneider Meadow

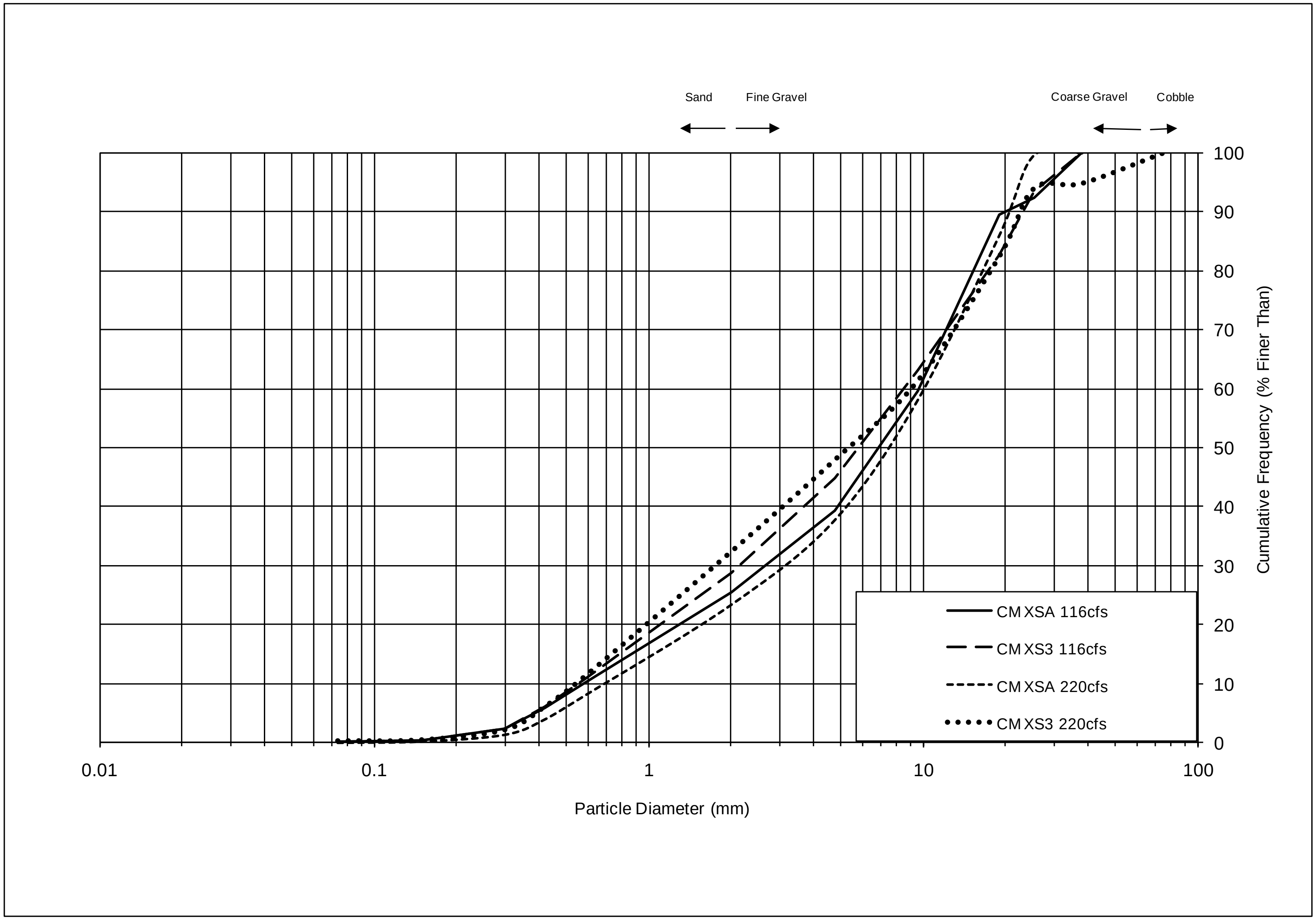


Figure 3-4 Bedload Grain Size Distributions Measured with Helley-Smith Sampler at Caples Meadow

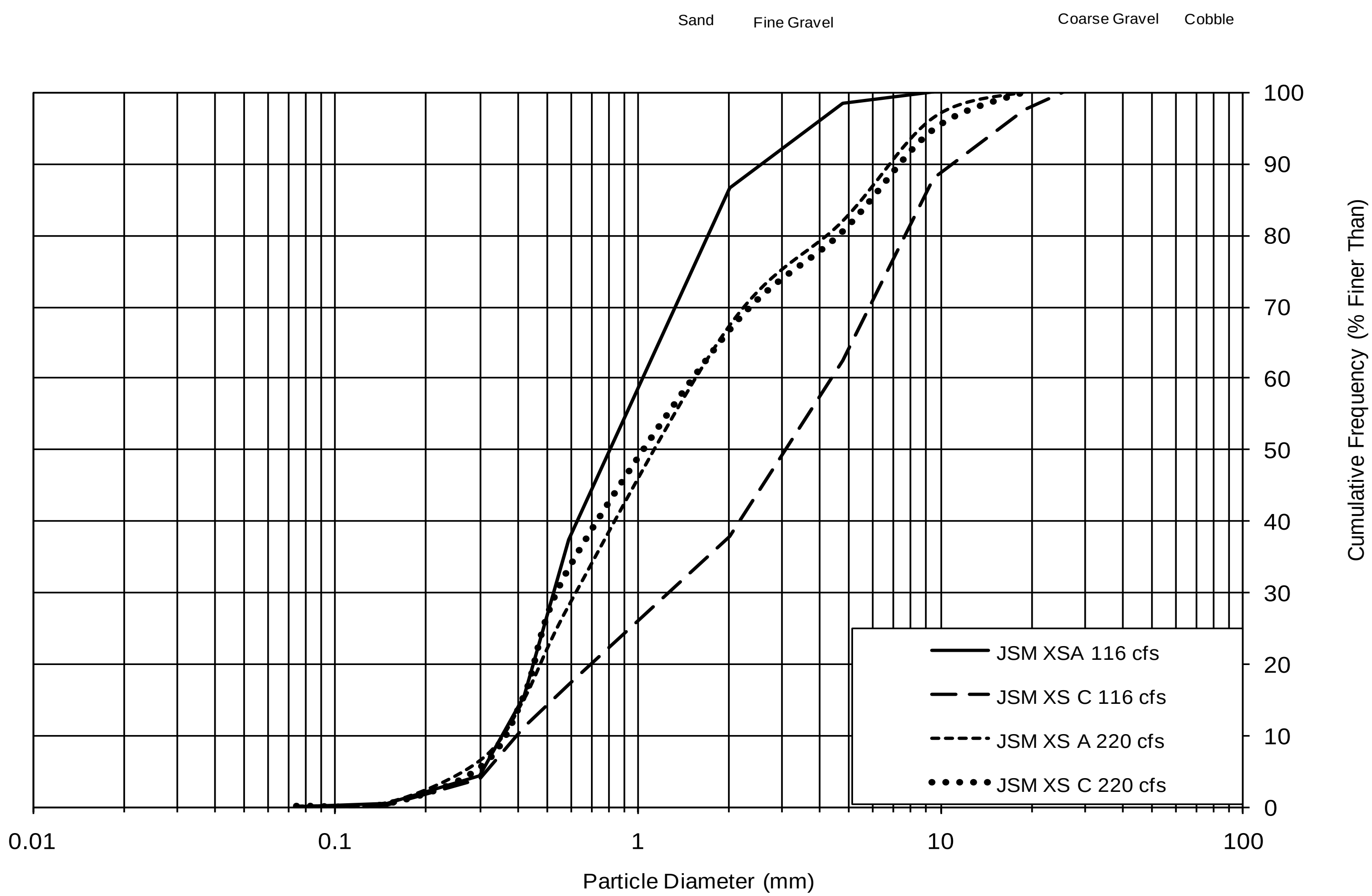


Figure 3-5 Bedload Grain Size Distributions Measured with Helley-Smith Sampler at Jake Schneider Meadow

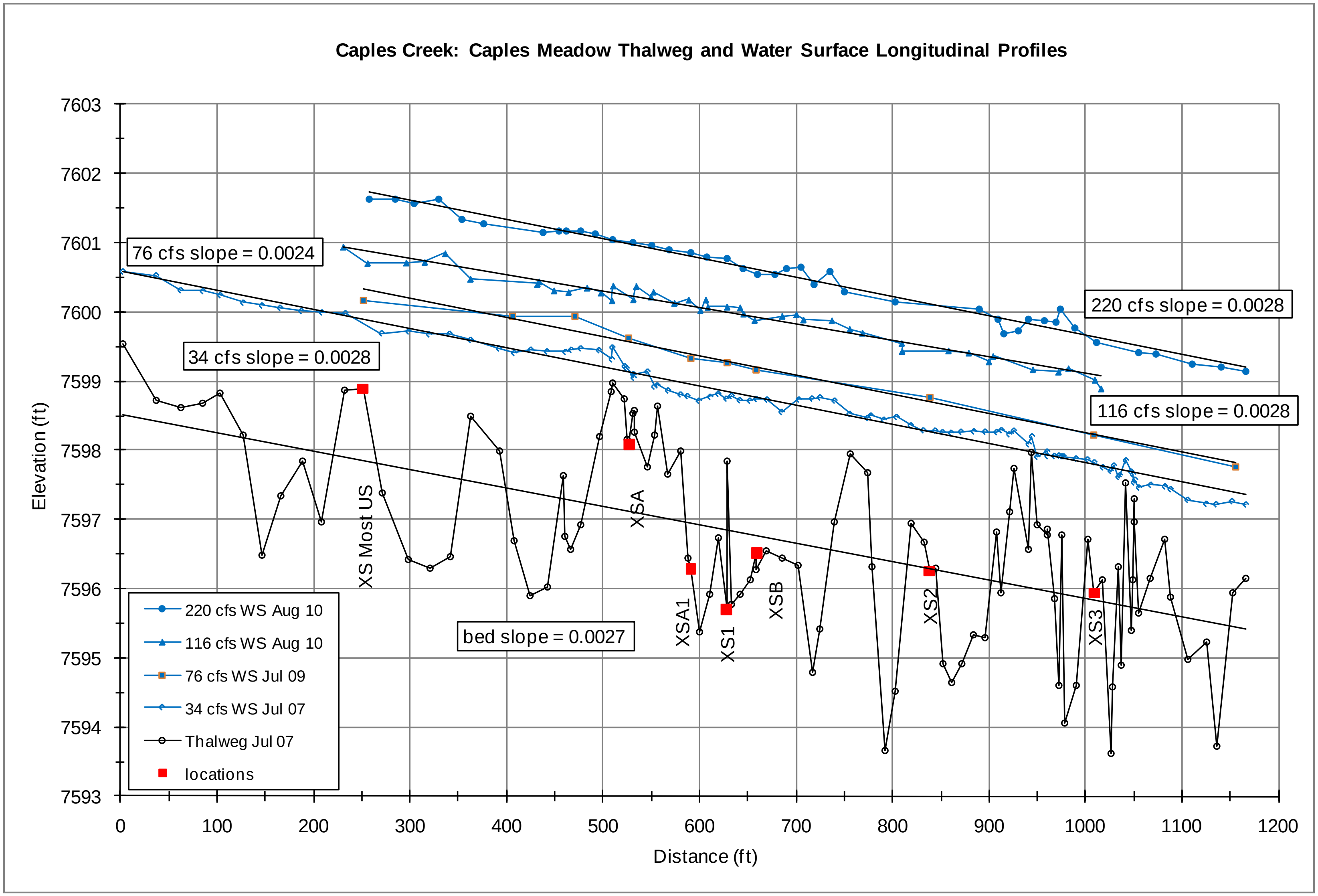


Figure 4-1 Surveyed Water Surface and Thalweg Elevation Profiles at Caples Meadow for Calibration Flows

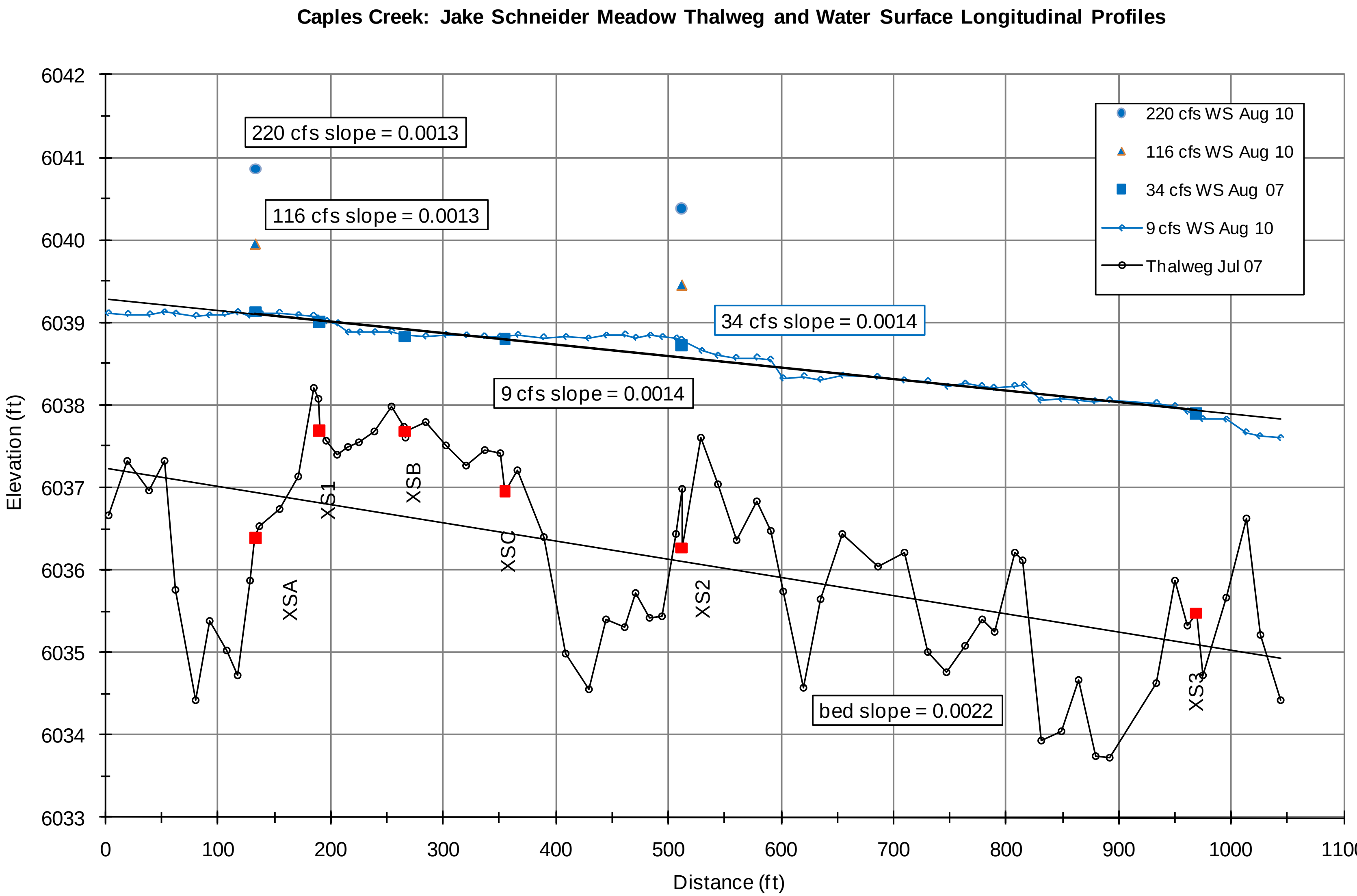


Figure 4-2 Surveyed Water Surface and Thalweg Elevation Profiles at JSM for Calibration Flows

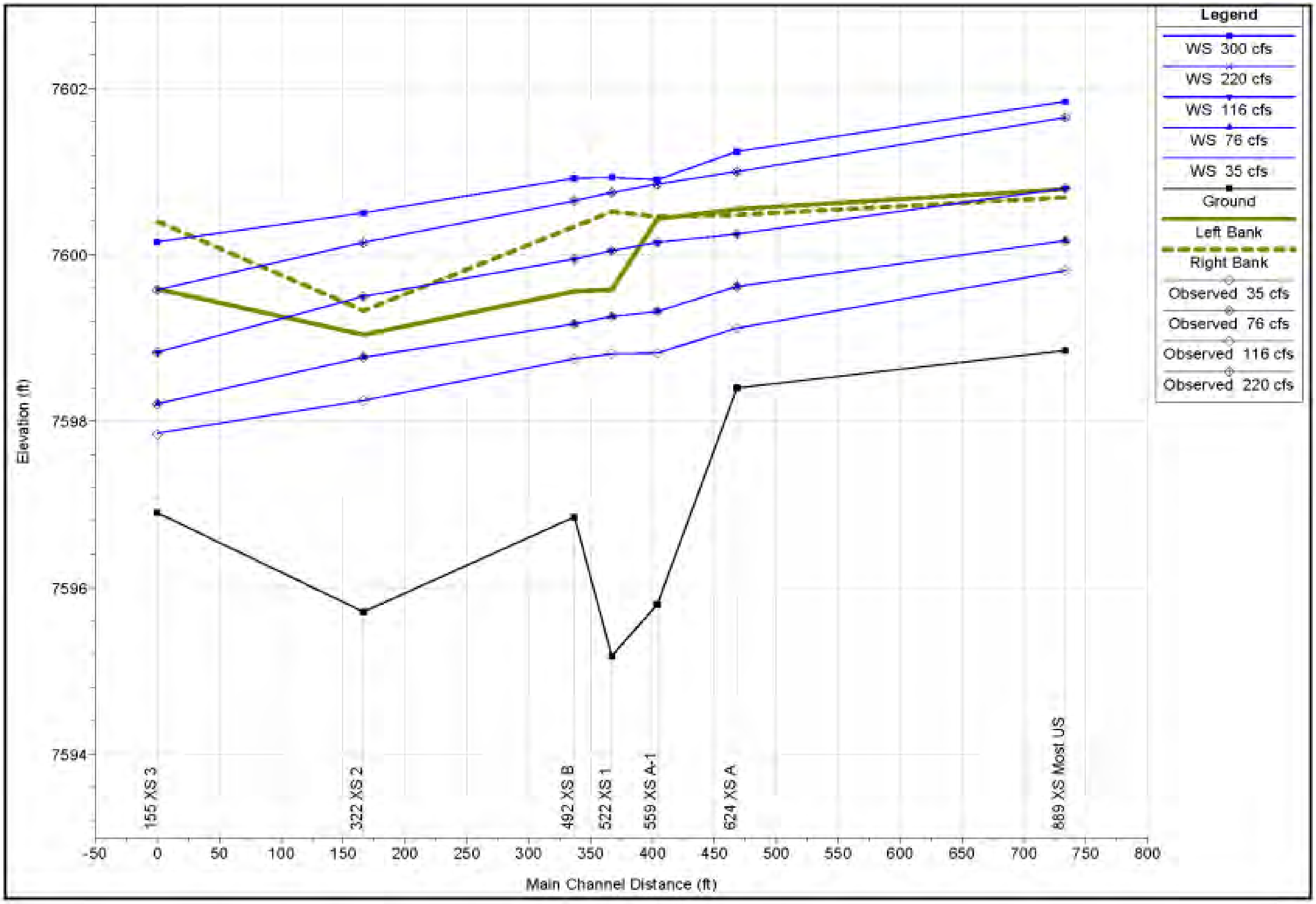


Figure 4-3 Thalweg, left and right top of banks, modeled water surface elevation at Caples Meadow Study Site

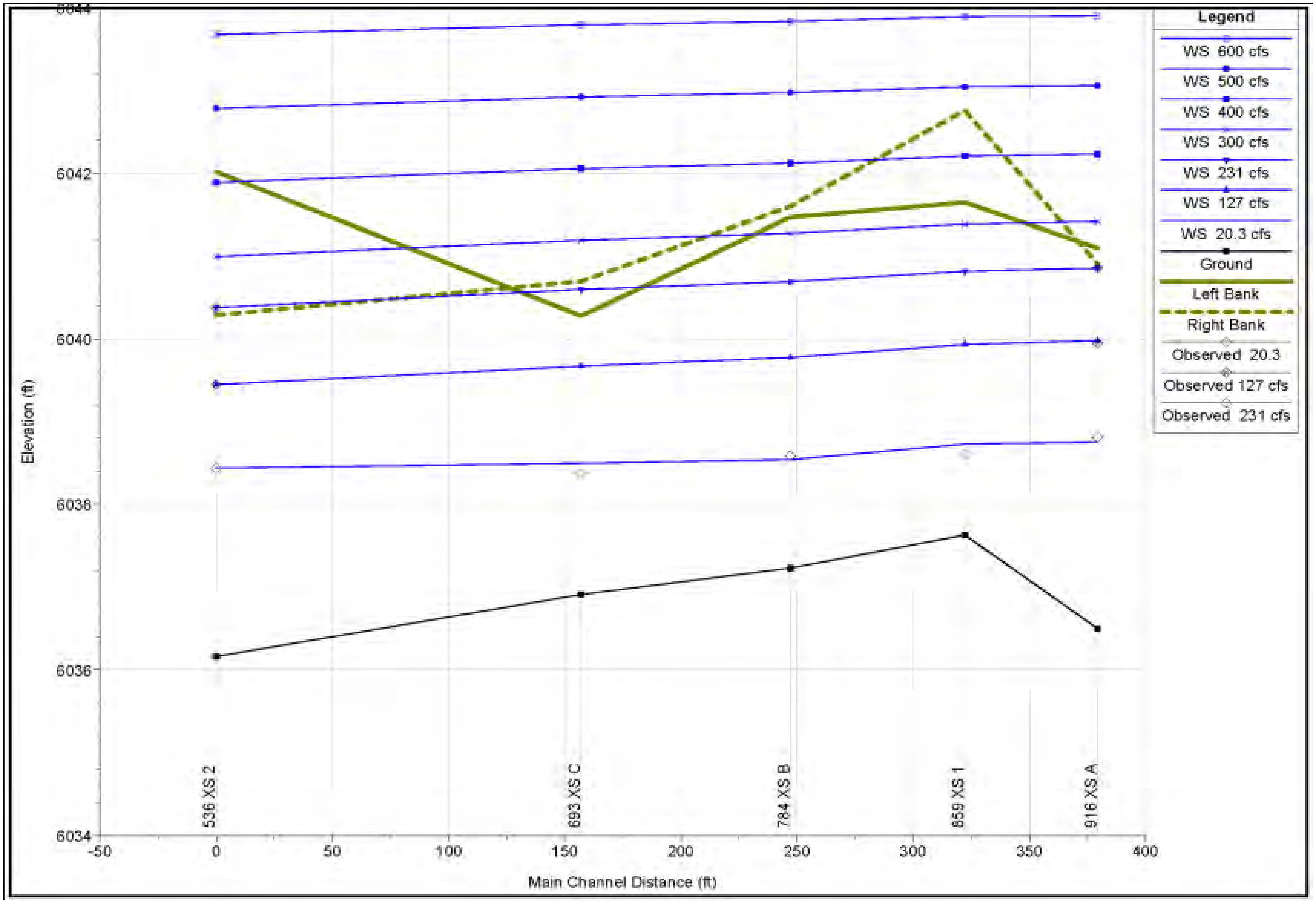


Figure 4-4 Thalweg, left and right top of banks, and modeled water surface elevation at JSM Study Site

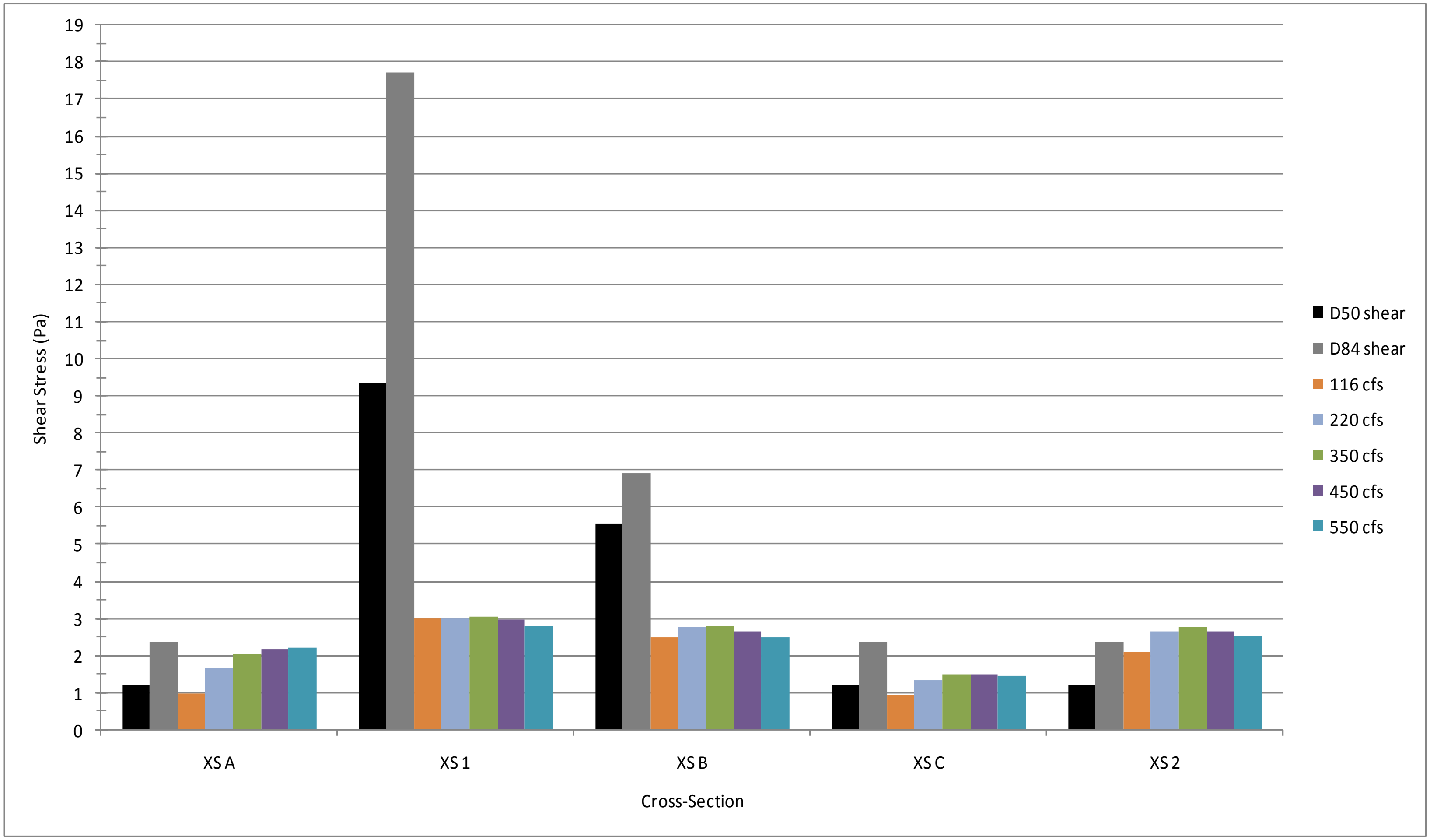


Figure 4-5 Modeled shear stresses compared to the shear stress needed to mobilize the D_{50} and D_{84} at Jake Schneider Meadow

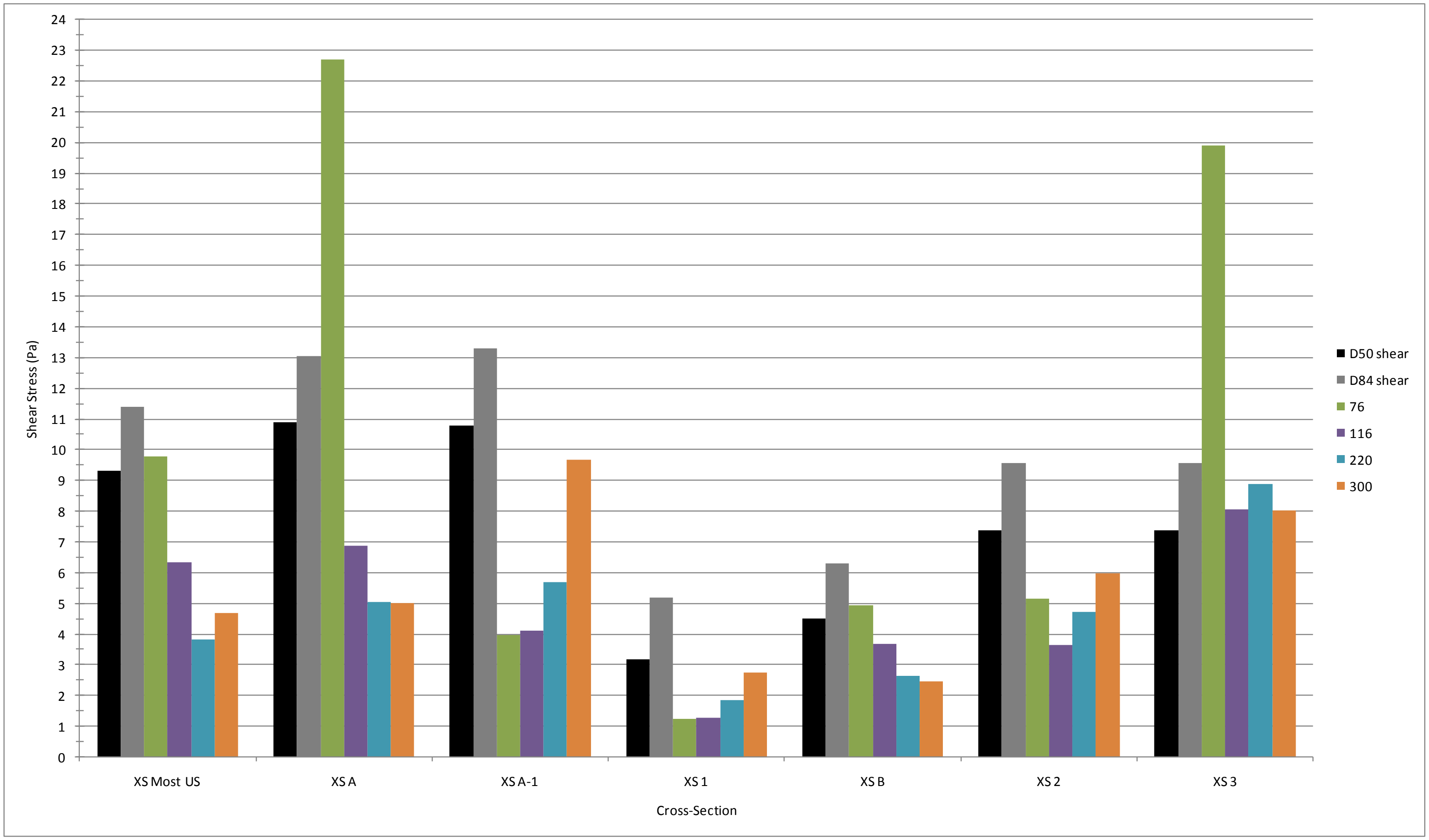
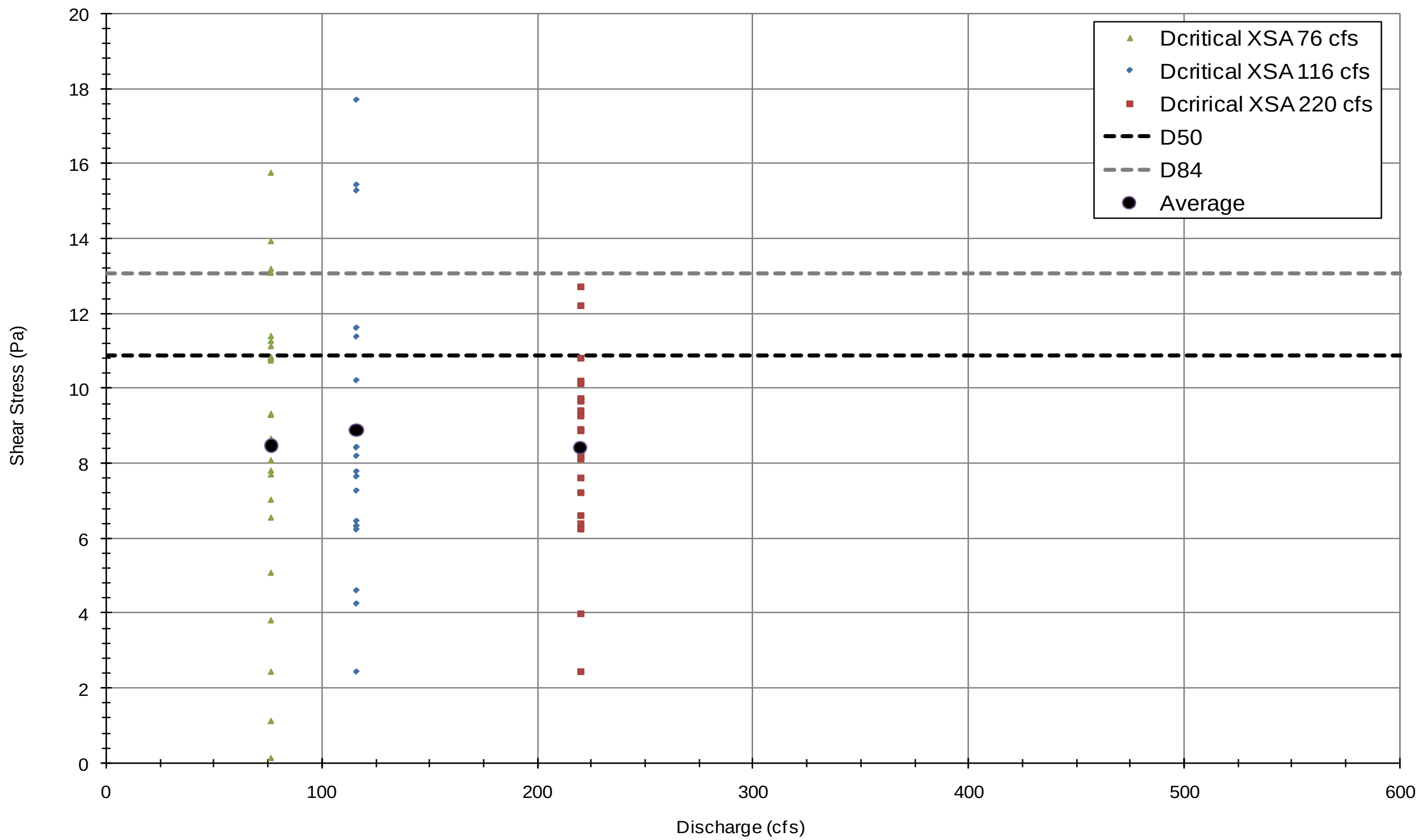
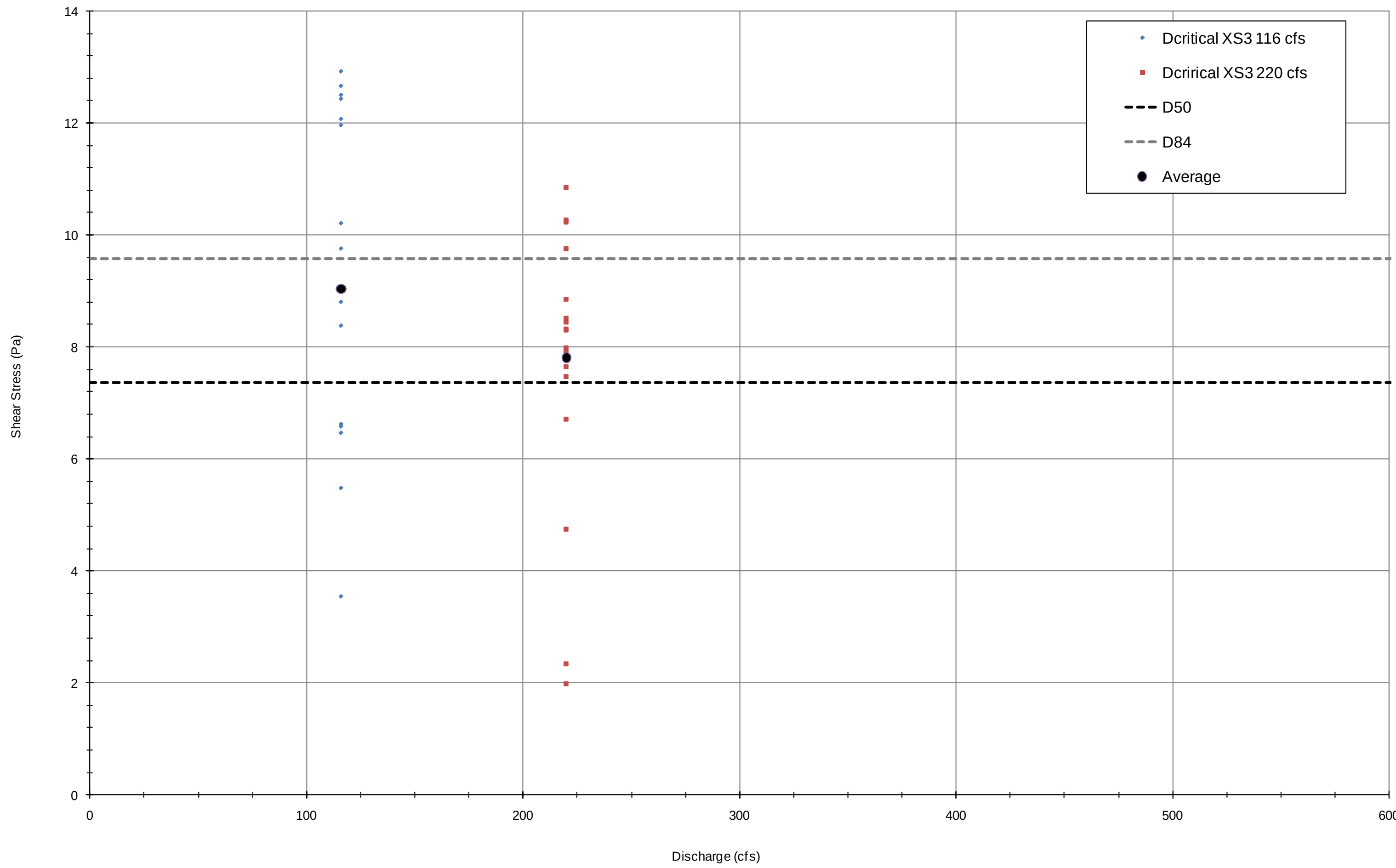


Figure 4-6 Modeled shear stresses compared to the shear stress needed to mobilize the D_{50} and D_{84} at Caples Meadow Study Site



Note: Bed shear stress data points that plot above the horizontal lines indicate the shear stress is great enough to mobilize the D50 or D84 sediment

Figure 4-7 Local bed shear stress obtained from measured depths and velocities compared to the shear stress needed to mobilize the D_{50} (dark horizontal line) and D_{84} (grey horizontal line) at Caples Meadow XS A



Note: Bed shear stress data points that plot above the horizontal lines indicate the shear stress is great enough to mobilize the D50 or D84 sediment.

Figure 4-8 Local bed shear stress obtained from measured depths and velocities compared to the shear stress needed to mobilize the D_{50} and D_{84} at Caples Meadow XS 3

Photos

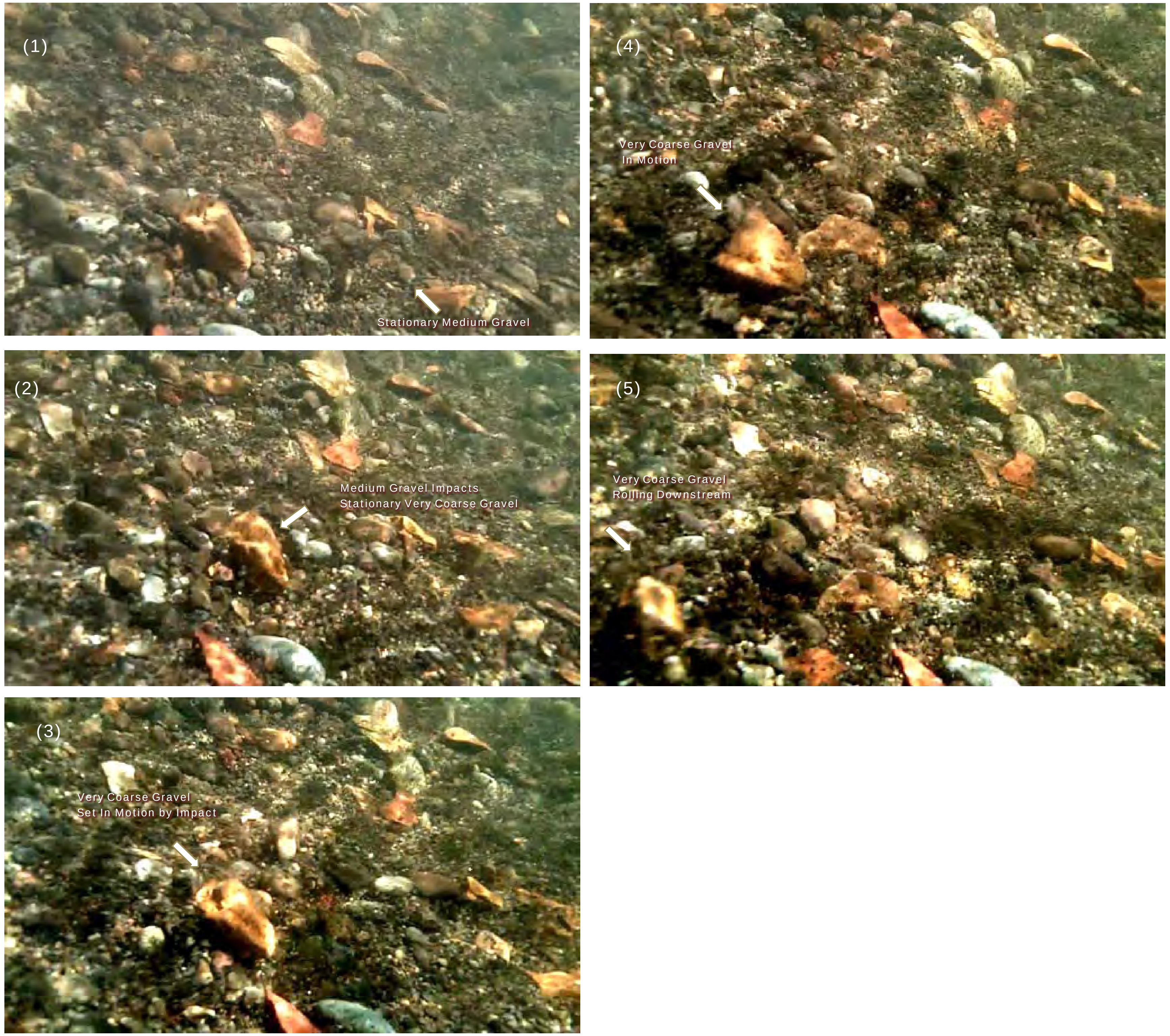


Photo 3-1 Still frames from video taken downstream of Caples Meadow XS 3 on August 5, 2010 at approximately 220 cfs. The photo sequence shows bedload movement

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Photo 3-2 Bedload traps deployed at Caples Meadow XS A prior to the 116 cfs test flow

Photo 3-3 Organic debris from the bedload traps deployed at Caples Meadow XS A

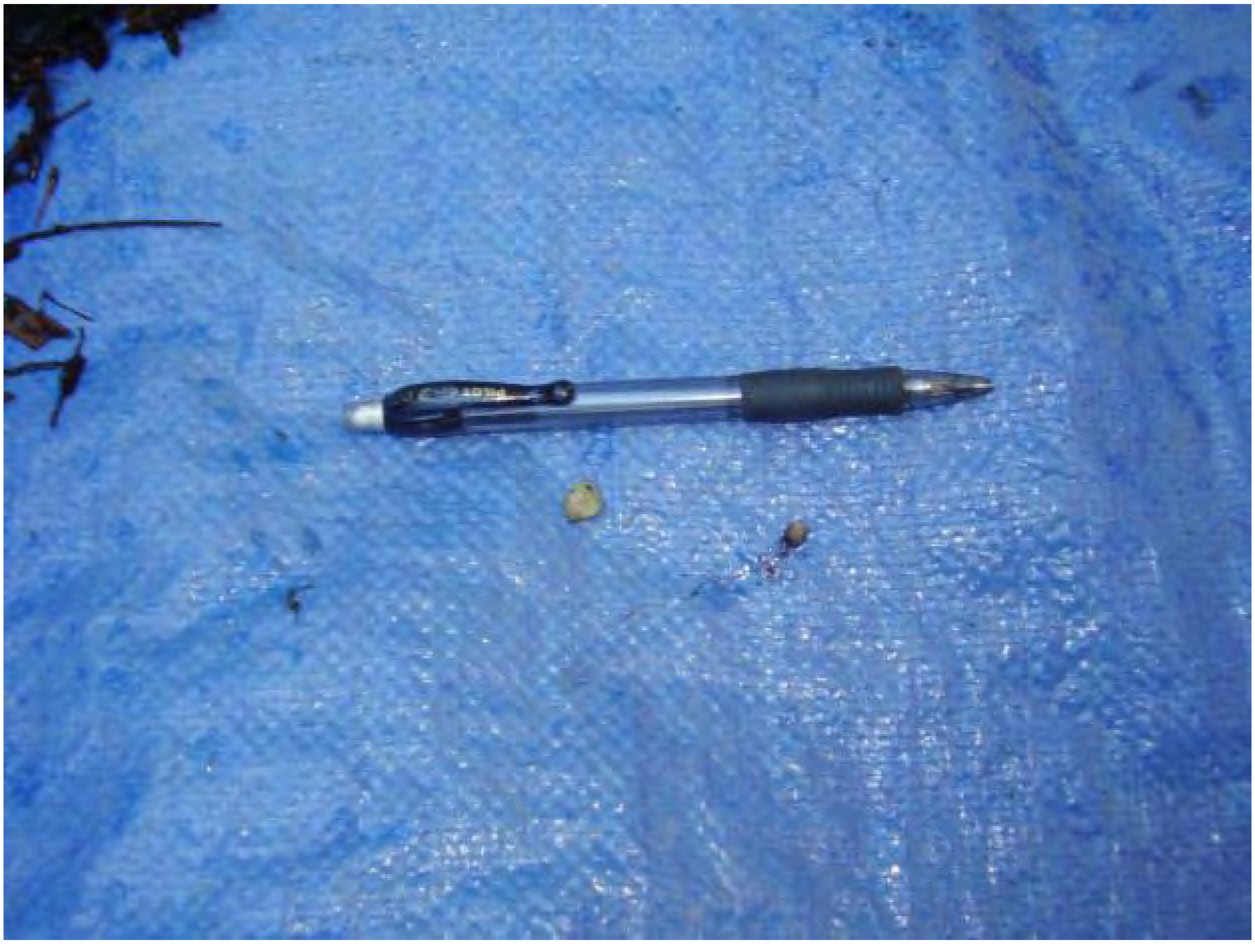

Photo 3-4 Fine Gravels Caught In Net Frame Sampler during 116 cfs Flow at JSM

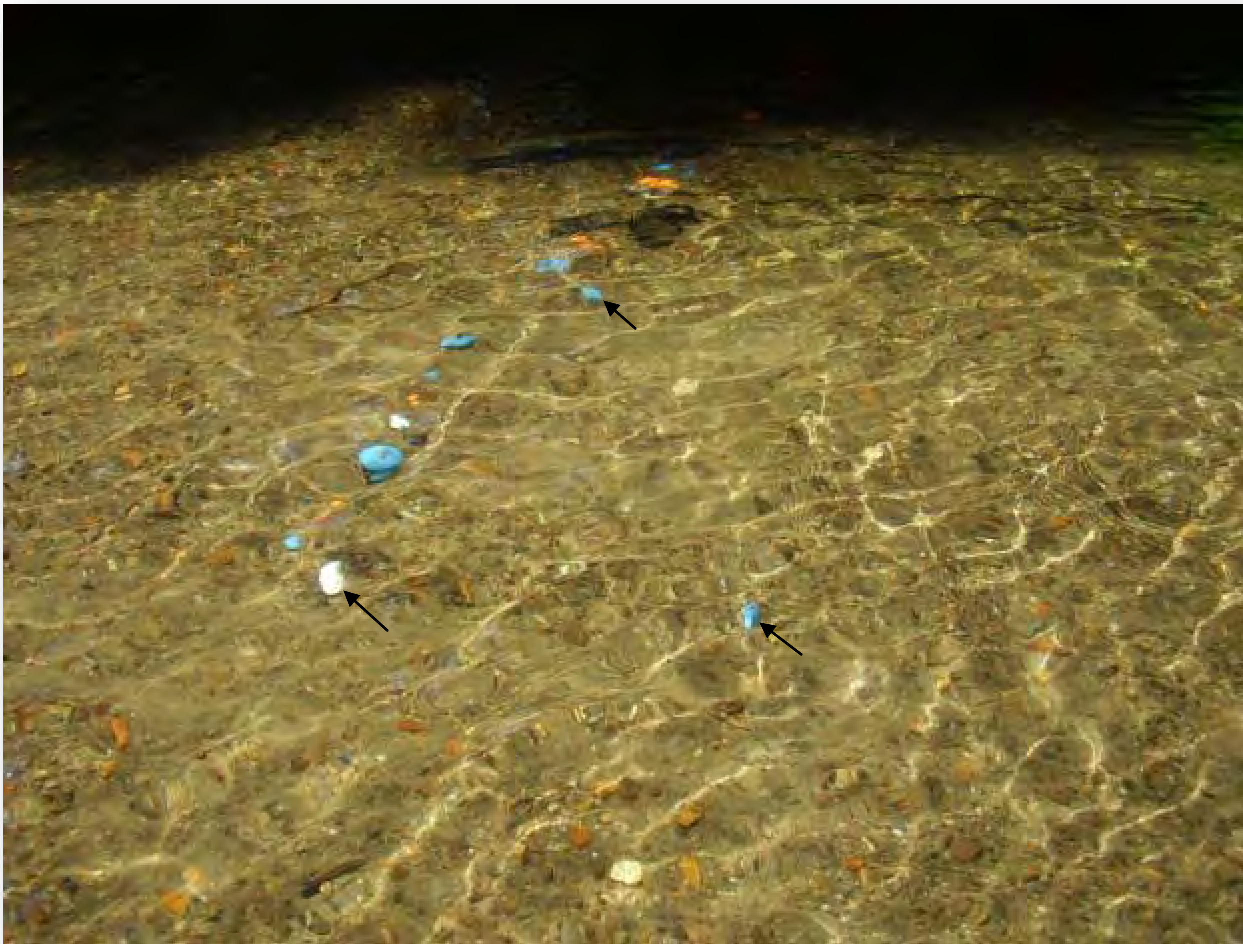

Photo 3-5 Tracers at JSM XS-C After 220 cfs Flow. Three tracers that moved are marked with arrows

Photo 4-1 Floodplain flow on Caples Meadow east of XS 2 at 220 cfs

Photo 4-2 Caples Creek Upstream of Kirkwood Creek Right Overbanking Flow at 220 cfs

Photo 4-3 Oblique aerial of Caples Meadow at approximately 350 cfs release from Caples Dam on June 11, 2010

Photos 4-4 (top) and 4-5 (bottom) Comparison of Caples Creek in Caples Meadow near XS 3 for flows of 7 cfs and 350 cfs release from Caples Dam

Photos 4-6 (top) and 4-7 (bottom) Comparison of Caples Creek in Caples Meadow near XS Most US for flows of 5cfs and 350 cfs from Caples Dam

Photo 4-8 Jake Schneider Meadow Inset Floodplain at XS-A Right Bank. Floodplain is 5 feet wide sandy flat (blue line)

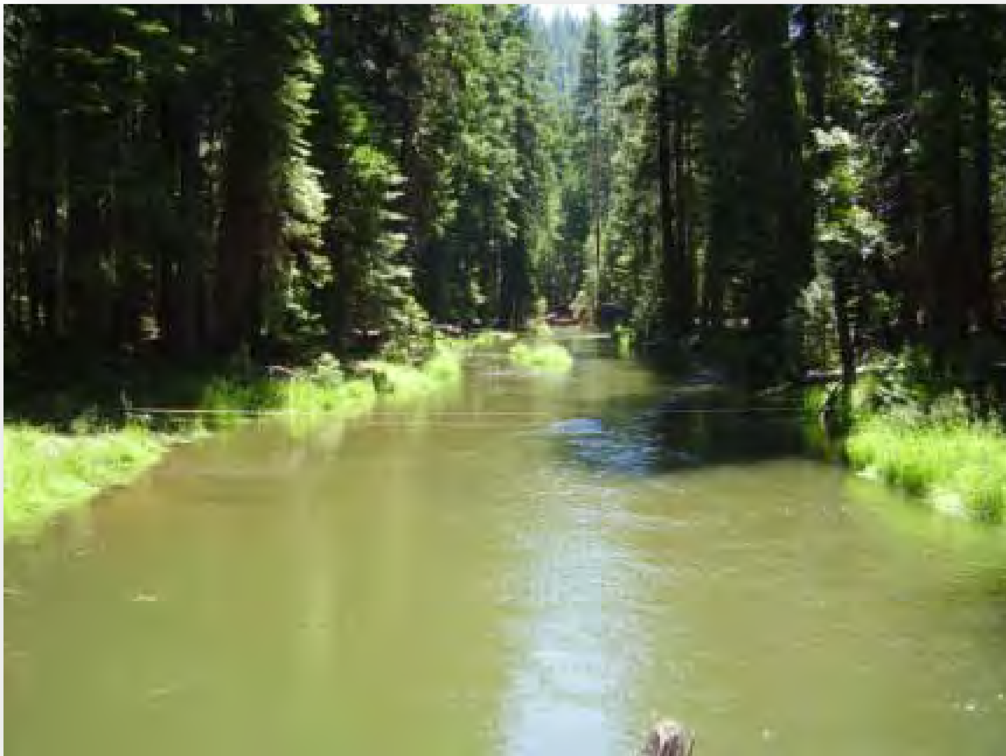

Photo 4-9 Jake Schneider Meadow at 220 cfs (view Upstream to XS-B). Flow is just at level of floodplain, but below top of bank at elevation of trees which is the forested valley floor

Photo 4-10 Jake Schneider Meadow (view upstream, right bank) with mature coniferous trees and young tree seedlings growing along sandy depositional floodplain close to channel.

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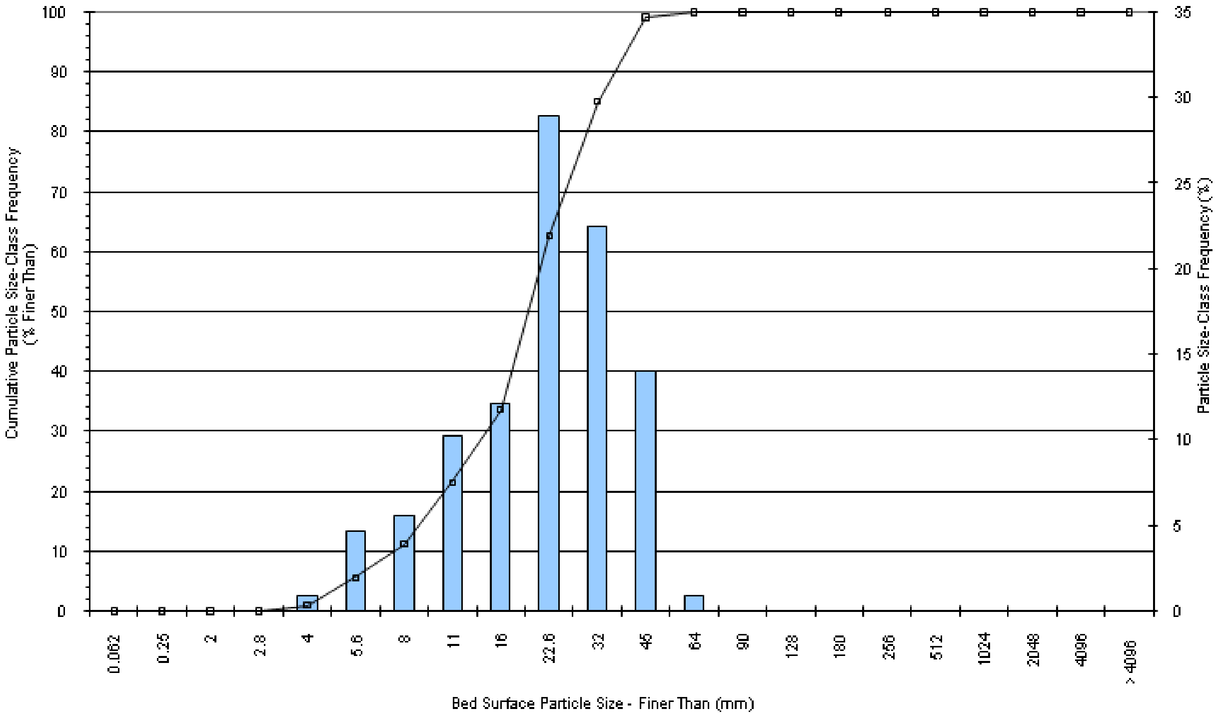
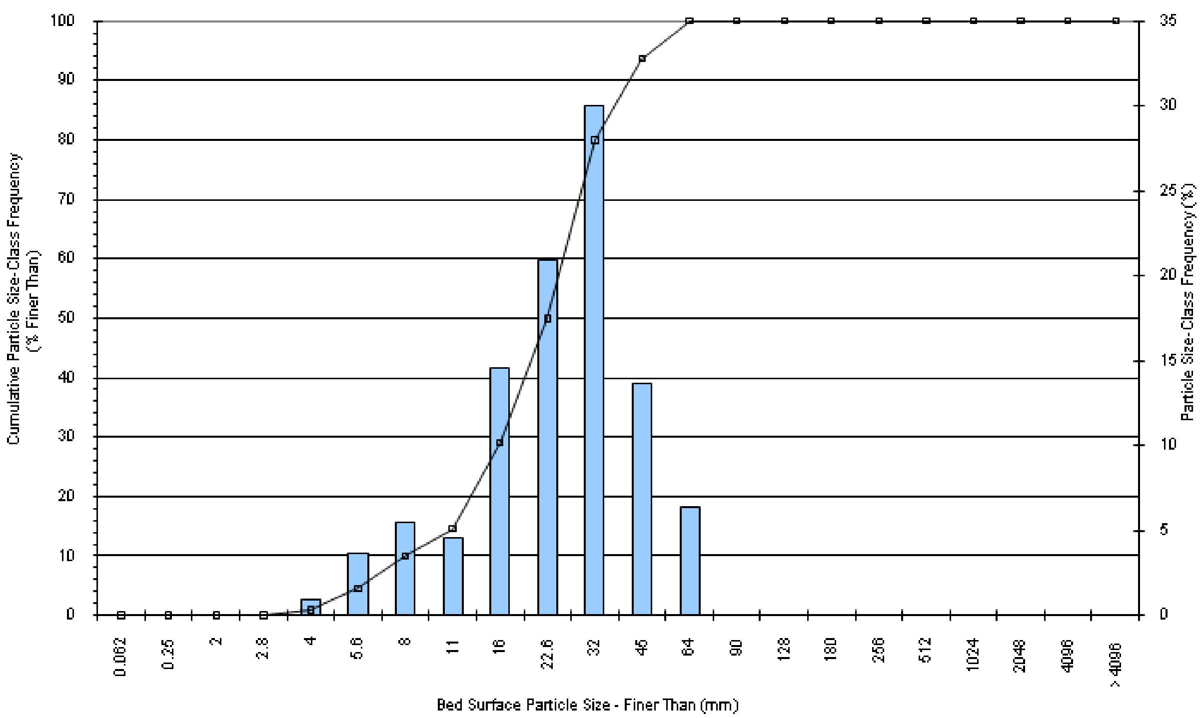
Appendix A

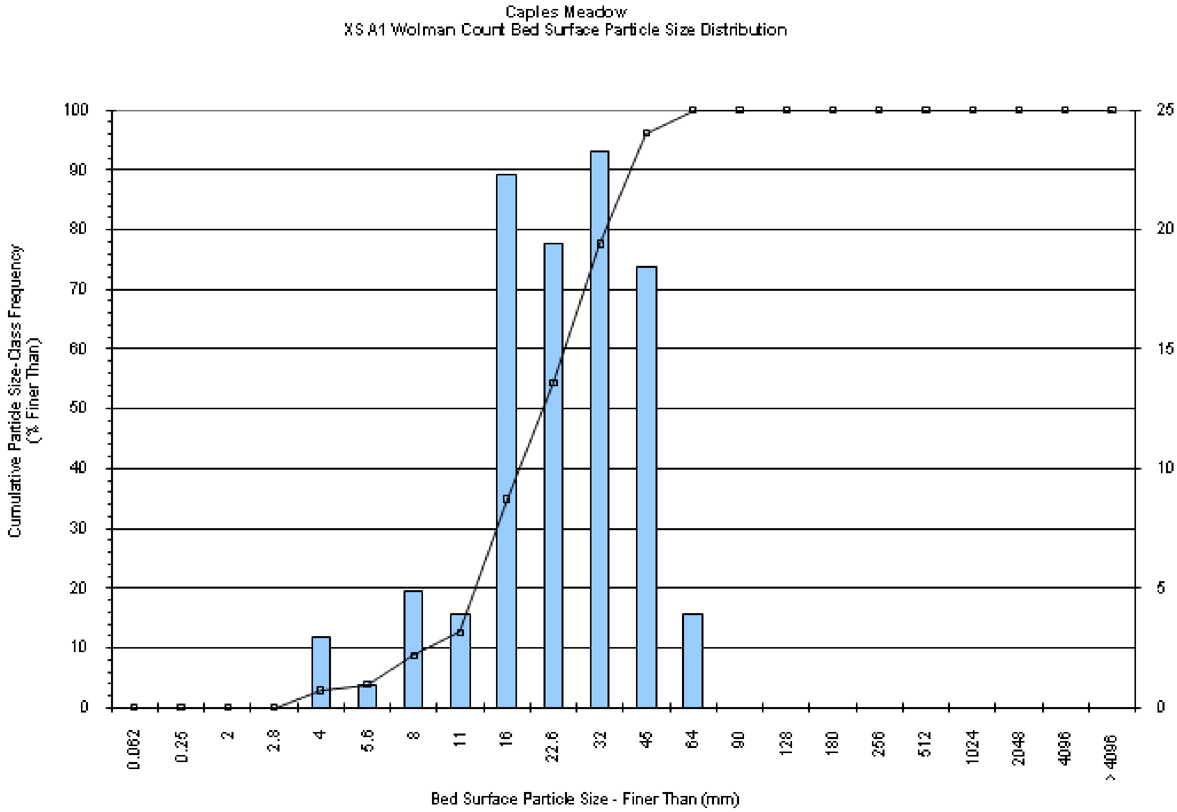
Caples Meadow Study Site Particle Size Data

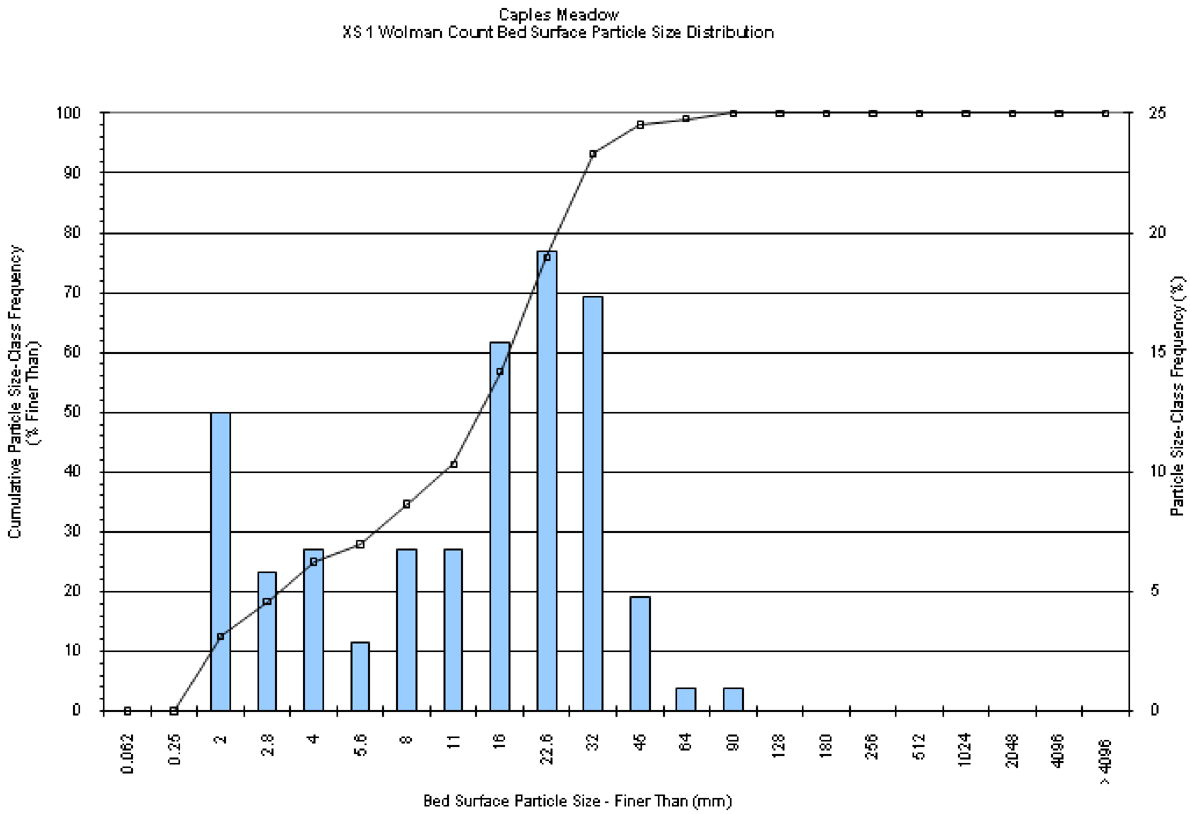
Caples Meadow
XS Most Upstream Wolman Count Bed Surface Particle Size Distribution

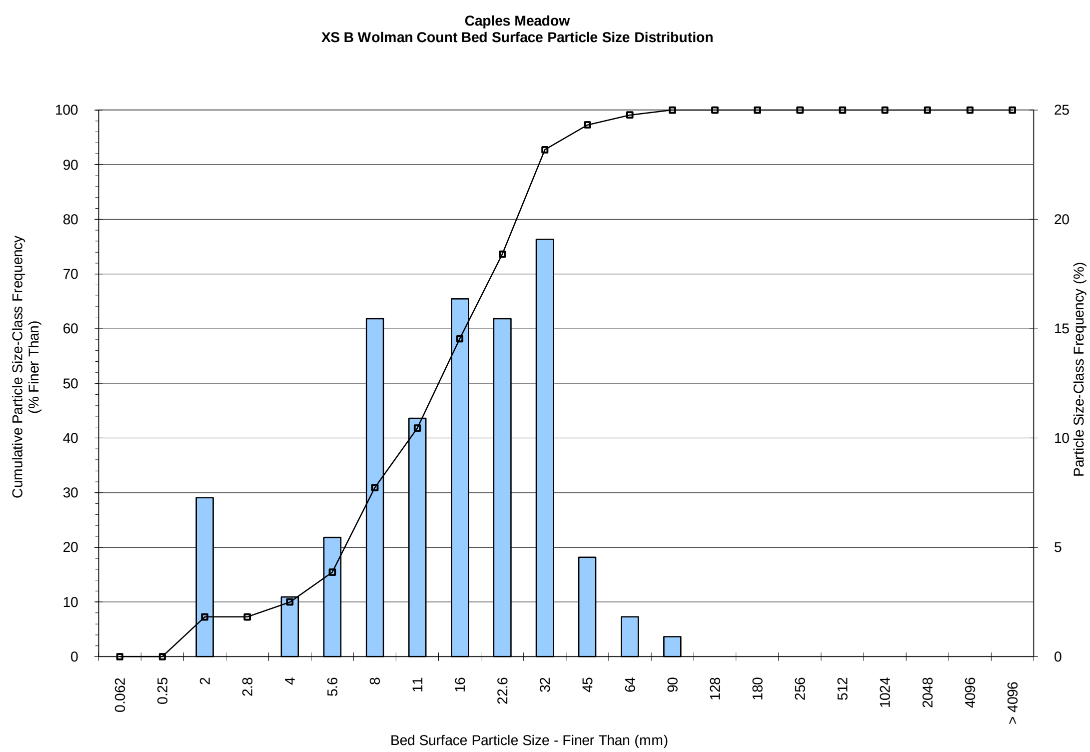


Caples Meadow
XS A Wolman Count Bed Surface Particle Size Distribution

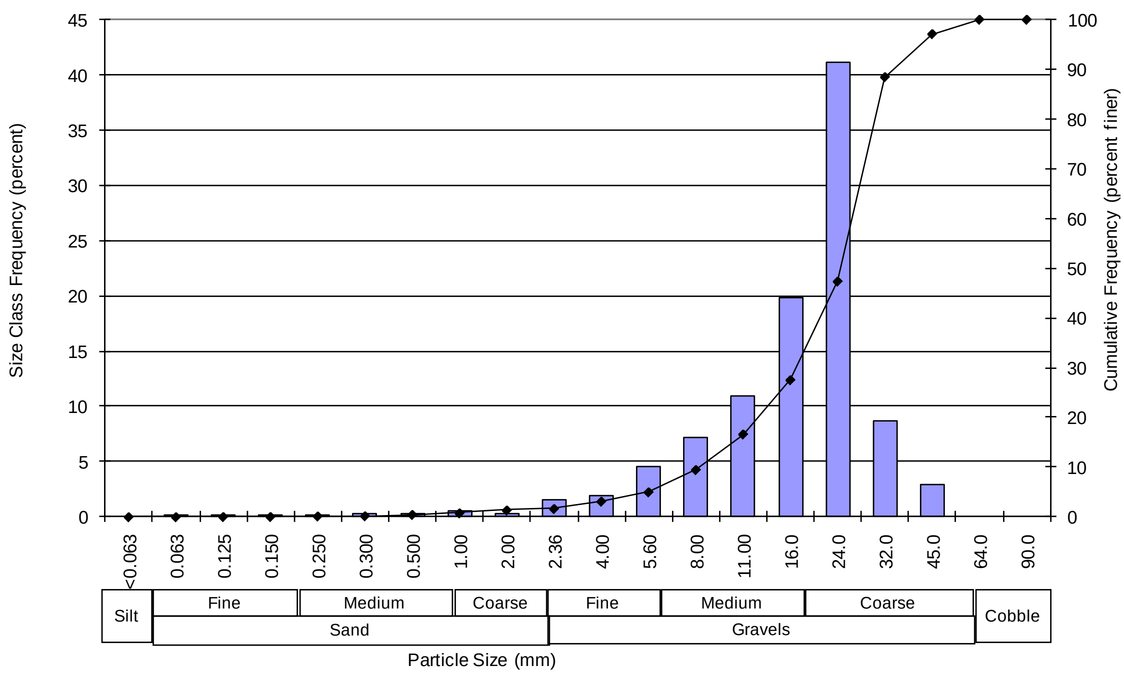



Caples Meadow
XS A1 Wolman Count Bed Surface Particle Size Distribution
Cumulative Particle Size-Class Frequency (% Finer Than)
Particle Size-Class Frequency (%)
100
90
80
70
60
50
40
30
20
10
0
25
20
15
10
5
0
0.062
0.25
2
2.8
4
5.6
8
11
16
22.6
32
45
64
90
128
180
256
512
1024
2048
4096
> 4096
Bed Surface Particle Size - Finer Than (mm)

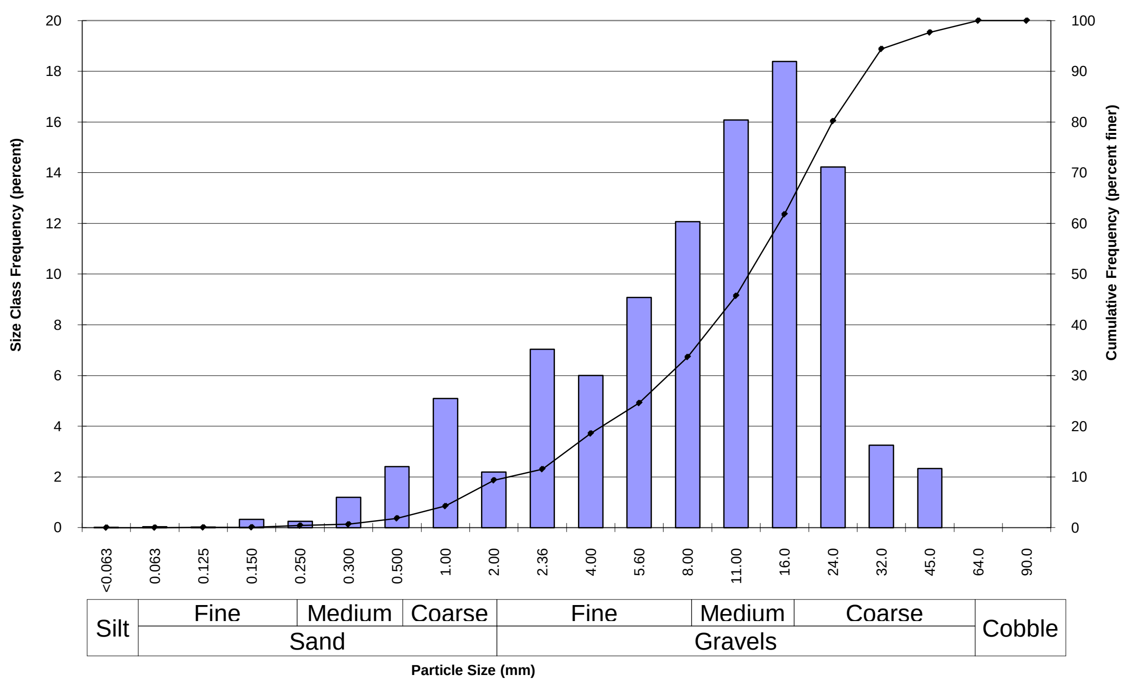

Caples Meadow
XS 1 Wolman Count Bed Surface Particle Size Distribution
Cumulative Particle Size-Class Frequency (% Finer Than)
Particle Size-Class Frequency (%)
Bed Surface Particle Size - Finer Than (mm)
0.062
0.25
2
2.8
4
5.6
8
11
16
22.6
32
45
64
90
128
180
256
512
1024
2048
4096
> 4096


Caples Meadow
XS B Wolman Count Bed Surface Particle Size Distribution
Cumulative Particle Size-Class Frequency (% Finer Than)
Particle Size-Class Frequency (%)
Bed Surface Particle Size - Finer Than (mm)
0.062
0.25
2
2.8
4
5.6
8
11
16
22.6
32
45
64
90
128
180
256
512
1024
2048
4096
> 4096

Caples Creek Surface Bulk Sediment at XS-B

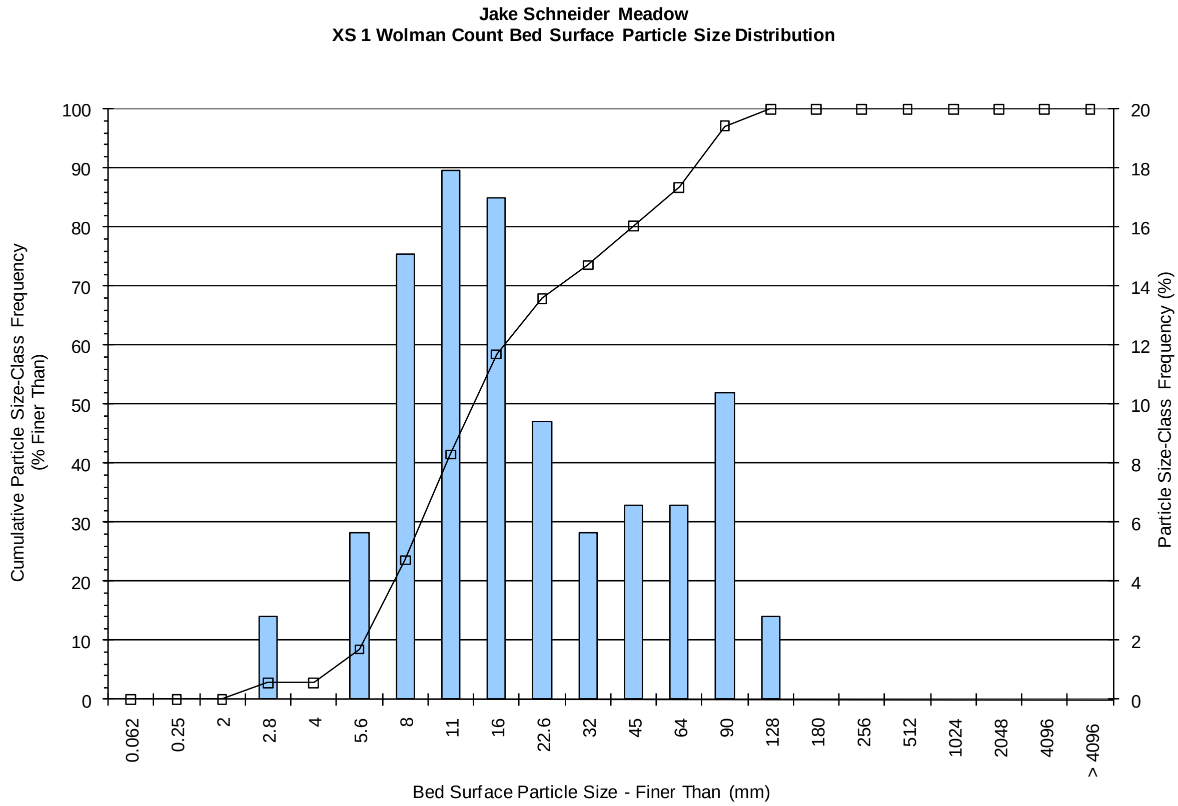


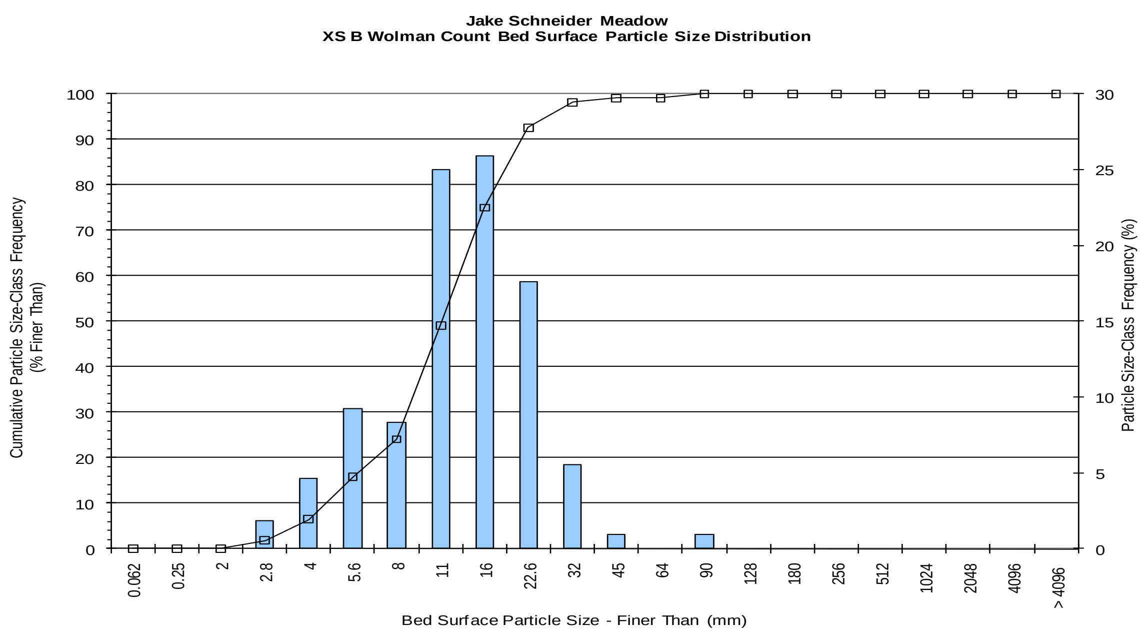
Caples Creek Meadow
Bulk Subsurface Sample at XS-B
Histogram and Cumulative Particle Size Distribution



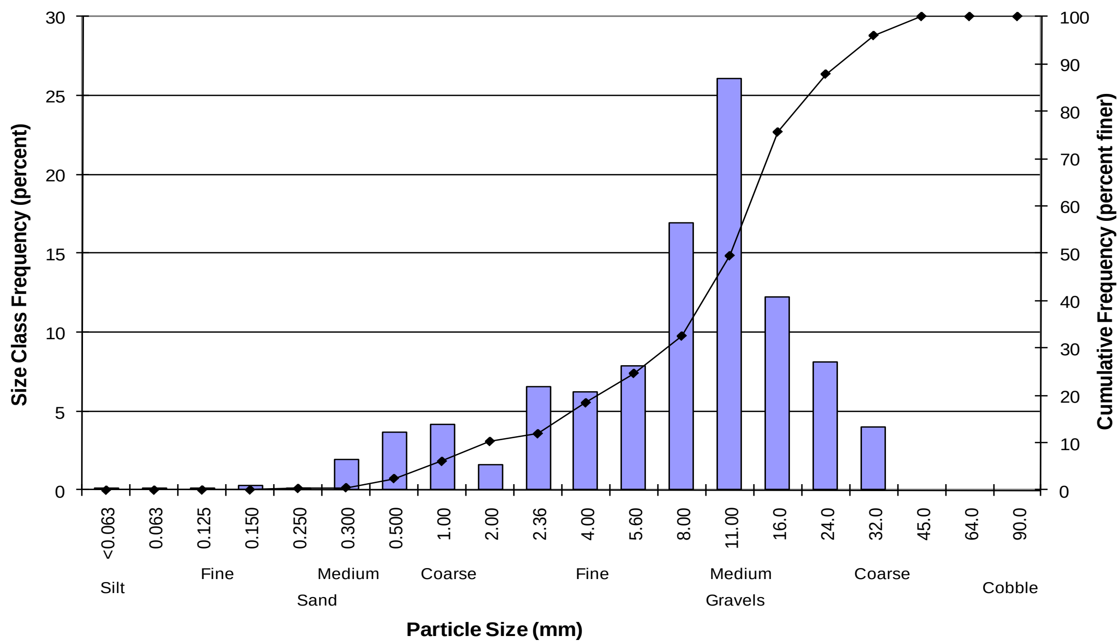
Appendix B

Jake Schneider Meadow Study Site Particle Size Data

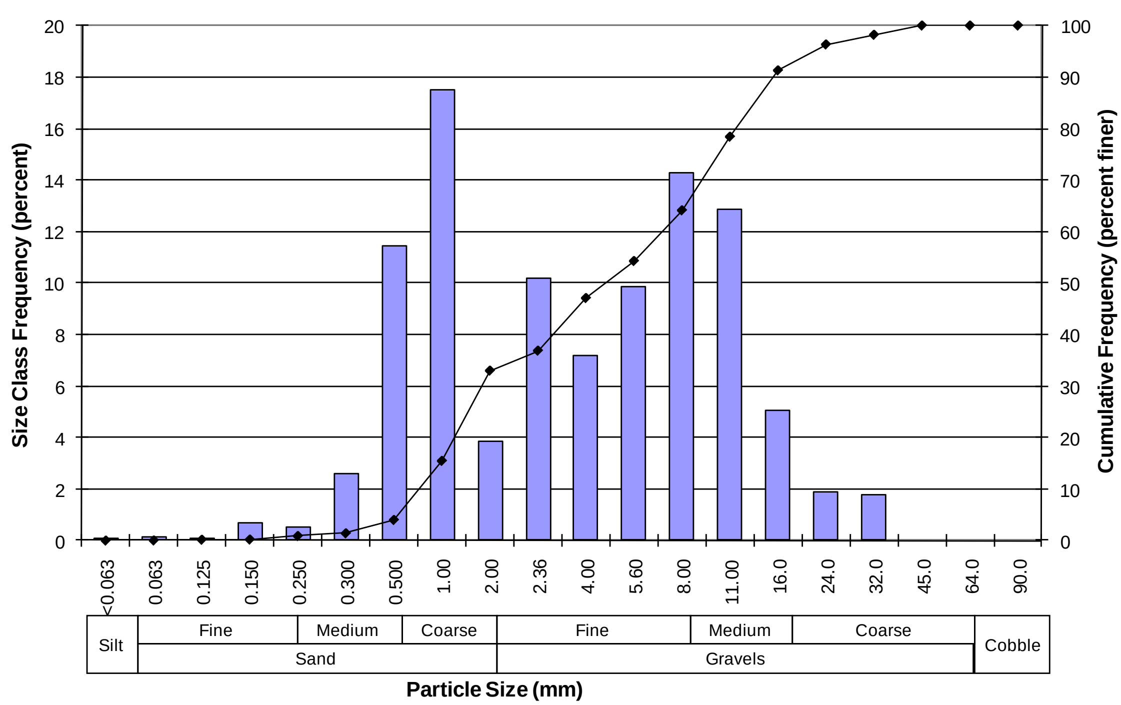

Jake Schneider Meadow
XS 1 Wolman Count Bed Surface Particle Size Distribution
Cumulative Particle Size-Class Frequency (% Finer Than)
Particle Size-Class Frequency (%)
Bed Surface Particle Size - Finer Than (mm)
0.062
0.25
2
2.8
4
5.6
8
11
16
22.6
32
45
64
90
128
180
256
512
1024
2048
4096
> 4096


Jake Schneider Meadow
XS B Wolman Count Bed Surface Particle Size Distribution
Cumulative Particle Size-Class Frequency (% Finer Than)
Particle Size-Class Frequency (%)
Bed Surface Particle Size - Finer Than (mm)
0.062
0.25
2
2.8
4
5.6
8
11
16
22.6
32
45
64
90
128
180
256
512
1024
2048
4096
> 4096

Jake Schneider Meadow
Bulk Surface Sample at XS-B
Histogram and Cumulative Particle Size Distribution

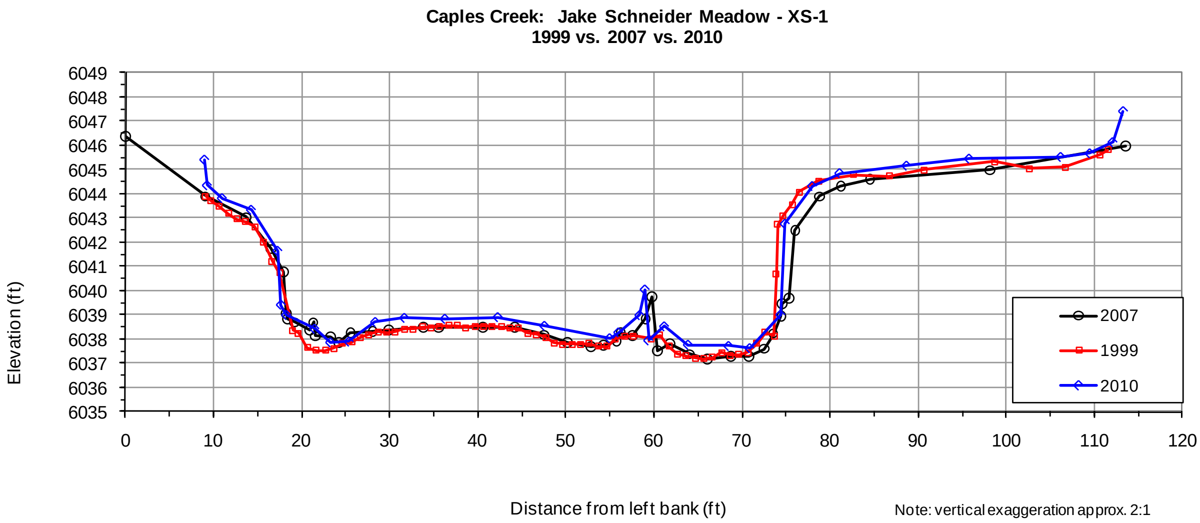


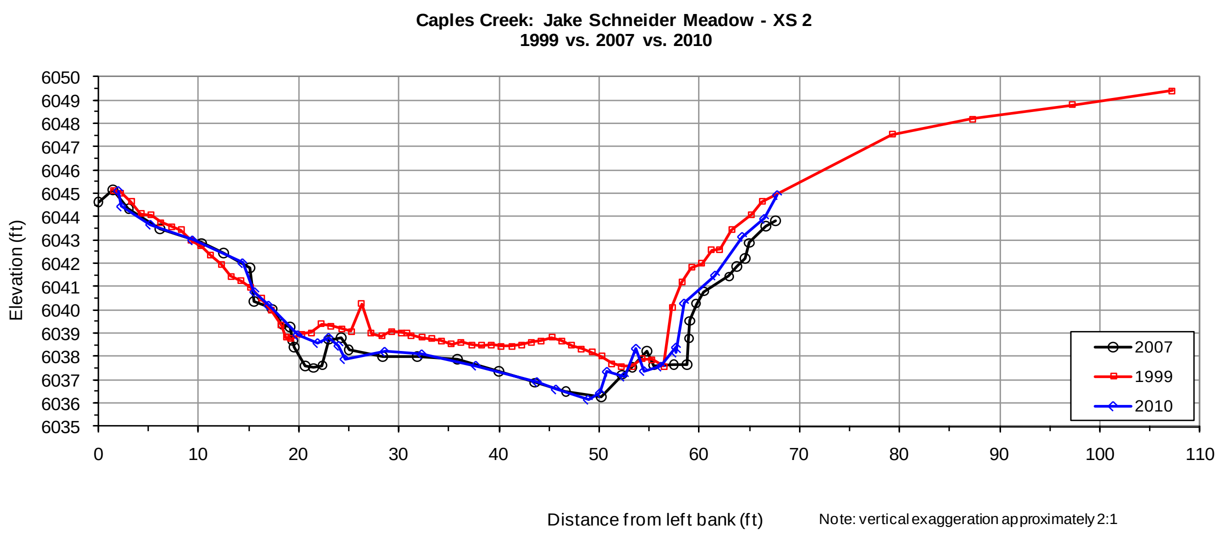
Jake Schneider Meadow
Bulk Subsurface Sample at XS-B
Histogram and Cumulative Particle Size Distribution

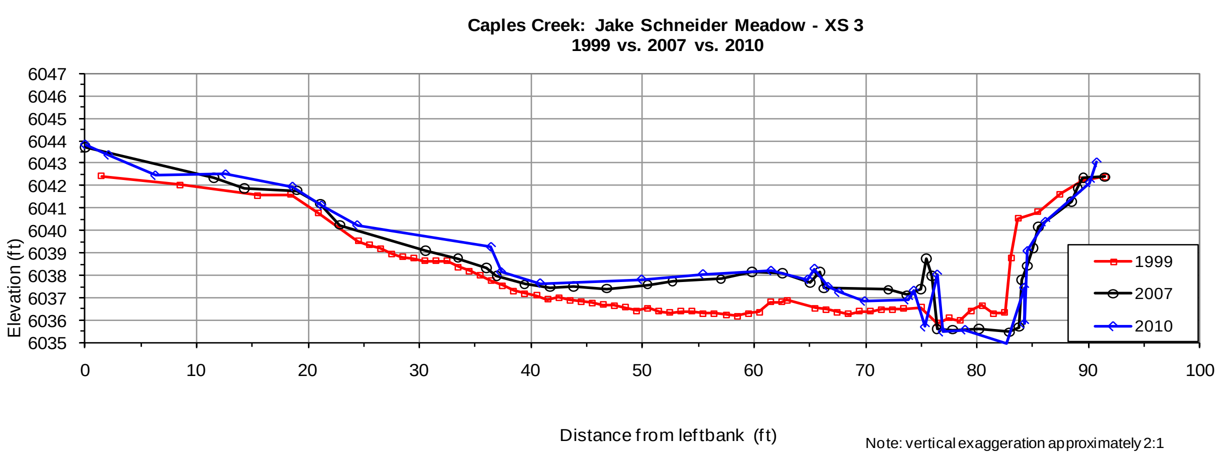


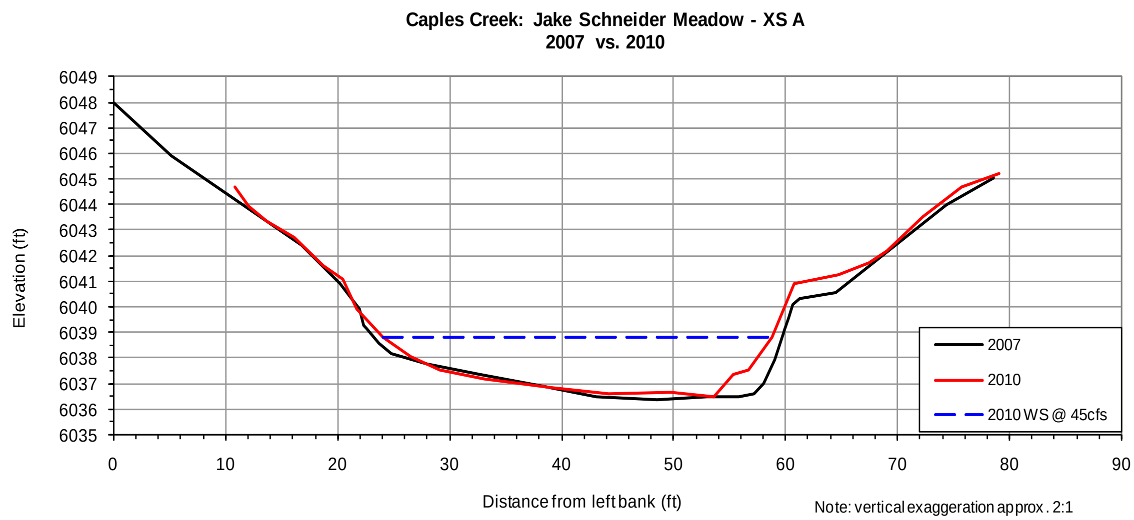
Appendix C

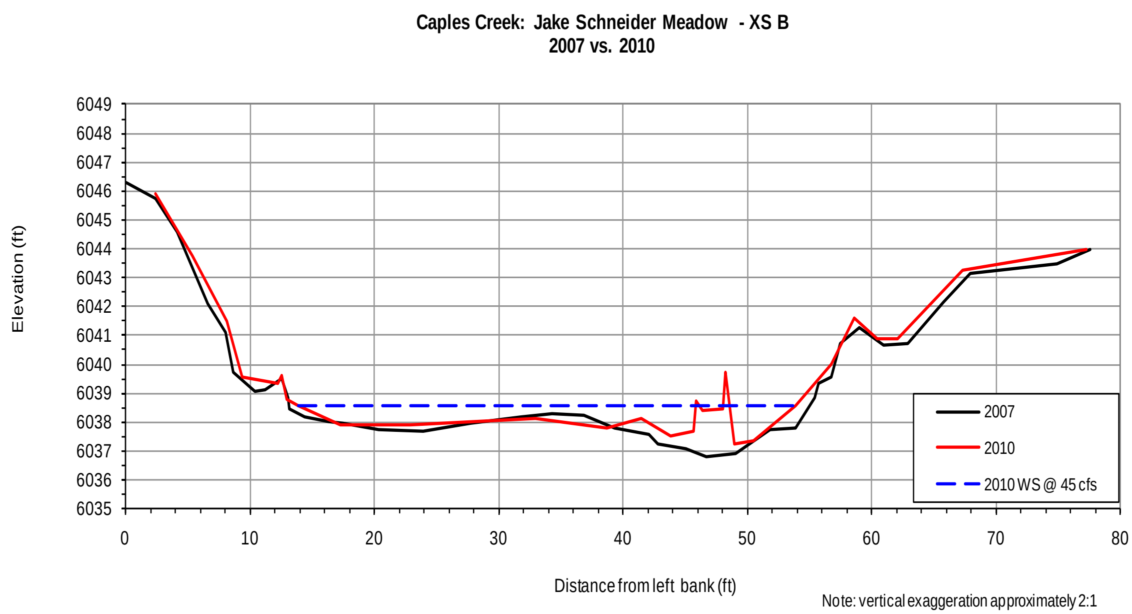
Time Series of Cross-Section Plots for Caples Meadow and JSM Study Sites

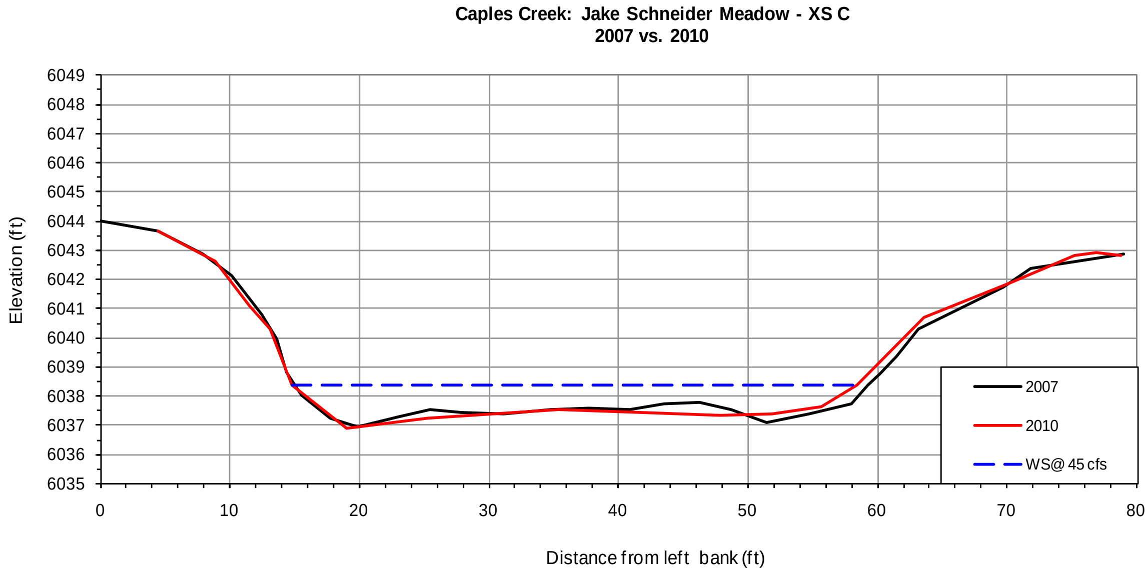

Caples Creek: Jake Schneider Meadow - XS-1
1999 vs. 2007 vs. 2010
Elevation (ft)
6049
6048
6047
6046
6045
6044
6043
6042
6041
6040
6039
6038
6037
6036
6035
0
10
20
30
40
50
60
70
80
90
100
110
120
2007
1999
2010
Distance from left bank (ft)
Note: vertical exaggeration approx. 2:1

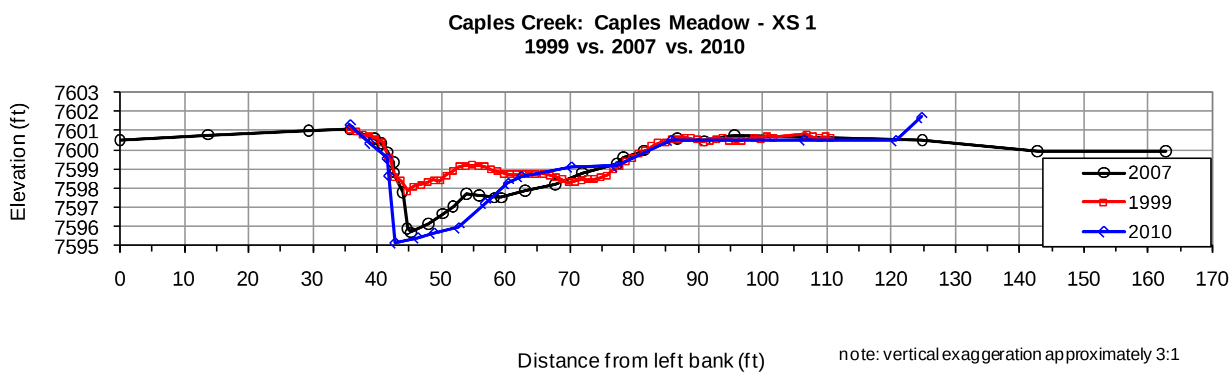

Caples Creek: Jake Schneider Meadow - XS 2
1999 vs. 2007 vs. 2010
Elevation (ft)
6050
6049
6048
6047
6046
6045
6044
6043
6042
6041
6040
6039
6038
6037
6036
6035
0
10
20
30
40
50
60
70
80
90
100
110
2007
1999
2010
Distance from left bank (ft)
Note: vertical exaggeration approximately 2:1

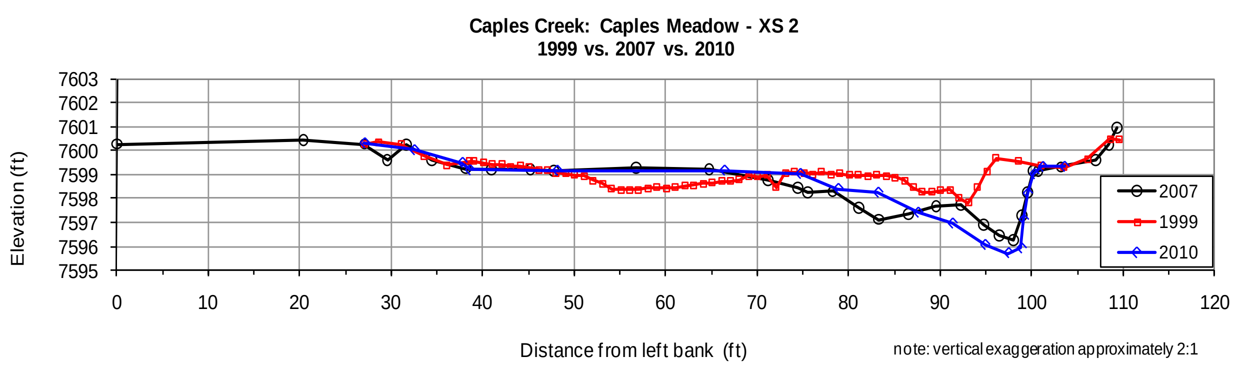

Caples Creek: Jake Schneider Meadow - XS 3
1999 vs. 2007 vs. 2010
Elevation (ft)
6047
6046
6045
6044
6043
6042
6041
6040
6039
6038
6037
6036
6035
0
10
20
30
40
50
60
70
80
90
100
1999
2007
2010
Distance from leftbank (ft)
Note: vertical exaggeration approximately 2:1

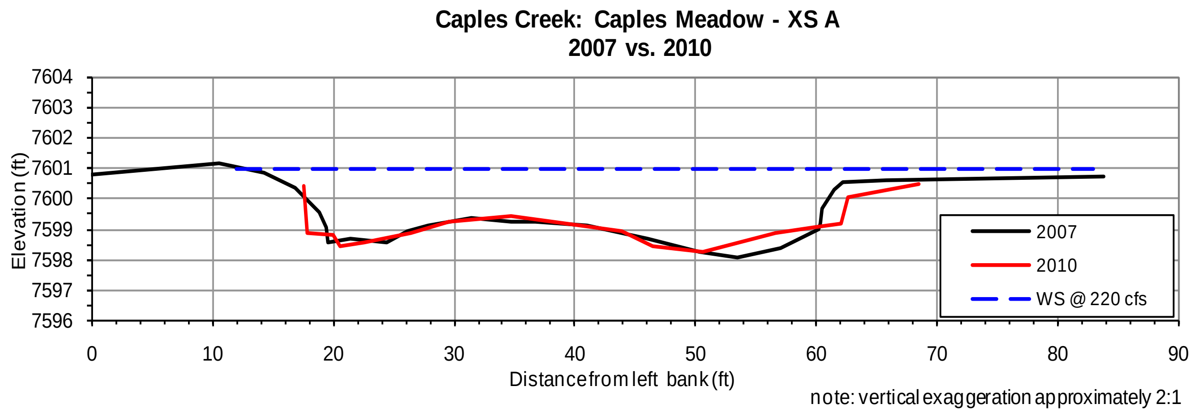

Caples Creek: Jake Schneider Meadow - XS A
2007 vs. 2010
Elevation (ft)
6049
6048
6047
6046
6045
6044
6043
6042
6041
6040
6039
6038
6037
6036
6035
0
10
20
30
40
50
60
70
80
90
Distance from left bank (ft)
2007
2010
2010 WS @ 45cfs
Note: vertical exaggeration approx. 2:1

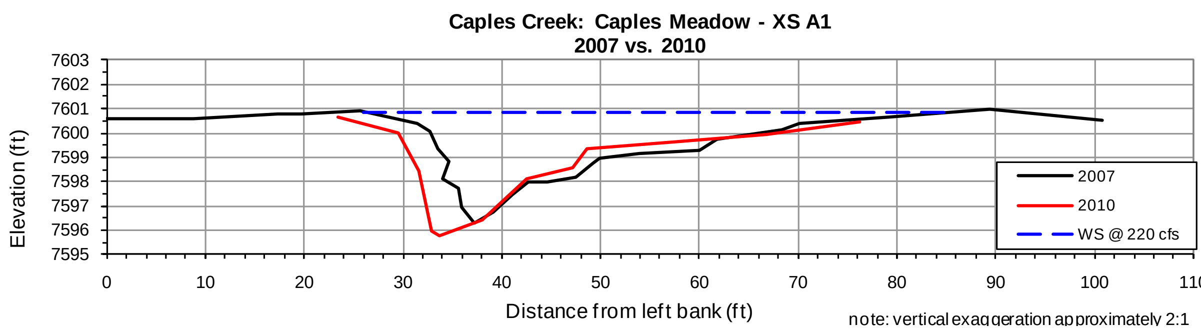

Caples Creek: Jake Schneider Meadow - XS B
2007 vs. 2010
Elevation (ft)
6049
6048
6047
6046
6045
6044
6043
6042
6041
6040
6039
6038
6037
6036
6035
0
10
20
30
40
50
60
70
80
Distance from left bank (ft)
2007
2010
2010 WS @ 45 cfs
Note: vertical exaggeration approximately 2:1

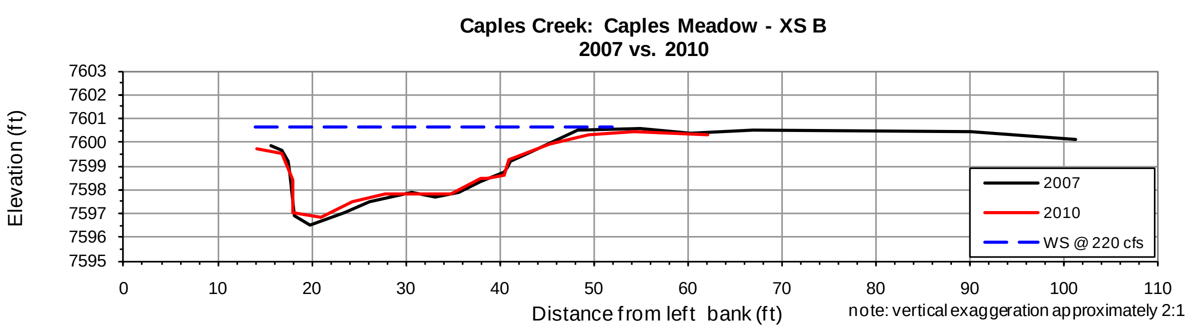

Caples Creek: Jake Schneider Meadow - XS C
2007 vs. 2010
Elevation (ft)
6049
6048
6047
6046
6045
6044
6043
6042
6041
6040
6039
6038
6037
6036
6035
0
10
20
30
40
50
60
70
80
Distance from left bank (ft)
2007
2010
WS@ 45 cfs


Caples Creek: Caples Meadow - XS 1
1999 vs. 2007 vs. 2010
Elevation (ft)
7603
7602
7601
7600
7599
7598
7597
7596
7595
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
Distance from left bank (ft)
note: vertical exaggeration approximately 3:1
2007
1999
2010


Caples Creek: Caples Meadow - XS 2
1999 vs. 2007 vs. 2010
Elevation (ft)
7603
7602
7601
7600
7599
7598
7597
7596
7595
0
10
20
30
40
50
60
70
80
90
100
110
120
Distance from left bank (ft)
note: vertical exaggeration approximately 2:1
2007
1999
2010

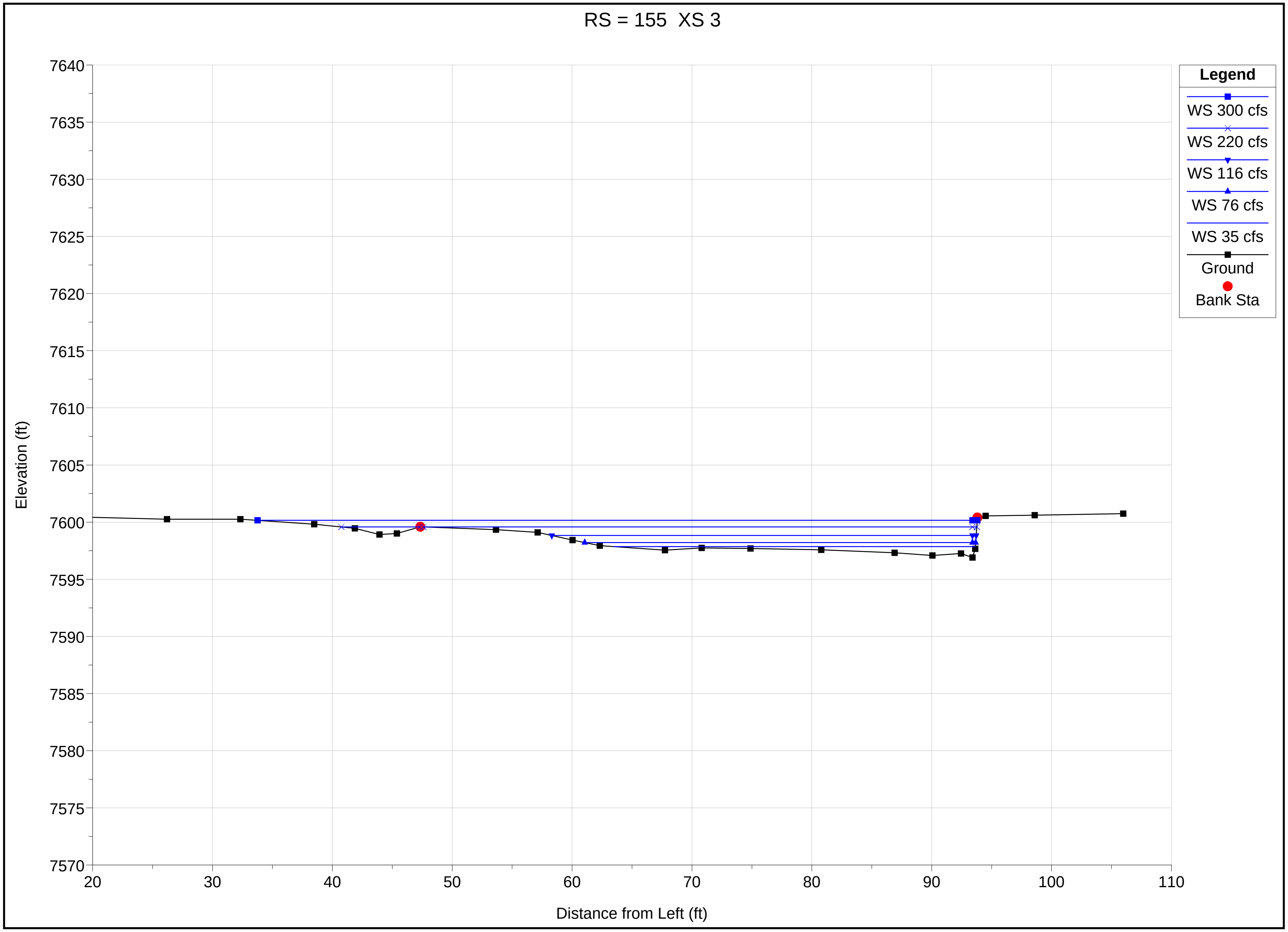

Caples Creek: Caples Meadow - XS A
2007 vs. 2010
Elevation (ft)
7604
7603
7602
7601
7600
7599
7598
7597
7596
0
10
20
30
40
50
60
70
80
90
Distance from left bank (ft)
2007
2010
WS @ 220 cfs
note: vertical exaggeration approximately 2:1


Caples Creek: Caples Meadow - XS A1
2007 vs. 2010
Elevation (ft)
7603
7602
7601
7600
7599
7598
7597
7596
7595
0
10
20
30
40
50
60
70
80
90
100
110
Distance from left bank (ft)
2007
2010
WS @ 220 cfs
note: vertical exaggeration approximately 2:1

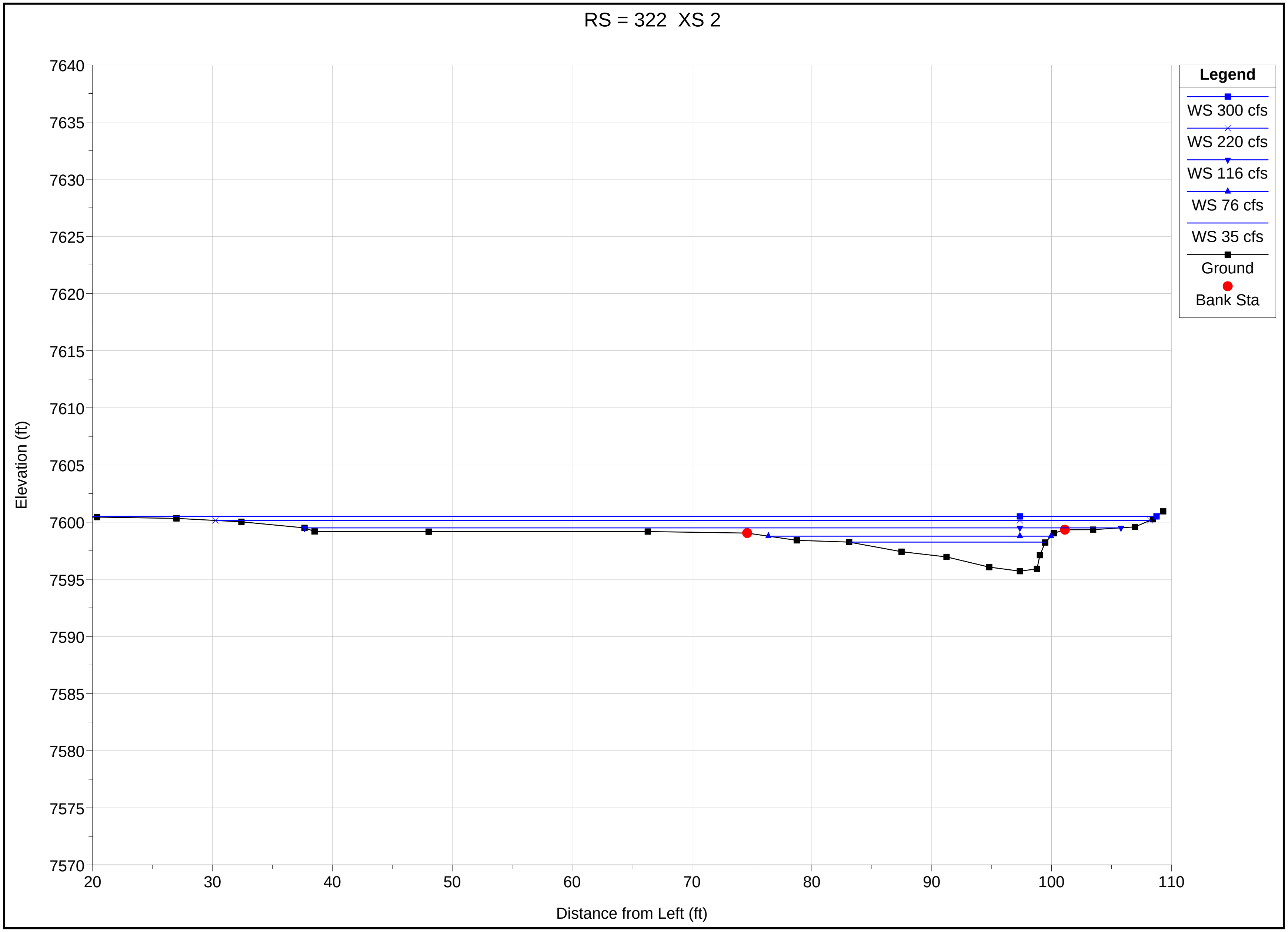

Caples Creek: Caples Meadow - XS B
2007 vs. 2010
Elevation (ft)
7603
7602
7601
7600
7599
7598
7597
7596
7595
0
10
20
30
40
50
60
70
80
90
100
110
Distance from left bank (ft)
2007
2010
WS @ 220 cfs
note: vertical exaggeration approximately 2:1

Appendix D

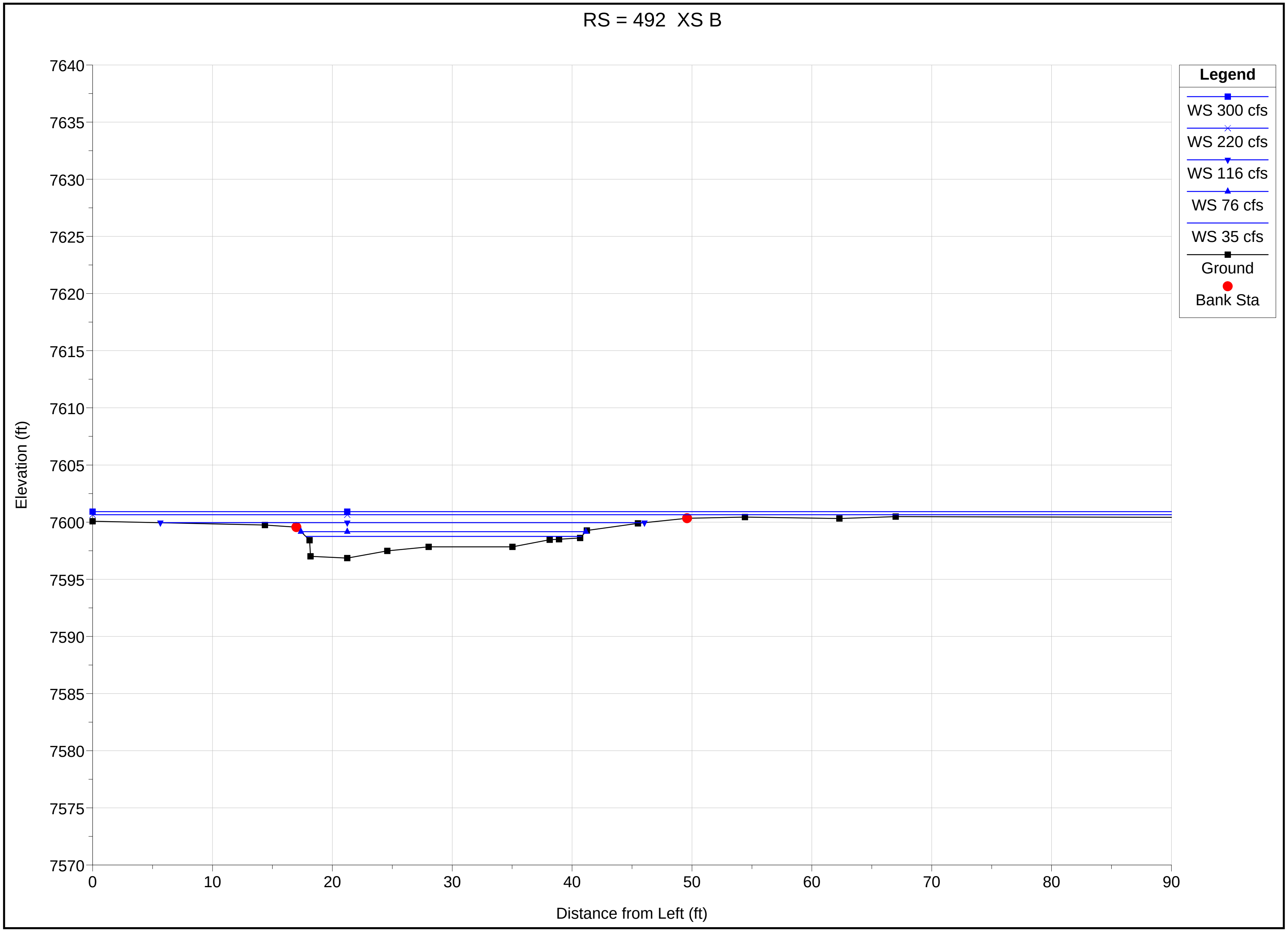
Caples Meadow HEC 1 to 1 XS Plots

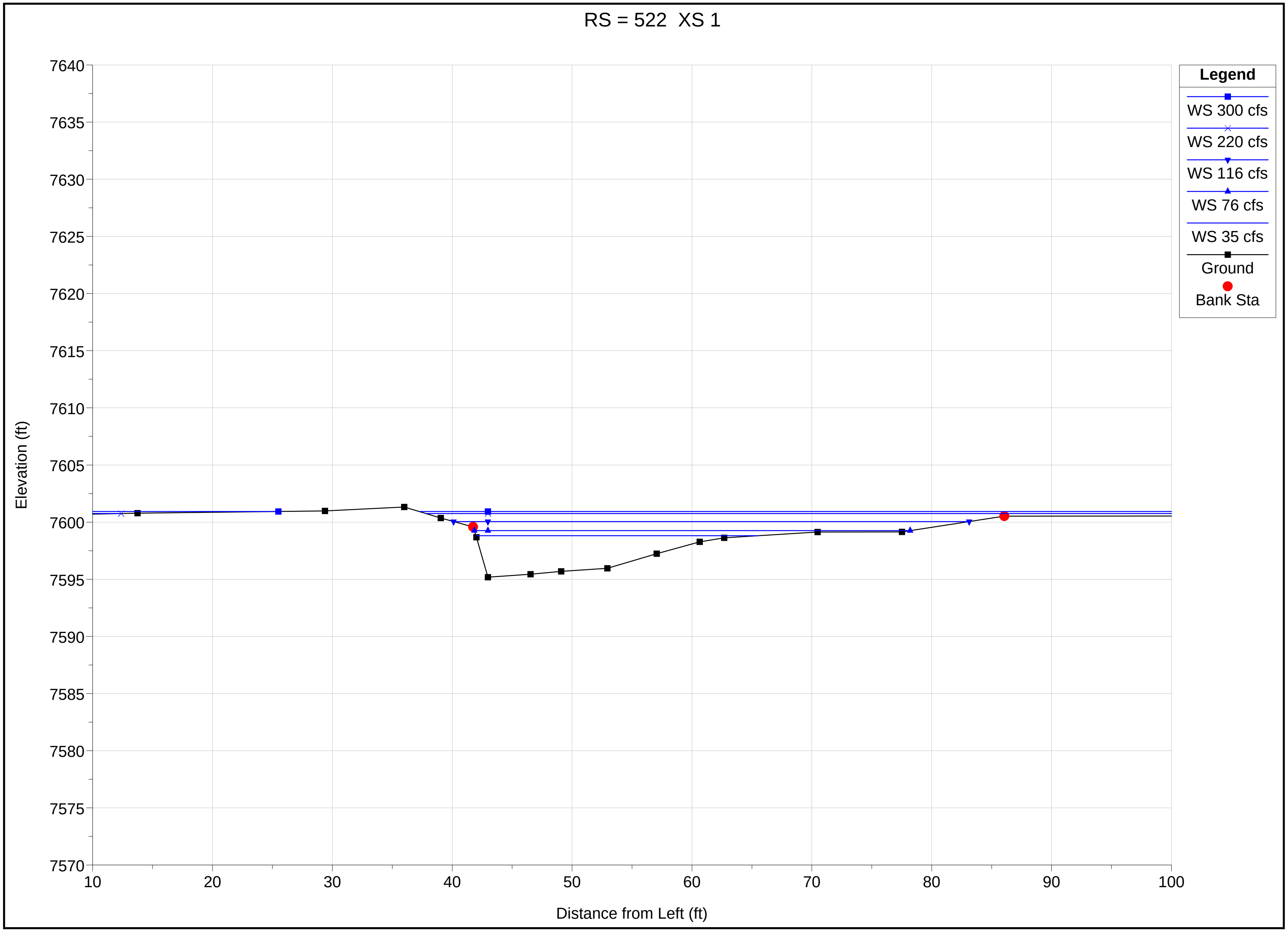


RS = 155 XS 3
Legend
WS 300 cfs
WS 220 cfs
WS 116 cfs
WS 76 cfs
WS 35 cfs
Ground
Bank Sta
Elevation (ft)
7640
7635
7630
7625
7620
7615
7610
7605
7600
7595
7590
7585
7580
7575
7570
20
30
40
50
60
70
80
90
100
110
Distance from Left (ft)

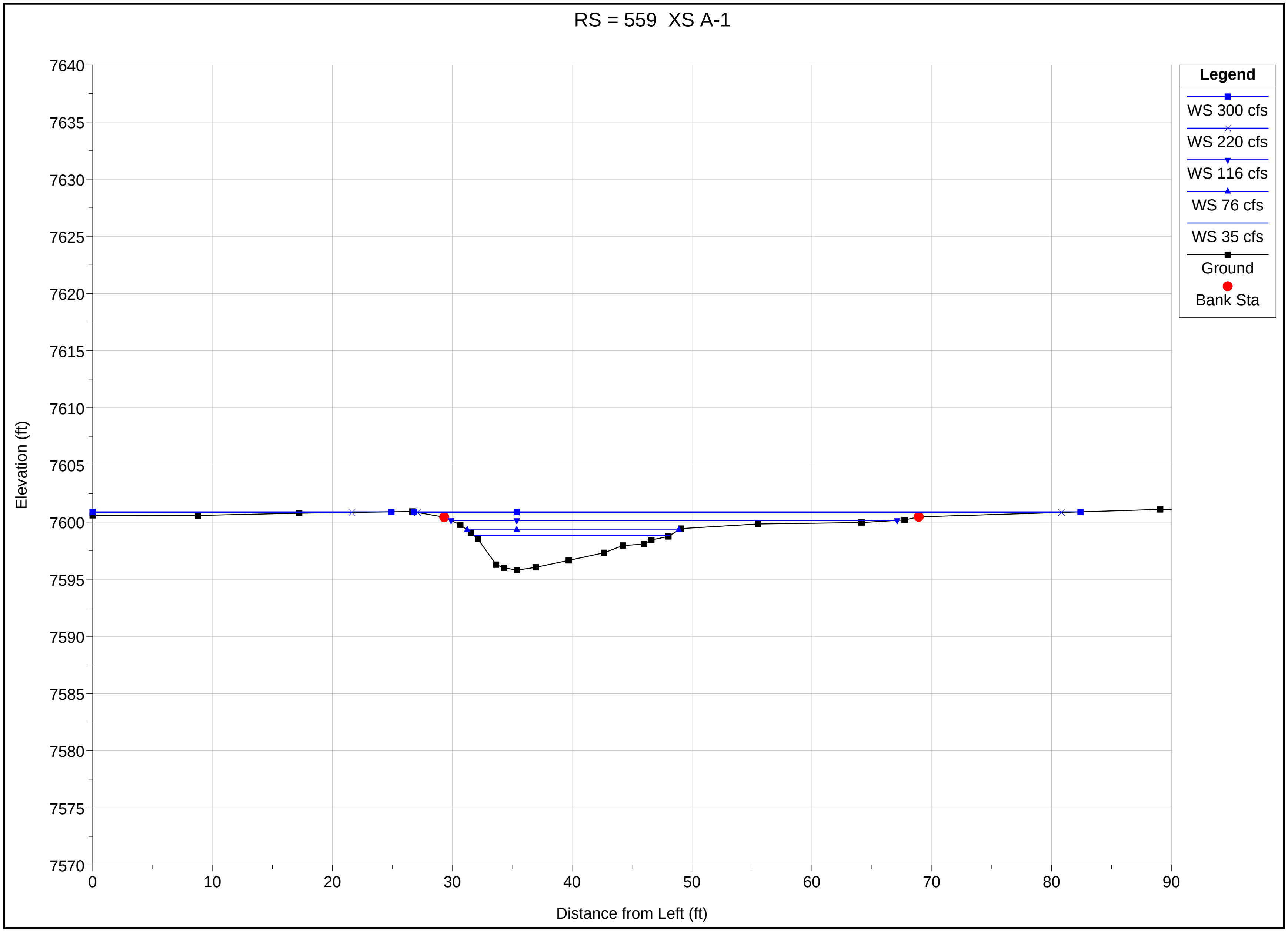


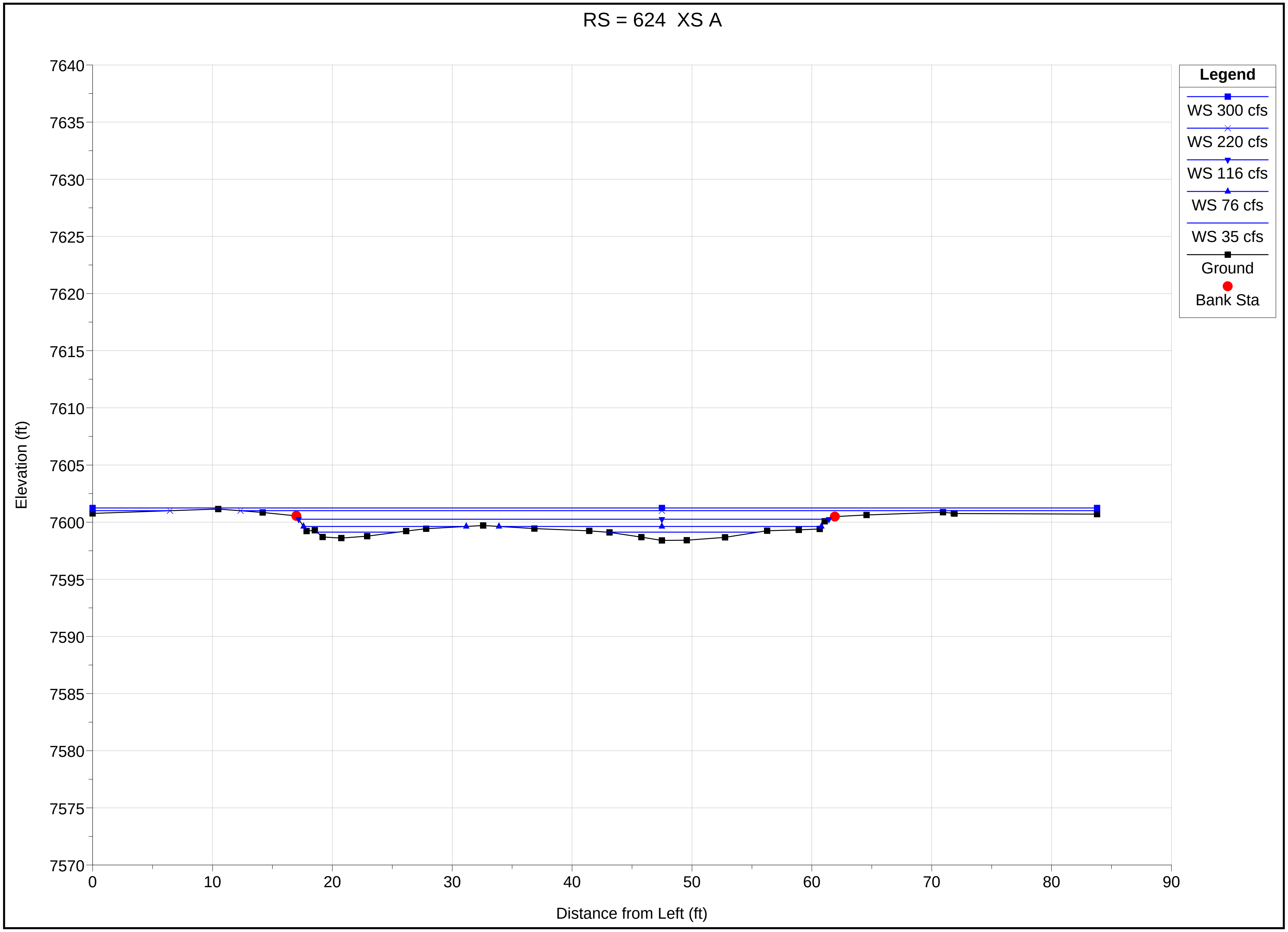
RS = 322 XS 2
Legend
WS 300 cfs
WS 220 cfs
WS 116 cfs
WS 76 cfs
WS 35 cfs
Ground
Bank Sta
Elevation (ft)
7640
7635
7630
7625
7620
7615
7610
7605
7600
7595
7590
7585
7580
7575
7570
20
30
40
50
60
70
80
90
100
110
Distance from Left (ft)


RS = 492 XS B
Legend
WS 300 cfs
WS 220 cfs
WS 116 cfs
WS 76 cfs
WS 35 cfs
Ground
Bank Sta
Elevation (ft)
7640
7635
7630
7625
7620
7615
7610
7605
7600
7595
7590
7585
7580
7575
7570
0
10
20
30
40
50
60
70
80
90
Distance from Left (ft)

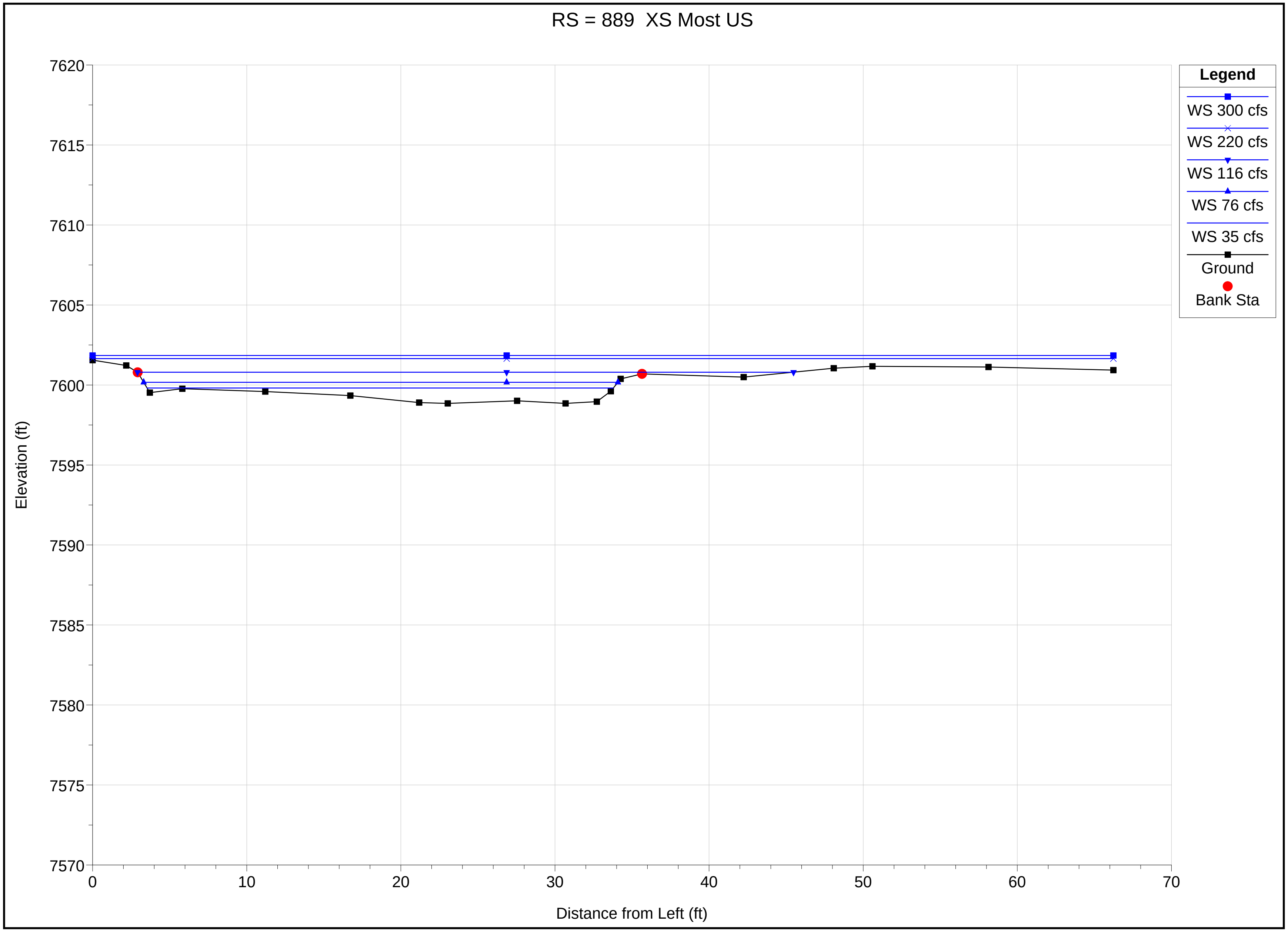


RS = 522 XS 1
Legend
WS 300 cfs
WS 220 cfs
WS 116 cfs
WS 76 cfs
WS 35 cfs
Ground
Bank Sta
Elevation (ft)
Distance from Left (ft)
7640
7635
7630
7625
7620
7615
7610
7605
7600
7595
7590
7585
7580
7575
7570
10
20
30
40
50
60
70
80
90
100


RS = 559 XS A-1
Legend
WS 300 cfs
WS 220 cfs
WS 116 cfs
WS 76 cfs
WS 35 cfs
Ground
Bank Sta
Elevation (ft)
Distance from Left (ft)
7640
7635
7630
7625
7620
7615
7610
7605
7600
7595
7590
7585
7580
7575
7570
0
10
20
30
40
50
60
70
80
90



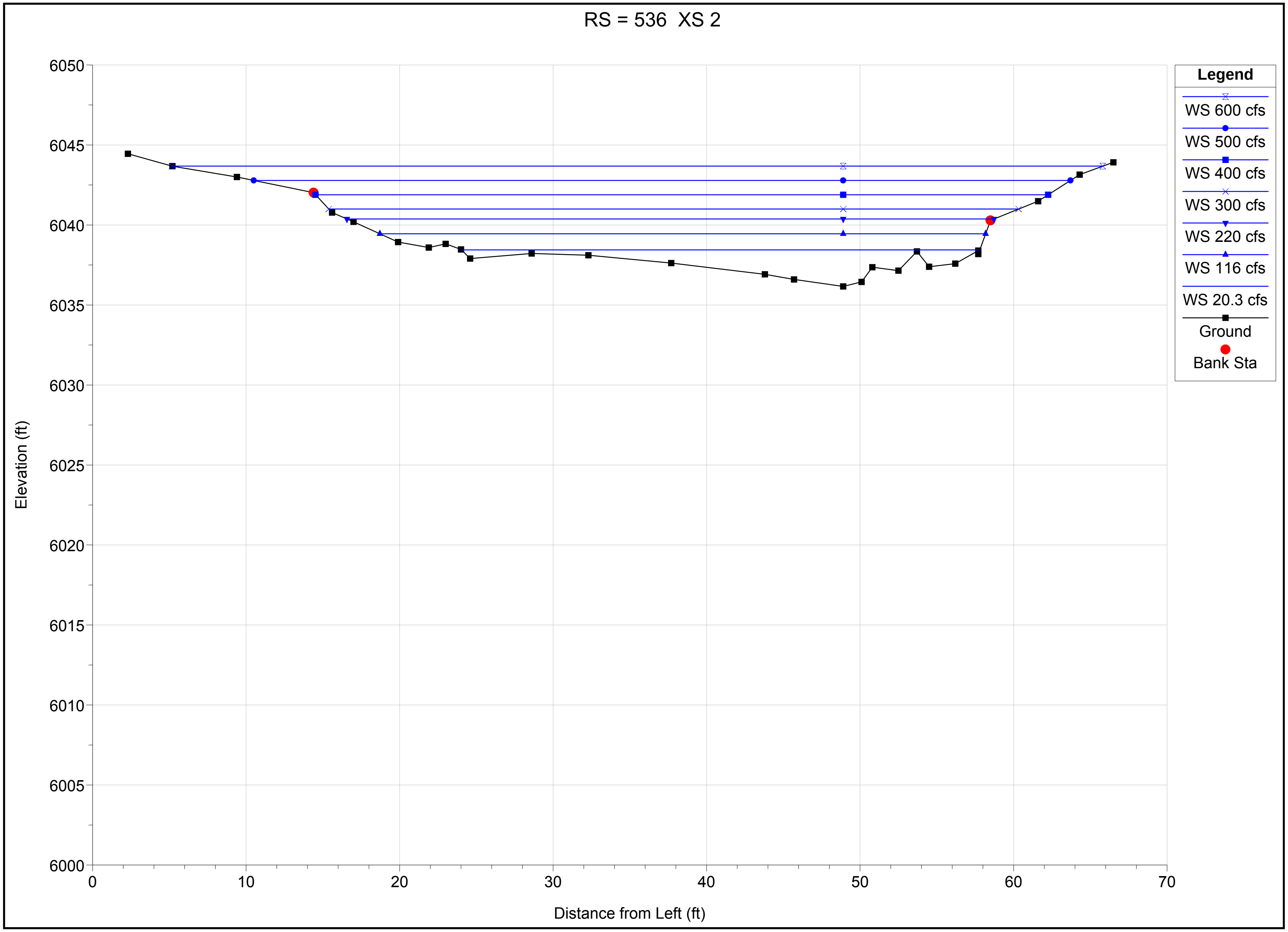
RS = 624 XS A
Elevation (ft)
Distance from Left (ft)
7640
7635
7630
7625
7620
7615
7610
7605
7600
7595
7590
7585
7580
7575
7570
0
10
20
30
40
50
60
70
80
90
Legend
WS 300 cfs
WS 220 cfs
WS 116 cfs
WS 76 cfs
WS 35 cfs
Ground
Bank Sta



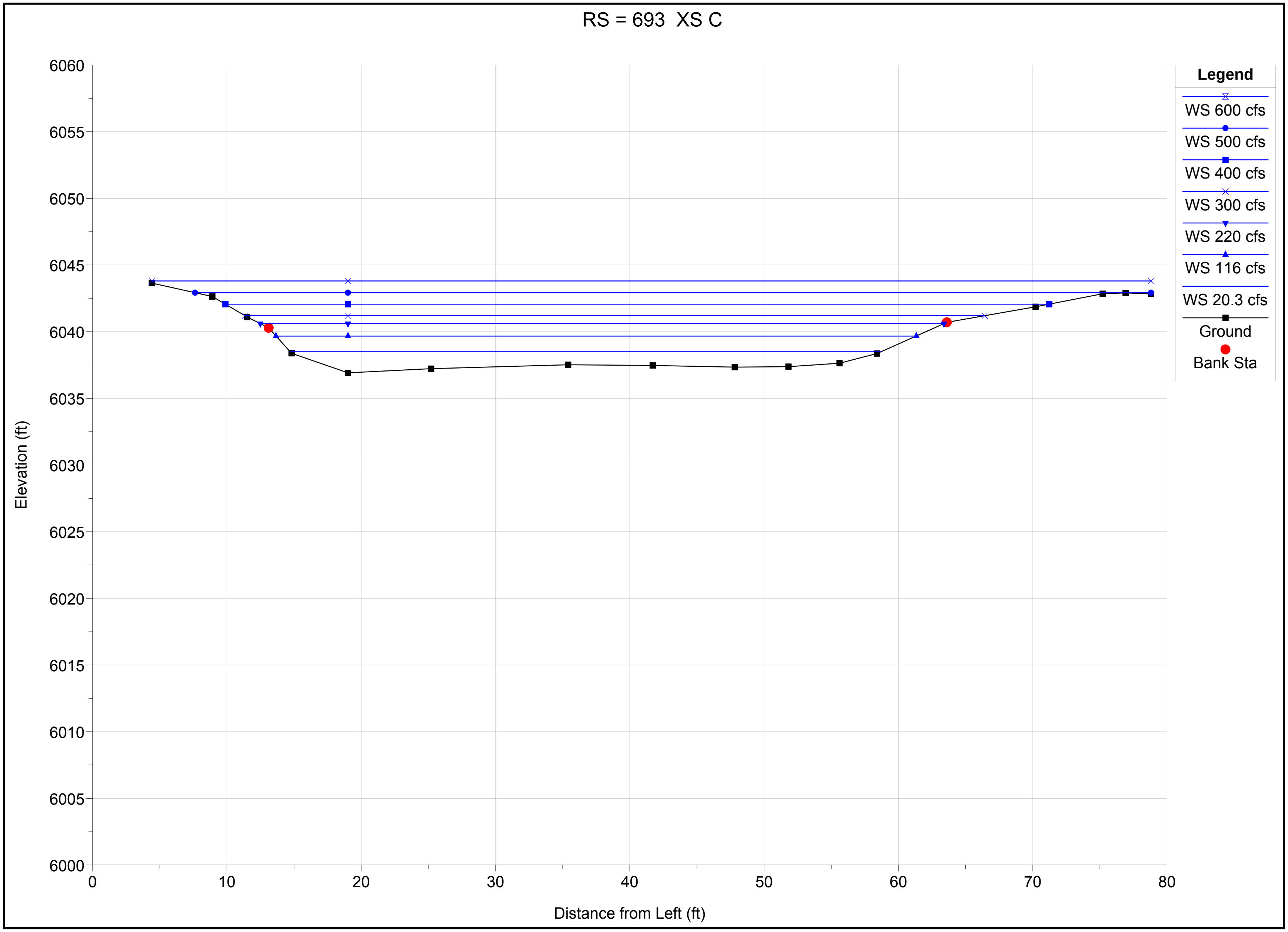
RS = 889 XS Most US
Legend
WS 300 cfs
WS 220 cfs
WS 116 cfs
WS 76 cfs
WS 35 cfs
Ground
Bank Sta
Elevation (ft)
7620
7615
7610
7605
7600
7595
7590
7585
7580
7575
7570
0
10
20
30
40
50
60
70
Distance from Left (ft)

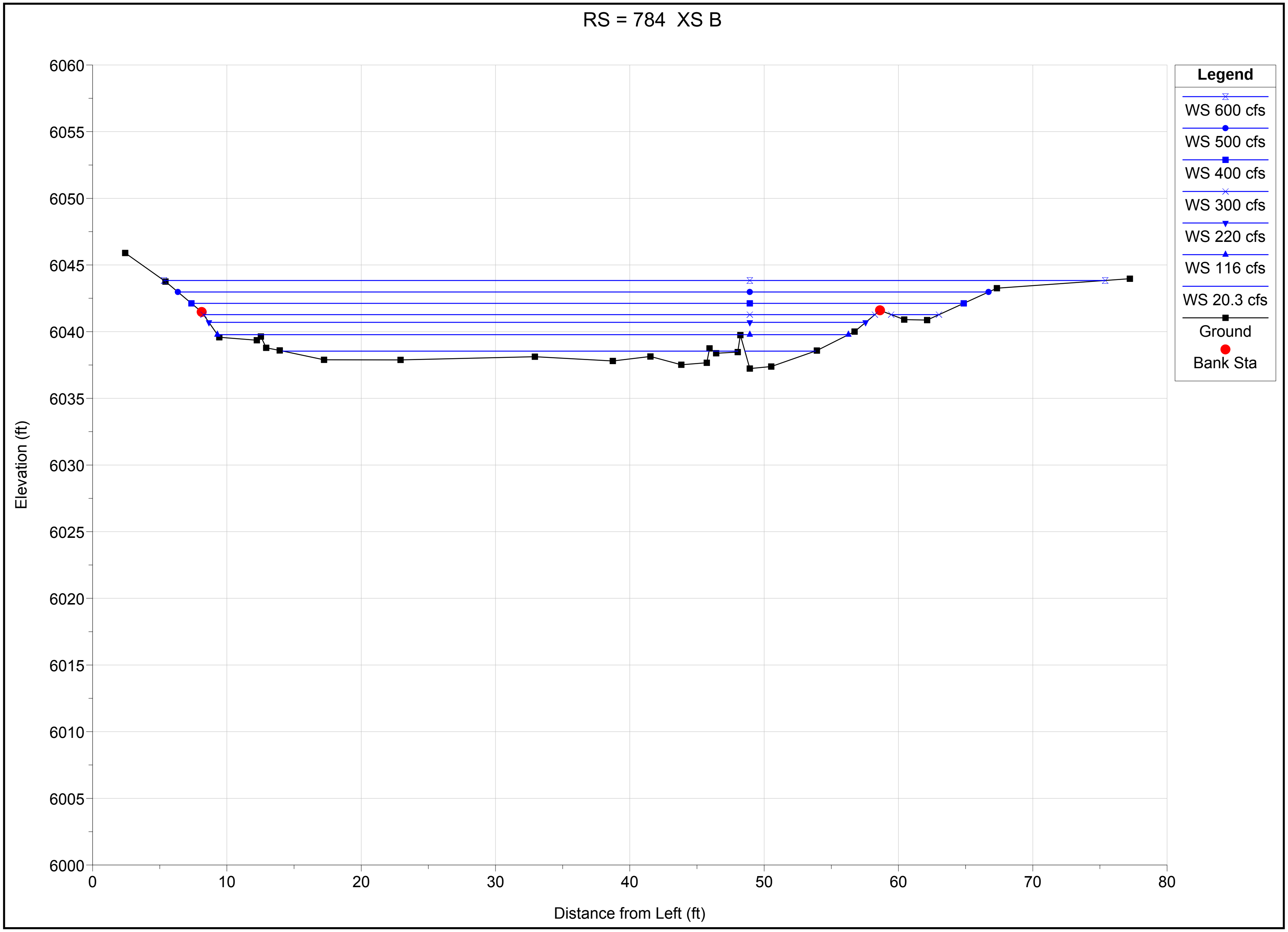
Appendix E

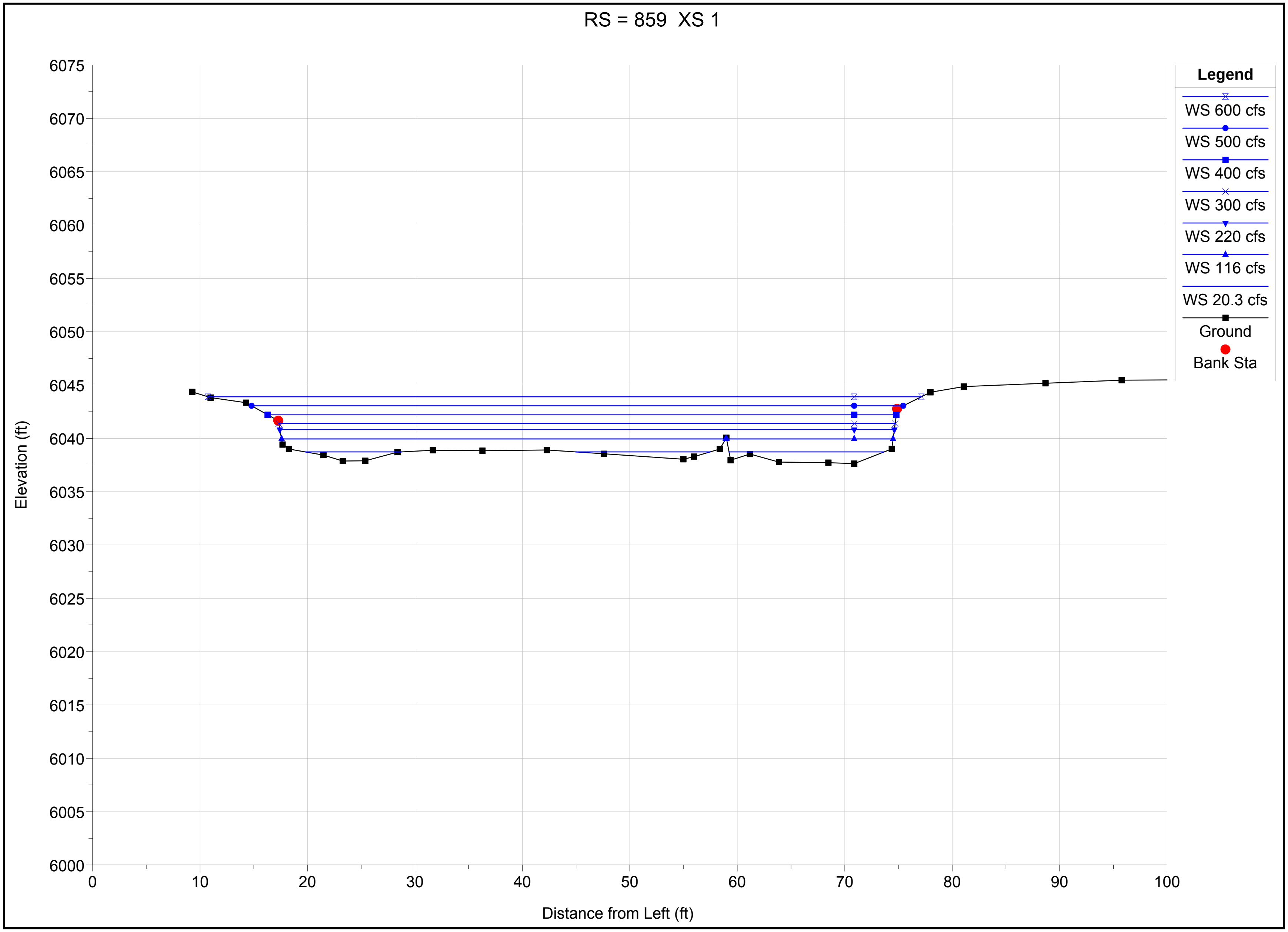
JSM HEC 1 to 1 XS Plots



RS = 536 XS 2
Elevation (ft)
6050
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
0
10
20
30
40
50
60
70
Distance from Left (ft)
Legend
WS 600 cfs
WS 500 cfs
WS 400 cfs
WS 300 cfs
WS 220 cfs
WS 116 cfs
WS 20.3 cfs
Ground
Bank Sta


RS = 693 XS C
Elevation (ft)
6060
6055
6050
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
0
10
20
30
40
50
60
70
80
Distance from Left (ft)
Legend
WS 600 cfs
WS 500 cfs
WS 400 cfs
WS 300 cfs
WS 220 cfs
WS 116 cfs
WS 20.3 cfs
Ground
Bank Sta


RS = 784 XS B
Legend
WS 600 cfs
WS 500 cfs
WS 400 cfs
WS 300 cfs
WS 220 cfs
WS 116 cfs
WS 20.3 cfs
Ground
Bank Sta
Elevation (ft)
Distance from Left (ft)
6060
6055
6050
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
0
10
20
30
40
50
60
70
80



RS = 859 XS 1
Legend
WS 600 cfs
WS 500 cfs
WS 400 cfs
WS 300 cfs
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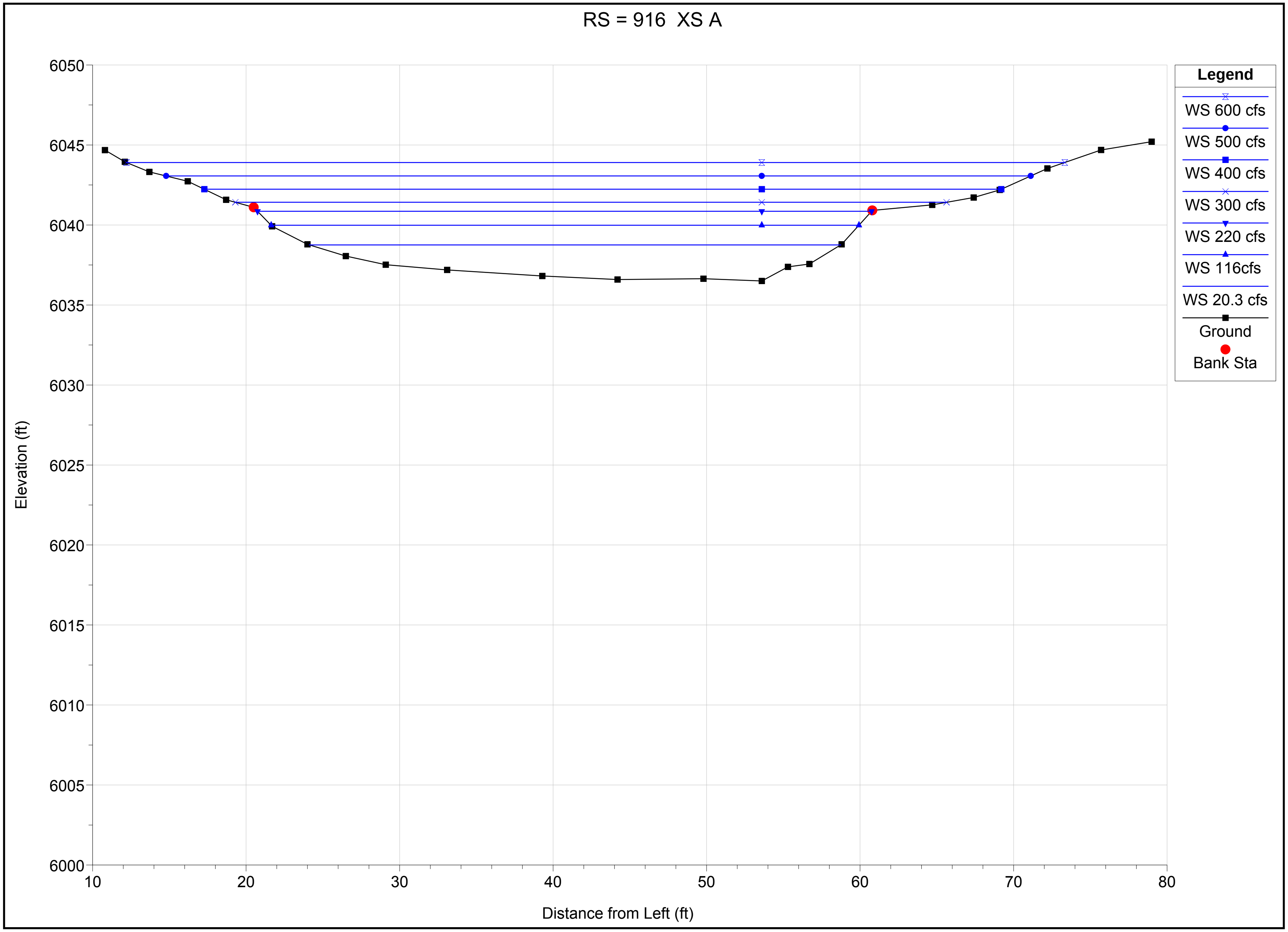
WS 116 cfs
WS 20.3 cfs
Ground
Bank Sta
Elevation (ft)
6075
6070
6065
6060
6055
6050
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
0
10
20
30
40
50
60
70
80
90
100
Distance from Left (ft)



RS = 916 XS A
Elevation (ft)
6050
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
10
20
30
40
50
60
70
80
Distance from Left (ft)
Legend
WS 600 cfs
WS 500 cfs
WS 400 cfs
WS 300 cfs
WS 220 cfs
WS 116cfs
WS 20.3 cfs
Ground
Bank Sta

Appendix F

Incipient Motion Calculation

Shear Stress

Calculation of the stream's bed shear stress (τ_0), or tangential force per unit bed area, is necessary to understand flow intensity and its ability to mobilize and transport sediment particles resting on the bed. Bedload transport rates are steep and non-linear, which means relatively small changes in shear stress can create large changes in sediment transport. Therefore, obtaining accurate shear stress estimates is critical in calculating sediment transport.

For steady, uniform flow the momentum equation states a balance must exist between shear forces (resisting forces) and gravity component (driving forces).

$$\tau_0 P_w \Delta s = \rho g A \Delta s S$$

or

$$\tau_0 = \rho g R S$$

where τ_0 is bottom shear stress, P_w is wetted perimeter, Δs is length of control volume, ρ is fluid density, g is gravity acceleration, A is cross-section area, S is the bed slope, and R is the hydraulic radius.

To calculate bed shear stress for steady, gradually varied flow conditions common to most streams, the friction slope S_f is often substituted for the bed slope S. And for relatively wide channels where the hydraulic radius and mean flow depth are approximately similar, the "depth*slope" product is used to calculate the mean cross-sectionally averaged boundary shear stress

$$\tau_0 = \rho g H S_f$$

where H is mean flow depth.

The mean boundary shear stress includes forces acting on debris jams, vegetation, channel banks, bar forms, and other features that add resistance and increase flow depth. Research has shown that the actual bed shear stress available for sediment transport (effective shear stress) is often a third to a half the mean boundary shear stress (Dietrich 1987). To gain a better estimate of only the portion of the shear stress that is acting on the sediment grains and available to transport sediment, a local estimate of shear stress directly above the area of the bed of interest is required. This local estimate is often referred to as a grain stress.

The following section describes the method used in this study to calculate local bed shear stress.

Time averaged fluid shear stress in a streamflow is defined as the rate of change of downstream momentum per unit cross-sectional area

$$\tau = -\rho \overline{u'v'}$$

where τ is turbulent shear stress, ρ is fluid density, *u*' is downstream velocity, and *v*' is vertical velocity.

Determining the vertical variation in flow velocity in turbulent flow requires knowledge of the mixing length *l*, or the vertical distance over which a fluid parcel's momentum changes. By equating the mixing length to

$$u' = -l\left(\frac{d\bar{u}}{d\bar{y}}\right) \text{ and } v' = l\left(\frac{d\bar{u}}{d\bar{y}}\right)$$

then turbulent shear stress is

$$\tau = -\rho \overline{u'v'} = \rho l^2 \left(\frac{d\bar{u}}{dy}\right)^2$$

By assuming that 1) the fluid shear is approximately equal to the bed shear near the streambed, and 2) mixing length increases linearly with distance from the bed, the law of the wall equation for determining the velocity gradient near the streambed (i.e., "wall") is calculated from

$$\frac{\bar{u}}{u*} = \frac{1}{\kappa}\ln\left(\frac{y}{y_0}\right)$$

where κ is Von Karman's constant (commonly set at 0.41), $\bar{u}$ is time averaged velocity at flow depth *y* above the bed, and y_0 is the flow depth where flow velocity equals zero. The shear velocity, *u**, is a measure of the velocity gradient near the bed, from which local bed shear stress can be calculated

$$\tau_0 = u*^2 \rho$$

In reality, flow velocity is only zero where $y = 0$. Therefore, in order to solve the equation for hydraulically rough flows, y_0 is related to the equivalent roughness height, k_s, by

$$y_0 = \frac{k_s}{30}$$

And k_s is based on the dominant coarse bed substrate, such as the D_{84} (the particle size in which 84 percent of the bed surface is finer).

Integration of the law of the wall equation above over the entire flow depth (h) shows that the mean flow velocity occurs at a distance of 0.368h from the bed. By inserting the 0.368h and k_s values into the law of the wall equation above, the local shear velocity, and thus local shear stress related to grain-induced resistance can be determined from mean channel velocity (U) using Keulegan's (1938) resistance law for rough flow:

$$\frac{U}{u*} = \frac{1}{\kappa}\ln\left(\frac{h}{k_s}\right) + 6$$

This equation, or variations of it, is commonly used to calculate local shear stress values for use in incipient motion and sediment transport analysis.

The following equation (from Wilcock 1996) was used to calculate local grain stress in this study:

$$\frac{U}{u*} = \frac{1}{\kappa}\ln\left(\frac{h}{ez_0}\right)$$

where z_0 (the bed roughness length where flow velocity (u) is 0) is calculated from

$$z_o = \frac{3D_{84}}{30}$$

Thus, an increase in velocity for a given depth and grain size will result in a higher shear stress on the bed whereas an increase in depth for a given velocity and grain size will result in lower shear stress.

Initiation of Motion

Whether or not a particle on the stream bed will be entrained by the flow or remain in place depends on: 1) randomness (grain placement and turbulence), and 2) balance of driving fluid drag (F_D) and resisting gravity forces (F_G)

$$F_D \propto \tau_0 D^2 \text{, and } F_G \propto (\rho_s - \rho) g D^3$$

and

$$\frac{F_D}{F_G} \propto \frac{\tau_0}{(\rho_s - \rho) g D} = \Theta = \tau^*$$

Where D is grain diameter and ρ_s is sediment density. The dimensionless bed shear stress (Θ, commonly called the Shields number, or τ^*) is a measure of sediment mobility. If τ^* is greater than the threshold required for sediment motion (τ^*_c, critical dimensionless bed shear stress), then sediment motion is predicted to occur.

Selection of τ^*_c is not a minor task. Much research continues to be performed in the field of sediment movement initiation. Figure H-1 below shows initiation of motion curves from which τ^*_c is determined from the particle Reynolds number (R_{ep}). If the τ^*_c value plots above the curve, then sediment motion is predicted to occur, whereas if the value is under the curve, then no motion is predicted to occur. Both curves show that as particle size increases from coarse sand to gravel, the increased resistance to movement from the weight of the particle exceeds the additional drag exerted on the particle, and thus the critical dimensionless shear stress required for movement increases. The curves flatten out at as particle size approaches coarse gravel (32 to 64 mm) and coarser particles. Several researchers have shown the original Shields curve (in blue) values for initiation of motion are too high, and thus predict too much shear stress is required for sediment movement. Therefore, Figure H-2 shows a modified curve (in red) in which the initiation of motion curve flattens out around 0.045 instead of 0.06.

The same two original and modified Shields curves are plotted in dimensional units in Figure H-2. From this plot, the amount of shear stress (Pascal units) needed to initiate motion of a given particle size (mm units) can be determined.

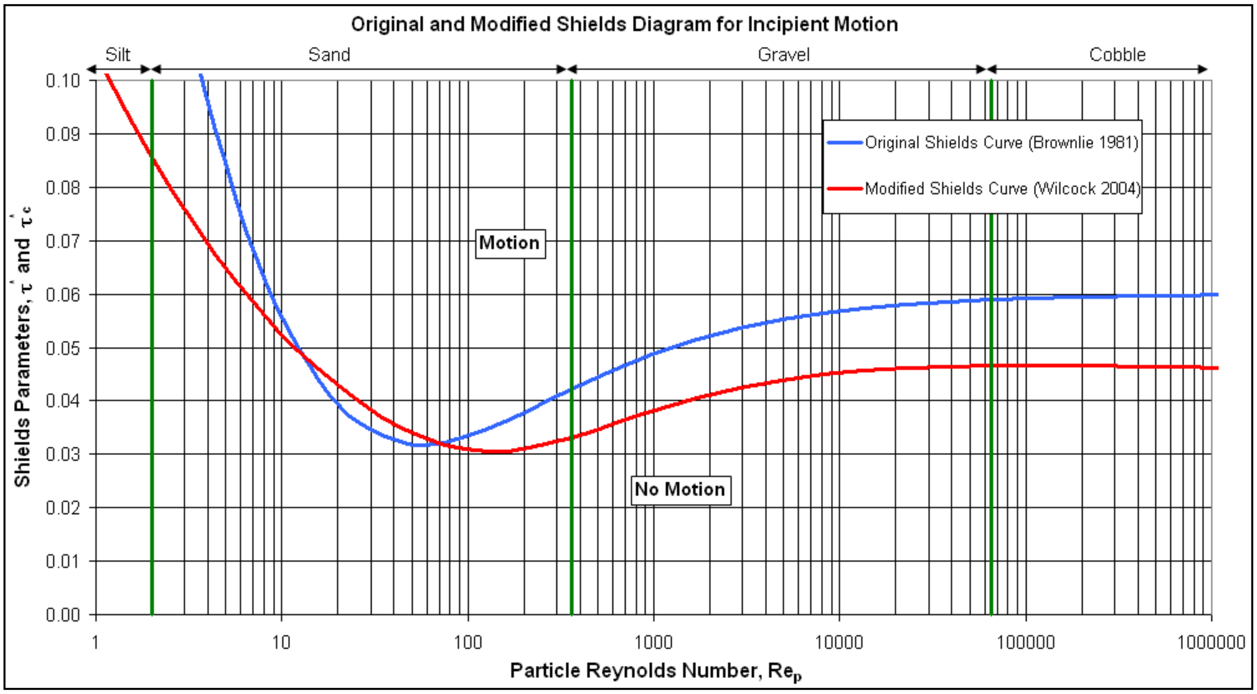


Figure F-1 Orignal and Modified Sheilds Diagram for Incipient Motion

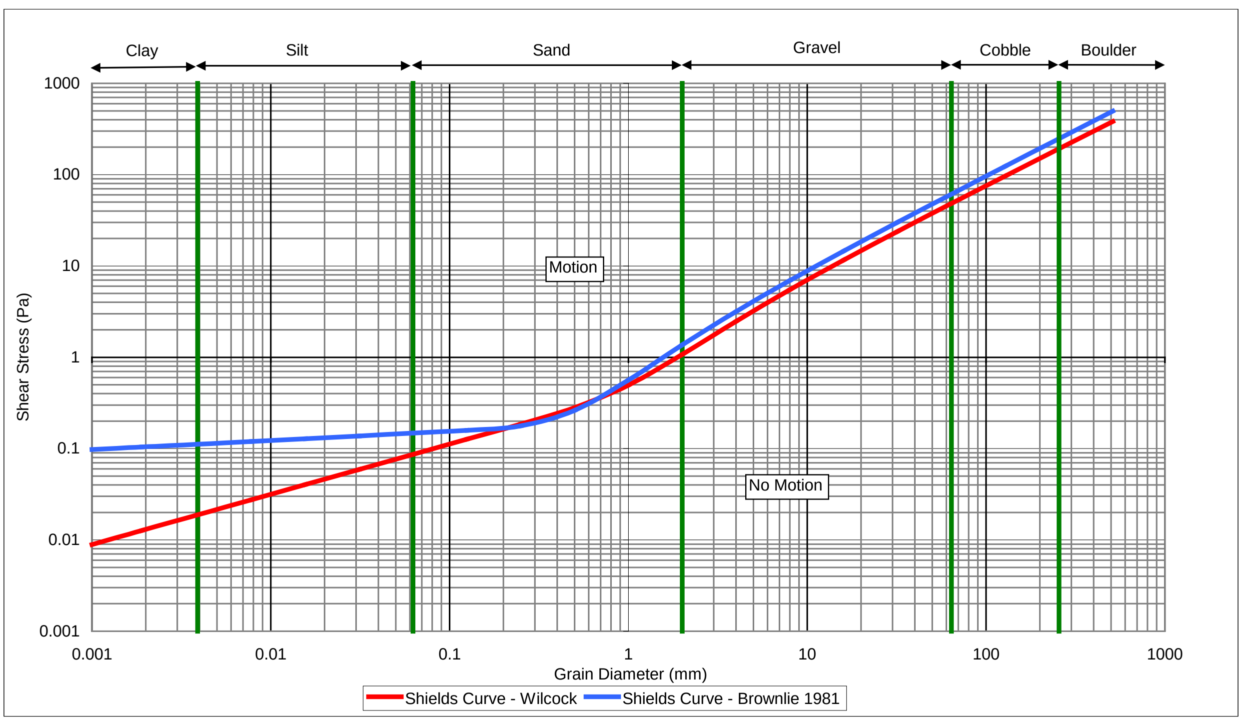


Figure F-2 Orignal and Modified Sheilds Diagram for Incipient Motion

Initiation of Motion for Sediment Mixtures

The initiation of motion curves in FiguresH-3 andH-4 represent critical shear stress values needed to mobilize sediment of a uniform size resting on a nearly flat channel bed. The curves do not consider how the relative variability of grain sizes in a sediment mixture influence initiation of motion values for individual particle sizes (D_i) within the mixture. For sediment mixtures of coarse and fine particles, the coarser particles (e.g., gravel) in the mixture can be relatively easier to mobilize than if all the sediment was the same size because the coarser grains protrude higher into the flow where flow velocities are greater, and they have relatively lower pivoting angles. By contrast, the smaller particles in the sediment mixture have higher pivot angles, and are shielded from the higher flow velocities by the larger particles. Therefore, the finer (e.g., sand) particles in a mixture can be relatively harder to mobilize than if all the sediment was the same size.

Additionally, research has shown the importance of the percentage of sand in a sediment mixture on the critical shear stress needed to mobilize both sand and gravel particles (Wilcock 1998; Wilcock and Crowe 2003). As the sand content increases on the bed to larger percentages, the gravel particles become less constrained by other gravel particles, and thus more of the particle is exposed to fluid drag since it is becoming larger than its surroundings. Once the gravel particle is entrained, it moves faster over the relatively smooth bed created by the sand, and it may move a greater distance because potential resting areas are filled with sand. At even higher percentages of sand, gravel particles can be mobilized through undercutting of the underlying sand, and once mobilized the gravel keeps going over the relatively smooth sand bed. Figure H-3[6] shows how variations in bed surface sand content influence the critical dimensionless shear stress needed to initiate motion of a sediment mixtures mean particle size (D_m) (Wilcock and Crowe 2003). Figure H-4 is the same plot but with dimensional critical shear stress values for different D_m values. The plots show that as surface sand content increases from 0 to 20 percent, the shear stress needed to mobilize the D_m decreases. Sand content increases greater than 20 percent have little influence on the critical shear stress needed for sediment initiation.

The Wilcock and Crowe (2003) method for calculating the critical shear stress needed to initiate sediment movement for mixed-size sediment was used for this study. This method was chosen since it considers how relative particle size variation within the sediment mixture and sand content influence sediment mobility.

6 The reference shear stress values presented in Wilcock and Crowe (2003) were converted to critical shear stress values by reducing the reference shear stress by 10 percent, per Wilcock 1998.

Figure F-3 Influence of Sand Content on Dimensionless Critial Shear Stress

Figure F-4 Influence of Sand Content on Critical Shear Stress

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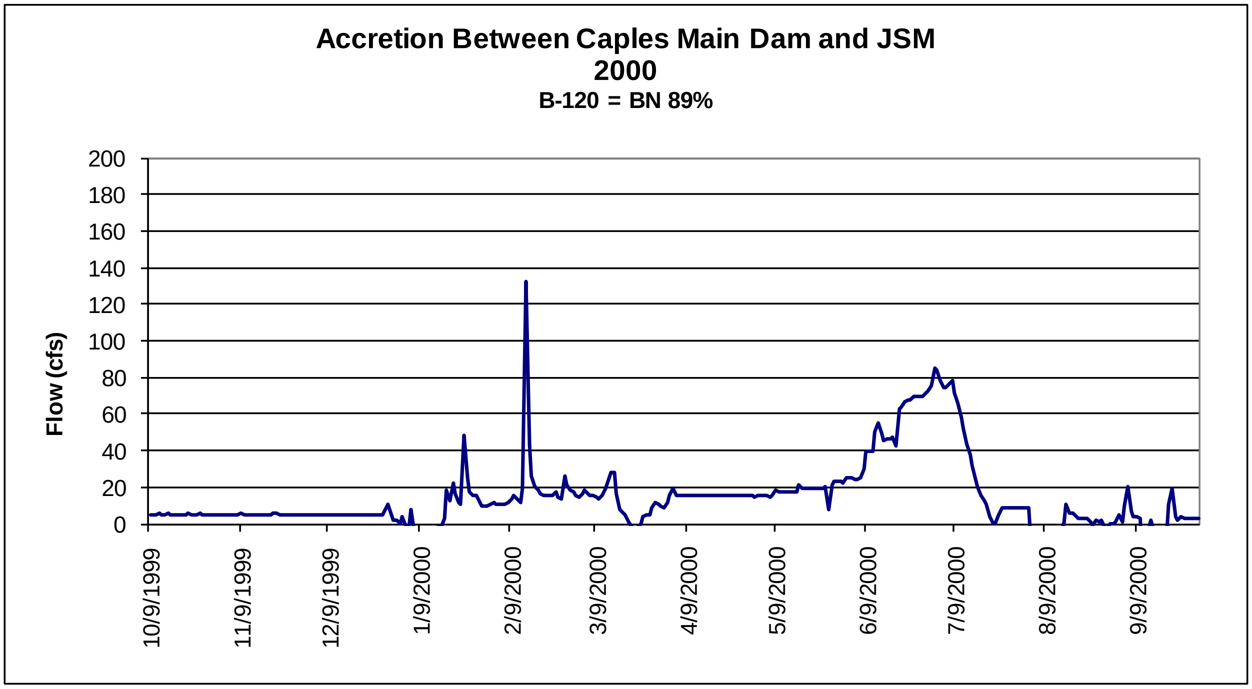
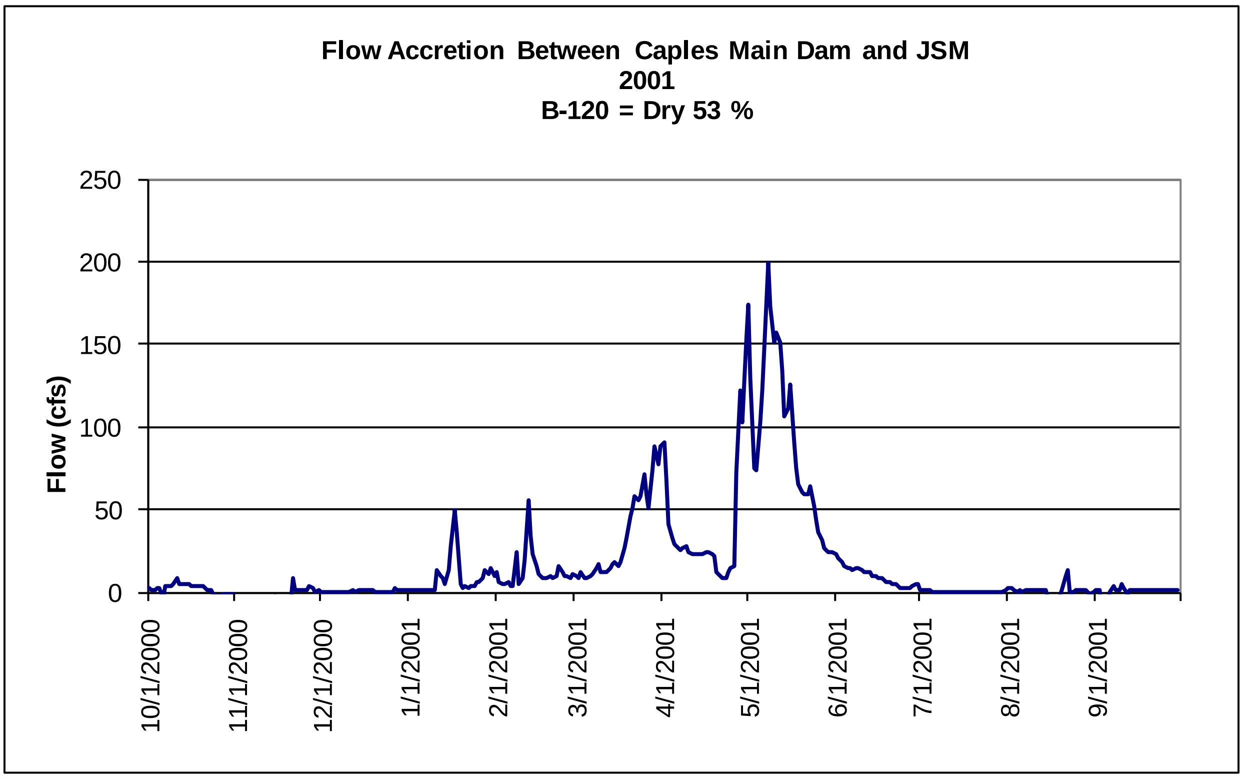
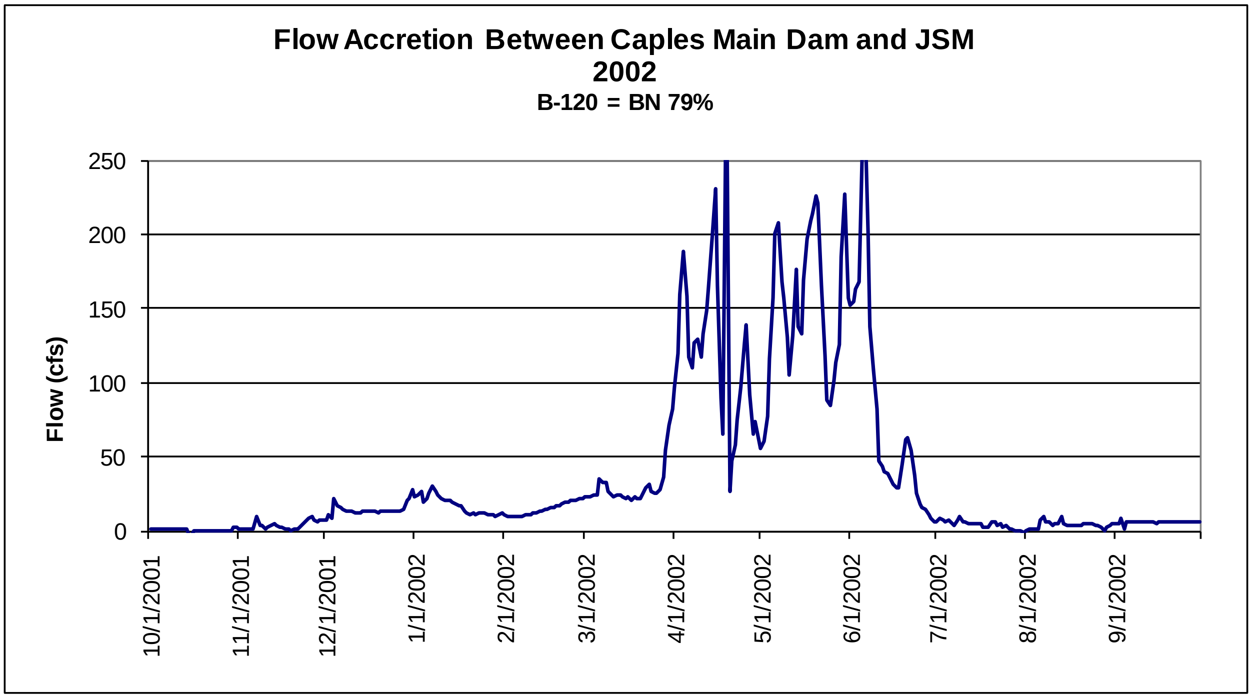
Appendix G

Peak Flow Kirkwood Creek AND Accretion Hydrographs to Jake Schneider Meadow

(USGS 11437560)


Accretion Between Caples Main Dam and JSM
2000
B-120 = BN 89%
Flow (cfs)
200
180
160
140
120
100
80
60
40
20
0
10/9/1999
11/9/1999
12/9/1999
1/9/2000
2/9/2000
3/9/2000
4/9/2000
5/9/2000
6/9/2000
7/9/2000
8/9/2000
9/9/2000


Flow Accretion Between Caples Main Dam and JSM
2001
B-120 = Dry 53 %
Flow (cfs)
250
200
150
100
50
0
10/1/2000
11/1/2000
12/1/2000
1/1/2001
2/1/2001
3/1/2001
4/1/2001
5/1/2001
6/1/2001
7/1/2001
8/1/2001
9/1/2001


Flow Accretion Between Caples Main Dam and JSM
2002
B-120 = BN 79%
Flow (cfs)
250
200
150
100
50
0
10/1/2001
11/1/2001
12/1/2001
1/1/2002
2/1/2002
3/1/2002
4/1/2002
5/1/2002
6/1/2002
7/1/2002
8/1/2002
9/1/2002

U.S. Geological Survey
National Water Information System
Retrieved: 2011-03-22 19:22:22 EDT
#
---------------------WARNING---------------------
The data you have obtained from this automated
U.S. Geological Survey database have not received
Director's approval and as such are provisional
and subject to revision. The data are released
on the condition that neither the USGS nor the
United States Government may be held liable for
any damages resulting from its use.
#
More data may be available offline.
For more information on these data, contact USGS Water Data Inquiries.
This file contains the annual peak streamflow data.
#
This information includes the following fields:
#

# agency_cd	Agency Code
# site_no	USGS station number
# peak_dt	Date of peak streamflow (format YYYY-MM-DD)
# peak_tm	Time of peak streamflow (24 hour format, 00:00 - 23:59)
# peak_va	Annual peak streamflow value in cfs
# peak_cd	Peak Discharge-Qualification codes (see explanation below)
# gage_ht	Gage height for the associated peak streamflow in feet
# gage_ht_cd	Gage height qualification codes
# year_last_pk	Peak streamflow reported is the highest since this year
# ag_dt	Date of maximum gage-height for water year (if not concurrent with peak)
# ag_tm	Time of maximum gage-height for water year (if not concurrent with peak
# ag_gage_ht	maximum Gage height for water year in feet (if not concurrent with peak
# ag_gage_ht_cd	maximum Gage height code

#
Sites in this file include:
USGS 11437560 KIRKWOOD C NR SILVER LAKE CA
#
Peak Streamflow-Qualification Codes(peak_cd):
1Discharge is a Maximum Daily Average
2 Discharge is an Estimate
3 Discharge affected by Dam Failure
4 Discharge less than indicated value,
which is Minimum Recordable Discharge at this site
5 Discharge affected to unknown degree by
Regulation or Diversion
6 Discharge affected by Regulation or Diversion
7 Discharge is an Historic Peak

8 Discharge actually greater than indicated value
9 Discharge due to Snowmelt, Hurricane,
Ice-Jam or Debris Dam breakup
AYear of occurrence is unknown or not exact
B Month or Day of occurrence is unknown or not exact
C All or part of the record affected by Urbanization,
Mining, Agricultural changes, Channelization, or other
D Base Discharge changed during this year
E Only Annual Maximum Peak available for this year
#
Gage height qualification codes(gage_ht_cd,ag_gage_ht_cd):
1 Gage height affected by backwater
2 Gage height not the maximum for the year
3 Gage height at different site and(or) datum
4 Gage height below minimum recordable elevation
5 Gage height is an estimate
6 Gage datum changed during this year
#
#

peak_dt	peak_va	peak_cd	peak_ht
1963-02-01	385		9.71
1964-05-13	116		5.14
1964-12-23	263		9.60
1966-05	105	B	4.98
1967-09-18	245		7.11
1968-05	77.0	B	4.86
1969-06	195	B	6.31
1970-05	131	B	5.36
1971-05	106	B	5.00
1972-06	92.0	B	4.80
1973-04	106	B	5.00

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