SACRAMENTO MUNICIPAL UTILITY DISTRICT
UPPER AMERICAN RIVER PROJECT
(FERC Project No. 2101)

and

PACIFIC GAS AND ELECTRIC COMPANY
CHILI BAR PROJECT
(FERC Project No. 2155)

CHILI BAR RESERVOIR
SEDIMENT DEPOSITION
TECHNICAL REPORT

Prepared by:

Devine Tarbell & Associates, Inc.
Sacramento, California

Stillwater Sciences
Davis, California

Prepared for:

Sacramento Municipal Utility District
Sacramento, California

and

Pacific Gas and Electric Company
San Francisco, California

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17.0 Chili Bar Reservoir Sediment Deposition Study Plan

This study is designed to investigate the quantity and general composition of sediment that has been deposited in Chili Bar Reservoir since the Chili Bar Dam was constructed in 1964, and the potential impacts of this sediment deposition on the 20-mile-long section of the South Fork American River from Chili Bar Dam to Folsom Reservoir (Reach Downstream of Chili Bar). The study would be conducted in three phases. Phase One would include a reservoir bathymetric study to determine the amount of deposition within the reservoir. Phase Two would occur concurrently with Phase One and would include sampling in the upper end of Chili Bar Reservoir at low water levels to characterize sediment composition. In Phase Three, the Licensees would then evaluate the significance of reduced sediment supply to the Reach Downstream of Chili Bar in context of the ongoing relicensing environmental studies. The results of the study would be reported to the UARP Relicensing Aquatic TWG and included in both the Sacramento Municipal Utility District's Upper American River Project (UARP) license application and Pacific Gas ad Electric Company's Chili Bar Project license application. For the purpose of this study plan, SMUD and Pacific Gas and Electric Company are referred to jointly as the Licensees.

17.1 Pertinent Issue Questions

The UARP Relicensing Aquatic Technical Working Group (TWG) has not developed specific issue questions for this study plan. At the March 11, 2004 Aquatic TWG Meeting, the Licensees agreed to develop this plan in response to a September 9, 2003, letter from Banky Curtis of the CDFG to Randal Livingston of Pacific Gas and Electric Company, which transmitted the CDFG's comments on Pacific Gas and Electric Company's Chili Bar Project First Stage Consultation Document (FSCD). Specifically, CDFG's comment was:

> Bathymetry and Reservoir Sediment Composition: The Department is concerned that disruption of natural bedload movement needs to be studied. The Department would like to discuss appropriate bathymetric sampling protocols to determine the quantity and composition of material being trapped behind the Chili Bar Dam and other upstream impoundments.

Also, in Pacific Gas and Electric Company's Chili Bar Relicensing Joint Meeting B, questions were raised by Bill Center of Camp Lotus:

> What are the effects of sediment in Chili Bar Reservoir? How is PG&E going to address the sediment that is in the reservoir?

17.2 Background

Interested parties in SMUD's UARP Relicensing and Pacific Gas and Electric Company's Chili Bar Relicensing have postulated that deposition in Chili Bar Reservoir impacts ecological resources in the Reach Downstream of Chili Bar. This Chili Bar Reservoir Sediment Deposition Study Plan assumes that sediment would deposit in Chili Bar Reservoir in a fashion typical to long sinuous reservoirs. Deposition is a function of sediment size and water velocity. Sediment that is mobilized in streams at high water velocities is deposited in reservoirs as water velocities decrease. Typically, the larger-sized sediment deposits in the upper portion of the reservoir where water velocities decrease rapidly, usually resulting in a depositional fan and sediment bars near the inlet, which are conspicuous when the reservoir is low. Finer-sized sediment, such as silt, remain mobilized at lower velocities and move further into the reservoir before depositing, or pass through the reservoir entirely. This often results in a layer of fine silt and sand on the bottom of the reservoir with the greatest depth of deposition near the toe of the dam where velocities are lowest. This general pattern of deposition was observed at SMUD's Slab Creek Reservoir during a 1992 bathymetric and sediment survey. At Slab Creek Reservoir, most of the sediment was found in the upper portions of the reservoir. Sediment deposition in the lower portion of the reservoir was generally less 10 inches deep and composed chiefly of silt or mud.

Note that Pacific Gas and Electric Company has not dredged or otherwise made special efforts to reduce sediment deposition in Chili Bar Reservoir since the dam was constructed, nor has Pacific Gas and Electric Company needed to alter Project operations due to sediment behind the dam.

17.3 Study Objective

The study objectives would be to: 1) estimate the amount of sediment deposition in Chili Bar Reservoir; 2) generally characterize the composition of the deposited sediment; and 3) place Chili Bar Reservoir sediment deposition in context with environmental conditions observed in the Reach Downstream of Chili Bar.

17.4 Study Area

The study area would include Chili Bar Reservoir and the Reach Downstream of Chili Bar. This study plan does not propose any additional fieldwork in the Reach Downstream of Chili Bar.

17.5 Information Needed From Other Studies

Information needed from other studies includes the Licensees' various environmental studies being performed in the Reach Downstream of Chili Bar. Information from SMUD's Slab Creek Reservoir Sediment/Turbidity Study may also be useful. In addition, the results from this study would be used in other relicensing studies. For instance, the change in Chili Bar Reservoir usable storage would be used in the Chili Bar Reservoir Incremental Storage Study, and the updated Chili Bar Reservoir area-capacity may be incorporated in the UARP/Chili Bar CHEOPS™ Water Balance Model, if appropriate.

17.6 Study Methods, Analyses, and Schedule

As described above, the study would be performed in three phases, each of which is described below.

Phase One – Estimate Quantity of Deposition in Chili Bar Reservoir

In Phase One, the Licensees would estimate the mount of sediment deposition currently in Chili Bar Reservoir by 1) comparing a current reservoir area-capacity curve to the project as-built area-capacity curve, and 2) examining existing aerial photographs, if available.

To develop a current Chili Bar Reservoir area-capacity curve, the Licensees would first prepare a bathymetric map of Chili Bar Reservoir. A Trimble Pro XRS differential Global Positioning System (GPS) and a digital depth sounder would be mounted on a motorboat to collect depth soundings at regular intervals according to a predetermined survey plan. Mapping would occur when Chili Bar Reservoir is at full pool. The GPS data logger would record sub-meter horizontal accuracy. Water surface elevations (and depth) would be monitored using a Solinst levelogger pressure transducer (accuracy of about 4 cm) that would be installed to reference a local benchmark and surveyed to a known United States Geological Survey (USGS) elevation. If a local USGS benchmark does not exist, one would be installed. Depths and positions would be collected in a predetermined grid pattern (about 150 feet between transects). Areas of greater sediment deposition concern, such as at the upstream end of the reservoir and near the toe of the dam, might require smaller grids to better map the changes in sediment levels. This determination would be made in the field as sampling is performed. The Licensees would generate a bottom profile map, and from this a current Chili Bar Reservoir area-capacity curve. To determine the net amount of deposition that has occurred since the Chili Bar Dam was constructed, the current area-capacity curve would be compared to the reservoir's as-built drawings. Due to typical inaccuracies in as-built drawings of this type, the Licensees would assume an error of at least plus or minus 10 percent in the as-built drawings.

The Licensees would compute the difference in gross storage (total volume of the reservoir) and the difference in usable storage (from the minimum operating level of 984 feet to the spill crest elevation of 997.5 feet) in Chili Bar Reservoir. The latter information would be incorporated into the Chili Bar Reservoir Incremental Storage Study to determine the extent to which sediment deposition has reduced usable storage (and the feasibility of reclaiming this storage capacity).

During Phase One, the Licensees would also take digital aerial photos of Chili Bar Reservoir at surface water elevation level of 984 feet, minimum operating pool. Photos at full pool are currently available. The Licensees would compare these photos to historic photos, if available, to determine any changes to the depositional pattern that has occurred over time.

Phase Two – Characterize Deposited Sediment

Concurrently with Phase One, the Licensees would generally characterize the composition of the material deposited in Chili Bar Reservoir. As discussed above, in reservoirs such as Chili Bar, most sediment deposits in fans or in sediment bars near the stream inlet. Therefore, the Licensees will focus study efforts in this area. The investigations would include:

- Generally estimating the depth of deposited sediment in the fan and sediment bars at the upstream end of Chili Bar Reservoir Dam. When the reservoir is drawn down, the Licensees would establish about five transects across each major fan and sediment bar, and estimate the depth of sediment along each transect at 50 foot intervals by pounding a graduated metal bar into the ground. The sediment depth would be considered to be the depth at which the bar meets firm resistance.

- Estimating sediment composition by performing at each location where depth is estimated as described above. At each of these locations, the Licensees would estimate streambed particle size by conducting Wolman (1954) pebble counts. In addition, the Licensees will make a good faith effort to use a standard, hollow-core, hand auger along the transects to determine the sediment composition in the fan and sediment bars at depths. All sediment size information will be presented using the Wentworth scale (Wentworth 1922).

Phase Three – Evaluate Effect of Chili Bar Dam Sediment Deposition on Ecological Effects in the Reach Downstream of Chili Bar

In Phase Three and using the information gathered in Phases One and Two and in the Licensees' relicensing studies in the Reach Downstream of Chili Bar, the Licensee will evaluate the significance of reduced sediment supply to the Reach Downstream of Chili Bar.

17.7 Study Output

The study plan output would be a technical report prepared in the same format as the UARP Relicensing technical reports have been prepared to date, unless requested to be revised by the TWGs. It is anticipated that the report would be summarized in SMUD's UARP license application and Pacific Gas and Electric Company's Chili Bar Project license application, and appended to each application.

17.8 Aquatic TWG And Plenary Group Endorsement

The Aquatics TWG approved this plan on March 25, 2004. The participants at the meetings who said they could "live with" this study plan were CDFG, USFS, BLM, SWRCB, Camp Lotus, PG&E and SMUD. None of the participants at the meeting said they could not "live with" this study plan. This study plan will be presented to the April 7, 2004 Plenary Group meeting for consideration for approval.

The study plan was approved by the Plenary Group on April 7, 2004 without modification. There was no one present at the meeting who objected to the study plan going forward for implementation.

17.9 Literature Cited

Wentworth, C. K., 1922. A scale of grade and class terms for clastic sediments. Journal of Geology 30:377-392.

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

CHILI BAR RESERVOIR SEDIMENT DEPOSITION TECHNICAL REPORT

SUMMARY

The UARP Relicensing Plenary Group approved the Chili Bar Reservoir Sediment Deposition Study Plan on April 7, 2004. Phase 1 of the study included a reservoir bathymetric study to determine the amount of deposition within Chili Bar Reservoir since original construction in 1964; Phase 2 included sampling in the upper end of Chili Bar Reservoir at low water levels to characterize sediment composition; and Phase 3 included an evaluation of the significance of reduced sediment supply to the Reach Downstream of Chili Bar. This report is considered an Overlapping Issues technical report that involves both the UARP and Chili Bar Project.

The bathymetric survey was performed from an 18-foot-long motor-driven boat using a transducer and a global positioning system (GPS) unit. Multiple transects were surveyed along the length of the reservoir in order to develop a contour map (2-feet intervals) that allowed calculation of current reservoir volume that could be compared to the "as-constructed" volume of the reservoir.

Sediment characterization was conducted on three bars while the reservoir was drawn down to a low pool elevation of 984 ft. (minimum preferred operating level of Chili Bar Reservoir). Sediment deposits were characterized by pebble counts and through the collection of bulk sediment samples. Along each transect, the depth of fine sediment was estimated by inserting a graduated metal rod into the bar until the rod contacted the underlying coarse material layer.

Based on a comparison between the as-constructed reservoir storage-elevation table and the results of the 2004 bathymetry and resultant storage-elevation table, total storage in Chili Bar Reservoir has been reduced by 1,011 ac-ft. (1,247,000 $m^{3)}$, and usable storage (storage between the spillway crest and the preferred operating minimum) has been reduced by 252 ac-ft.

The grain size distribution of the Powerhouse Bar (0.25 mile downstream of White Rock Powerhouse and the only bar with a combination of both fine and coarse material) had a pebble count with D_{50} values from 23.8 mm to 58.7 mm, while in the bulk samples the D_{50} ranged from 0.3 mm to 4.1 mm. The main sedimentary component of the bulk samples was sand, followed by gravel and cobble. The Big Rock Bar (approximately 0.75 mile downstream of White Rock Powerhouse) and the Second Bend Bar (approximately 1.25 mile downstream of White Rock Powerhouse) were composed entirely of fine sediment (<2 mm), with the main component being sand. Coarse and fine fractions of the sediment deposits were 22% and 78%, respectively. The average sediment depth for the Powerhouse Bar was 1.2 m, and the Big Rock Bar and Second Bend Bar was ≥ 2 m for each.

The trap efficiency of the Chili Bar Reservoir is 13.39%, meaning approximately 13 percent of the annual or long-term incoming sediment load is trapped in the reservoir and the remaining 87 percent is passed downstream. Virtually all of the sediment passed downstream is fine material (<2mm).

Most of the fine portion of the sediment load in the Reach Downstream of Chili Bar is carried downstream by high flows and is probably stored temporarily on the banks and in hydraulically quiet zones between events. The combined impact of coarse sediment interception and the continued existence of high flows is likely to result in some combination of reduced bed sediment storage (sediment exhaustion), channel incision and/or bed coarsening over time in the Reach Downstream of Chili Bar.

Although data on young-of-the-year (YOY) trout populations is sparse due to sampling method constraints in this reach, the age class distribution information does not indicate absence of YOY trout that would suggest significant spawning limitations related to lack of spawning gravels. Biological studies to date, including fish and BMI assessments, have not suggested that either spawning or BMI habitat is impaired due to fine sediment buildup (see *Flow and Fluctuation in the Reach Downstream of Chili Bar Technical Report*).

1.0 INTRODUCTION

This technical report is one in a series of reports prepared by Devine Tarbell and Associates, Inc., (DTA) for the Sacramento Municipal Utility District (SMUD) and Pacific Gas and Electric Company (PG&E) (jointly referred to as the Licensees) to support the relicensings of SMUD's Upper American River Project (UARP) and PG&E's Chili Bar Project. The Licensees intend to append this technical report to their respective applications to the Federal Energy Regulatory Commission (FERC) for new licenses. This report investigates the quantity and general composition of sediment that has been deposited in Chili Bar Reservoir, part of Chili Bar Project, since the Chili Bar Dam was constructed in 1964, and the potential impacts of this sediment deposition on the 19.1-mile-long section of the South Fork American River from Chili Bar Dam to Folsom Reservoir (Reach Downstream of Chili Bar). This report includes the following sections:

- **BACKGROUND** – Includes when the applicable study plan was approved by the UARP Relicensing Plenary Group; a brief description of the issue questions addressed, in part, by the study plan; the objectives of the study plan; and the study area. In addition, requests by resource agencies for additions to and modifications of this technical report are described in this section.
- **METHODS** – A description of the methods used in the study, including a listing of study sites.
- **RESULTS** – A description of the most important data results. Raw data, where copious, are provided in a separate compact disc (CD) for additional data analysis and review by interested parties.
- **LITERATURE CITED** – A listing of all literature cited in the report.

This technical report does not include a detailed description of the UARP Alternative Licensing Process (ALP) or the UARP, which can be found in the following sections of the Licensee's application for a new license: The UARP Relicensing Process, Exhibit A (Project Description), Exhibit B (Project Operations), and Exhibit C (Construction). Nor does this technical report include a detailed discussion of Pacific Gas and Electric Company's relicensing process or Chili Bar Project.

Also, this technical report does not include a discussion regarding the effects of the UARP and Chili Bar Project on environmental resources, nor does the report include a discussion of appropriate protection, mitigation, and enhancement (PME) measures. An impacts discussion regarding the UARP is included in SMUD's applicant-prepared preliminary draft environmental assessment (PDEA) document, which is part of the SMUD's application for a new license for the UARP. Similarly, an impacts discussion regarding the Chili Bar Project will be included in PG&E's Chili Bar Project license application. Development of protection, mitigation, and enhancement (PM&E) measures will occur in settlement discussions in 2004, and will be reported in the UARP application PDEA and the Chili Bar Project license application.

2.0 BACKGROUND

2.1 Chili Bar Reservoir Sediment Deposition Study Plan

On April 7, 2004, the UARP Relicensing Plenary Group approved the Chili Bar Reservoir Sediment Deposition Study Plan that was developed by the relicensing Aquatic Technical Working Group (TWG) and was approved by the TWG on March 25, 2004. The UARP Relicensing Aquatic Technical Working Group (TWG) has not developed specific issue questions for this study plan. At the March 11, 2004 Aquatic TWG meeting, the Licensees agreed to develop the study plan in response to a September 9, 2003 letter from Banky Curtis of CDFG to Randal Livingston of PG&E, which transmitted CDFG's comments on PG&E's Chili Bar Project First Stage Consultation Document (FSCD). Specifically, CDFG's comment was:

- Bathymetry and Reservoir Sediment Composition: "The Department is concerned that disruption of natural bedload movement needs to be studied. The Department would like to discuss appropriate bathymetric sampling protocols to determine the quantity and composition of material being trapped behind the Chili Bar Dam and other upstream impoundments."

Also, in Pacific Gas and Electric Company's Chili Bar Project Relicensing Joint Meeting "B" held on the evening of July 10, 2003, Bill Center of Camp Lotus asked:

- "What are the effects of sediment in Chili Bar Reservoir? How is PG&E going to address the sediment that is in the reservoir?"

The objectives of this study were to:

- Estimate the amount of sediment deposition in Chili Bar Reservoir;
- Generally characterize the composition of the deposited sediment; and
- Place Chili Bar Reservoir sediment deposition in context with environmental conditions observed in the Reach Downstream of Chili Bar.

The study area included Chili Bar Reservoir and the Reach Downstream of Chili Bar.

2.2 Agency Requested Information

The agencies have not requested any specific information be included in this technical report other than the information required by the study plan.

3.0 METHODS

The Plenary Group approved methods that included three phases: 1) Phase 1 included a reservoir bathymetric study to determine the amount of deposition within Chili Bar Reservoir; 2) Phase 2 included sampling in the upper end of Chili Bar Reservoir at low water levels to characterize sediment composition; and 3) Phase 3 included an evaluation of the significance of reduced sediment supply to the Reach Downstream of Chili Bar in context of the ongoing relicensing environmental studies.

3.1 Bathymetry Survey

The Chili Bar Reservoir bathymetric survey was conducted by DTA from about 9:00 AM to 1:30 PM on June 10, 2004, during which the sky was clear and sunny and the Chili Bar Reservoir surface elevation decreased by 2.6 feet from elevation 995.4 feet to 992.8 feet. Chili Bar Reservoir normal full pool (top of spillway crest) elevation is 997.5 feet, 2.1 feet above the survey starting elevation.

The survey was performed from an 18-feet-long, motor-driven boat using a Standard Communication Corporation DS50 transducer and a Trimble PRO-XRS global positioning system (GPS) unit. The DS50 transducer was mounted to the stern of the boat. The PRO-XRS GPS unit, which included a GPS dome antenna, was connected to the transducer. The accuracy of the DS50 transducer is ± 0.1 foot of depth and the accuracy of the PRO-XRS is less than one meter of linear distance.

Prior to initiating the survey, bottom depth at two locations was manually measured by rope soundings and the results were compared to the DS50 transducer readings at the locations to confirm that the transducer was working accurately (i.e., there were no problems due to salinity, turbidity, etc.).

The GPS unit used a National Maritime Electronics Association (NMEA) data stream from the transducer to imbed depth data into the GPS data unit once every 5 seconds. This provided depth data during the survey at a linear sequence of approximately 25-feet-long intervals with the normal boat speed of about 3-4 miles per hour. Data were collected as a GPS line feature (as compared to a GPS point or area feature).

Survey readings were taken as the boat was driven (at about 3-4 miles per hour) across the reservoir in transects roughly perpendicular to the longest shoreline, generally a north-south orientation. Transects were spaced roughly 100-200 feet apart beginning at the downstream end of the reservoir for a total of 85 transects. Figure 3.2-2 in the *Chili Bar Reservoir Incremental Storage Modification Technical Report* shows the specific locations of each transect.

As described above, the Chili Bar Reservoir surface elevation decreased by 2.6 feet during the 4.5-hours-long survey period. To compensate for this change, a spreadsheet was developed to prorate the water depth measured during the survey to the water surface elevation provided by Pacific Gas and Electric Company at the time the measurement was made. These spreadsheet data were imported into an Autodesk software package called "Field Survey" which was used to create the Chili Bar Reservoir bathymetric map in two-foot contour intervals, which is a three-dimensional (length, width and depth) model of Chili Bar Reservoir (see Figure 3.2-1 in the *Chili Bar Reservoir Incremental Storage Modification Technical Report*).

In addition, since the survey occurred when the reservoir was between 2.6 and 4.7 feet below full pool, the full pool reservoir shoreline could not be surveyed. To compensate, the shoreline was digitized from a high-resolution aerial photograph of Chili Bar Reservoir. The shoreline was then assigned the elevation of the water surface (as provide by PG&E) the day and time the photo was taken. This shoreline map and point data were incorporated into the Field Survey software package to develop the Chili Bar Reservoir bathymetric map. Reservoir surface area was calculated from this adjusted Field Survey map.

To calculate reservoir volume, the Chili Bar Reservoir bathymetric map created by the Field Survey software was imported into AutoDesk's "Land Development Desktop" (LDD) software to create an additional three-dimensional Triangulated Irregular Network (TIN). LDD then used this three dimensional model to cut two-dimensional bands to obtain volumes and surface acres in two-foot contours.

These methods resulted in good coverage for almost all of Chili Bar Reservoir. However, the survey could not be performed: 1) between the log boom and Chili Bar Dam (boats not allowed in this 200 feet wide area due to safety concerns); and 2) in the margins of the reservoir, especially at the most upstream area where the surveys were restricted to the narrow, wetted channel. Based on these limitations, DTA believes that the resulting Chili Bar Reservoir volume and surface area estimates are accurate with about 90-95 percent confidence because 90-95+ percent of the reservoir was surveyed. This accuracy could be improved by surveying the area near the Chili Bar Dam from a boat, and ground surveying the upstream end of the reservoir outside the wetted channel.

In addition to the bathymetric map, aerial photos were taken of the reservoir at low pool during the sediment characterization fieldwork. Appendix A (on CD only), provides these photos, with dates and elevation. Appendix A also includes full reservoir photographs.

3.2 Characterize Deposited Sediment

The second phase of the study involved the characterization of the sediment that has deposited in Chili Bar Reservoir. Since the majority of sediment has accumulated in the upstream end of the reservoir, the majority of work performed for this study focused in this area. In order to evaluate the extent of the depositional area, Chili Bar Reservoir was drawn down to the preferred minimum operating level (984 ft elevation) on October 4, 2004. Three bars were examined during: 1) a point bar approximately 0.25 mile downstream of the White Rock Powerhouse ("Powerhouse Bar"); 2) a point bar just opposite of the Big Rock in the middle of the reservoir, approximately 0.75 mile downstream of White Rock Powerhouse ("Big Rock Bar"); and 3) a large lateral bar near the second bend of the reservoir ("Second Bend Bar") approximately 1.25 mile downstream of White Rock Powerhouse. Field studies were performed at each of these bars to characterize Chili Bar Reservoir sediment grain size and density, which along with estimates of total sediment volume in the reservoir, were used to calculate annual sediment yield from the upstream watershed of the South Fork American River. The sequential steps of this methodology are described in the following subsections.

3.2.1 Characterization of Sediment Grain Size Density

Characterization of sediment grain size density is required to enable estimates of sediment volume to be converted to an estimate by mass. Analysis was achieved through a combination of field and empirical methods. At Powerhouse Bar, sediment deposits were characterized by pebble counts and through the collection of bulk sediment samples. The Big Rock and Second Bend Bar were composed of sediment finer than 2 mm, thus precluding the use of pebble counts. At these bars, sediment was characterized by collecting bulk sediment samples that were later analyzed at Taber Consultants' geology lab in West Sacramento.

At each bar, longitudinal (in the direction of flow) and lateral (perpendicular to flow) transects were established. Along each transect, the depth of fine sediment was estimated by inserting a graduated metal rod into the bar until the rod contacted the underlying coarse material layer.

The average density for each sedimentary unit was estimated from density values recorded in Vanoni (1975), Morris and Fan (1998), and from values published for systems with similar grain size distributions. To estimate the initial density of fine sediment, reservoir operation was classified into one of four categories: 1) sediment always submerged, 2) periodic drawdown, 3) normally empty reservoir, and 4) riverbed sediments (Morris and Fan 1998). Then, the density of fine sediment was estimated from the coefficient values of clay, silt, and sand for the corresponding reservoir operational condition (Lara and Pemberton 1963):

$$W = W_c P_c + W_m P_m + W_s P_s \qquad (1)$$

Where W = is the density of the deposit (tonnes/m^3) and P_c, P_m, P_s are the percentages of clay, silt, and sand, and W_c, W_m, and W_s are the initial estimated densities for clay, silt, and sand. The density of sediment was also adjusted for sediment compaction using Miller (1953):

$$W_t = W_i + 0.4343\ B\ (t/t\text{-}1\ (\ln t)\ \text{-}1) \qquad (2)$$

Where W_t is the average density of all deposits after t years of compaction, W_i is the initial density (W from above), and B is a constant based on the type of reservoir operation (how often the reservoir is drawn down), and from the percentages of clay, silt, and sand.

The overall estimated density of accumulated sediment within the Chili Bar Reservoir was weighted by the percent of fine to coarse sediment:

$$W_{total} = (W_{coarse})(P_{coarse}) + (W_{fine})(P_{fine}) \qquad (3)$$

Where W_{total} is the estimated average density of all accumulated sediment, W_{coarse} and W_{fine} are the densities of coarse and fine sediment, and P_{coarse} and P_{fine} are the percent of coarse and fine sediment.

3.2.2 Volume of Reservoir Sediment

The volume of accumulated sediment was estimated from the difference between the as-constructed storage capacity and the storage capacity determined from a bathymetric survey of the reservoir in 2004 (DTA 2004). Assuming that the change in capacity is due to accumulated sediment, the difference in storage volumes between the old and new storage-elevation tables was assumed equal to the volume of accumulated sediment.

3.2.3 Average Annual Sedimentation Rate and Sediment Yield

The average annual sedimentation rate is an estimate of the yearly amount of sediment that has deposited in Chili Bar Reservoir over the history of the reservoir. The sediment rate can be expressed on a volumetric basis and as a function of mass. Computations of the yearly volume of sediment accumulated in Chili Bar Reservoir were based on the total accumulated volume and the number of years of the reservoir's existence. The yearly mass of accumulated sediment is determined from the volume of sediment and its composition and density (described in Section 3.2.1).

Sediment yield is the amount of sediment that has entered the reservoir from the South Fork American River. This can be expressed as a total over the years of the reservoir existence or as a yearly rate. The sediment yield from the river and the amount of accumulated sediment in the reservoir are generally not the same, as a portion of the yield will pass through Chili Bar Reservoir. The amount of sediment yield that accumulates in the reservoir is determined by computing the trap efficiency of Chili Bar Reservoir.

The reservoir trap efficiency (TE) is an estimate of the proportion of incoming sediment that is deposited or trapped in a reservoir (Verstraeten and Poesen 2000). The reservoir trap efficiency for Chili Bar Reservoir was estimated from a procedure developed by Brune (1953), which gives reasonable results from limited data and is applicable to long-term average conditions (Morris and Fan 1998). Brune (1953) calculates TE from the ratio of the original reservoir capacity to the average annual inflow (Capacity/Inflow, or C/I). The TE can be estimated from a set of envelope curves or from Dendy (1974), who added more data to Brune's curves (USACE 1989):

$$\text{Trap Efficiency (TE)} = 100(0.97^{0.19\ \log C/I}) \qquad (4)$$

This is a widely used method to estimate the long-term trap efficiency of dams, but it does not consider features such as the grain size of the inflowing sediment, the outlet configuration, or the shape of the reservoir (Morris and Fan 1998).

The average annual sediment yield into Chili Bar Reservoir was estimated by converting the accumulated sediment volume to a mass using the estimates of sediment density and by applying the reservoir trap efficiency to obtain a total mass yield.

$$\text{Total mass yield} = \text{mass of accumulated sediment/TE} \qquad (5)$$

4.0 RESULTS

4.1 Reservoir Bathymetry

Based on the 2004 Chili Bar Reservoir bathymetry, reservoir volume was calculated in two-foot-contours from the bottom of the reservoir to normal full pool elevation and compared to volume data from the1965, as-constructed, Chili Bar Reservoir storage-elevation table (Table 4.1-1).

Table 4.1-1. Chili Bar Reservoir volume comparison between 1964 data as constructed and 2004 bathymetry survey.

Elevation	Volume (ac-ft)		
	1965 As-Built Drawings	2004 Bathymetry Survey	Difference
997.5[a]	3,139	2,128	1,011
996	2,976	1,990	986
994	2,763	1,812	951
992	2,555	1,640	915
990	2,353	1,475	878
988	2,159	1,320	839
986	1,974	1,175	799
984[b]	1,800	1,040	760
982	1,635	915	729
980	1,480	800	680
978	1,335	694	641
976	1,200	596	604
974	1,074	506	568
972	958	423	535
970	853	346	507
968	754	275	479
966	660	216	444
964	571	166	405
962	486	125	361
960	406	93	313
958	332	68	264
956	266	49	217
954	207	35	172
952[c]	156	25	131
950	112	17	95
948	76	12	64
946	47	7	40
944	26	4	22
942	13	2	11
940	7	1	6
938	5	0	5
924[d]	0	0	0

[a] Normal full pool elevation at top of spillway.
[b] Pacific Gas and Electric Company's preferred minimum operating elevation.
[c] Invert elevation of Chili Bar Powerhouse intake.
[d] Invert elevation of low level outlet.

Based on these data and the fact that Pacific Gas and Electric Company has not dredged Chili Bar Reservoir, and assuming that the 1965 data are accurate, one could conclude that since Chili Bar Reservoir was impounded in 1964, total storage has been reduced by 1,011 ac-ft (from 3,139 ac-ft to 2,128 ac-ft), and usable storage (between el. 997.5 ft and 984 ft) has been reduced by 252 ac-ft (from 1,340 ac-ft to 1,088 ac-ft), or about 407,000 cubic yards.

A Chili Bar Reservoir elevation-capacity curve based on the historical and revised per the 2004 bathymetry data in Table 4.1-1 is included on the Chili Bar Reservoir bathymetry map (see Figure 3.2-1 in the *Chili Bar Reservoir Incremental Storage Technical Report*) and shown below in Figure 4.1-1.

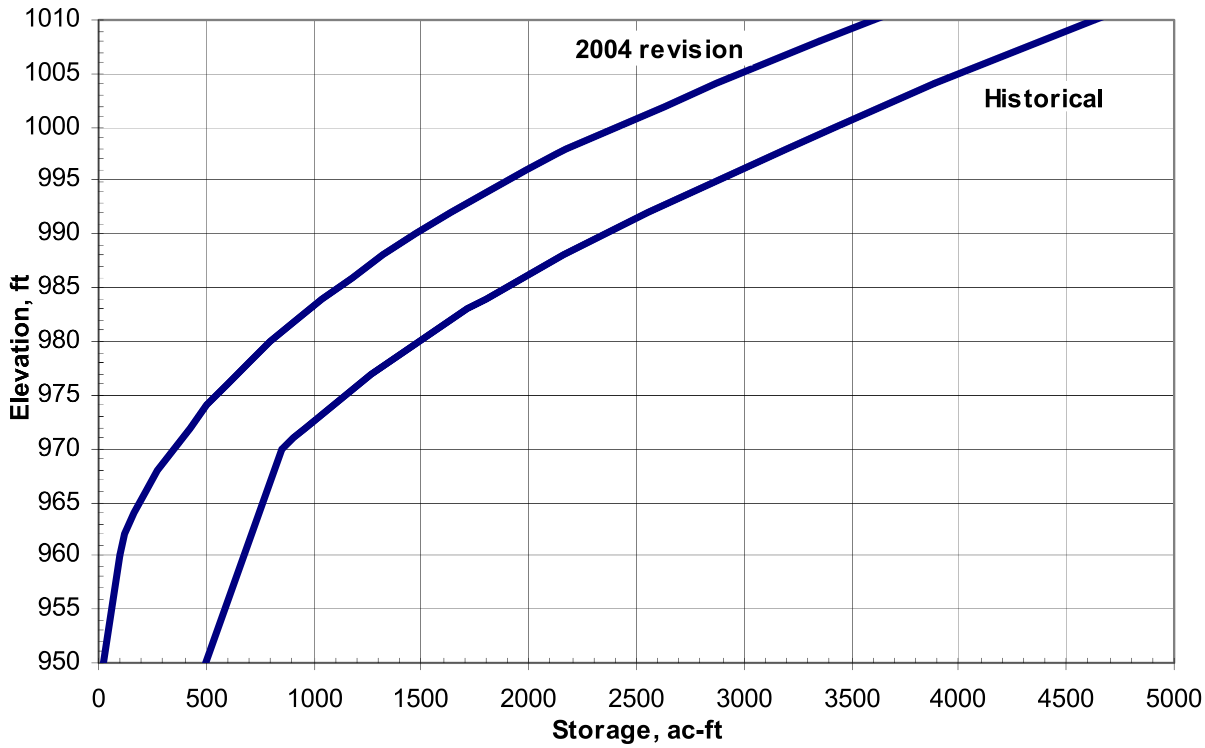

Figure 4.1-1. Reference data: 2004 bathymetric study.

4.2 Deposited Sediment Characterization

4.2.1 <u>Sediment Grain Size Distribution</u>

The grain size distribution of the Powerhouse Bar (the only bar with a combination of both fine and coarse material) was divided among the pebble count sites and the bulk samples. Among the pebble counts, the D_{50} ranged from 23.8 mm to 58.7 mm, while in the bulk samples the D_{50} ranged from 0.34 mm to 4.2 mm (Figure 4.2-1, Table 4.2-1). The main sedimentary component of the bulk samples was sand, followed by gravel and cobble. Overall, the bar was made a mixture of cobble, gravel, and sand with some silt and boulders. The larger grain size in the

Powerhouse Bar, compared to the two bars downstream, is largely a function of its location near the upstream end of the reservoir. Larger and heavier particles entering the reservoir (as bedload or in suspension) from upstream sources typically settle out first, with finer particles transported further into the reservoir.

The Big Rock Bar and the Second Bend Bar were composed entirely of fine sediment (<2 mm), with the main component being sand. The D_{50} for the Big Rock Bar was 0.60 mm, while at the Second Bend Bar the D_{50} was slightly lower at 0.25 mm. Accordingly, with the larger median grain size, the Big Rock Bar had a sand:silt mixture of 97:3 while at the Second Bend Bar it was 88:12 (Table 4.2-1).

The ratio of coarse-to-fine sediment was 1:3.55 (22% to 78%), which was estimated from the fractions of boulder, cobble, gravel, sand, silt, and clay for the Powerhouse, Big Rock, and Second Bend Bars. The fractions were summed across all sites to determine the overall fraction of coarse to fine sediment for Chili Bar Reservoir (Table 4.2-1).

The depth of fine sediment varied according to position along the transect for the Powerhouse Bar, while at the Big Rock and Second Bend Bars, there was little variation in sediment depth across the transects. The average sediment depth for the Powerhouse Bar was 1.2 m**,** but increased along a gradient from the water surface to the top of the bar. The average sediment depth of the Big Rock Bar and the Second Bend Bar was ≥ 2 m.

The initial densities for clay, silt, and sand were 561 kg/m^3, 1,170 kg/m^3, and 1,150 kg/m^3, taken from values for periodically drawn down reservoirs (Lara and Pemberton 1963), and the fractions of clay, silt, and sand were 0.00, 0.06, and 0.94, respectively, estimated from bulk samples and pebble counts. The density of fine sediment before compaction was:

$$W = (561)(0) + (1{,}170)(0.06) + (1{,}150)(0.94) = 1{,}151.2 \text{ kg/m}^3$$

After 41 years of compaction, the density of fine sediment from Miller (1953), where B is the compaction constant for periodically drawn down reservoirs that is scaled by the percentages of clay silt and sand:

$$B = (0.00)(135) + (0.06)(29) + (0.94)(0) = 1.77 \text{ kg/m}^3$$

The density of the fine fraction from (2):

$$W_t = 1{,}151.22 + 0.4343 + (1.77\ (41/40) * (3.71) – 1) = 1{,}153.47 \text{ kg/m}^3$$

The density of the coarse fraction of the sediment was 2,210.5 kg/m^3, taken from Vanoni (1975). The value is for grain sizes with D_{90} ranging from 128 mm to 64 mm.

The overall estimated density of accumulated sediment within the Chili Bar Reservoir was weighted by the percent of fine to coarse sediment where:

$$W_{overall}\text{: } (2{,}210.5 \text{ kg/m}^3)(0.22) + (1{,}153.37 \text{ kg/m}^3)(0.78) = 1{,}383.7 \text{ kg/m}^3 \text{ } (1.38 \text{ tonnes/m}^3)$$

This value is the basis for converting sediment volume estimates to sediment mass.

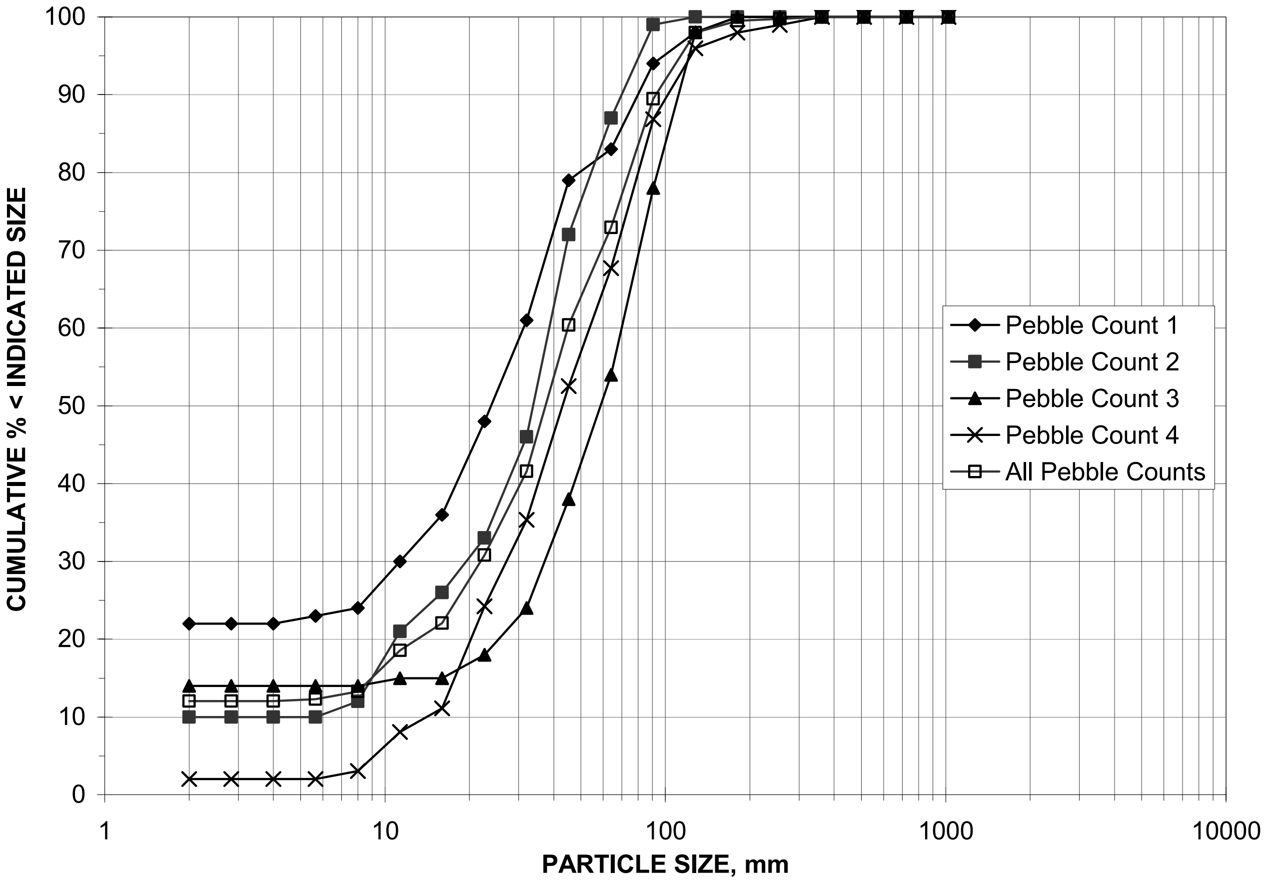

Figure 4.2-1. Grain size distribution for pebble counts on Powerhouse Bar.

Table 4.2-1. Grain size distributions for the three bars surveyed at Chili Bar Reservoir.[1]

BIG ROCK BAR							
	% Boulder	% Cobble	% Gravel	% Sand	% Silt	% Clay	D_{50}
T1 50 ft	0	0	0	94	6	0	0.53
T1 250 ft	0	0	0	98	2	0	0.56
T2 0 ft	0	0	0	99	1	0	0.74
T2 250 ft	0	0	0	93	7	0	0.61
T2 300 ft	0	0	0	99	1	0	0.61
T3 71 ft	0	0	0	.98	2	0	0.50

Table 4.2-1. Grain size distributions for the three bars surveyed at Chili Bar Reservoir.[1]

T3 142 ft	0	0	0	97	3	0	0.61
Mean	0	0	0	97	0	0	0.60
SECOND BEND BAR							
	% Boulder	% Cobble	% Gravel	% Sand	% Silt	% Clay	D_{50}
T1 0 ft	0	0	0	90	10	0	0.27
T1 300	0	0	0	91	9	0	0.30
T1 600 ft	0	0	0	86	14	0	0.20
T2 0 ft	0	0	0	93	7	0	0.25
T2 150 ft	0	0	0	81	19	0	0.23
Mean	0	0	0	88	12	0	0.25
POWERHOUSE BAR							
	% Boulder	% Cobble	% Gravel	% Sand	% Silt	% Clay	D_{50}
T1 25 ft	0	0	0	99	1	0	0.52
T2 50 ft	0	0	46	52	2	0	4.16
T3 50 ft	0	0	38	59	3	0	0.72
T4 250 ft	0	0	0	93	7	0	0.34
Pebble Count 1	0	17	61	21	1	0	23.85
Pebble Count 2	0	13	77	09	1	0	33.67
Pebble Count 3	0	46	40	13	1	0	58.74
Pebble Count 4	1	31	66	02	0	0	43.05
Mean	0	13	41	44	2	0	20.63
ALL SITES							
	% Boulder	% Cobble	% Gravel	% Sand	% Silt	% Clay	
Mean of all sites	0	5	16	.73	5	0	
	% Coarse			% Fine			
Mean of fine and coarse sediment	22			78			
	% Boulder	% Cobble	% Gravel	% Sand	% Silt	% Clay	
Mean within coarse and fine fractions	0	25	75	94	6	0	

[1] The size class distribution of observed sediment: boulders > 256 mm, cobbles 256-64 mm, gravel 64-2 mm, sand 2-0.0625 mm, silt 0.625-0.0039 mm, and clay 0.0039-0.001 mm (according to Wentworth grain size scale). D50 is the median particle diameter, where 50% of the sample is finer.

4.2.2 Volume of Accumulated Sediment

The storage volume of the as-constructed Chili Bar Reservoir was 3,871,899.5 m^3 (3,139 acre-feet) and the storage volume of the 2004 reservoir was 2,624,849.4 m^3 (2,128 acre-feet) for a reduction of 1,011 acre feet (see Section 4.1). Assuming that this reduction in capacity has been replaced by sediment, the volume of total accumulated sediment in Chili Bar Reservoir in 41 years is 1,247,050.2 m^3.

4.2.3 Average Annual Sedimentation Rate

The trap efficiency of the Chili Bar Reservoir is 13.39%, based on Brune (1953). This estimate is based on the original capacity of the reservoir of 3,139 acre-feet (136,734,841.4 ft^3) and the average annual inflow rate from the South Fork American River of 1,401 cfs (44,201,803,680 ft^3/yr) for a Capacity/Inflow ratio (C/I) of 0.003. The inflow was estimated from the USGS stream gage just downstream of the reservoir (USGS gage #11444500, American River near Placerville), with outflow from the reservoir assumed to be equal to inflow in the long-term.

$$\text{Trap Efficiency (TE)} = 100(0.97^{0.19^{\log 0.003}}) = 13.39$$

The average annual sedimentation rate is calculated by dividing the total estimated volume by the duration of accumulation, or 41 years, since Chili Bar Dam was placed in service in 1964. Thus, the average annual sedimentation rate is 30,420 m^3/yr. A total accumulated sediment mass of 1,726,000 tonnes is derived by multiplying the accumulated sediment volume (1,247,000 m^3) by the weighted-average sediment density (1.384 tonnes/m^3) (Table 4.2-2). Total average annual yield of 314,400 tonnes/yr is calculated by dividing the accumulated sediment mass by the estimated 13.39% reservoir trap efficiency and duration of accumulation (41 yrs). This value is then multiplied by a coarse (grains > 2 mm) to total load ratio of 0.22 obtained from sampling (Table 4.2-1) to derive an average annual mass coarse yield of 9,260 tonnes/yr.

Table 4.2-2. Reservoir sedimentation in Chili Bar Reservoir.

Parameter	Source/Equation	Units	Value
Duration of sediment accumulation	years since construction of Chili Bar Dam	yr	41
Total accumulated sediment volume in Chili Bar Reservoir	"as-built" capacity - current capacity	m^3	1,247,000
Average sediment density	weighted overall sediment density	tonnes m^{-3}	1.384
Total accumulated sediment mass	(total accumulated sediment volume in Chili Bar Reservoir)*(average sediment density)	tonnes	1,726,000
Total average annual sediment yield	(total accumulated sediment mass)/(years since construction of Chili Bar Dam)/(trap efficiency)	tonnes yr^{-1}	314,400
Coarse-to-total load ratio	coarse-to-fine percentages based on field samples		0.22
Average annual coarse sediment yield	((total accumulated sediment mass)*(coarse-to-total load ratio))/(years since construction of Chili Bar Dam)	tonnes yr^{-1}	9,260
Trap efficiency	estimated trap efficiency of Chili Bar Dam	percent	13.39

4.3 Effects on the Reach Downstream of Chili Bar

Dams disrupt the downstream movement of sediment and water, and have the potential to negatively impact geomorphic and, consequently, biological resources in downstream reaches.

Results from geomorphological studies to date indicate how the UARP and Chili Bar Dam and Reservoir may affect sediment supply and transport in the Reach Downstream of Chili Bar.

Analysis of reservoir sediments in Chili Bar Reservoir indicates that approximately 30,420 m^3yr^{-1} of sediment is retained in the reservoir on an average annual basis (recognizing, however, that sediment loads vary widely from one year to the next). This represents approximately 13 percent of the incoming sediment load, with the remaining 87 percent passed downstream. Virtually all of the sediment passed downstream is fine material (<2mm), since both field observations at the upstream end of the reservoir, and valve maintenance activities at the upstream dam face indicate that the reservoir is trapping almost all of the larger sediment particles (>2mm).

There are several geomorphic implications of Chili Bar Dam. Coarse sediment trapping in the reservoir results in the sediment load to the Reach Downstream of Chili Bar being largely bereft of coarse sediment immediately below Chili Bar Dam and until tributary and bank supplies of coarse sediment are accumulated. As such, and despite the fact that some reduction in fine sediment load occurs (fine sediment caught behind the dam), the *relative* proportion of fine to coarse sediment supply downstream of the dam is increased. The effect of these changes on the downstream morphology and habitat in the river depends not only on the changes in sediment load, but also upon the degree of flow regulation, especially of large (greater than 5,000 cfs) flows. The relatively small storage capacity of the reservoir means that large flow events, such as large snowmelt flood peaks and midwinter storm flows in excess of 5,000 cfs, still occur during most normal and wet water years in the Reach Downstream of Chili Bar.

The combined effect of coarse sediment interception and the continued existence of high flows is likely to result in some combination of reduced bed sediment storage (sediment exhaustion), channel incision and/or bed coarsening over time. Conclusive evidence of these effects would require knowledge of historical conditions in the reach. However, we can begin to infer probable impacts through knowledge of the current conditions in the Reach Downstream of Chili Bar. Results from channel morphology surveys conducted in the Reach Downstream of Chili Bar indicate that three out of four study sites are designated transport reaches (i.e., limited sediment storage and bedrock control) and that the channel bed at all four sites primarily consists of small to medium sized cobble (Table 4.2-3; see *Channel Morphology Technical Report* for further details).

Table 4.2-3. Reach Downstream of Chili Bar geomorphic data summary.

			Particle Size Distribution[2] (mm)			Channel Type		
Site	**Sub-reach**	**XS[1]**	**D_{84}**	**D_{50}**	**D_{16}**	**Level II**	**Morphology**	**Type**
Upper Canyon (CB-G1)	Upper	Upper	230	89	34	F3	Bedrock/ Plane-bed	Transport
		Middle	220	92	35			
		Lower	290	90	40			

Table 4.2-3. Reach Downstream of Chili Bar geomorphic data summary.

			Particle Size Distribution[2] (mm)			Channel Type		
Site	**Sub-reach**	**XS[1]**	**D_{84}**	**D_{50}**	**D_{16}**	**Level II**	**Morphology**	**Type**
Upper Coloma (CB-G2)	Middle	Upper	243	104	51	C3	Pool-riffle	Response
		Middle	246	122	71			
		Lower	284	158	89			
Lower Coloma (CB-G3)		Upper	169	84	7	C3	Pool-riffle	Transport
		Middle	211	108	45			
		Lower	211	125	52			
Gorge (CB-G4)	Lower	Upper	132	66	33	F3	Pool-riffle	Transport
		Middle	150	90	52			
		Lower	175	88	56			

[1]XS = Cross-section
[2]D_{50} = bed particle size where 50 percent is finer

From this information, the following prospects exist with regard to the effects on coarse sediment supply to the Reach Downstream of Chili Bar:

- either the storage volume of alluvial bed sediments below the dam has been reduced or the storage volume was historically low and has been little affected; or some combination of the two;

- channel incision may have occurred. Historical data would be required for verification but it can be assumed that, because the reaches are primarily bedrock controlled, the total amount of incision will have been far less than if the reaches were alluvial; or

- bed coarsening may have occurred, but its extent is difficult to verify when the current channel is capable of transporting the majority of sediment delivered to it.

The combined effect of relatively greater fine sediment supply and flow regulation may, in some cases, result in fine sediment accumulation. Because most of the channel in the Reach Downstream of Chili Bar is classified as a transport reach, the following sediment transport and deposition-related effects seem likely to have occurred:

- the majority of fine sediment is carried through the reach during flood events in excess of the capacity of UARP and/or Chili Bar Project. Thus, the fine sediment present on the channel bed between flood events may primarily reflect the concentration of sediment in suspension as the flood wanes;

- fine sediment naturally deposits preferentially in hydraulically quiet zones such as around large roughness elements and in the channel margins and, where permitted by reach morphology, over bank;

- the residence time of the deposited material in these reaches will be relatively short, that is, deposited material will be replaced during each flood event. As such, the extent to which fine sediment storage either increases or decreases over time may be largely a reflection of the concentration of fine sediment present during individual flood events and will vary according to upstream sediment supply conditions. This fact makes it far more difficult to separate long-term trends in fine sediment accumulation from the short-term effect of the most recent flood event; and

- sediment-producing development is occurring in the contributing area to the Reach Downstream of Chili Bar, and delivery of this fine sediment to the river during storm events may further affect long-term trends in fine sediment accumulation.

In summary, results from channel morphology studies indicate that most of the fine portion of the sediment load in the Reach Downstream of Chili Bar is carried downstream by high flows and is probably stored temporarily on the banks and in hydraulically quiet zones between events. Although it is very likely that some manner of geomorphic change has occurred due to the lack of upstream coarse supply, conclusive evidence of this would require knowledge of historical conditions in the reach for comparison purposes.

Two primary mechanisms for sediment supply and transport effects on biological resources are: 1) bed coarsening that can reduce the availability of spawning gravels and substrates that support the fish, benthic macroinvertebrate (BMI), and riparian communities; and 2) excessive fine sediment buildup that can fill interstitial spaces and thereby reduce suitability for spawning and BMI production.

Significant bed coarsening would presumably lead to limitations in salmonid spawning habitat. However, spawning gravel deposits in the reach were noted in the *Channel Morphology Technical Report*, and lack of spawning gravel limitation is discussed in the *Flow and Fluctuation in the Reach Downstream of Chili Bar Technical Report*. Although data on YOY trout populations is sparse due to sampling method constraints in this reach, the age class distribution information (see *Stream Fisheries Technical Report*) documents YOY trout, which indicates that successful spawning does occur.

Biological studies to date, including fish and BMI assessments, have not suggested that either spawning or BMI habitat is impaired due to fine sediment buildup. Riparian resources, specifically cottonwood, appear to be affected by project operations, but the effects are primarily flow related rather than substrate related (see *Flow and Fluctuation in the Reach Downstream of Chili Bar Technical Report)*.

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APPENDIX A

CHILI BAR RESERVOIR
AERIAL PHOTOGRAPHS

- **FULL RESERVOIR**
- **LOW POOL**

(Provided on CD)