EL DORADO IRRIGATION DISTRICT

Caples Spillway Channel Sensitive Site Investigation Project 184 Geomorphology Monitoring

FEBRUARY 2010

PREPARED BY

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SECTION 1

Introduction

1.1 BACKGROUND

The Caples Lake spillway channel (hereafter referred to as the "spillway channel") conveys water released from the Caples Lake Auxiliary Dam downstream to Caples Creek. Previous geomorphic investigations conducted during the Federal Energy Regulatory Commission (FERC) relicensing of the El Dorado Hydroelectric Project (Project 184) indicate that spill flows have over time resulted in incision and bank erosion of the spillway channel (ENTRIX, 2002). A Sensitive Site Investigation/Geomorphology Monitoring Plan (Monitoring Plan) (EID, 2008) was developed in consultation with the U.S. Forest Service, California State Water Resources Control Board (SWRCB), Project 184 Ecological Resources Committee (ERC), and the FERC to provide a "detailed investigation of fluvial geomorphic properties" of the spillway channel. This Monitoring Report presents the results of the Monitoring Plan. This Monitoring Report has been completed in partial fulfillment of requirements set forth in the Project 184 USFS 4(e) Condition No. 37.6, SWRCB Clean Water Act Section 401 Water Quality Certification Condition No. 13, and Section 7 of the Project 184 Settlement Agreement (EID 2003).

1.2 STUDY OBJECTIVES

This Monitoring Report has been prepared to satisfy the study objectives described in the Monitoring Plan including:

- Field assessment of spillway channel stability
- Hydraulic modeling to predict velocities, depths, and shear forces on bed and banks, needed to provide a basis for developing stabilization measures
- Perform a test flow release to provide hydraulic model calibration; observations of bed/bank stability, and conduct empirical sediment balance/sediment transport studies

Consideration and development of mitigation measures to be incorporated into a stabilization plan is the final study objective, but which is to be prepared separately to address other Project 184 license conditions. As such, this monitoring report focuses on describing the studies performed, data collected, and results to-date, but does not present mitigation measures or a stabilization plan at this time. This report completes the collection of field data for the spillway channel as identified in the Monitoring Plan.

The sections of this report provide descriptions and details of the studies conducted to-date. Section 2.0 of this report describes the spillway channel geomorphology and stability, based on field reconnaissance and data collection performed in 2007. Section 3.0 describes the spillway channel hydraulics, based largely on studies performed during a controlled flow release in July 2009. Section 4.0 describes the sediment transport studies and results of a bank erosion assessment, also based on the July 2009 controlled flow release. References used in the report are listed in Section 5.0.

SECTION 2

Spillway Channel Morphology and Stability

A field survey of the spillway channel was performed in September 2007, which included:

- Assessment of channel morphology including identification of channel geomorphology, locations and photo-documentation of headcuts, bank erosion, and large wood debris jams
- Longitudinal bed profile survey
- Cross-section surveys
- Sediment composition of bed and banks at cross-sections

A main objective of the field survey was to characterize existing geomorphic conditions in the spillway channel, including identification of locations that are unstable and subject to bank erosion.

2.1 CHANNEL GEOMORPHOLOGY AND EROSION

The spillway channel is an altered channel form. It was likely a much smaller natural drainage prior to project development that has been incised and enlarged by historic spill flows (ENTRIX, 2002). The spillway channel is just over 3,000 ft in length beginning at the auxiliary dam spillway until its confluence with Caples Creek in Caples Meadow (Figure 2-1). The spillway channel can be divided into two distinct sections based on channel type: 1) an upper cascade channel type, and 2) a lower pool-riffle channel type.

The upper 2,200 ft of the spillway channel is predominantly a cascade channel type. Cascade channels occur on steep gradients, are straight, narrowly confined by valley walls, with longitudinally and laterally disorganized coarse bed material, and typically compiled of cobbles and boulders (Figures 2-2 and 2-3). Energy dissipation in the cascade reach is dominated by continuous tumbling and jet and-wake flow over and around individual large clasts. Large particle size relative to flow depth makes the largest bed-forming material of cascade type channels relatively immobile during most flows (Montgomery and Buffington, 1997). When flows are sufficient to mobilize bedload material, it is transported over the more stable, coarse bed-forming clasts.

Sediment sources to cascade type channels are usually associated with hillslope processes such as landslides, creep, and debris flows. Sediment storage in-channel is relatively insignificant, associated with finer material locally stored in the lee and stoss of flow obstructions (boulders and large woody debris jams), and in short sections of flatter gradients between cascades.

The lowermost 840 ft of the spillway channel is a pool-riffle channel type. The channel laterally oscillates (meander pattern), with an associated sequence of bar-pool-riffle. Substrate varies widely from coarser cobbles mixed with gravels at the upstream end of the reach, but grading to sand toward the middle portion of the reach. Figure 2-4 shows a section of the pool-riffle reach of the spillway channel. Sediment storage in pool-riffle channels occurs within bars, and often in overbank floodplain areas. The bar-pool-riffle sequences in the spillway channel although present, are not well-developed probably due to the fact that flows are not natural and occur only intermittently. About one-half of this lower reach is well-entrenched within high banks so that there is no connection to a floodplain, until the channel reaches the backwater section along the lowermost 350 ft of channel (Figure 2-5). Sediment sources in pool-riffle channel types are generally associated with bank failure (Montgomery and Buffington, 1997).

Table 2-1 summarizes the field observations of spillway channel morphology, including bed materials, gradient, potential for sediment recruitment to the channel, evidence of bank erosion and vulnerability to future erosion along the channel length. A rating of the overall channel stability, based on evidence of existing bank erosion is also provided. Two significant sites with bank instability and erosion were identified, one within the cascade channel reach, and one within the pool-riffle reach, both are described below. There are other, smaller areas of isolated erosion throughout the spillway channel but they did not represent a potential for substantial recruitment of sediment.

2.1.1 Unstable Sites

Most of the cascade channel reach is stable, with only localized areas of bank erosion (see Table 2-1). Considerable protection from erosion is afforded by boulders and bedrock outcrops, by the root structure of standing trees, and by large woody debris. The localized areas of bank slumping and erosion occur in relatively short channel sections less than 20 ft in length. One significant site of instability and erosion was identified in the cascade reach (hereafter referred to as the "upstream" erosion site), located on Figure 2-1.

The upstream erosion site (see Table 2-1, Station 850-1200) is located beginning approximately 850 ft downstream from the auxiliary dam. The site is about 350 ft long, although about 250 ft is unstable. Banks are 6-8 ft tall, comprised of fine-grained material, with most of the bank height eroding. Approximately 150 ft of the channel length at the upstream end of the site is actively eroding along both the right and left banks. Another 100 ft of the channel is actively eroding on the right bank at the lower end of the site where bedrock is sloping on the left bank and forcing flow against the right bank (Figure 2-7). There is also a short section of more moderately stable channel bank between these two eroding sections.

All of the lower pool-riffle reach upstream from the backwater area see Figure 2-1 has been subjected to past bank erosion, and remains vulnerable to future erosion (see Table 2-1, Station 2197-2600). Approximately 500 ft of channel length along most of both the right and left banks, which average about 6 ft high, are eroding (Figure 2-8). Undercutting of the fine-grained bank material and subsequent slumping and collapse are apparent, leaving standing trees with exposed roots (Figure 2-9). There is a large woody debris jam close to the upstream end of the lower erosion site, with about 50 ft of erosion along the right bank just upstream of the debris jam. Below the most downstream portion of the lower erosion site (see Table 2-1, Station 2600-3000), within the 350 ft backwater section to the confluence with Caples Creek, is relatively stable with only localized bank erosion. This is probably due to the influence of the backwater on channel hydraulics, which dissipates energy and allows high flows to spread out over the top of banks onto the floodplain. This provides a "hydraulic release" from the shear forces that occur during high flows.

2.2 LONGITUDINAL BED PROFILE SURVEY

A topographic survey of the spillway channel was performed to determine channel gradient and to provide data for input into hydraulic modeling. Approximately 3,000 ft of the spillway channel thalwag (deepest part of the channel) was surveyed with a total station from the confluence with Caples Creek upstream to the auxiliary Caples Dam spillway. The profile is plotted in Figure 2-10.

The upper 2,200 ft of the cascade reach is very steep with an overall slope of 8.7%. The slope of the 840 ft long pool-riffle reach (and the lower erosion site) is dramatically lower, approximately 0.06%. The slope along the 350 ft length of the upstream erosion site is 3.2%.

2.3 CROSS-SECTION SURVEYS

Twelve channel cross-sections were surveyed to characterize channel morphology and for input into a hydraulic model. The cross-sections are plotted in Appendix A. Figure 2-10 shows the locations of the surveyed cross-sections on the longitudinal profile (also see Figure 2-1).

Three cross-sections were surveyed within the upstream erosion site (approximately stations 960 ft, 1100ft, and 1175 ft downstream of the dam spillway, see Figure 2-10). Nine of the cross-sections were surveyed in the lower 950 ft of the pool-riffle channel between the confluence with Caples Creek, upstream to the transition into the cascade channel. Three of the cross-sections located in the pool-riffle reach were originally surveyed in August 1999 in support of EID relicensing studies (BLXS1, BLXS2, and BLXS3). These 1999 cross-sections were located in the field and re-surveyed by ENTRIX in 2007. The latest survey shows that these three cross-sections have remained essentially unchanged in the 8-year period between 1999-2007 (see comparison cross-section plots in Appendix A).

2.4 BED AND BANK MATERIAL CHARACTERISTICS

Pebble counts (Wolman 1954) were conducted at three cross-sections to characterize bed surface sediment grain size within the lower erosion site (see results in Table 2-2). Grain size in the bed varies widely and the material is typically a poorly sorted mixture of sand and gravel sediment. The median particle size (D_{50}) is gravel, but widely ranging from 2.8mm to 59.9mm. In addition to the pebble counts, a bulk sample of material was collected in the pool-riffle reach. Results from a bulk sample of the combined bed surface and subsurface at Backwater XS 1 show 70% of the bed in the depositional zone near the confluence with Caples Creek is sand-size material (0.063 mm to 2 mm), with the remainder largely fine and medium size gravel.

A bulk sample of bank material was also collected midway up the left bank (looking downstream) at BLXS 2. The bank material is 84% sand-size with the remaining 16% fine and medium size gravel. Sandy, largely unconsolidated banks are typical within the pool-riffle reach.

At the upper erosion site bed material size is much coarser, predominantly cobbles and small boulders, with a small proportion of gravel and sand present based on visual observations. Banks are comprised of sand-size material similar to that collected from the lower erosion site.

SECTION 3

Channel Hydraulics

3.1 OVERVIEW OF CONTROLLED FLOW RELEASE STUDY

A controlled flow release study in the spillway channel at the lower and upper erosion sites was conducted July 22-24, 2009. The objectives of the flow study were to provide target flow releases of 10 cfs, 30 cfs, and 60 cfs so that field measurements could be taken to: 1) measure water surface elevations and stage for use in developing and calibrating hydraulic models, 2) measure suspended load and bedload transport, 3) measure bank erosion rates, and 4) photo document channel conditions. The water surface elevations for input to hydraulic modeling are documented in this section. The suspended load and bedload transport, and bank erosion rates are documented in Section 4.0

Three staff gages were erected at the lower erosion site, and two at the upper site at previously surveyed cross-sections so that stage observations could be recorded throughout the study. A discharge measurement site was established 500 ft upstream of the confluence with Caples Creek, just upstream of where the trail to Lake Margaret crosses the spillway channel. Discharge was measured using the area-velocity method (Rantz et al. 1982) with velocities measured by a Marsh-McBirney Flo-Mate current meter. Velocity and depth readings were taken at approximately 25 intervals along the cross-section with the average velocity obtained over a 30 second period. Stage readings were made from a staff plate erected at the measurement site both before and after each measurement to ensure that the water surface elevation did not change over the course of the measurement.

Aerial photo-base maps showing the location of staff gages, cross-section surveys, discharge measurement, sediment transport and bank erosion monitoring studies are provided in Figures 3-1 and 3-2 for the lower erosion site and upper erosion site, respectively.

Figure 3-3 is a hydrograph plot that shows the discharge magnitudes and durations for the study. The first release (flashboards are removed from the auxiliary dam spillway) occurred on the afternoon of Tuesday, July 22, 2009. The first discharge measurement was taken and the flow was determined to be 4.2 cfs. EID operators removed additional flashboards and the second discharge measurement was 13 cfs. On Wednesday morning (July 23), the decrease in lake level (and resultant decrease in head pressure) had caused the discharge to decrease to 9.5 cfs. Sediment transport and bank erosion data was collected during the morning and afternoon of July 23 after approximately a 24-hr flow release duration. On Wednesday afternoon, additional flashboards were removed to obtain the 30 cfs release. The first discharge measurement was taken and the flow was determined to be 25.6 cfs. EID operators removed additional flashboards and the second discharge measurement was 31.9 cfs. On Thursday morning (July 24), the discharge had decreased to 24.3 cfs. Sediment transport and bank erosion data was collected during the late morning and early afternoon of Thursday, July 24 after approximately a 24-hr duration flow release. To obtain the final target flow release of 60 cfs, more flashboards were removed late Thursday afternoon. The first discharge measurement was 41.8 cfs, so additional flashboards were removed. The second discharge measurement was 58 cfs. Sediment transport and bank erosion data was collected during the late afternoon of Thursday, July 24 at the 58 cfs flow after approximately 2-3 hour flow duration. The flow release study ended on Thursday evening.

3.2 HYDRAULIC RESULTS

Water surface elevations at each of the three flow releases were recorded at the five installed staff gages (two at the upper and three at the lower erosion sites), surveyed with an auto-level, and tied into the elevations of the 2007 ground survey of cross-sections. Figure 3-4 (also see Appendix A) shows the observed water surface elevations at each of the flow releases. At the highest 58 cfs release, mean flow depths at each of the cross-sections are approximately 2 ft, and the water surface is at least 4 ft from the top-of-bank at most cross-sections. Examples of flow conditions and water surface elevations for the controlled flow releases are provided in field photos in Appendix B.

A continuous longitudinal water surface profile was surveyed for the entire lower and upper sites during the 10 cfs release. The water surface profile for the upper and lower erosion sites are plotted in Figures 3-5 and 3-6, respectively.

3.3 MODEL DEVELOPMENT AND CALIBRATION

The observed water surface elevations recorded at the monitoring cross-sections and the water surface profile will enable calibration of the HEC-RAS hydraulic model. The model will be used to determine the flow depths, velocity, and shear stress for the maximum design flows potentially up to 250 cfs for the stabilization plan. No modeling simulations or calibration have been prepared at this time. The hydraulic modeling will be completed as soon as the maximum design flow capacity needed for the spillway channel stabilization is determined. The design flow for the spillway channel is dependent upon the maximum flow release capacity of Caples Dam into Caples Creek. The maximum flow release capacity of the recently re-constructed Caples Dam outlet gate into Caples Creek will be measured in spring 2010 if sufficient water is available.

SECTION 4

Sediment Transport and Bank Erosion

During the controlled spillway channel release, studies of bedload transport, suspended load transport, and bank erosion were performed at the lower erosion site, in addition to the stage-discharge monitoring conducted at both the upper and lower erosion sites (see Section 3.0).

4.1 BEDLOAD AND SUSPENDED LOAD TRANSPORT SAMPLING METHODS

Bedload sediment measurements were collected at the lower erosion site to quantify the particle sizes and amount of material transported as bedload for each of the target release flows. Two techniques were used to measure bedload transport; net samplers and Helley-Smith samplers. Bedload traps are net samplers that are secured to the channel bed with a metal plate (Figure 4-1). The frame of the sampler is 1 ft wide with a 2 ft 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 and enabling more accurate measurements of transport. Eight bedload trap samplers were installed using the U.S. Forest Service guidelines (Bunte et al. 2007). Five bedload traps were installed just upstream of the discharge measurement cross-section location, and three were installed just downstream of XSA (Surveyed cross-section) site (see Figure 3-1), above the large woody debris jam. The bedload traps were allowed to collect sediment over approximately a 24-hr period for the targeted 10 cfs and 30 cfs releases. The bedload traps were deployed for approximately 2 hours for the targeted 60 cfs 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, which are discussed below in Section 4.2.

In addition to the bedload traps, bedload samples were also collected with a hand-held Helley-Smith sampler. The Helley-Smith sampler functions similarly to the bedload trap by allowing sediment to pass through a metal opening and into a collecting net except it has a smaller opening (3 in by 3 in) and sample times are considerably shorter (Figure 4-2). The Helley-Smith sampler was used to collect bedload across the entire wetted channel width at several cross-sections. The sampler was placed on the bed at 2 ft intervals along the cross-section and timed for a one-minute period at each sampling station, following the standard U.S. Geological Survey sampling methods (Edwards and Glysson 1999). Material collected from the Helley-Smith samplers was bagged and sent to a laboratory where it was dried, weighed, and analyzed for particle size gradation and calculation of bedload transport rate.

Suspended sediment measurements were collected at several transects throughout the lower erosion monitoring site to quantify the amount of material transported in suspension and the associated particle size for each of the flow releases. A DH-48 model hand-held sampler was used to collect depth-integrated suspended sediment samples based on standard U.S. Geological Survey (USGS) sampling protocols (Edwards and Glysson 1999). The depth-integrating sampler continuously samples sediment at a uniform rate as it is lowered and raised through the water column to obtain a discharge or velocity-weighted sample. The equal-width-increment method was used to sample a volume of water proportional to the flow at each equally spaced vertical. Water and sediment collected in the DH-48 sample bottles was sent to a laboratory where it was dried, weighed, and analyzed for particle size gradation.

4.2 BEDLOAD TRANSPORT RESULTS

For this monitoring study, the bedload traps were not an effective method of sampling bedload. Following their deployment and each of the controlled flow releases, the nets quickly filled up with pine needles, pine cones, and other woody organic debris (Figure 4-3). As the nets filled with organic debris their ability to accurately trap the sediment load in transport diminished until ultimately the nets were completely full of organic debris and could not trap any sediment. The problem with the organic debris was likely exacerbated by the unique circumstances of the spillway channel. Years can pass without the spillway channel conveying any substantial flow yet organic debris is constantly shedding from the bordering pine forest and collecting in the channel. As such, each of the flow releases washed the accumulated debris downstream where it clogged the sampler nets. Organic debris was a problem for the entire duration of all three flow releases, including the much shorter 2-3 hour release at 58 cfs. When the bedload trap nets were emptied onto tarps on the bank, well over 90% of the material was organic debris. Because the hydraulic function of the bedload traps were so impaired by the organic debris, the small amount of sediment collected in the nets could not be considered a reliable sampling of the actual bedload, and was therefore not used to calculate bedload transport.

Because of the problems with the bedload trap samplers, bedload transport results are based on the eight measurements collected with the Helley-Smith samplers. The bedload transport rate (in tons/day), and particle size gradations of the samples are reported in Table 4-1. A sediment transport rating curve showing bedload transport vs. discharge with a best-fit trend line is displayed in Figure 4-4.

The data show that typically 80%-90% of the bedload material was sand with the remainder a mixture of silt/clay and very fine to fine gravel sizes. The lowest flow of 9.5 cfs is capable of transporting the finer silt/clay fraction of the bedload. It is not until the higher 24.3 cfs discharge that a large percentage of coarser sand sized material is in transport. The coarsest material transported was 6 mm (fine gravel). The highest calculated bedload transport rate, approximately 140 tons/day, is associated with the highest flow release of 58 cfs. A small amount of sediment (silt/clay), 0.8 tons/day, was transported as bedload during the lowest 9.5 cfs release. There was a fairly wide variability in the measured transport rates for a given discharge. This is not unusual for bedload transport measurements, in part reflecting the variable nature of bedload transport which tends to occur in random discontinuous pulses at lower flows, particularly when patches of sand are migrating downstream.

4.3 SUSPENDED LOAD TRANSPORT RESULTS

Suspended load measurements were made at each of the flow releases throughout the lower erosion monitoring site. A suspended load rating curve showing the rate of transport vs. discharge with an exponential trendline is presented in Figure 4-5. Suspended load increases from 0.5 tons/day at a flow of 9.5 cfs to over 60 tons/day at a flow of 58 cfs. In general, the median particle size of the suspended load increases with increasing discharge from silt size sediment to fine sand (Figure 4-6).

4.4 BANK EROSION RESULTS

Nine erosion pins were installed at 5 locations within the lower erosion monitoring site. The erosion pins were 1 ft lengths of rebar driven horizontally into the streambank with the head of the pin nearly flush to the bank. Following the completion of each flow release, the length of pin exposed was measured to track the amount of bank retreat.

The cumulative amount of lateral bank erosion that occurred at each of the bank erosion pin sites is displayed in Table 4-2. A negligible amount of bank erosion occurred at 9.5 cfs for all sites. Bank erosion cumulatively ranged from 0.01 ft to 0.55 ft by the 24 cfs release, and from 0.01 ft to 0.97 ft by the completion of the 58 cfs release. Note that the 58 cfs release was conducted for a period of approximately 2 hours before the controlled flow was shut-off, whereas the previous releases proceeded for a period of approximately 24-hrs each. The only location that showed virtually no bank erosion was pin 1. Examples of bank erosion measured at pin sites after the various flow releases are shown in Appendix C. Nighttime darkness fell soon after completion of the 58 cfs flow release, this unfortunately prevented obtaining useable photographs of the pins at the end of the study.

Although no erosion pins were installed at the upper erosion site, field observations indicate that bank retreat was similar here to the lower erosion site. The bank material is of a similar fine-grained composition, and the banks are eroded, unvegetated, and at a similar steep angle as the lower erosion site.

4.5 CONCLUSION

All of the data required by the Monitoring Plan for the Caples spillway channel have been collected, including the field assessment of spillway channel stability, conducting the test flow release, and collection of data needed for incorporation to hydraulic modeling. This report nearly completes the geomorphology analysis with the exception of performing the hydraulic modeling. The hydraulic modeling will be completed as soon as the maximum design flow capacity needed for the spillway channel stabilization plan is determined.

SECTION 5

References

Bunte K., K.W. Swingle, et al, 2007. *Guidelines for using bedload traps in coarse-bedded mountain streams: Construction, installation, operation, and sample processing.* General Technical Report RMRS-GTR-191. Fort Collins, CO, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station**:** 91.

Edwards, T.K. and G.D. Glysson, 1999. *Field methods for measurement of fluvial sediment. In, Techniques of Water-Resources Investigation of the U.S. Geological Survey, Book 3, Applications of Hydraulics.* Reston, Virginia.

El Dorado Irrigation District (EID), 2008. *Project 184 Geomorphology Monitoring Plan: Sensitive Site Investigation and Mitigation Plan Development.* Version 6.0, July 9, 2008.

ENTRIX, Inc 2002. *EID Project 184 Geomorphic Site Assessment*. December 2002.

Montgomery, David R. and John M. Buffington, 1997. *Channel-reach morphology in mountain drainage basins*. GSA Bulletin, v.109, no.5, p. 596-611, May 1997.

Rantz, S.E., et al, 1982. *Measurement and computation of streamflow: Vol. 1. Measurement of stage and discharge*. Washington, D.C., U.S. Government Printing Office.

Wolman, M.G., 1954. *A method of sampling coarse river-bed material: Transactions of the American Geophysical Union (EOS)*, v. 35, p. 951-956.

SECTION 6

Tables and Figures

Table 2-1 Summary of Caples Spillway Channel Stability and Erosion

Station *(ft)	Channel Description	Bank Stability and Risk of Erosion
0-250	US of Hwy 88, stable bedrock channel scoured along bedrock joint patterns; RB roadside drainage enters via culvert outfall, LB roadside drainage enters in concrete lined swale; At Hwy 88 crossing, grouted rip-rap bed and banks (but riprap loose); Hwy 88 bridge crossing (low roughness, high velocities, narrow/deep channel directs flow DS)	Stable, (but some loose rip-rap under Hwy 88)
260-400	Multi-thread channel area with even-age lodgepole pine rooted in debris fan lodged upstream of large bedrock boulders. Channel splits around boulder cluster with defined channel to the left, approx 10 ft bottom width and 3 ft depth. Forested reach, scour over tree roots evidence of high flows out of channel. Small concrete weir at station 400 abuts large boulder.	Moderately Stable, well-treed. Flows spread into multiple channels. High spill flows could increase scour around tree roots.
400-600	Steep drop from large boulders downstream of weir into next reach. Boulders and bedrock dominant channel material, steep, entrenched. Localized evidence of erosion against right bank near old flow measurement station, but reach is mostly stable. Local fine sediment sources from hillslope on RB (~535 ft)	Stable
600 to 625	Decrease in gradient, wider channel, but still boulder and bedrock controlled. Continuation of steep, bedrock/bldr entrenched channel reach, but gets wider at station 615.	Stable
625-750	Woody debris in wider channel areas (~645 ft). Localized bank erosion on left and right banks at ~ 750 ft, but hillslope bank is gentle gradient with standing trees (on rt bank)	Stable
750-850	Bldr, entrenched channel reach, but lower gradient than just upstream. Several pieces of LWD spanning channel and pinned against trees on left bank at station 770, some local erosion around tree roots against right and left banks. LWD at sta. 850, and scour around roots of several standing trees.	Stable
850-925	Gradient flattens, entrenched. Left and right bank erosion. Some LWD in channel. LWD in mid channel bar that splits flows and increases bank erosion and widening. Bank materials include fines (much finer than bed materials) and may increase suspended sediment delivered downstream.	Unstable, existing erosion both banks
925-975	Channel narrows, banks higher and still undercut, and still finer texture than bed materials. Channel bed is boulder lag residual from erosion of fine matrix in overlying deposits.	Unstable, existing erosion both banks
975-1080	Appears mostly stable	Moderately stable
1080-1200	Exposed sloping bedrock on left bank to centerline of channel forcing flow against right bank, eroding. [photo 20, 21]. Fewer trees along undercut RB at 1150; downstream end of bedrock control is ~1250.	Unstable, existing erosion against right bank
1250-1300	Bedrock cascade with stable, controlled LB and RB	Stable
1200-1380	Gradient flattens more, moving downstream into this reach, less entrenched, wider, and more poorly defined channel as valley walls pull-back. RB could be locally vulnerable to erosion at upstream end of the reach. Shallow colluvium mantling over small boulders and bedrock from 1300-1380. Little erosion in less confined channel reach. From 1325 to 1380, no real source of fine sediment and limited LWD too; channel is shallow to bedrock and no incision risks.	Stable
1380-1425	Bedrock exposed, gradient still flat, but increases starting at 1425	Stable
1425-1515	Small boulders comprise bed. Debris accumulations in lower gradient section upstream of narrow, bedrock controlled downstream reach—LWD oblique to flow and reduce conveyance area.	Stable
1515-1575	Bedrock and boulders, some concerns about split flow around boulders, but total flow conveyance is adequate.	Stable
1575-1700	Boulder dominated channel, gradient increases, channel relatively wider. At station 1660, approx 25 ft of left bank is eroding from top of bank to toe into colluvium.	Stable
1700-1960	Moderately steep, channel still relatively wider than more upstream reaches, boulder, bedrock, and cobble bed. Small local sites of bank erosion, but mostly	Moderately Stable

Station *(ft)	Channel Description	Bank Stability and Risk of Erosion
	stable – likely due to greater channel width. ~1800 broken log jam with downstream bedrock pool. Colluvial soils on banks about 4-5 ft high with cobble; not a large volume of fines at risk. ~1825 LB thin residual soils over bedrock. This reach has conveyance, but steep slope and large boulders may have high turbulence and velocity as flows exit to downstream lower gradient 'valley' reach.	
1960-2100	Substantial gradient reduction as channel leaves steep side slopes and begins to cross valley floor. Bank and bed material finer than upstream, with pockets of gravel on bed. Right bank eroding just upstream of large LWD jam at station 2100.	Stable, until approximately 75 ft upstream of LWD on Right bank is Unstable and actively eroding
2100-2197	LWD jam, flattened gradient just upstream of jam due to sediment deposition behind jam	LWD jam itself is stable
2197-2600	Flat gradient, bed material grades from cobble immediately above and below LWD jam, to gravel and then to sand in downstream direction. Backwater at sta. 2600. Stream bank material changes from colluvial and residual to alluvial, fine grained materials. Left and right banks exhibit nearly continuous erosion. LWD scattered in reach. A few scattered willows are growing in channel, despite moist soils… due to backwater inundation frequency?	Unstable, actively eroding
2600-3000	Backwater reach. LWD in-channel, a couple of localized, short bank erosion sections. Approaching Caples Ck confluence, streambanks are lower, high flows can easily overbank into Caples Meadow. LWD is scouring a pool at station 2757.	Stable

*Distance downstream from auxiliary dam.

Table 2-2 Bed Surface Particle Size

Cross-Section	Geometric Mean	Geometric Standard Deviation	D_{10}	D_{16}	D_{50}	D_{65}	D_{84}	D_{90}
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
BLXS 1	29.5	9.5	1.7	6.0	59.9	97.7	170.9	209.4
BLXS 2	1.3	9.0	0.1	0.1	2.8	7.3	13.9	17.5
BLXS 3	6.2	8.0	0.1	0.2	14.3	21.4	28.8	31.4

Table 4-1 Bedload transport rate and particle size distribution based on Helly-Smith samples

Sample Location	Date	Discharge	Bedload Transport	Gravel	Sand	Silt/Clay	D_{10}	D_{50}	D_{90}
		(cfs)	(tons/day)	(%)	(%)	(%)	(mm)	(mm)	(mm)
Staff 2	7/23/2009	9.5	0.8	0.0	31.8	68.2	<0.063	<0.063	1.00
Staff 1	7/24/2009	24.3	0.5	0.6	89.1	10.3	0.08	0.35	1.00
Staff 2	7/24/2009	24.3	5.4	8.1	85.0	6.9	0.11	0.80	4.00
Staff 3	7/24/2009	24.3	0.4	14.6	82.5	2.9	0.20	0.75	6.00
Staff 2	7/24/2009	41.8	82.6	4.6	85.2	10.2	0.08	0.45	2.00
Between Staff 1 and Staff 2	7/24/2009	58	6.4	3.5	91.5	5.0	0.14	0.30	1.10
Staff 1	7/24/2009	58	2.7	5.0	86.4	8.6	0.09	0.35	2.50
Staff 2	7/24/2009	58	139.6	13.0	77.3	9.7	0.08	0.60	6.00

Table 4-2 Bank Erosion Measurements, lower monitoring site

Pin ID	Site	Height Above Leakage Flow Water Surface (ft)	Cumulative Bank Retreat After 9.5 cfs* (ft)	Cumulative Bank retreat After 24 cfs* (ft)	Cumulative Bank retreat After 58 cfs* (ft)
Pin 1	1	1.2	0.01	0.01	0.01
Pin 2	2	0.8	0.03	0.13	0.38
Pin 3	2	1.2	0.14	0.26	0.72
Pin 4	3	0.6	0.0	0.55	0.97
Pin 5	4	0.6	0.14	0.48	0.93
Pin 6	4	1.3	0.04	0.45	0.74
Pin A	5	0.5	n.a.	n.a.	0.27
Pin B	5	2.0	n.a.	n.a.	0.04
Pin C	5	2.7	n.a.	n.a.	0.08

n.a. – not applicable, pins A, B, C were not installed until the 58 cfs release. * The bank erosion rates measured during the 9.5 cfs and 24 cfs releases were after a 24-hr flow duration, and the 58 cfs bank erosion was measured after a 2-3 hr flow duration.

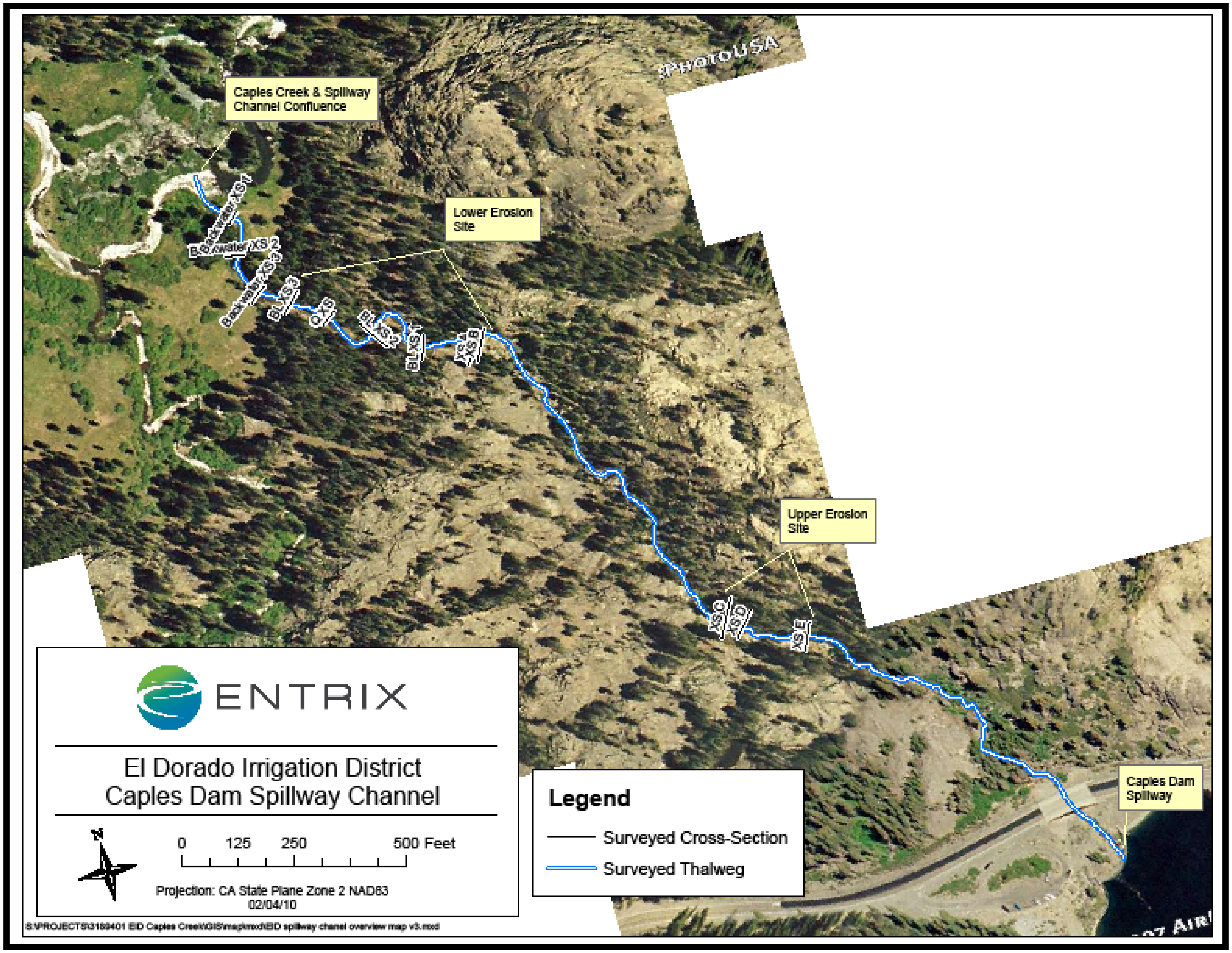


Figure 2-1 Location of the spillway channel

Figure 2-2 Cascade channel type. Location is approximately 700 ft downstream from the auxiliary spillway. View is downstream.

Figure 2-3 Cascade channel type. Flow is 30 cfs, upstream view.

Figure 2-4 Pool-Riffle channel type in lowermost 840 ft section of channel. Note the meander planform and the bar on the inside of the meander against the right bank. (flow is 10 cfs, view downstream)

Figure 2-5 Pool-Riffle channel type in backwater section of spillway channel, approximately 150 ft upstream from Caples Creek. Note the low banks that allow a floodplain connection

Figure 2-6 Upper Erosion Site, view upstream of right bank (left bank also eroding, not in view)

Figure 2-7 Upper Erosion Site right bank, with sloping bedrock on left bank

Figure 2-8 Lower Erosion Site, view downstream

Figure 2-9 Lower Erosion Site. Left Bank, view upstream

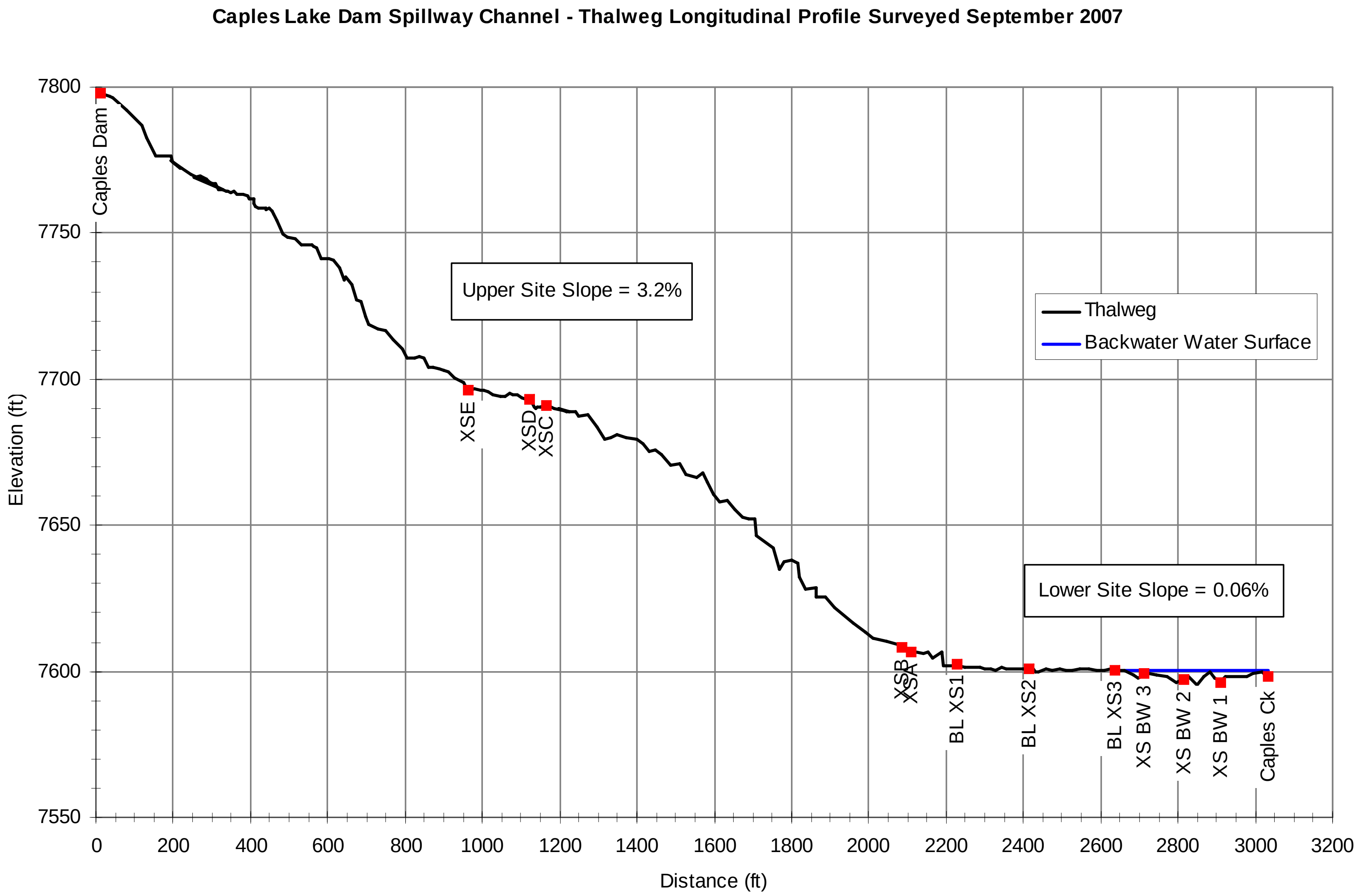


Figure 2-10 Caples spillway channel longitudinal profile

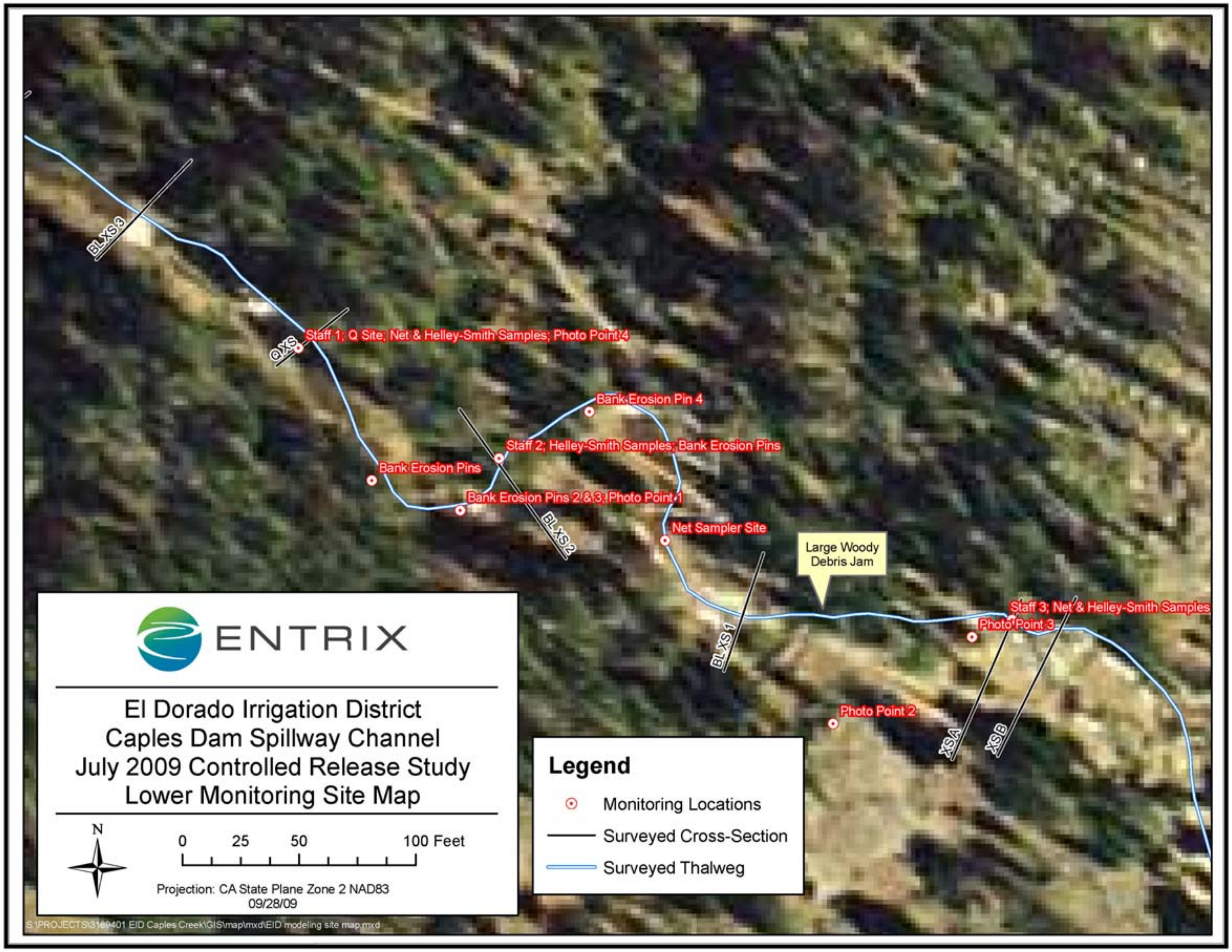


Figure 3-1 Lower erosion site monitoring locations

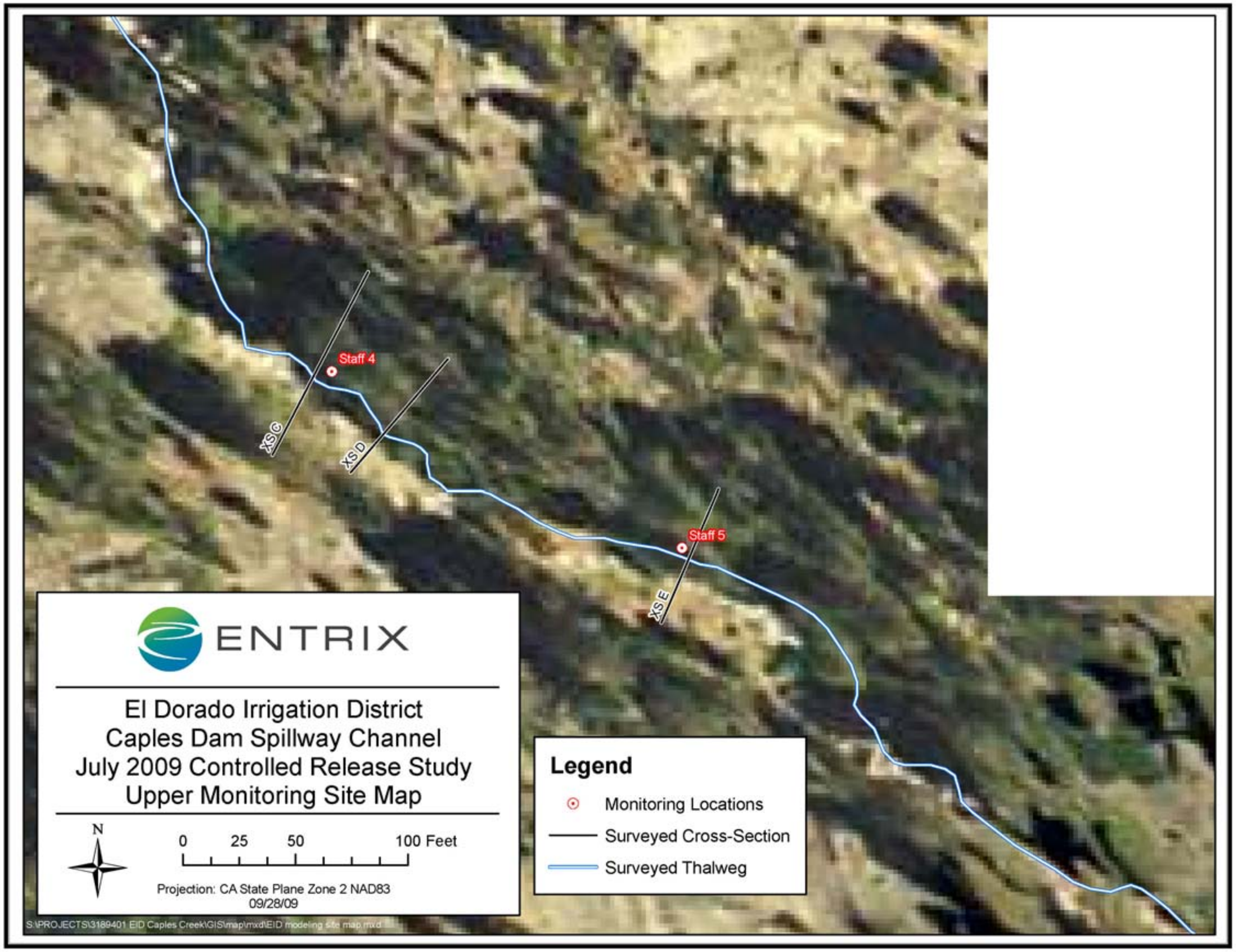


Figure 3-2 Upper erosion site monitoring locations

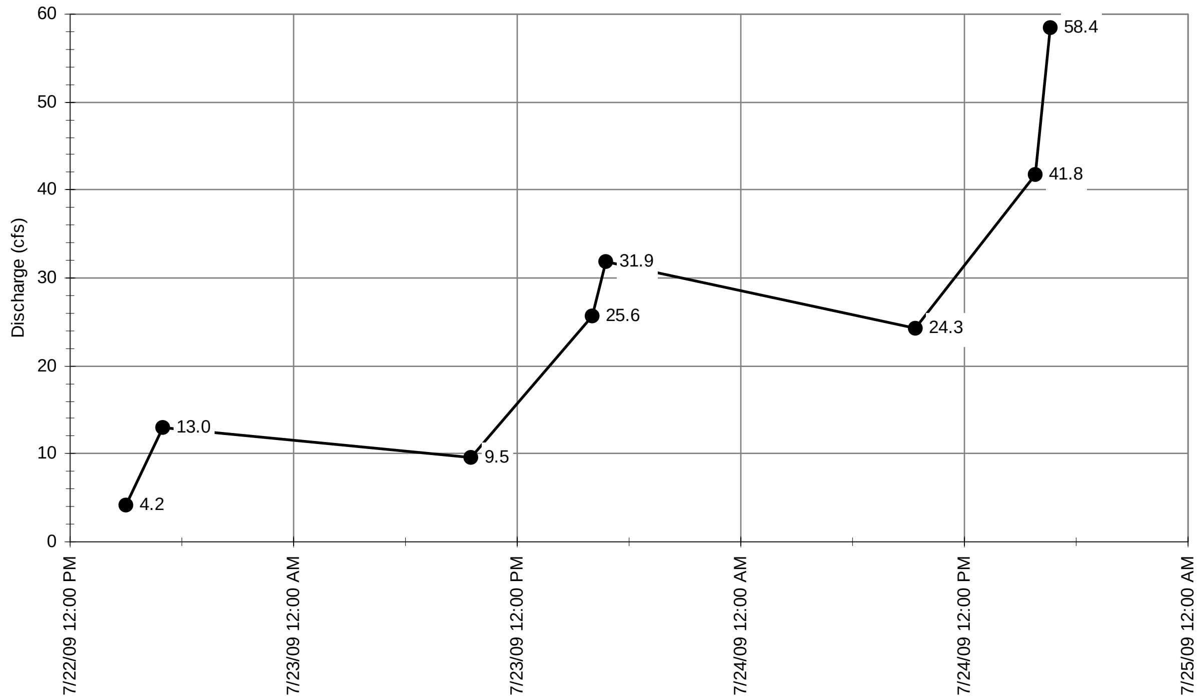


Figure 3-3 Spillway channel hydrograph for controlled flow release study

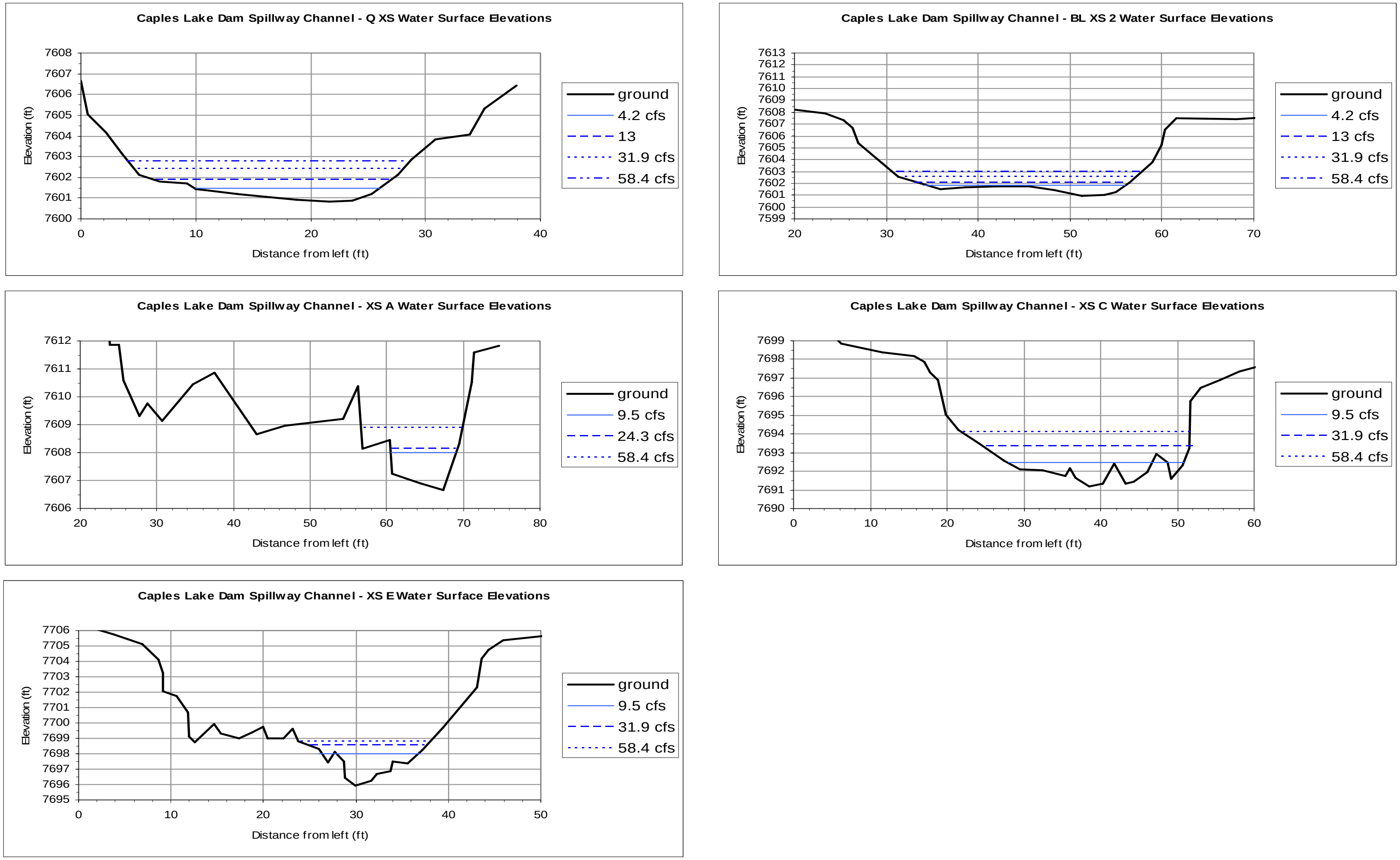


Figure 3-4 Water surface elevations at five monitoring cross-sections (XS C and E are upper erosion monitoring site; xs Q, xs 2, and xs A are the lower erosion monitoring site)

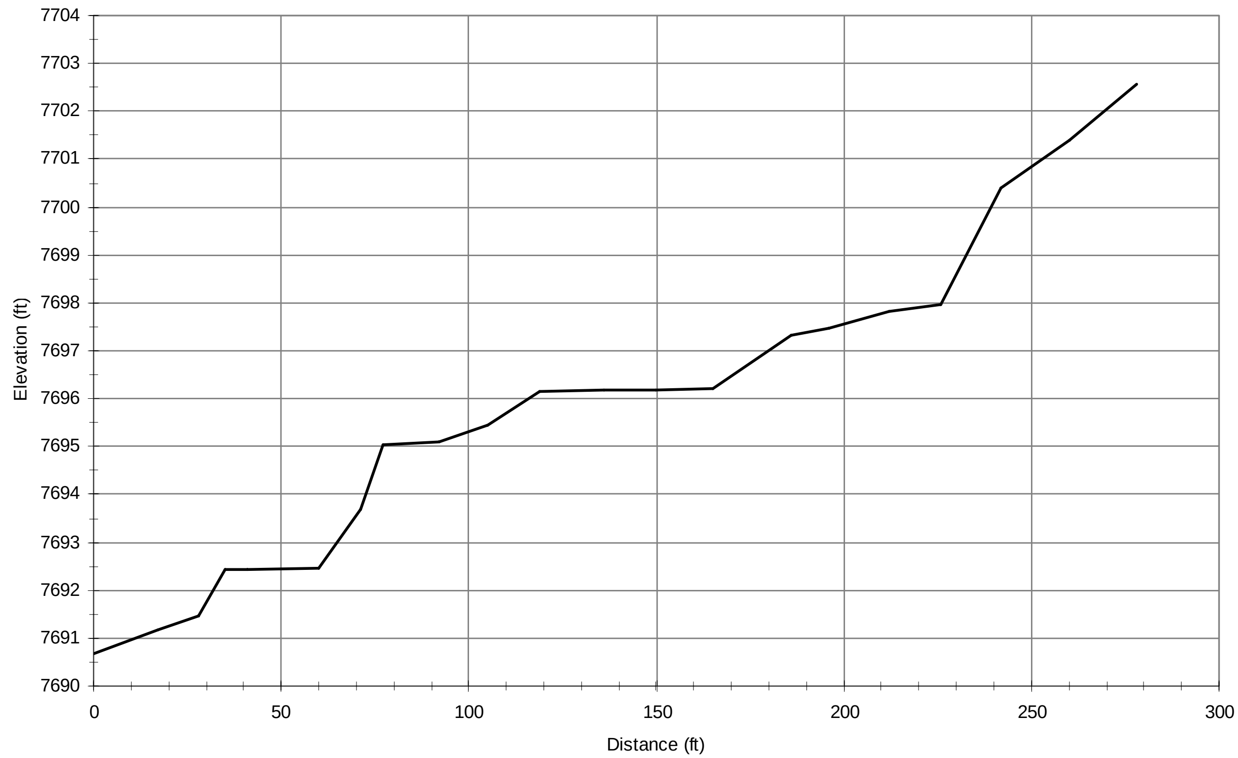


Figure 3-5 Upper erosion monitoring site water surface profile at 10 cfs

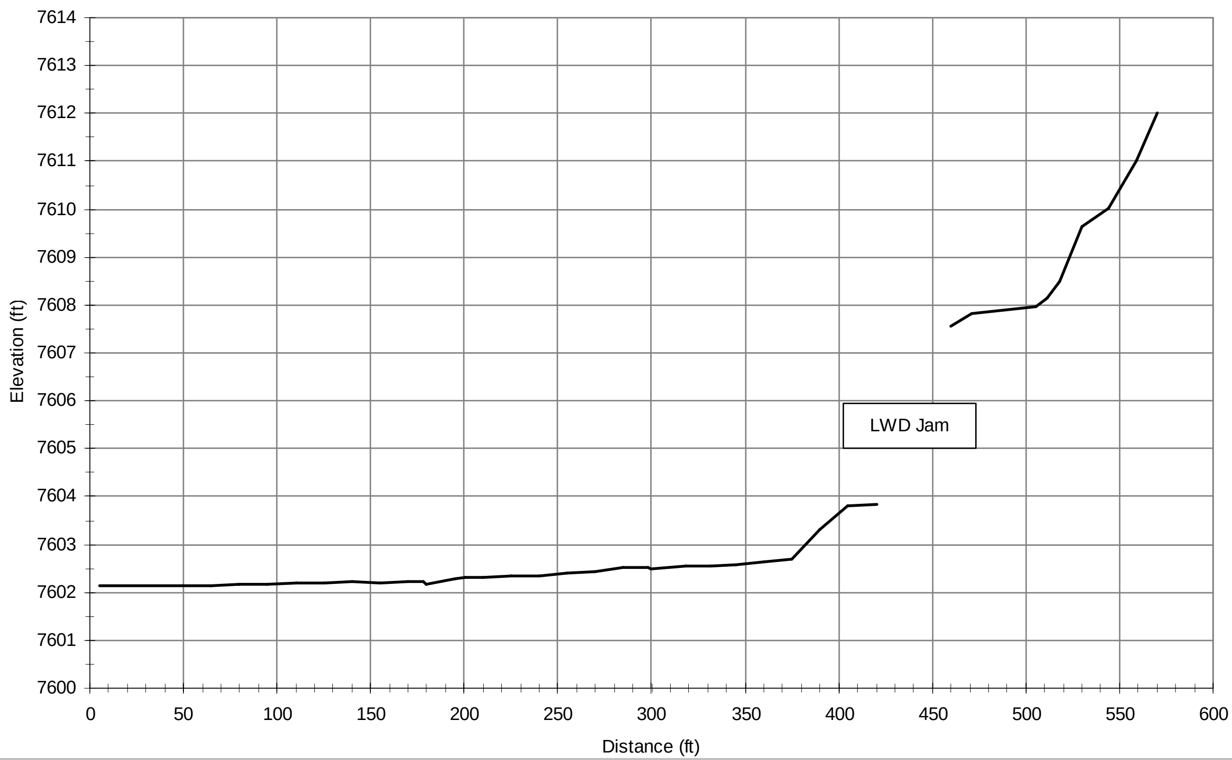


Figure 3-6 Lower erosion monitoring site water surface profile at 10 cfs

Figure 4-1 Net samplers installed at cross-section Q (left) and at cross-section A (right)

Figure 4-2 Helly-Smith bedload samplers (right) and sampling with Helly-Smith along a cross-section (left)

Figure 4-3 Deployed bedload trap samplers full of organic debris following the 30 cfs release (left), and trapped organic debris (e.g., needles, pine cones) with a small amount of intermixed sand and gravel emptied from one sampler drying onto tarp (right)

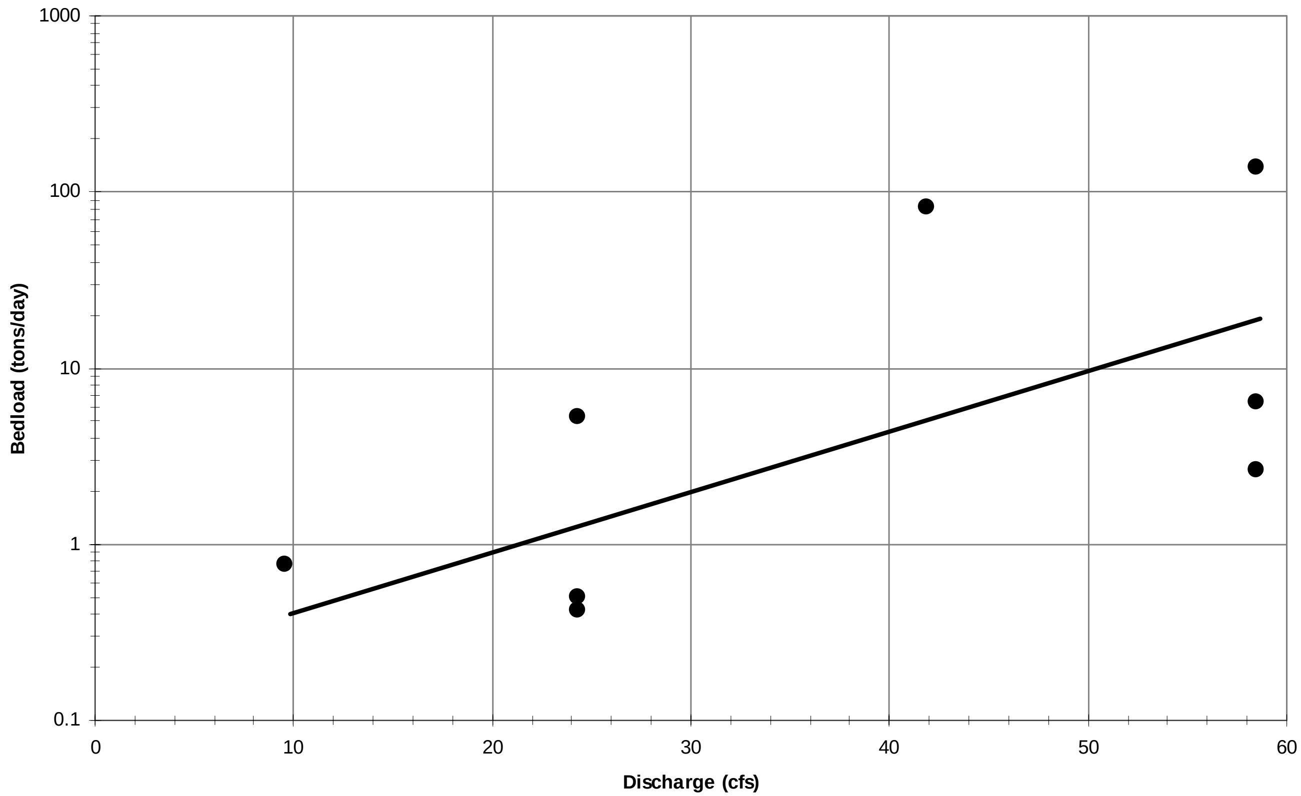


Figure 4-4 Caples dam spillway channel bedload transport rating curve. Based on July 2009 measured data from Helly-Smith samples

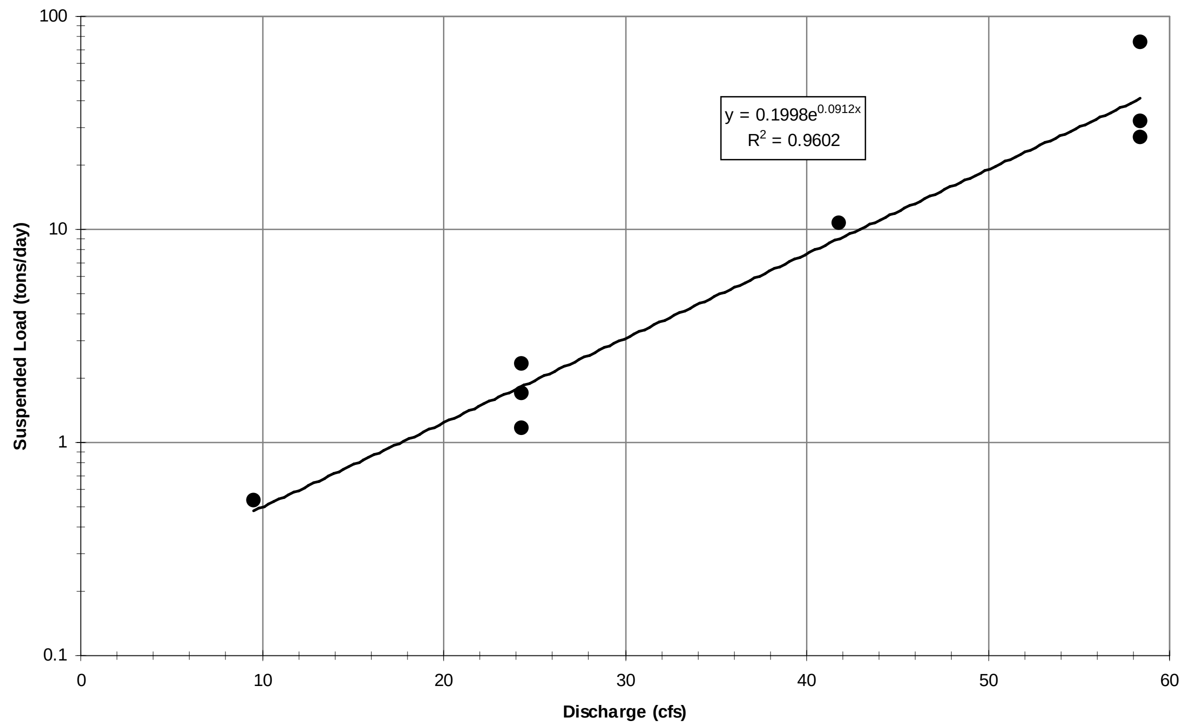


Figure 4-5 Suspended sediment load rating curve. Caples dam spillway channel July 2009

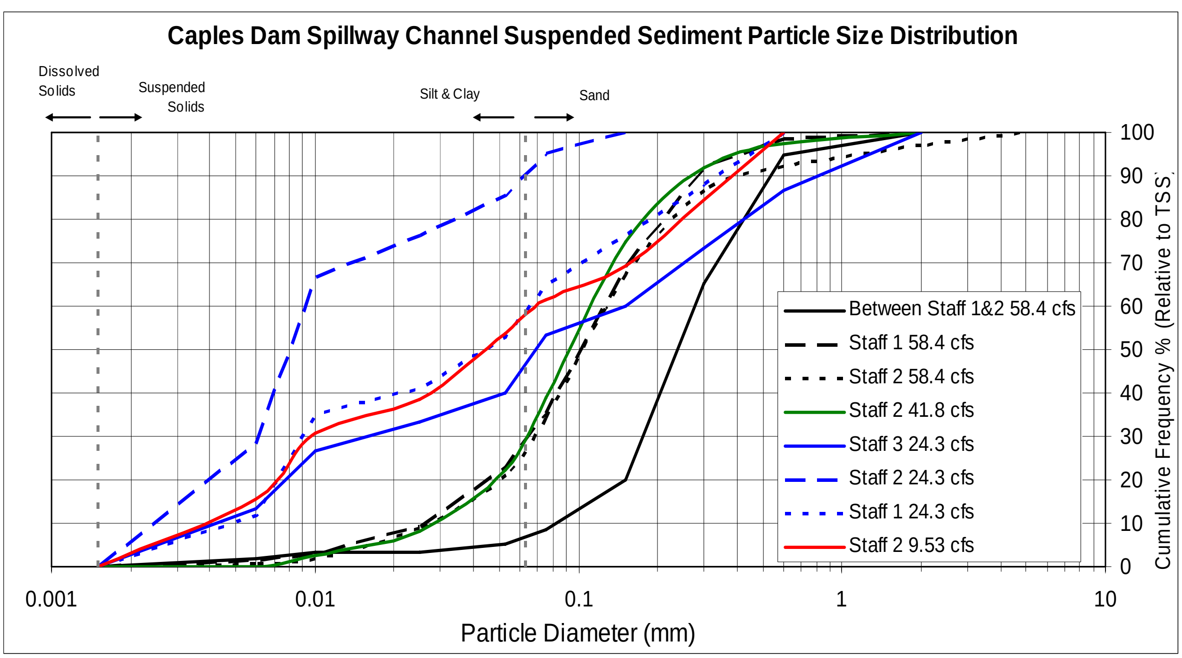
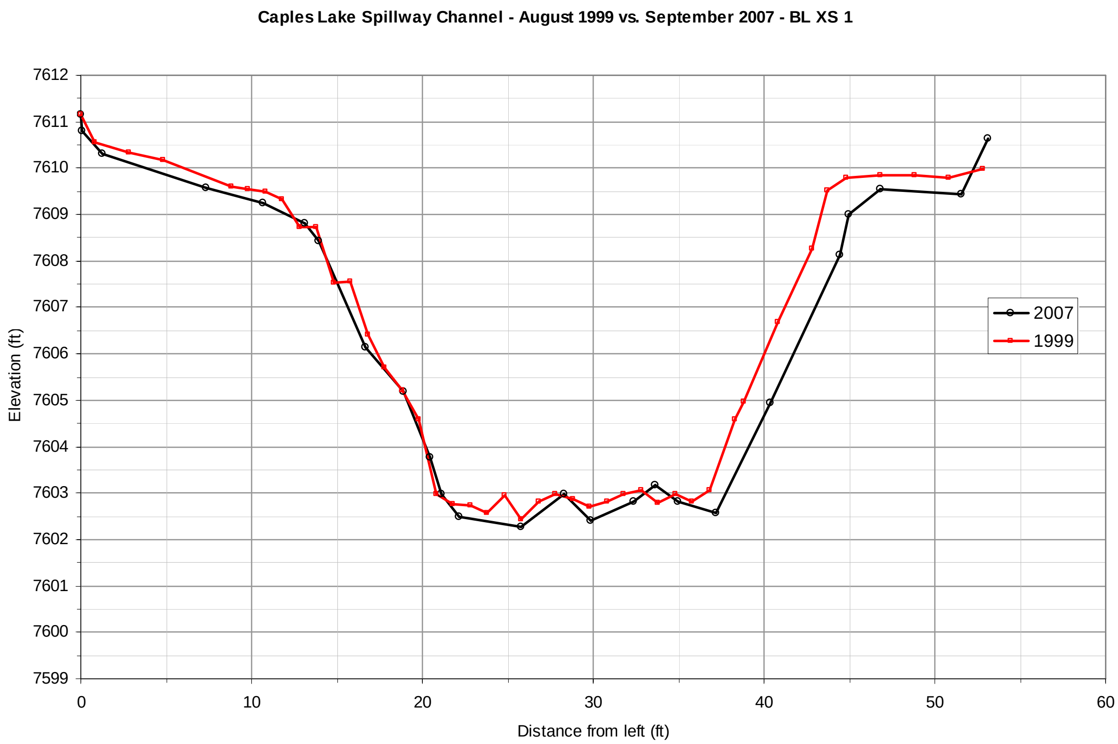


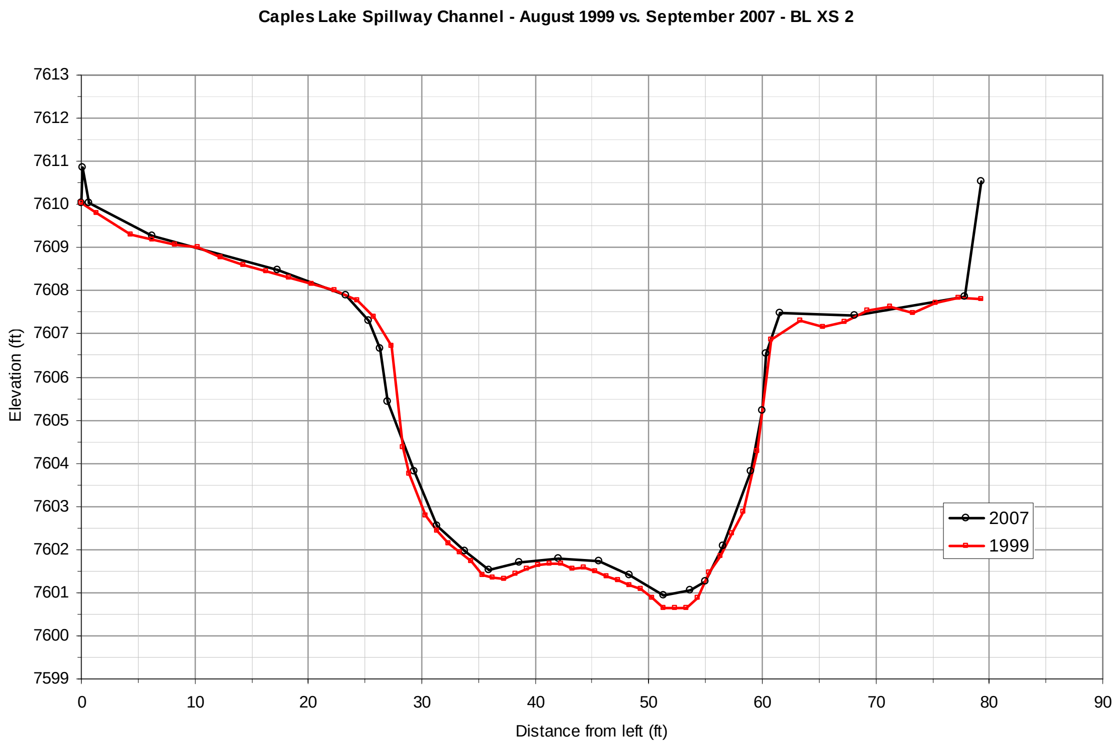
Figure 4-6 Suspended sediment particle size, Caples dam spillway channel July 2009

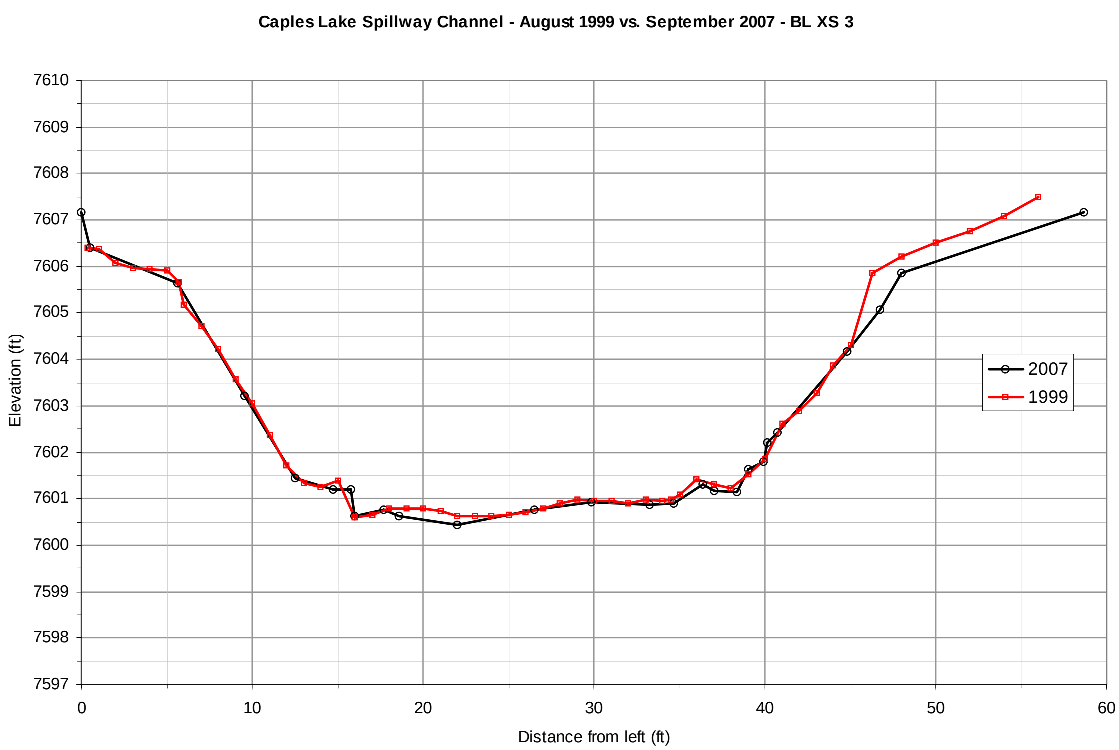
APPENDIX A

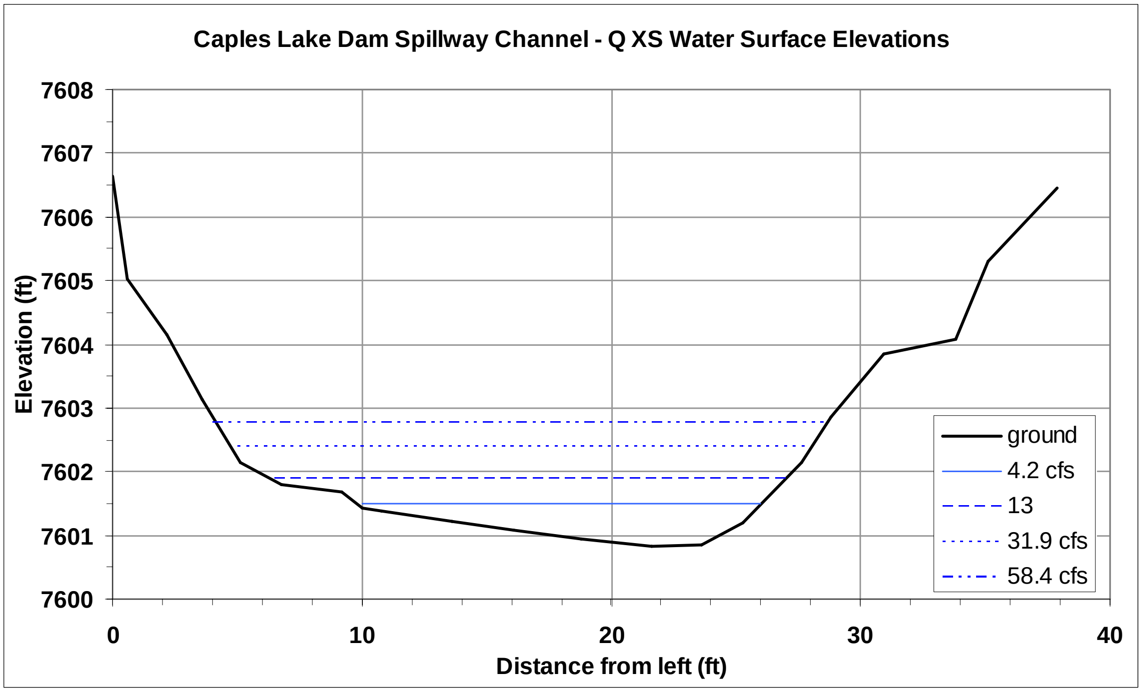
Cross-Section Surveys

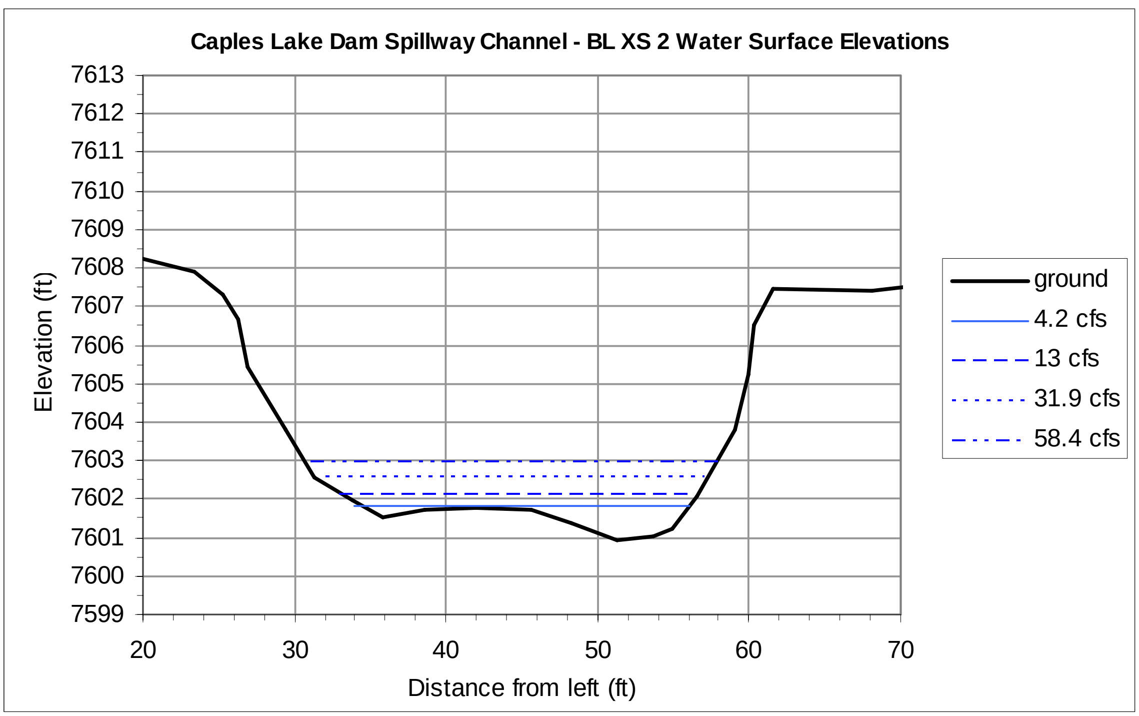
LOWER EROSION MONITORING SITE
CROSS-SECTION SURVEYS

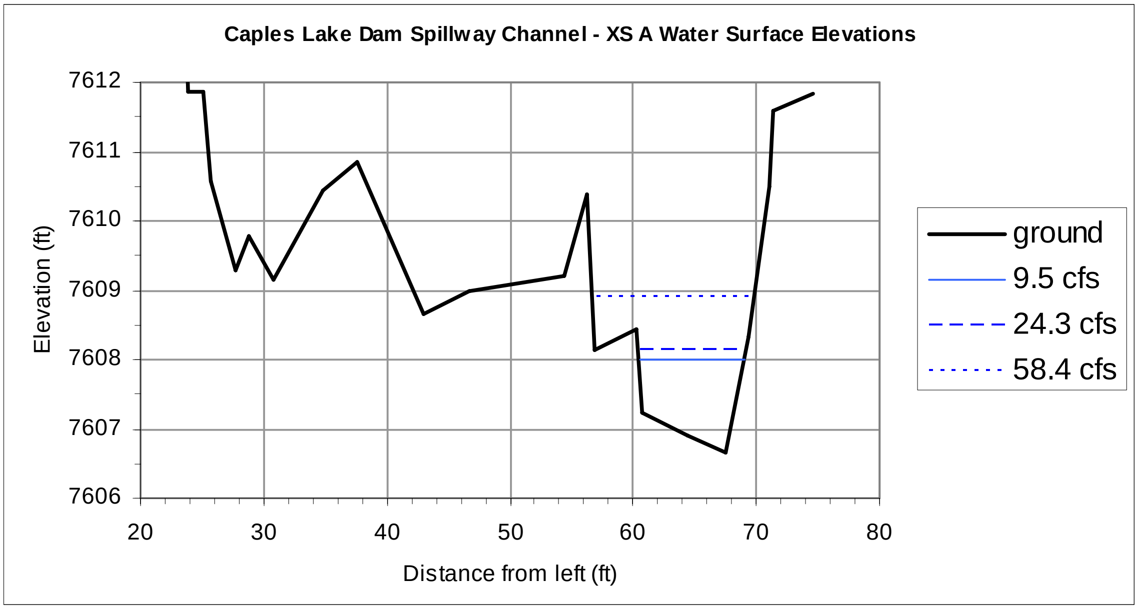


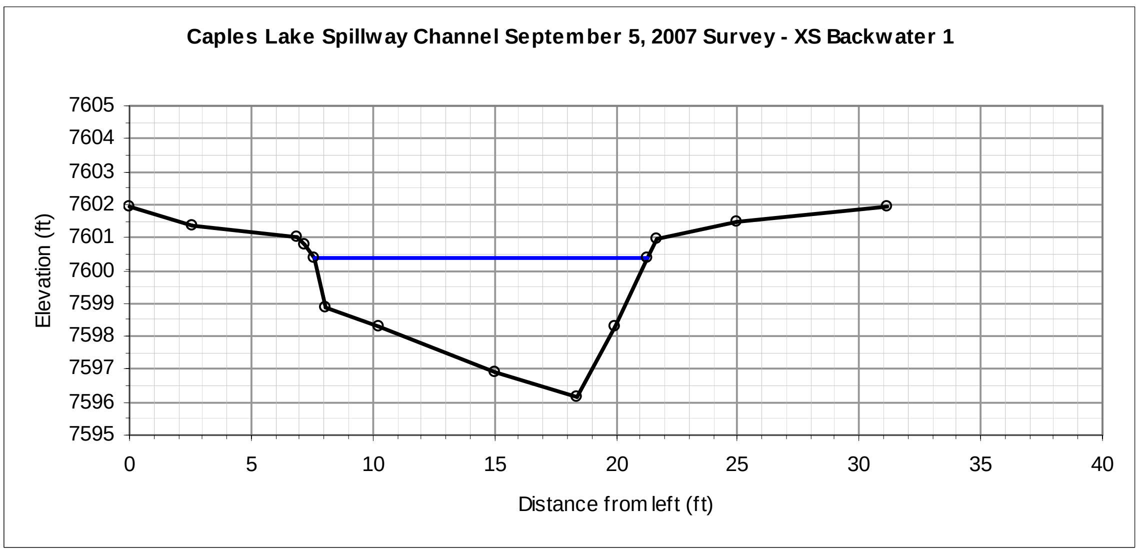

Caples Lake Spillway Channel - August 1999 vs. September 2007 - BL XS 2
Elevation (ft)
Distance from left (ft)
2007
1999

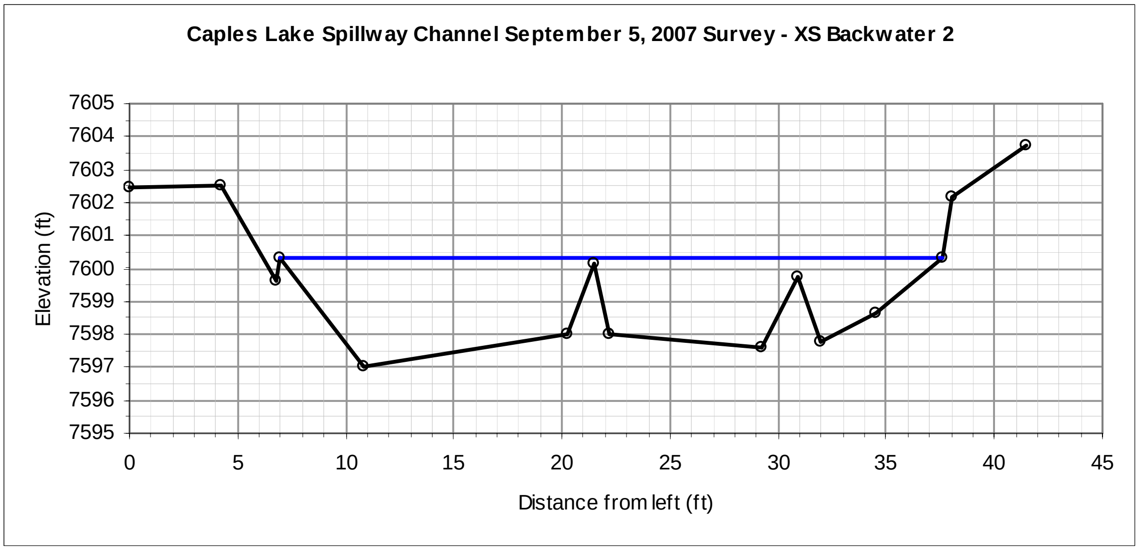

Caples Lake Spillway Channel - August 1999 vs. September 2007 - BL XS 3
Elevation (ft)
Distance from left (ft)
2007
1999

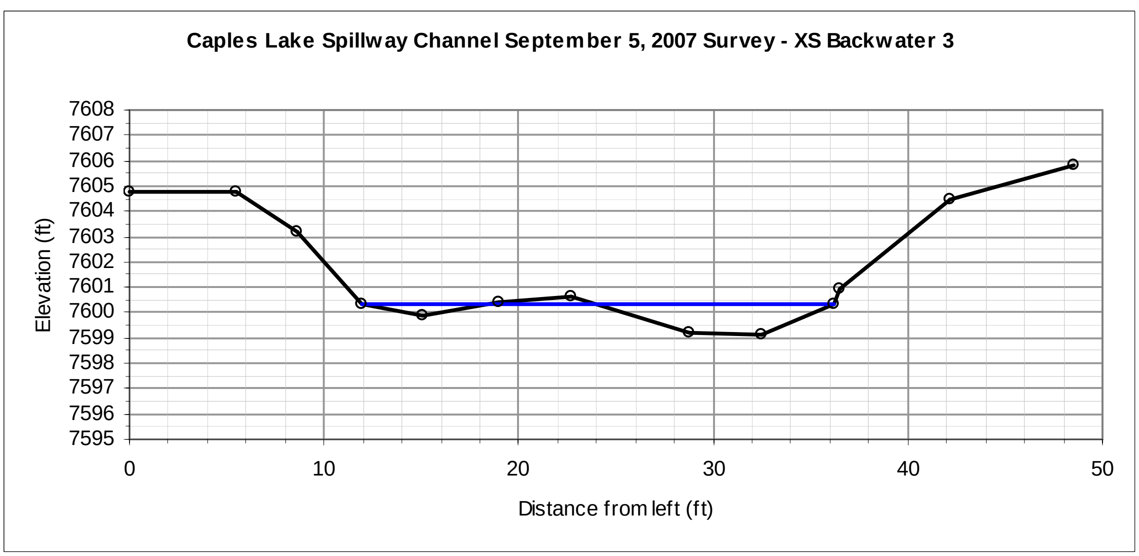

Caples Lake Dam Spillway Channel - Q XS Water Surface Elevations
Elevation (ft)
7608
7607
7606
7605
7604
7603
7602
7601
7600
0
10
20
30
40
Distance from left (ft)
ground
4.2 cfs
13
31.9 cfs
58.4 cfs


Caples Lake Dam Spillway Channel - BL XS 2 Water Surface Elevations
Elevation (ft)
7613
7612
7611
7610
7609
7608
7607
7606
7605
7604
7603
7602
7601
7600
7599
20
30
40
50
60
70
Distance from left (ft)
ground
4.2 cfs
13 cfs
31.9 cfs
58.4 cfs

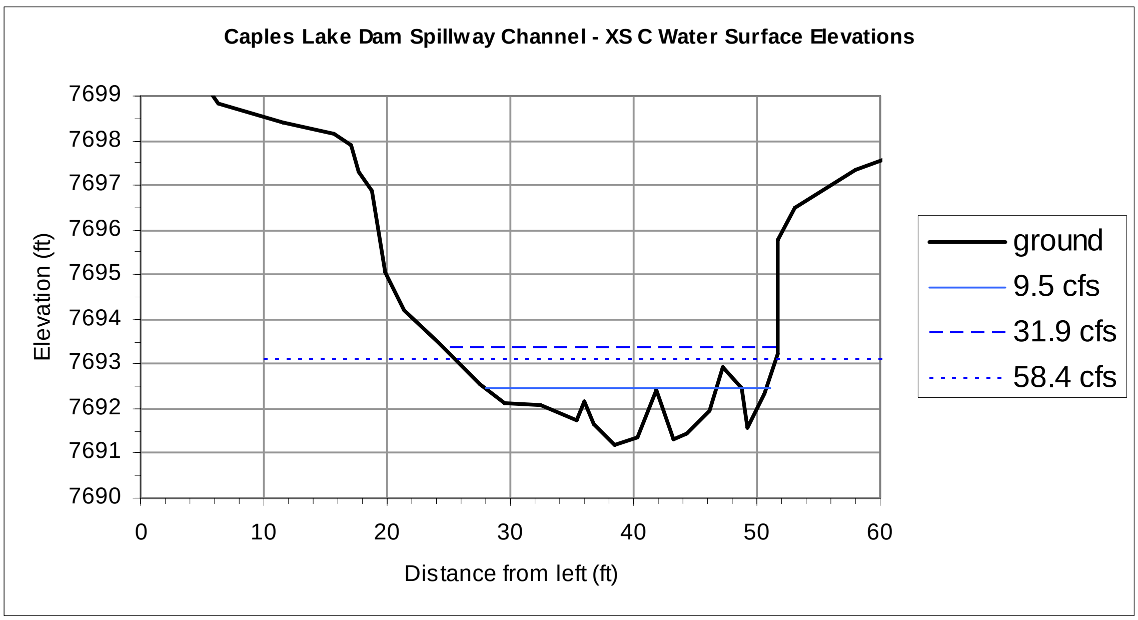

Caples Lake Dam Spillway Channel - XS A Water Surface Elevations
7612
7611
7610
7609
7608
7607
7606
Elevation (ft)
20
30
40
50
60
70
80
Distance from left (ft)
ground
9.5 cfs
24.3 cfs
58.4 cfs

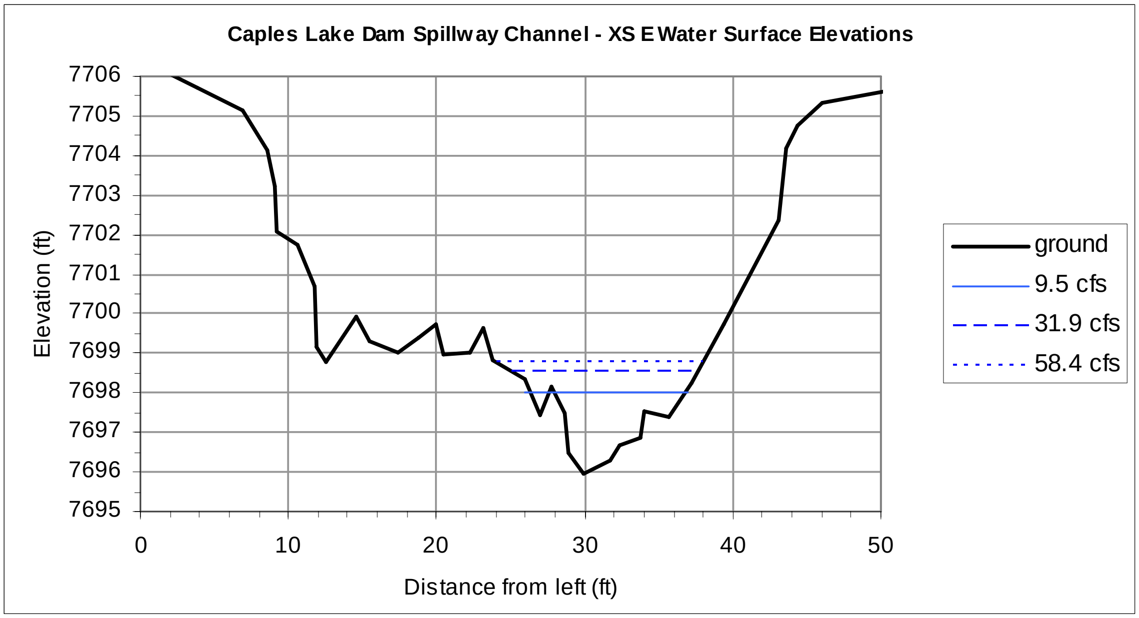

Caples Lake Spillway Channel September 5, 2007 Survey - XS Backwater 1
7605
7604
7603
7602
7601
7600
7599
7598
7597
7596
7595
Elevation (ft)
0
5
10
15
20
25
30
35
40
Distance from left (ft)

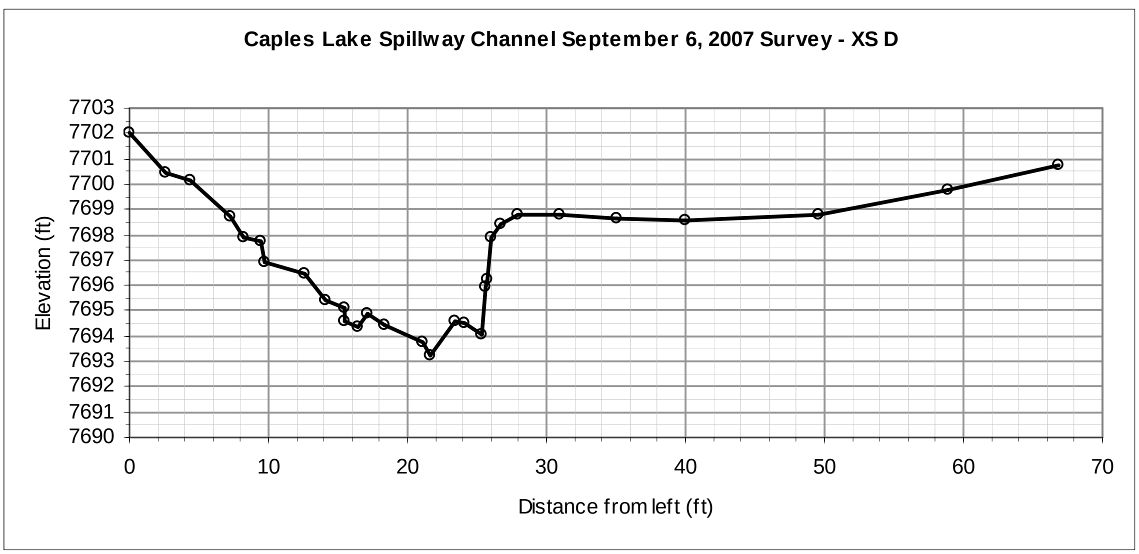

Caples Lake Spillway Channel September 5, 2007 Survey - XS Backwater 2
7605
7604
7603
7602
7601
7600
7599
7598
7597
7596
7595
Elevation (ft)
0
5
10
15
20
25
30
35
40
45
Distance from left (ft)


Caples Lake Spillway Channel September 5, 2007 Survey - XS Backwater 3
7608
7607
7606
7605
7604
7603
7602
7601
7600
7599
7598
7597
7596
7595
Elevation (ft)
0
10
20
30
40
50
Distance from left (ft)

UPPER EROSION MONITORING SITE
CROSS-SECTION SURVEYS




Caples Lake Dam Spillway Channel - XS E Water Surface Elevations
7706
7705
7704
7703
7702
7701
7700
7699
7698
7697
7696
7695
Elevation (ft)
0
10
20
30
40
50
Distance from left (ft)
ground
9.5 cfs
31.9 cfs
58.4 cfs


Caples Lake Spillway Channel September 6, 2007 Survey - XS D
7703
7702
7701
7700
7699
7698
7697
7696
7695
7694
7693
7692
7691
7690
Elevation (ft)
0
10
20
30
40
50
60
70
Distance from left (ft)

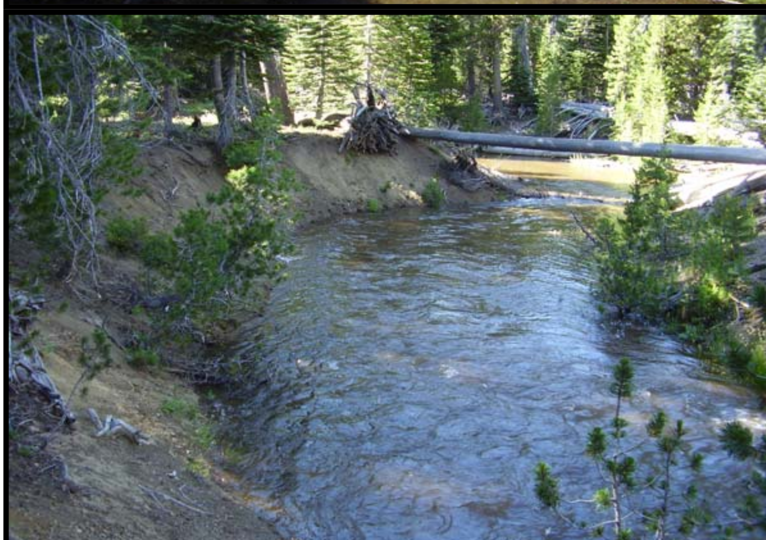
APPENDIX B

Photographs Taken During Controlled Flow Releases

LOWER EROSION MONITORING SITE

Downstream of Staff Gage 2, looking toward
XS Q, at 25 cfs (top) and 58 cfs (bottom)

Staff Gage 2 upstream view at 10 cfs (Top), 24 cfs (middle), and 58 cfs (bottom)

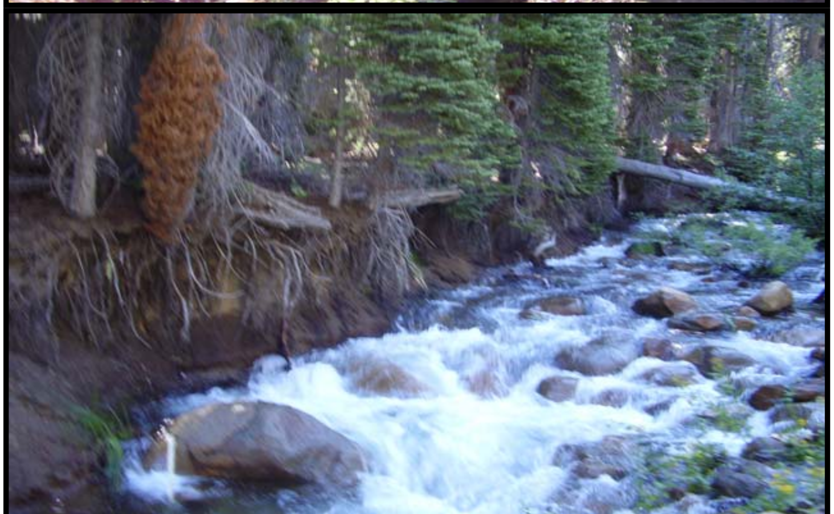


Below large woody debris jam at 10 cfs (top), 24 cfs (middle), and 58 cfs (bottom)

Below large woody debris jam, view upstream at 10 cfs (top), 28 cfs (middle), and 58 cfs (bottom).

Right bank above large woody debris jam, staff gage 3 at 9.5 cfs (top) and 24 cfs (bottom)

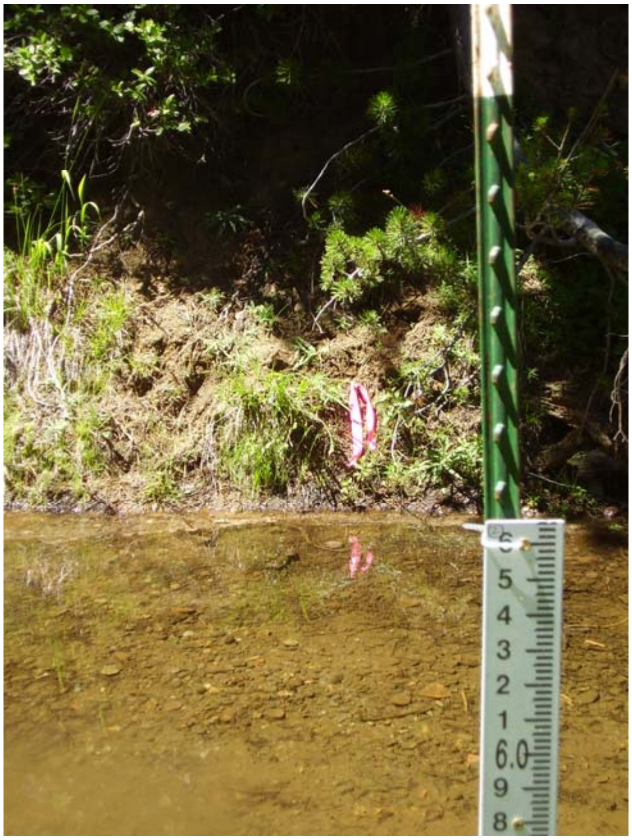
UPPER EROSION MONITORING SITE



Staff gage 5, right bank view upstream at 9.5 cfs (top), 24 cfs (middle), and 58 cfs (bottom)

APPENDIX C

Bank Erosion Pin Photographs



Pin 1 installed. There was virtually no bank retreat at Pin 1 after all of the flow releases

Pin 2 (at water line) and Pin 3 (above pin 2)

.26 ft bank retreat at Pin 3 and .13 ft at Pin 2 after 24 cfs flow release

Pin 4 installed.

.55 ft bank retreat after 24 cfs release

Pins 5 and 6 installed.

Approximately .5 ft bank retreat for both pins after 24 cfs release

Erosion pins A, B, C (arranged vertically on left bank) installed just prior to the 58 cfs release. No photo available for post-flow release.