6.0 ANALYSIS OF PROJECT EFFECTS ON SEDIMENT TRANSPORT AND RIVER GEOMORPHOLOGY

6.1 DESCRIPTION AND PURPOSE

The purpose of this study is to characterize sediment transport and geomorphic conditions and controlling factors in the Project area, including understanding the potential effects of Project operations. As one component of this study, PacifiCorp assesses fluvial geomorphic processes and conditions in various river reaches by evaluating the range and trends of bed material size and channel form, estimating flows required to mobilize the riverbed material, and identifying bed armoring and channel change. As another component of this study, PacifiCorp assesses the character and quantity of sediments being retained in Project reservoirs. The results from this study will enable PacifiCorp to identify distinct geomorphic reaches, determine the important factors that control geomorphic processes and conditions in these reaches, assess potential sediment sources and transport through these reaches, and describe potential Project effects on these geomorphic processes and conditions.

Specific reaches or segments of the Klamath River in the Project area contain different Project facilities and operations. River geomorphology in these reaches varies, with distinct River flows through Lake Ewauna and Keno reservoir (approximately RM 254 to RM 233), which is a relatively low gradient, wide, and slow-moving section of the river. By contrast, the reach from J.C. Boyle dam to Copco No. 1 reservoir extends about 20 miles (RM 225 to RM 204) in a confined canyon with a relatively high gradient channel composed predominantly of a step-pool or riffle-pool morphology, with minor alluvial reaches. Downstream of its confluence with Cottonwood Creek, the Klamath River leaves the predominantly volcanic Cascade province and traverses the Klamath Mountains within a valley of more diverse local geology and lithology.

6.2 OBJECTIVES

The objectives and key questions addressed by the analysis described in this report are as follows:

- How do the environmental features of the Project area relate to fluvial geomorphology?
- Classify general geomorphic characteristics for reaches of the Klamath River within the Project area and downstream to Seiad Valley.
- How do the Project facilities and the operation of those facilities affect fluvial geomorphic processes?
- What are the potential measures or actions that can be taken to meet resource management objectives related to potential Project effects on sediment transport and river geomorphology?

6.3 RELICENSING RELEVANCE AND USE IN DECISIONMAKING

This study helps PacifiCorp address resources issues related to Project effects on river geomorphology and sediment transport. The results of this task, together with the results of the study of hydrology effects, are used to assess channel morphology and sediment transport characteristics in the Project area. It also helps determine the effects of Project operations on sediment transport and geomorphic processes.

Relicensing of the Project requires Section 401 certifications from relevant state agencies and compliance with requirements of the federal Clean Water Act. This task helps PacifiCorp assess channel morphology and sediment transport effects as they relate to water quality objectives and standards as promulgated by these agencies. Water quality can be affected by channel morphology and sediment transport conditions, such as by sediment accumulation or channel changes that can occur within and downstream of reservoirs (Ligon et al. 1995). Therefore, the tasks described in this study provide information for the assessment of water quality as well as geomorphic conditions.

Relicensing of the Project also requires PacifiCorp to assess channel morphology and sediment transport effects as they relate to other key aquatic resources issues, such as fisheries resources and riparian habitats. For example, salmon and steelhead below Iron Gate dam require sediment sources and sizes that are sufficient to support spawning. As another example, channel morphology and sediment transport conditions are important factors in the establishment and maintenance of riparian vegetation (Ligon et al. 1995). Therefore, the tasks described in this study provide information for the assessment of aquatic resources as well as geomorphic conditions.

6.4 METHODS AND GEOGRAPHIC SCOPE

6.4.1 Geographic Scope

The geographic scope of this study generally extends from Link River dam (RM 254.3) to Seiad Valley (RM 128.5) in the Klamath River. However, the reaches within the Project area from Link River dam to Iron Gate dam (RM 190), and downstream to the confluence of the Shasta River (RM 176.7), are the primary focus of field surveys and data collection and analysis. It is within this area that PacifiCorp operations have the most potential to significantly affect hydrology, geomorphology, and sediment transport. Given the rapid downstream increase in flow and sediment from Klamath tributaries, it is expected that the principal Project influence will extend downstream to the confluence of the Shasta River. This expectation was reinforced by results of geomorphic investigations at Seiad Valley sites in 2002. In addition, the study area extends upstream along tributaries and onto slopes as needed to assess sources of sediment and sediment yield from various geologic units and land use types.

Review of existing data and information on Klamath River geomorphology, together with examination of current and historical aerial photographs of the river channel, includes the Klamath River from Link River dam (RM 253.7) continuously to the confluence of the Scott River (RM 143). USFS geologic and sediment yield information was assessed for reaches downstream of Iron Gate dam. Spot observations of channel conditions at sites downstream to Seiad Valley (including Seiad Valley, important tributary confluences, and sites for which good historical aerial photographs were available) provided further information on sediment sources and yields. Project geomorphologists estimate that this area is adequate to establish the current and historical basin-level geomorphic setting for this study.

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6.4.2 Reservoir Sedimentation Study

6.4.2.1 Bathymetry and Calculation of Sediment Accumulation in Project Reservoirs

PacifiCorp collected bathymetric data from Keno, J.C. Boyle, Copco, and Iron Gate reservoirs in the fall of 2001 using SONAR/DGPS equipment with a positional accuracy of approximately 6 centimeters (cm). Additional survey work was concluded in Keno reservoir in August 2003. The positional accuracy was verified against available registered benchmarks for the area. The acoustic data were generated at a frequency of every second along transects from 50 to 100 meters (m), depending on the size of the domain being mapped. Sediment cores were collected in specific locations of each reservoir to determine the size distribution of materials transported to the reservoir. These data were edited and entered into a geographic coordinate system (e.g., NAD83), consistent with PacifiCorp's GIS system for the Project area. The edge of shoreline was generated using a recent satellite image that has been rectified and has suitable pixel size for the application (e.g., 1 m).

For each reservoir or lake, the following products were produced:

- Digital and paper copies of the impoundment bathymetry
- Topographic representation of the Project sites prior to impoundment (assuming the original topographic maps can be located)
- Hypsographic curves of the Project reservoirs, with detailed information on lake surface area, maximum depth, mean depth, and volume
- Calculations of estimated accumulated sediment volume in each reservoir

Sediment accumulation in the reservoirs was calculated by comparing reservoir volume differences between the new bathymetry and previous reservoir volumes as derived from available information (such as City of Klamath Falls, 1986; Johnson et al. 1985) and calculated from original topographic maps. Classification of Sediments in Project Reservoirs

The sediment classification for the Project reservoirs consisted of a multistep approach involving preclassification of the sediments using hydroacoustics, stratified sediment sampling, and postclassification using the sediment data. Each step is described as follows.

Step 1. Hydroacoustic Pre-Classification

The hydroacoustic data were collected using a SIMRAD EY500 split-beam hydroacoustic system linked with an Ashtech DGPS receiver mounted on the Workskiff vessel. The acoustic signals received include the bottom depth and two echoes (E1 and E2), which provide information on the reflectivity and acoustic scattering. The E1 and E2 signals are post-processed to yield up to six classes of sediment for a system ranging from very soft gyjtta to hard, angular rock substrate. The classes are generated and overlain with the draft bathymetric data to yield maps of unsupervised sediment classes.

The unsupervised sediment classes were mapped for each system, and systematic, stratified sampling zones were identified on the maps. These sampling sites were used in Step 2 to guide the field collection of sediment samples for the supervised portion of the sediment classification exercise.

Step 2. Sediment Sampling

The sediment maps were used to guide the field crew to sediment sampling areas. The crews used the same Ashtech DGPS to locate over the sampling area. The precision and accuracy of the positioning device is < 5 cm; consequently, most of the error in positioning is attributed to positioning of the sediment sampling devices relative to the DGPS signal.

The sediment sampling was conducted using three devices, depending largely on the nature of the material being sampled. Where the sediment was sufficiently cohesive, yet not resistant to penetration (which was expected for most of the sites), a mini-Glew gravity coring device equipped with either a 3.75-cm- or 5.0-cm-diameter, polycarbonate coring tube was gently lowered into the sediments. A weighted messenger was deployed to close the top of the corer, thus allowing the sediment to be retrieved. The clear polycarbonate tube was capped prior to lifting the corer out of the water, and the core tube was visually inspected to ensure that the sediment sample was relatively undisturbed. The depth of sediment sampled was recorded. The core was then photographed in the field and was extruded on site to yield two samples—one from the upper 5 cm and one from the lower 5 cm of the core. The sediment samples were placed in WhirlPac® bags, labeled, and stored on ice.

When the sediments did not allow for coring, two other devices were used. For sandy or gravel-dominated sediments, an Ekman box sampler was used. In these cases, the sampler was lowered to the sediments and triggered with a messenger. The Ekman sampler does not allow for consistent vertical subsampling; consequently, the entire contents of the Ekman sampler were placed in a bucket, and a subsample of the sediment was drawn from the bucket after the contents were thoroughly mixed. Again, the sediment samples were placed in WhirlPacs and stored on ice.

The third method of sampling the sediments consisted of using direct imagery. An infrared-sensitive camera (Sea-Viewer® 550 B&W Sea-Drop System) was lowered to the site. The view of the sediment is visible with an on-board monitor and is recorded on videotape. The infrared camera allows for operation in total darkness without the benefit of external lighting. The image is sufficiently clear (minimum focal length is approximately 10 cm) that the nature of the sediment can be described visually with considerable reliability. The camera was then allowed to contact the sediment. Soft sediments are identifiable as the surface sediments are disturbed. Hard, rocky sediments are clearly distinguished by the nature of the contact and the image itself.

Regardless of the method used to sample the sediments, duplicate samples of the sediment were collected in close proximity to document the fine-scale heterogeneity in sediment composition. Approximately 20 sediment samples were collected from each reservoir to develop a rigorous classification.

The sediment samples were shipped via overnight courier to Oregon State University Central Analytical Laboratory for analysis of percent water, total phosphorus, carbon, and nitrogen. Percent water was determined by drying sediments to 105 °C. Total phosphorus was measured using a Kjeldahl digestion, and carbon and nitrogen were measured using a CNS analyzer. Detailed analytical methods are on file with the laboratory.

Step 3. Post-Classification of Sediments

The information on sediments was used to develop a series of supervised maps of sediment composition. The classification information available consists of percent water content, depth of sediment penetration (available for the Glew core only), sediment nutrient concentrations, and sediment carbon content. Statistical correlation evaluation of the field and analytical data was conducted to develop a classification that can reasonably explain the heterogeneity of sediment composition as a function of sample variables.

Sediment composition maps were generated for each impoundment at the same scale as the bathymetric maps by relating the sediment composition data to the hydroacoustic data. The hydroacoustic information allows for spatial representation of the sediment composition of the reservoirs. Uncertainty in the supervised classification maps was also estimated.

6.4.3 Qualitative Geomorphic Characterization and Initial Delineation of Reaches

Existing information on hydrology, geology, and geomorphology in and downstream of the Project area was reviewed to provide background and context for geomorphic characterization. Existing topographic maps and recent aerial photographs were used to develop detailed map-based estimates of channel gradient and confinement. Initial reach segmentation was based on distinct changes in channel slope, channel width and confinement, and other major channel features. Hydrologic data from the USGS and PacifiCorp were used to identify changes in flow magnitude, frequency, and duration in the Project area and from Project facilities. Results of these analyses helped guide the selection of field study sites, as described below.

As described in Reid and Dunne (1996), the initial analysis of topographic maps (1:24,000 scale) and aerial photographs was used to divide the channel “into distinct reaches according to whether they are bounded by floodplains and terraces, and thus contain potential sediment storage sites, or are constrained by bedrock and colluvial slopes, and so are more likely to serve primarily as transport reaches. This categorization provides an immediate guide to the locales most useful for particular kinds of measurements or for diagnosis of past channel changes. Alluvial reaches are at greatest risk of aggradation, and aggrading sites can often be recognized on aerial photographs because of their vegetation characteristics and surface morphology.”

In addition, a map-based longitudinal profile for the entire Project reach was developed to provide an immediate basis for distinguishing reaches based on gradient and significant slope breaks. Moreover, the alternation between geologically controlled lower and higher gradient reaches (because of the specific geological setting of the Klamath River) imposes important constraints on the system, as does the sediment storage behind Project dams. These factors were used to develop an initial reach characterization "from the bottom up"; i.e., based on patterns evident from the Klamath River data without reference to any preconceived classification system. As a separate step, these data were used with field data to classify reaches under the systems of Rosgen (1994) and Montgomery and Buffington (1993). These classification systems are described in later sections of this report.

6.4.4 Review of Previous Studies

Previous studies were reviewed that pertain to Klamath River hydrology, geomorphology, and potential Project effects on channel form and fish habitat. These reviewed included Buer (1981), McBain and Trush (1995), Balance Hydrologics (1996), Ayres Associates (1999), and Hardy and Addley (2001). In this review, the hypotheses advanced by these various studies were noted, along with methods, results, and any issues of concern that may be at least partially pertinent to this study. Conclusions from these previous studies were evaluated only in light of their applicability to specific geomorphic and hydrologic conditions in the study area. These documents were used as appropriate to draw sources of data and location of field transects and measurements of potential use in this study.

6.4.5 Review of Historical Aerial Photographs

Available historical photography (mostly vertical, but also oblique aerial photographs and ground photographs) was compiled and examined to document former channel conditions. The availability of historical vertical aerial photography of the study area was assessed from potential sources, such as the U.S. Army Corps of Engineers, BLM, USBR, USFWS, the USFS and Soil Conservation Service Aerial Photography Center in Salt Lake City, the National Archives (for federal aerial photography prior to 1955), the California Department of Water Resources (DWR) and the Department of Transportation, private aerial photography firms such as WAC Corp., and private entities that have done work on or adjacent to the Klamath River in the study area. Several sets of aerial photographs were obtained at various scales and coverages, including for the years 1944, 1952, 1955, 1960, 1964, 1965, 1968, 1971, 1975, 1979, 1980, 1982, 1984, 1988, 1989, 1993, 1994, 1998, 1999, and 2000. Historical oblique aerial photographs and ground photographs were searched from sources such as the Oregon Institute of Technology Shaw Library, the Klamath County Museum, and ODFW.

As a first step, the photographs for the study reaches were examined (in stereo where possible for vertical aerial photographs) to determine, at a reconnaissance level, whether large or systematic changes in channel form and/or riparian vegetation distribution were evident, and to assess the extent to which historical channel and riparian conditions could be identified and measured from the photographs.

As a next step, the reaches with significant visible changes in channel form or riparian vegetation were examined more closely to attempt to determine if the visible changes could be directly linked to Project facilities or operations.

6.4.6 Selection of Representative Study Reaches

Fourteen representative reaches were selected in the Klamath River from Link River dam (RM 253.7) downstream to Seiad Valley (RM 128.5) as locations for field observations and measurements. These reaches are distributed relative to Project areas as follows: one in Link River (RM 253.1-254.3), one in the Keno reach (RM 228-233), two in the J.C. Boyle bypass and four in the J.C. Boyle peaking reaches (RM 204-224.7), one in the bypass reach downstream of Copco No. 2 dam (RM 196.8-198.3), and five from Iron Gate dam downstream to Seiad Valley (RM 128.5-190). Study reach selection was based on the following:

- The initial reach delineation (see Section 6.7.4)
- Review of topographic maps, longitudinal profiles, aerial photographs, and geologic and hydrologic information
- Field reconnaissance by the principal investigators and a PacifiCorp representative to provide insights into dam operations, access, and other logistical issues
- Coordination with fish and riparian vegetation studies, and field review with members of the Geomorphology Subgroup (GSG).

Each representative reach was approximately ten channel widths in length, selected in part to capture examples of channel and habitat features, such as pools, riffles, rapids, and bars, and to capture both highly constrained and wider alluvial reaches. Where feasible and where it made sense from the perspective of the geomorphic study, the geomorphic study reaches were sited at USGS gauge sites or in study reaches from previous studies (e.g., City of Klamath Falls, 1986; Hardy and Addley, 2001) to take advantage of existing stage-discharge relationships and previously surveyed reach topography.

6.4.7 Measurements and Observations at Representative Reaches

Measurements and observations at representative reaches were conducted mostly during August 2002. Data collection activities are described in the following subsections.

6.4.7.1 Cross Section and Long Profile Surveys

In each representative reach, two to four cross sections were surveyed in order to adequately capture variety in channel form. Elevations were surveyed at regular intervals to capture channel geometry (including all major slope breaks) and characteristics. Surface sediment and vegetation characteristics were recorded at each elevation point. A long profile was surveyed over the length of the representative reach, at least ten channel widths in length. The long profile was surveyed through the thalweg of the channel and also captured all significant slope breaks. All cross section survey end points, long profile reference points, and benchmarks were permanently monumented.

6.4.7.2 Photo Points and Reach Maps

Within each representative reach, permanent photo points were established in locations that provide comprehensive views of the channel and important features. Sketch maps of each study reach were also prepared showing channel features, sites of bed material measurement, cross sections, and exact locations of monuments to facilitate future reoccupation if needed. Sketch maps were also used to develop facies maps (i.e., maps that identify distinct geomorphic features or units) for each study reach.

6.4.7.3 Bed Material Sampling

Within each representative reach, the distribution of units of distinct bed material composition (facies) were mapped, and pebble counts (Wolman, 1954) were conducted on all major facies. While most facies were identified at a coarser scale of tens of feet, the field team sought to identify and map deposits of gravel potentially suitable for spawning by salmon and trout, which may occur as small "pocket gravels" less than 3 feet in length and width. The lithology of stones sampled in selected pebble counts were also recorded for comparison with pebble counts conducted throughout the Project area to help identify changes in sediment source characteristics.

6.4.7.4 Floodplain and Terrace Features, Riparian Vegetation, and Large Woody Debris

Within each representative study reach, floodplain and terrace attributes were noted, such as elevation above the active channel; grain size; stratigraphy, if visible in cut banks; and the distribution of woody riparian vegetation with respect to the channel, as well as distance above and away from the channel. Where possible, large woody riparian vegetation on the banks was also assessed for its potential contribution to the large woody debris in the channel. The distribution of large wood in the channel was recorded, including the dimensions (to calculate volume per unit area and river length) and locations of individual pieces of wood and jams in each reach.

In addition, Project geomorphologists coordinated with the Project riparian specialists conducting the Wetland and Riparian Plant Community Characterization (Study 2.2) to explore the observed patterns of riparian vegetation distribution in relation to hydrology and geomorphology. The investigators for the geomorphology and riparian studies collaborated on the development of an analysis to integrate these two studies. At the site scale, the Project geomorphologists used information collected in the Wetland and Riparian Plant Community Characterization to correlate vegetation species present with water surface elevations for a range of flows and to assess vegetation establishment in relation to seasonal stage changes. Many of the cross sections established at study sites were used in the riparian vegetation data collection efforts. Reach maps and detailed cross sections from this study were also used in the riparian vegetation analyses. In addition, site visits were conducted to document geomorphic surface and riparian vegetation inundation levels and interactions.

The Project geomorphologists also examined aerial photographs (scale: 1:12,000 to 1:20,000) for sequential years (approximately once per decade) to detect changes in riparian vegetation from one photograph set to the next, and developed hypotheses about how these features correlated with major floods, onset of Project operations, or other possible causes. These initial assessments guided the formal coordination of the riparian and geomorphology studies. The following tasks were performed to formally integrate the findings of the geomorphology study and the riparian vegetation study with respect to Project operations.

- Examine historical aerial photographs of Project reaches for evidence of significant changes to vegetation or geomorphology.

- Assess channel geomorphology and riparian vegetation changes during the Project operation period, specifically with respect to the range of the natural hydrographs most affected by Project facilities.

- Assess hydrology of each project reach, focusing specifically on flows expected to alter channel geomorphology and riparian vegetation.

- Overlay riparian vegetation zones and inundation levels of a range of flow events (from low to high frequency) on surveyed geomorphology transects.

- Discuss geomorphic processes occurring at each inundation level and vegetation zone (e.g., bed load transport, erosion and deposition, and point bar growth), how these processes have changed because of Project operations, and how these changes have altered communities of riparian vegetation.

- “Ground truth” assessment at a subset of sites in the field.

An additional analysis related to geomorphology and riparian vegetation was conducted to investigate anecdotal evidence of cobble/gravel bar fossilization by willows between Iron Gate dam and Seiad Valley and the potential impact of the Project on this phenomenon. Stakeholders familiar with this stretch of the river have identified areas where it appears that formerly loose, mobile bars have been locked in place by extensive willow root networks. It was assumed that willow recruitment and growth in this part of the Klamath River are tightly linked to hydrology, with summer base flows controlling the viable growth area during the growing season and floods at some frequency scouring established willows, thereby freshening the bar. The details of this analysis are summarized below:

- Identify three potentially fossilized bars using aerial photographs, topographic maps, and field reconnaissance (only one significantly fossilized bar was identified in this study).
- Examine and compare bar condition (i.e., density and extent of willow cover) through time using historical aerial photographs.
- “Overlay” annual peak flood hydrology on aerial photograph observations to confirm fossilization and link to project impacts on hydrology.

6.4.7.5 Surficial Bed Material Size Sampling and Reconnaissance Throughout the Study Area

The Project's potential effect on the availability and quality of spawning gravels, particularly downstream of Iron Gate dam, is an important issue. To assess the problem of excessive fine sediment in spawning gravels, bulk sediment samples are appropriate to measure interstitial fine sediment content (Kondolf, 2000a). To assess whether a given target fish can use the gravel present in a reach, the framework size of the gravels should be measured and compared with the sizes movable by the target fish. The framework size can be assessed more efficiently by using the pebble count method (Wolman, 1954) because it provides a good measure of median grain size and can be conducted in a fraction of the time required to collect and analyze a bulk sample.

Because of the small size of Project reservoirs relative to the Klamath River's annual runoff, the Project reservoirs are unlikely to significantly affect high flows, but they trap all bed load sediment, making downstream bed coarsening a potential concern. To address potential coarsening, pebble counts were performed throughout the Project area, thereby collecting a data set of framework sizes from many sites instead of focusing the sampling effort on bulk samples from a few sites.

In addition to performing pebble counts and sketching facies maps in the 14 detailed representative reaches (as described above), pebble counts were performed in between the detailed study reaches on bars and riffles, at roughly regular intervals, but concentrated in important fish habitat sites and in reaches where coarsening might be expected, for an overall total of approximately 75 pebble counts. Downstream of Iron Gate dam, pebble counts were performed at all public access points between the Tree of Heaven Campground and Seiad Valley. Collection and analysis methods for these additional pebble counts were similar to the study reach pebble counts, and the results of all the pebble counts are presented together.

6.4.8 Fitting Channel Classification Systems to Klamath River Channels

6.4.8.1 Rosgen System Classification

Each representative reach was classified using the Rosgen Level 1 and Level 2 geomorphic characterization method (Rosgen, 1994). The purpose of Level 1 classifications is to provide for the initial integration of basin characteristics, valley types, and landforms with stream system morphology; provide a consistent initial framework for organizing river information and communicating the aspects of river morphology; assist in the setting of priorities for conducting more detailed assessments; and correlate similar general level inventories. The purpose of Level 2 classifications is to address questions of sediment supply, stream sensitivity to disturbance, potential for natural recovery, channel responses to changes in flow regime, and fish habitat potential (Rosgen, 1994).

Rosgen's criteria for entrenchment ratio, width-to-depth ratio, sinuosity, slope, and channel material were used to determine the Level 1 and Level 2 stream types for each representative reach. Entrenchment ratio, width-to-depth ratio, and slope were determined from the cross section and long profile survey data measured at the study reaches. Sinuosity was determined from aerial photographs and USGS 7.5-minute topographic maps. Channel material type was determined from the pebble counts and facies maps. Figure 6.4-1 summarizes the criteria for each stream type. All values were recorded for each criterion, and the stream type that best fit the set of criteria was selected. In some cases, the study reaches did not exhibit all criteria needed for a given stream type. In such cases, the problem was noted and the reaches were recorded as belonging to the classes they most closely resembled.

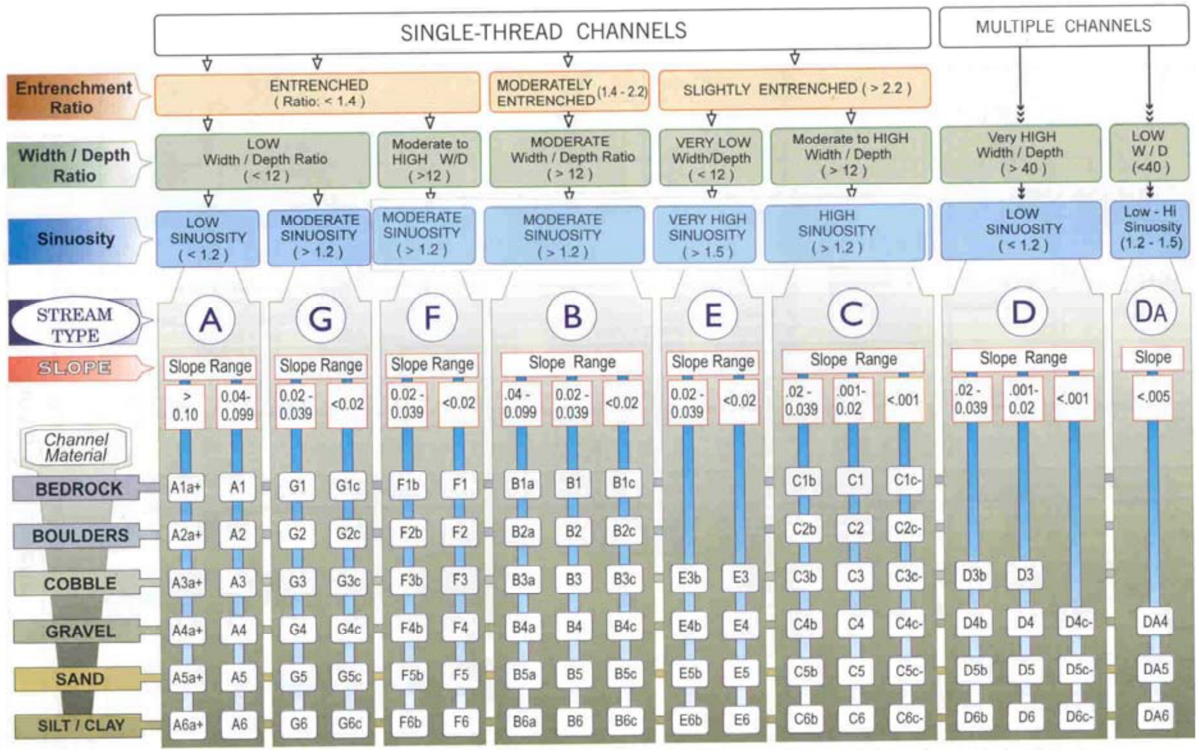

Figure 6.4-1. Key to the Rosgen (1994) classification scheme.

6.4.8.2 Montgomery and Buffington System Classification

Each representative reach was also classified using the Montgomery and Buffington (1993) hierarchical levels of channel classification. The Montgomery and Buffington criteria were applied at the spatial scale of 100 to 10,000 m. The Montgomery and Buffington landscape and channel classification scheme provides a process-based framework for geomorphic, biologic, and land management applications. Channel types are delineated on the basis of channel morphology, sediment transport processes, and sediment flux characteristics, as controlled by hydraulic discharge and sediment supply. Table 6.4-1 summarizes the details of each level of channel classification in the Montgomery and Buffington scheme. Each representative reach was classified using aerial photographs, topographic maps, survey data, and site reconnaissance.

Table 6.4-1. Montgomery and Buffington channel types and characteristics.

Channel Type	Typical Characteristics
Plane-bed	Plane-bed channels lack well-defined bed forms and are characterized by long stretches of relatively planar channel bed that may be punctuated by occasional channel-spanning rapids.
Pool-riffle	Pool-riffle channels have an undulating bed that defines a sequence of bars, pools, and riffles. Pools are topographic low points within the channel, and bars are the corresponding high points.
Bedrock	Bed rock reaches exhibit little, if any, alluvial bed material, and they are generally confined by valley walls and lack floodplains. Bedrock reaches occur on steeper slopes than alluvial reaches with similar drainage areas.
Step-pool	Large clasts are organized into discrete channel-spanning accumulations that form a series of steps separating pools containing finer material.
Cascade	Cascade reaches occur on steep slopes with high rates of energy dissipation and are characterized by longitudinally and laterally disorganized bed material, typically consisting of cobbles and boulders confined by valley walls.

Source: Modified from Montgomery and Buffington, 1993.

6.4.9 Bed Load and Suspended Sediment Sampling

Bed load and suspended sediment transport has been sampled at one site on the mainstem Klamath River in the J.C. Boyle peaking reach upstream of Copco reservoir (at the railroad boxcar bridge just upstream of the Shovel Creek confluence). When bed mobilizing flows next occur, bed load and suspended load samples will be collected at two additional sites: (1) the Klamathon Bridge (or from catarafts at a better section nearby but above the Cottonwood Creek confluence), and (2) the bridge at the Interstate 5 (I-5) rest area (or from catarafts at a better section nearby). Sampling was originally planned to occur during the spring-summer 2002 snowmelt runoff period, but snowmelt runoff in 2002 was so low that no spill occurred from the Project dams; consequently, snowmelt bed load sampling was postponed to the 2003 water year. Potential bed mobilizing flows occurred for only a few days in 2003, so only one bed load transport sample was possible.

The first site was selected to characterize bed load transport from the river reach between J.C. Boyle dam and Copco reservoir. This site is near the lower end of the reach. Because of likely sediment trapping by J.C. Boyle dam, this site provides a characterization of bed load from sediment stored in the channel, in bars and banks, and contributed from tributaries and slope erosion over the river reaches between J.C. Boyle dam and Copco reservoir. The site was also chosen because of the availability of a bridge from which sampling was possible.

The second sampling site, in the vicinity of the Klamathon Bridge, was selected to characterize bed load transport between Iron Gate dam and Cottonwood Creek. This site is in the reach most directly affected by Iron Gate dam, and it is also the most downstream reach entirely within the volcanic lithologies before the river's bed character becomes affected by sediment supplied from the Klamath terrane. This site reflects transport under conditions of possible armor development from sediment trapping by Iron Gate dam.

The third sampling site, in the vicinity of the I-5 rest area, was selected to characterize bed load transport just upstream of the Shasta River and because of the availability of a bridge from which sampling would be possible.

In the 2002-2003 flow season, sampling was conducted only in the J.C. Boyle peaking reach upstream of the Shovel Creek confluence because the river had sufficiently high flows for only a brief period. This bed load sampling was conducted with Helley-Smith samplers, cable-deployed from the bridge upstream of the Shovel Creek confluence. Suspended sediment was sampled with D-74 samples, also cable-deployed. The bed load samples in the J.C. Boyle peaking reach were obtained at flows of approximately 3,000 cfs, which is the approximate flow release when J.C. Boyle generators are running. These 3,000-cfs samples provide a basis for assessing possible effects of the hydroelectric-generation-induced fluctuating flows on sediment transport. If sufficiently high flows occur in 2004, bed load sampling will be conducted at the Klamathon Bridge and I-5 rest area sites from the bridges or from cranes mounted on catarafts.

6.4.10 Sediment Sources and Pathways

In addition to the sampling of sediment in transport and reservoir sedimentation rates, evidence of sediment generation, delivery to channels, transport, storage, and deposition was noted in the analysis of topographic maps and aerial photographs described earlier (section 6.4.5). While large-scale features were resolved on the 1:24,000-scale topographic map, this analysis yielded further questions that required field inspection to resolve. Similarly, the patterns of sediment size, bar, and bedforms that were measured and observed in the mainstem and tributary channels produced additional questions about sediment source areas. Although it was not feasible in this study to make direct measurements of most sediment sources in the basin, the field team conducted reconnaissance-level surveys and took advantage of opportunities to measure erosion, sediment transport, and deposition of the sort detailed in Reid and Dunne (1996). These data are incorporated into the sediment budget, as described in section 6.4.15.

Detailed measurements of direct sediment inputs to the mainstem Klamath River included an assessment of a large washout in the J.C. Boyle bypass reach on the right bank below the power canal emergency spillway (just upstream of the entrance to the penstock tunnel). Using a rod and level, the field team surveyed the surface dimensions of the failure and estimated the former, pre-erosion slope extent. From this information, the approximate volume of sediment eroded from the slope was calculated. Rough measurements of the cone of debris at the base of the washout and of the gravel bars developed just downstream were also made. Upstream, the void space in gullies eroded in the sidecast slopes along the right bank below the canal road were measured in order to estimate minimum sediment volumes delivered to the channel from these sources. The volume of left bank slope material that eroded as a result of deflection of flow into the left bank, caused by sidecast material encroaching into the channel from the right bank, was also measured.

In addition, direct hillslope inputs to the Klamath River were estimated for the sediment budget. Hillslope landslides along the Klamath River from Link dam to Seiad Valley were identified from the most recent set of aerial photographs with the most complete, continuous coverage of the study area. Landslides were classified as shallow landslides, rotational slumps, or debris flows. All slides related to roads were noted so that the number and volume of slides related to roads could be compared to the total volume of slides. Where significant landslides were identified, historical aerial photographs of the same region were reviewed in an attempt to determine their age. The surface area of individual slides was determined by digitizing slide features from aerial photographs to a GIS topographic layer of 1:24,000-scale topographic maps. No attempt was made to correct aerial photographs that were not orthorectified, nor was any correction made for hillside slope. Landslide depth was estimated by reviewing stereo photo pairs or from field measurements. The total volume of each slide was estimated as the product of the slide area and slide depth. The volume of material delivered directly to the Klamath River channel was estimated by comparing the volume of material transported downslope with the volume of material retained in the slide scar.

The connectivity of each slide to the channel was assessed by reviewing the gradient of the hillslope and the topography of the runout into the channel. Slide connection to the channel was classified as high, medium, or low. Landslides located on tributaries to the mainstem were not investigated because they were included in the sediment yield determined by tributary delta surveys, as described in section 6.4.11.

6.4.11 Tributary Delta Surveys

Streams tributary to the Klamath River deliver both bed load and suspended load to the mainstem. The Aquatics Workgroup, the GSG, and the Project geomorphologists concluded that Project facilities could have important impacts on the delivery and distribution of sediment from tributaries. To assess these impacts, a representative set of tributary delta deposits (formed where tributaries flow directly into Project reservoirs) were surveyed to quantify coarse sediment supply (particles greater than 2 millimeters, mm) from tributaries. This information was used in the sediment budget developed for this study.

Potential tributary delta survey sites were identified by an assessment of sequential aerial photographs from 1955 to the 1990s of the visible delta deposits at the confluences of Scotch, Camp/Dutch, Jenny, and Fall creeks with Iron Gate reservoir. The Project geomorphologists performed a field reconnaissance of these deltas in January 2003 during a temporary drawdown of Iron Gate reservoir. Bucket-auger coring suggested that sand and gravel make up about 15 to 20 percent of the surface deposits at the Scotch Creek delta. Material at Camp Creek delta was finer-grained, and the distal (farther offshore) parts of the deposit consisted of partially degraded organic material beneath a thin surface layer of sand and thin gravel. By contrast, the Jenny Creek delta was found to be coarse, with an emergent (and thickly vegetated) portion to the west of the mouth and large bars to the east. These bars consisted mostly of sand and gravel, and surface gravels of 64 to 90 mm were common. As expected from study of historical aerial photographs, reconnaissance at the Fall Creek delta revealed no evidence of significant delta deposition. The final sites include the deltas of Scotch, Camp/Dutch, and Jenny creeks at Iron Gate reservoir and Spencer Creek at the J.C. Boyle reservoir. These sites were selected based on analysis of aerial photographs, field reconnaissance, and GSG input.

Surveys of tributary deltas included a combination of detailed bathymetric and terrestrial surveys. Detailed field surveys of the entire delta deposit were completed and compared to the pre-dam topography obtained from PacifiCorp. The process included field surveys, preparation of digital terrain models for both sets of survey data, and computation of net change in volume between the two surfaces. Quality assurance measures (described below) were implemented to ensure that a significant proportion of the computed volumes was not simply errors resulting from imprecision in the pre-dam mapping. To translate volumes into yield, values in cubic yards were converted to tons using a multiplier, either determined directly from delta sediment properties or simply by assuming a bulk density, such as 100 pounds per cubic foot, and then dividing by the number of years since closure of the dam and the drainage area. A detailed description of the tributary delta surveying methods is presented below. The complete report for this effort is presented in Appendix 6B.

6.4.11.1 Control

Accurate survey control was established at each site, and a control network was developed. Survey-grade GPS equipment (Trimble 4700/4800 kinematic GPS system) was used to bring horizontal and vertical control to each site, and a series of benchmarks was established to create an accurate control network. In addition, several temporary control points were established to allow full coverage of the sites and to work around all of the existing vegetation. All survey data were in the units of U.S. feet, based on local California State Plane coordinated system, NAD 83, and NAVD 88.

6.4.11.2 Terrestrial Field Surveys

Survey data were obtained in several ways. Points in shallow water along the edges of the deltas were surveyed with either a Topcon APL-1A robotic total station or a Trimble 4700/4800 kinematic GPS system. Open areas with sparse vegetation were mapped using GPS equipment and methods. Areas of dense riparian vegetation presented significant survey challenges. Areas of exceedingly dense vegetation where field survey accuracy could be impaired were identified by surveying a “dense vegetation” boundary. These areas were kept as small as possible. Inside these areas, portions of the vegetation were removed with hand tools to obtain survey data along linear transects; 25-foot and 45-foot stadia rods were used as necessary to obtain challenging points.

The focus of the field mapping was to provide a reasonably detailed topographic map of the delta deposits, though without the rigor needed to produce 1-foot contour maps that would meet national map accuracy standards. Ground points were much easier to survey along the margins of the vegetation and delta deposits than in the middle of the dense vegetation. The banks of the active stream channel and the channel itself were mapped by crew members working their way along the channel through the dense vegetation. Finally, a minimum of three transects were surveyed across the deposits through the dense vegetation, with some vegetation clearing as necessary.

6.4.11.3 Bathymetric Field Surveys

The primary bathymetric data collection involved use of the Trimble 4700/4800 kinematic GPS system aligned with a SonTek 3.0-Mhz Acoustic Doppler Profiler (ADP). This instrument measures bathymetry and velocity profiles. It is implemented with a routine that corrects the three beams used by the ADP to obtain accurate vertical depths (to within +/- 0.2 foot) and appropriate horizontal coordinates. The ADP was deployed from a small cataraft (10-foot tubes) with an electric trolling motor specifically set up for this purpose. Longitudinal arrays of survey points were typically 10 feet apart.

The terrestrial survey and bathymetric survey together included several thousand data points for each tributary delta area, with intensity of coverage varying by condition and type of survey. In general, the ADP was used to collect 500 to 1,000 points in the bathymetric portion of each delta area; the total station was used to collect points approximately every 50 feet to define the delta, in addition to several hundred additional points to define existing ground outside of the delta to estimate pre-delta topography and to match pre-dam topography.

6.4.11.4 Pre-Dam Topography

Pre-dam topography was developed several ways: (1) from 10-foot contour maps surveyed prior to dam construction that have been scanned by PacifiCorp staff and converted to point files; (2) from field surveys of areas outside of the delta deposits, followed by construction of a Digital Terrain Model (DTM) from the extension of these slopes under the deposit, and (3) from probing to the original ground at a number of locations and transects across the deposits.

6.4.11.5 Existing Topography

Delta topography and bathymetry were developed from all of the survey data collected. Data values were downloaded into AutoCAD, and Land Development Desktop 3 (LDD3) DTM software was used to create surface topography models and produce the contour map. All point data were incorporated into a project file and separated into distinct point groups, as needed, based on standard survey practice. The point groups and their associated breaklines were used to create a topographic surface in LDD3 that is the basis for contours. The software calculates volumetric changes between the two surfaces. An isopach plot demonstrates the location and magnitude of site changes by constructing “contour” lines of equal change (e.g., a +1-foot contour line connects the points on a surface that are 1 foot higher than the preceding surface).

6.4.11.6 Grain Sizes of Delta Deposits

Particle size characteristics of the delta deposits were determined by bulk sampling and surface pebble counts. Bulk samples were collected at four equally (roughly) spaced points longitudinally along the exposed delta deposits by hand excavation of a pit with a shovel in an effort to reach the level of the water table. A representative sample from the entire pit depth was collected and transported to the laboratory for sieve analysis. The surface and subsurface portions of the deposit horizon were not segregated. At the laboratory, the sample was thoroughly dried and then sieved using a Gilson TS-1 sample processor. The TS-1 processes samples down to 2 mm. The remaining finer materials are split, and a split is processed in 8-inch brass sleeves, using a Gilson SS-15 shaker.

Surface particle counts (Wolman, 1954) were also conducted at each bulk sample site, with 100+ particles obtained by the heel-toe method and measured using a “gravelometer” with square openings. The pebble counts were entered as the number of particles retained in each sieve class and converted to the cumulative percentage (by number) finer than the corresponding sieve size. Surface particle count results were entered in the project field book at the sampling location.

Data obtained from bulk samples and pebble counts were entered into a spreadsheet as the number of particles retained in each sieve size class and converted to the cumulative percentage (by number) finer than the corresponding sieve size, and so entered into the project database. Size descriptors (such as D_{50} and D_{84}) were read from the curve, and indices of dispersion and skewness were computed. Where possible, relationships were drawn between the surface sediment size distribution (from pebble count data) and the subsurface sediment size distribution (from bulk sample data). Additional pebble counts were conducted at three sites on active features in the creek channel upstream of the delta and at sites selected to capture significant surface heterogeneity on the delta. The relationships developed to relate surface to subsurface particle size distributions were used to estimate subsurface sediment size distribution at the additional pebble count sites.

6.4.12 Tracer Gravel Study

Following the recommendations of Wilcock et al. (1996) that estimates of bed mobility and bed load transport be based on actual observations of bed movement, tracer gravel studies were initiated in 2002 to provide data on flows initiating bed movement. Tracer gravel studies involve the use of particles that are somehow distinctive from the other gravels to document movement of the gravel bed (Hassan and Ergenzinger, 2003). Basic information on bed mobility can be provided by tracer gravel at various flow levels, and, with suitable assumptions, this information can be used to provide independent estimates of bed load flux (e.g., Kondolf and Matthews, 1986). Most important, however, tracer gravel observations can potentially be used to provide useful calibration for sediment transport functions, whose results can be notoriously variable. Tracer gravel results are most informative during flows at or near the threshold of motion because they can thereby help to specify when the bed moves. If a large flood occurs after tracer gravels are set out, and the tracer gravels are all swept downstream, there is little information gained from the tracer gravels because it is usually obvious from other evidence that the bed has moved. If the tracer particles can be recovered downstream or if they have small radio transmitters installed, they may yield information on transport lengths.

Vein quartz particles were used as tracers in the Klamath River study because they are distinctive in color (white) and clearly exotic to the basin. Before being placed in the river, the quartz stones were measured and sorted into size classes (e.g., 45-64 mm, 64-90 mm). The stones were marked with the length of its intermediate axis in marker, and batches of the stones were put in bags by size class. The tracer particles were placed during flows low enough to safely wade in.

The bags of tracers (sorted into size classes occurring at the transect) were carried in backpacks, and straight-line transects were walked across the channel. At approximately regular intervals, stones were removed from the bed, with the hole from which they came marked with the toe of a boot. The b-axis of the stone removed was measured and its shape noted; from the bag holding the appropriate sized stones (in the backpacks), a stone with a similar size and shape was removed. The tracer (vein quartz) stone was inserted into the hole from which the native stone was withdrawn. Thus, the tracers were integrated into the framework of the bed, and there is no reason to expect them to be any more mobile than the surrounding stones. The densities of the vein quartz and the native stones were not measured, but the vein quartz is typically denser than most of the volcanic rocks it would replace (especially vesicular basalts); if anything, the tracer particles used would be less mobile than the surrounding native stones.

When the tracer gravel transects were returned to, after intervening high flows, the tracer lines were visually inspected to see if all the stones were in their original positions. If they had moved, the offset was measured. The white quartz gravels were visible against the darker native gravel.

Tracer gravels were initially placed in the Klamath River in the following locations to document bed mobility during the 2002 snowmelt flow season: (1) in the J.C. Boyle reach upstream of the Shovel Creek confluence, (2) near R-Ranch downstream of Iron Gate dam, (3) above the Cottonwood Creek confluence downstream of Iron Gate dam, (4) at the I-5 rest area downstream of Iron Gate dam, and (5) in two tributaries (Shovel Creek and Humbug Creek). As flows were inadequate to produce movement of the tracer gravels (as was expected, given the lack of spill and confirmed by observation of the tracer sites), these tracer gravel sites were revisited during fall 2002, winter 2003, and/or spring 2003 to confirm that tracer gravels were undisturbed. Also at this time, new tracer gravel study sites were added to the J.C. Boyle bypass reach near the emergency overflow spillway, in the J.C. Boyle peaking reach at the USGS gauge, and in the Frain Ranch area of the J.C. Boyle reach (unsurveyed “tracer pockets” only at this location). Tracer sites were revisited in summer 2003.

6.4.13 Estimation of Threshold of Bed Mobility

The effects of the Project on channel form, riparian vegetation, and aquatic habitats (notably salmonid spawning beds) are a function largely of the flows needed to mobilize the bed, any possible effect of Project operations on these flows, and the frequency and duration of bed mobility and sediment transport given the lack of gravel recruitment from above the dams. In estimating this threshold for with-Project and without-Project conditions, one must consider both the bed material composition and the hydrology for with-Project conditions and without-Project conditions. Accordingly, the tracer gravel and bed load sampling data were used, along with cross-sectional and long profile data for the representative reaches and hydrologic records, to evaluate flows needed to mobilize the bed and the frequency and duration of mobilization under with-Project and without-Project conditions.

For each cross section at each study site, the most representative pebble count data were selected to characterize the grain size distribution of the bed and bars at that cross section for estimates of the with-Project threshold of bed mobility. In most cases, these bed mobility analyses were performed using pebble count data from geomorphic surfaces that appeared to have been recently active (e.g., relatively fresh, unvegetated gravel or cobble bars).

The following analysis was performed to modify the without-Project bed condition. Sediment yields developed for selected tributaries obtained by measuring the deposition at tributary deltas (see subsection 6.4.10.1) were applied to all other tributaries in the Project reach from Keno reservoir to Iron Gate dam. Sediment yield was adjusted for each tributary based on its connection to the mainstem river (see section 6.4.14). The trapped sediment was assumed to have covered 10 percent of the bed from J.C. Boyle dam to the confluence with the Shasta River, a distance of 48 river miles. The 10 percent coverage assumption was consistent with analyses conducted for the Ecosystem Diagnosis and Treatment (EDT) study to determine potential spawnable area beneath Project reservoirs. Spawnable area for the river reaches beneath Project reservoirs ranged from 7 to 18 percent of the total channel area. Since these estimates were for the lower gradient reaches (and therefore higher likelihood of spawnable bedforms) beneath the reservoirs, the estimate of 10 percent for the entire reach from J.C. Boyle dam to the Shasta River was assumed reasonable. Distribution of trapped sediment was only carried downstream to the confluence with the Shasta River because sediment yields from the tributaries to the Klamath River in the volcanic terrain of the upper watershed are much lower than the sediment yields from the tributaries in the Klamath terrain. The transition between the two different terrains occurs near the confluence of the Klamath River with Cottonwood Creek. As a comparison, the sediment yield from the Salmon River was calculated at 450 tons per square mile per year (tons/mi^2/yr) (de la Fuente and Hessig, 1993) while sediment yields from the tributary delta surveys were approximately 197 tons/mi^2/yr. The sediment yield from the Link River reach was not included in the total sediment yield distributed through the J.C. Boyle dam to Shasta River reach because the naturally formed Lake Ewauna acted as a sediment trap prior to the Project. The average annual depth of sediment deposition over 10 percent of the active channel from J.C. Boyle dam to the Shasta River confluence was 0.22 foot. This depth was considered significant and from this it was assumed that at least 10 percent of the channel was composed of finer sediment prior to the completion of the Project. Therefore, the particle size distributions used in the without-Project threshold calculations were based on pebble counts taken in the tributaries to the Klamath River in the reach regulated by Project facilities.

The resulting bed material composition for without-Project estimates of the threshold of mobility was represented as the average median grain size (34.16 mm) recorded for the primary tributaries of Humbug Creek, Cottonwood Creek, and Shovel Creek. This median grain size was applied to the study site reaches below J.C. Boyle dam. The bed material composition was not adjusted for with-Project and without-Project estimates at the Link River and Keno study reaches.

Total critical shear stress was calculated for with- and without-Project bed conditions in each study reach. The total critical shear stress (shear stress that just mobilizes the bed) was determined using the following equation:

$$\tau_c = \tau_{*c}(\rho_s - \rho_w)gD_{50}$$

where:

τ_c is the critical shear stress required to mobilize the bed
τ_{*c} is the Shield’s number at mobilization (back calculated from available tracer observations)
ρ_s is the density of sediment (varies by sediment type)
ρ_w is the density of water (1,000 kg/m^3)
g is gravitational acceleration (9.81 m/s^2)
D_{50} is the median grain size

A significant fraction of the total shear stress is not actually available to mobilize the bed. (i.e., it is lost to vegetation, immovable bed elements, and other factors). Therefore, the estimates of flow at incipient motion produced here likely underestimate the flow required to mobilize the bed for both with-Project and without-Project conditions. Total critical shear stress for with-Project estimates was calculated for a Shield's number selected on the basis of observations of tracer gravel movement within the J.C. Boyle peaking reach at the USGS gauge study site (0.059). The total critical shear stress for the without-Project estimates was an experimentally derived Shield’s number generated for studies on gravel-bed systems (0.047). The critical shear stress was used to determine the flow depth required to mobilize the bed. The following equation was applied for each cross section at each study site to determine that depth:

$$h_i = \frac{\tau_{*c}(\rho_s - \rho_w)gD_{50}}{(\rho_w gS)}$$

where:

h_i is the depth of flow required to mobilize the bed (depth at incipient motion)
τ_{*c} is the Shield's number at mobilization
ρ_s is the density of sediment (varies by sediment type)
ρ_w is the density of water (1,000 kg/m^3)
g is gravitational acceleration (9.81 m/s^2)
D_{50} is the median grain size
S is the average local water surface slope at the study reach

Using the calculated depth of flow required to mobilize the bed, the flow cross-sectional area was calculated (assuming the depth was above the geomorphic surface where the substrate D_{50} was determined).

Next, the average flow velocity for each cross section was calculated using Manning's equation (Chow, 1964):

$$u = \frac{(R^{2/3}S^{1/2})}{n}$$

where:

u is the average velocity
R is the hydraulic radius of the cross section
S is the local water surface slope at the cross section
n is the Manning's roughness coefficient

The Manning's roughness coefficient was back-calculated for study sites located at USGS gauges. These values were applied to ungauged study sites based on site conditions.

Finally, the discharge required to mobilize the bed was calculated as the product of the cross-sectional area and the flow velocity. The frequency of bed mobilization for both with-Project and without-Project hydrology and with-Project and without-Project median grain size were compared and are presented as ratios for each study reach in section 6.7.13.

The frequency of bed mobility was determined using mean daily flow data from water years 1968 to 2001. The hydrology data used in this analysis are summarized in Table 6.4-2.

With-Project hydrology and without-Project hydrology were developed for each study site. With-Project hydrology data consists of USGS gauge data, Pacificorp's spill data (J.C. Boyle bypass and Copco No. 2 bypass reaches), and partitioned flows for study sites not located at a USGS gauge. The partitioned flow data were developed by interpolating a watershed area for each study site based on the watershed areas of the USGS gauges located upstream and downstream of the study site. The flow at the ungauged study site was then calculated as a percent of the accretion between the USGS gauges.

Table 6.4-2. Summary of hydrology data.

Study Site	Source of Hydrology Data	Daily Flow Data Water Years 1968 – 2001[1]	
		With Project	**Without Project**
Link River	USGS gauge data	X	X[2]
Keno	USGS gauge data	X	X[2]
J.C. Boyle Bypass - Upstream of Blowout	PacifiCorp spill data/Partitioned USGS gauge data	X[3]	X[3]
J.C. Boyle Bypass - Downstream of Blowout	PacifiCorp spill data/USGS gauge data	X[4]	X[4]
J.C. Boyle Peaking - USGS Gauge	USGS gauge data	X	X
J.C. Boyle Peaking - BLM Campground	USGS gauge data	X[5]	X[5]
J.C. Boyle Peaking - Gorge	USGS gauge data	X[5]	X[5]
J.C. Boyle Peaking - Shovel Creek	Partitioned from gauge data	X	X
Copco No. 2	PacifiCorp spill data / Partitioned USGS gauge data	X	X
Downstream of Iron Gate Reservoir - USGS Gauge	USGS gauge data	X	X
Downstream of Iron Gate Reservoir – R-Ranch	Partitioned USGS gauge data	X	X
Downstream of Iron Gate Reservoir - I-5 Rest Area	Partitioned USGS gauge data	X	X
Downstream of Iron Gate Reservoir - Tree of Heaven Campground	Partitioned USGS gauge data	X	X
Downstream of Iron Gate Reservoir - Seiad Valley-Hardy Site	Partitioned USGS gauge data	X	X
Downstream of Iron Gate Reservoir – Seiad Valley at USGS Gauge	USGS gauge data	X	X

X = Data applied to determination of frequency of threshold of bed mobility.

[1] Data missing from period of record: October 1, 1971, to October 2, 1974; October 1, 1979, to October 2, 1982; and October 1, 1987, to January 2, 1990.

[2] Without-Project hydrology is assumed to be the same as with-Project hydrology.

[3] With-Project hydrology is assumed to be equal to the PacifiCorp spill data. The without-Project hydrology is assumed to be 200 cfs less than the flow at the J.C. Boyle USGS gauge.

[4] With-Project hydrology is assumed to be equal to the PacifiCorp spill data plus 200 cfs to account for spring contributions. The without-Project hydrology is assumed to be equal to the J.C. Boyle USGS gauge.

[5] With- and without-Project hydrology is assumed to be equal to the hydrology at the J.C. Boyle USGS gauge.

The without-Project daily flow estimates were developed using a "daily change in storage method" for the J.C. Boyle peaking reach study site at the USGS gauge, the study site downstream of Iron Gate dam at the USGS gauge near Bogus Creek, and the study site at the USGS gauge at Seiad Valley. "Without-Project" is a hypothetical concept by which the impact of daily change in storage in Project reservoirs (J.C. Boyle, Copco, and Iron Gate) on river flow rates is estimated and controlled. The purpose of this effort was to separate out the impacts of Project operations, while leaving intact in the record any other upstream anthropogenic impacts, such as USBR and irrigation activities.

The “daily change in storage method” relies on daily reservoir water surface elevation information provided by PacifiCorp and average daily stream flow data obtained from USGS gauges (J.C. Boyle, Iron Gate, and Seiad Valley). A daily change in storage for each reservoir was estimated by first calculating the total reservoir storage for each day of the record and then subtracting the total storage for a prior day from the total reservoir storage (in acre-feet) for the day of interest. The resulting daily change in storage was then converted to an average daily flow (cfs) and added to or subtracted from the published USGS average daily flow rate for that day.

Because the coordination of data from one reservoir to the next at a daily time step is imperfect and may lead to misleading estimates of without-Project flow, the daily data set produced from this change-in-storage without-Project method was smoothed with a 3-day moving average. This smoothing technique largely eliminated potential over- or under-correction resulting from sub-daily time shifts between reservoirs. Several hours of delay caused by instream travel time may exist between reservoir locations and/or stream gauge sites; thus, observed changes in reservoir storage (or reservoir outflow) may not be transmitted entirely within the same day to downstream reservoirs or gauging stations. It is impossible to otherwise remove these sub-daily time shifts in a daily flow record. The estimated routing time shift for the reach between Iron Gate dam and the Seiad Valley gauging station was estimated at 1 day and controlled for in the without-Project estimate.

Without-Project daily flow estimates for the USGS gauge at Link River and Keno were not developed as part of this study. From 1992 to the present, operational directives due to ESA objectives effectively removed any control PacifiCorp had over Link River dam operations and Upper Klamath Lake water surface elevations. Before 1992, PacifiCorp (formerly COPCO) had an agreement with USBR for shared control over the Link River dam facility. For the years of shared control, the analysis period prior to 1992, it is generally understood by Klamath River basin experts that PacifiCorp was the junior partner to USBR with respect to control over dam releases and lake level in Upper Klamath Lake. Because of the shared control over Upper Klamath Lake storage and downstream river flows, it is impossible to generate an estimate of a without-Project hydrograph that controls for the impact of only PacifiCorp operations. In addition, the process of determining anthropogenic impacts on flows in the Link River (via the change in storage method described above) is further complicated by the seasonal changes in storage observed for most natural lakes.

Impacts from change in storage behind Keno dam, Lake Ewauna, have also been omitted from this analysis. Keno dam has historically been operated as a run-of-river facility, with very little change in water surface elevation or storage from day to day. PacifiCorp does not regulate Lake Ewauna water surface elevations for the benefit of hydropower production, but rather to control a steady water surface elevation for the benefit of upstream water users. The data for the 35-year period evaluated (1966-2000) indicate that the Lake Ewauna water surface elevation had a typical range of variation limited to plus or minus 0.2 foot from the average over the entire period of record (0.21 foot is one standard deviation from the mean lake elevation).

6.4.14 Bed Load Transport Rate

Three bed load transport models—Meyer-Peter and Muller (1948), Bagnold (1980), and Parker (1990)—were explored as a means of estimating average annual bed load transport for each cross section at each study site. Each of these models is described briefly in the following subsections, with references to literature that fully documents each model. As noted by authorities such as the American Society of Civil Engineers (Vanoni, 1975), different bed load transport formulas with the same hydraulic input data can yield results differing by several orders of magnitude. Moreover, these equations assume an infinite supply of bed material available for transport, i.e., wherever the current applies adequate force on the bed to move the specified size, it is assumed that mobile material is available. In fact, steep, bedrock-controlled rivers like the Klamath are commonly supply limited, and much of the energy potentially available to transport sediment is instead dissipated in friction on bedrock irregularities, boulders, and so forth. Thus, to provide a more reliable basis for estimating bed load transport rates, tracer gravel studies and direct sampling of bed load was initiated, as described in sections 6.4.11 and 6.4.12. However, the relatively low flows during the study period (2002 and 2003) provided only one opportunity to sample (and a relatively low flow). To provide some basis to assess relative differences in bed load transport with and without the Project, one of the three models (the Meyer-Peter Muller equation) was used to estimate with-Project and without-Project bed load transport rates, which were also considered in the sediment budget.

6.4.14.1 Meyer-Peter Muller

The Meyer-Peter Muller equation was used to calculate the bed load transport rate for each cross section at each study reach for both with-Project and without-Project hydrology and bed material composition, as described in section 6.4.12. The Meyer-Peter Muller equation (below) is a bed load formula based on the median grain size that estimates a transport rate per unit width as a function of excess shear stress.

$$q_b = 8\left[\left(\frac{\rho_w gRS}{(\rho_s - \rho_w)gD_{50}}\right) - \tau_{*c}\right]^{1.5}\left[\left(\frac{\rho_s}{\rho_w} - 1\right)gD_{50}{}^3\right]^{1/2}$$

where:

q_b is the bed load transport rate (m^2/s)
ρ_w is the density of water (1,000 kg/m^3)
g is gravitational acceleration (9.81 m/s^2)
R is the hydraulic radius (m)
S is the slope (dimensionless)
ρ_s is the density of sediment (2,650 kg/m^3)
D_{50} is the median grain size (m)
τ_{*c} is the Shield's number at mobilization (dimensionless)

For sites with tracer gravel results, Shield's numbers were back-calculated and used in the sediment transport model. A bed load transport rating curve was developed for each cross section at each study site for a range of flows between the flow at the threshold of motion and the highest recorded flow for the period of record. The bed load transport rates per unit width were multiplied by the channel width estimated to be covered by mobile bed material (as distinct from the relatively immobile boulders and interlocked cobbles characteristic of much of the bed), which were estimated to be 10 percent of the channel width corresponding to each flow (as described in section 6.4.13) unless local conditions were significantly different, yielding channel-wide bed load transport rate in cubic meters per second (cms). This value was converted to bed load transport by weight (tons per day). The rating curves were then applied to the with-Project and without-Project hydrology to estimate the average annual bed load transport rates (tons per year) for each cross section and an average for each study reach. Because these transport rates were calculated from an equation assuming infinite sediment supply, they are theoretical bed load transport capacities, rather than actual bed load transport rates as would come from the sampling program.

A theoretical bed load transport capacity was calculated for each cross section for use in the sediment budget using with-Project hydrology. As most of the existing bed is coarse and probably immobile most of the time, the average median grain size (34.16 mm) measured from the primary tributaries was used as input to the model, to better reflect the probable size of the population of mobile sediment. These bed load transport rates were calculated using mean daily flows for all study reaches except the J.C. Boyle peaking reach, where hourly flow data were also used to identify potential bed load transport rate differences resulting from peaking that would not be captured using mean daily flows.

6.4.14.2 Bagnold

The Bagnold equation relates excess stream power to bed load transport. As described in the introduction to subsection 6.4.13, this model was not applied in the final analysis.

6.4.14.3 Parker

Parker's ACRONYM models include a series of computer programs for computing bed load transport in gravel rivers. As described in the introduction to subsection 6.4.13, this model was not applied in the final analysis.

6.4.15 Sediment Budget

A sediment budget for the Project area was developed using the various study reach measurements and observations, together with the insights gleaned from the aerial photograph analyses, sediment sampling, tracer gravel studies, and reservoir sedimentation studies. The bed load transport rates calculated for the without-Project bed condition and the with-Project hydrology (section 6.4.14) were also used in the development of the sediment budget. The sediment budget describes sediment production and routing through reservoirs and river reaches in the Project area, provides a framework to describe the relative importance of various sediment sources, and thereby provides a basic framework within which the relative magnitude of Project effects can be evaluated.

Following the protocol of Reid and Dunne (1996) for development of sediment budgets, a qualitative characterization of the Klamath River basin in the Project area was first developed, through which processes and influences important to determining channel character were identified. The qualitative characterization for the sediment budget was based on Project geomorphologists' map and field reconnaissance of channel characteristics, hillslope and tributary basin forms, sediment sources, geologic controls on channel gradient, and location of dams (sediment sinks). The pre-existing quantitative data were few. A previous USFS study systematically measured landslides and estimated sediment yields for the Salmon River, which joins the Klamath well downstream of Iron Gate dam and below the study area (de la Fuente and Haessig, 1993). These estimates were later calibrated by observations during the 1997 runoff year. No sediment yield data were available for tributaries upstream, and this lack of data was a concern, especially upstream of Cottonwood Creek where the geology changes to volcanic Cascades and Modoc provinces. Accordingly, collecting data on sediment yields from the upstream basin was a priority, and an initial reservoir sedimentation study measured mostly fine-grained sediment deposited along the axis of the reservoirs, but uncertainties in the pre-Project topography (based on old maps with coarse contours) resulted in large uncertainties in the results. (With the large areas involved, a difference in thickness of a few inches would make a large difference in total sediment yield.) Moreover, this initial survey did not provide data on the bed load sediments entering from the tributaries. Some of the tributaries entering Iron Gate reservoir have well-developed deltas, whose growth can be documented on aerial photographs. By measuring these delta deposits, sediment yields for the tributaries were obtained. These tributary sediment yields constituted the single best source of data on sediment yields and the most empirically based component of the sediment budget.

In addition, GIS layers of topography, watershed areas, and stream networks obtained from the Klamath National Forest and USGS were used to develop contributing areas of different estimated sediment yields. Unfortunately, without good empirical data on sediment yields for watersheds downstream of Cottonwood Creek, little basis besides professional judgment and local observations of erosion and deposition processes were available to estimate yield downstream of Cottonwood Creek. The tributary delta surveys provided the primary means of estimating sediment yields for tributaries draining the volcanic terrain upstream of Cottonwood Creek.

The sediment budget was constructed for discrete “cells” along the length of the river, with boundaries corresponding to primary sediment traps (Project reservoirs) and other important changes, using the basic sediment budget equation:

$$I + dS = O$$

where:

I is input:

For each cell, inputs were defined as sediment added from tributaries, sediment carried from upstream in the river, and sediment directly contributed from slopes. Tributary delta surveys allowed extrapolation of tributary inputs to all tributaries in the Project area (see Tributary Delta Survey Final Report). A schematic diagram showing the location of sediment inputs and transport capacity calculations was created for each Project reach. Based on a study of tributary deltas, the sediment delivery to the mainstem ranges widely among tributaries. One of the principal factors controlling sediment delivery to the mainstem appears to be the tributary channel gradient, especially the presence of low gradient reaches in which sediment can be deposited. Based on analysis of 1:24,000-scale maps, each tributary in each reach was assigned a rating of low, medium, or high based on its level of connectivity to the mainstem Klamath River. This rating was based on the following properties:

- Slope
- Presence of significant depositional zone in upstream reaches
- Presence of depositional zone immediately prior to entering the mainstem

For each unmeasured tributary, the most appropriate (as determined by proximity to tributary and geologic similarity) sediment yield value from the tributary delta surveys at Scotch, Camp/ Dutch, Jenny, and Spencer creeks was weighted for connectivity and multiplied by watershed area to estimate sediment input for the tributary. Scotch, Camp, and Dutch creeks had a yield of 197 tons/mi^2/yr, which was considered a high sediment yield for the upper basin based on the extent of their delta deposits. Tributaries with high channel gradients and without depositional zones were considered to be well connected and were assigned a weight of 1.0—i.e., their sediment yield was assumed to be the same as that measured for Scotch/Camp/Dutch creeks. Tributaries with shallower slopes and/or some depositional zones upstream were classified as medium in connection, and were assigned a weight of 0.5—i.e., their sediment yields were assumed to be 0.5 of that measured for Scotch/Camp/Dutch creeks. Tributaries with low connection to the mainstem were assigned a weight of 0.25. For watersheds downstream of Cottonwood Creek, the sediment yield from the Salmon River (450 tons/mi^2/yr) was applied (de la Fuente and Haessig, 1993).

As outlined in section 6.4.10, direct sediment input from slopes was estimated for each reach based on an aerial photograph assessment of landslides. The quantity of sediment estimated from these sources was relatively low compared to the amount of sediment delivered by tributaries. In addition, estimates of sediment contributed directly from slopes have been completed for major erosion sites (e.g., near emergency spillway in J.C. Boyle bypass reach). An estimate of sediment inputs from landslides observed in the field indicated that only very small quantities of sediment in the mainstem are derived from this source in the Project area.

Theoretical transport capacities were used to determine potential inputs from upstream reaches (for many of the reaches in the sediment budget, this input is captured in an upstream reservoir).

dS is change in storage:

Changes in storage are primarily reservoir sedimentation, bank erosion or deposition, and inferred aggradation/degradation.

O is output:

Outputs are sediment transported downstream from the cell and are expressed as the average annual theoretical transport capacity for each reach (see section 6.4.14).

The completed sediment budget presents inputs as total average annual sediment yield in each reach. Outputs from discrete cells (and therefore inputs to downstream cells not obstructed by dams) were determined using the average annual theoretical transport capacity for each reach. The change in storage for each reach was presented in the sediment budget as potential sediment deficit or surplus for the reach. Sediment inputs were also compared to theoretical minimum and maximum annual transport capacities to identify important changes in sediment transport dynamics through time.

6.4.16 Estimating Downstream Extent of Project Impact

Past studies of the Klamath River downstream of Iron Gate dam have failed to adequately address the downstream extent of the Project impact on sediment transport and fluvial geomorphology (see review of previous studies in section 6.7.4). This study attempted to identify the downstream extent of Project impact using the following two analyses:

- Quantification of alluvial features with distance downstream of Iron Gate dam

- Quantification of contributing watershed area and approximations of flow and sediment input with distance downstream of Iron Gate dam

6.4.16.1 Alluvial Features Quantification

Active alluvial features (e.g., bars, islands) were identified using the most recent and best resolution aerial photographs of the Klamath River between Iron Gate dam and Seiad Valley. The photographs were delineated by hand onto USGS topographic maps (1:24,000 scale). Features were delineated as active alluvial features if they met the following criteria:

- An elevation within the range of regular (i.e., 2- to 5-year return interval) flow events
- Scoured appearance or presence of relatively clean sand, gravel, and cobble composition
- Lack of vegetation or presence of immature vegetation in a linear alignment.

Submerged bars visible on the aerial photographs were also delineated as active alluvial features. The alluvial features were digitized with GIS using USGS topographic maps (1:24,000 scale) as base maps, and the area of each digitized feature was calculated. The areas were summed over each river mile between Iron Gate dam and Seiad Valley. The valley bottom width was also calculated at each alluvial feature as an indicator of geologic control on deposition. These widths were averaged for each river mile.

6.4.16.2 Watershed Area Quantification and Approximations of Flow and Sediment Input with Distance Downstream of Iron Gate Dam

The watershed area of the Klamath River basin was assembled in GIS. The USGS Hydrologic Units were used as the underlying layer, which was refined with finer scale data. Lost River and Butte Cataloging Units were eliminated from the total watershed area as they do not contribute significant flow to the Klamath River basin because of irrigation diversions. Downstream of Upper Klamath Lake, finer scale watershed areas delineated by the Klamath National Forest were used. For the J.C. Boyle reach, the Klamath National Forest layer was further refined by either digitizing subwatersheds on screen using USGS topographic base maps (1:24,000 scale) or running a watershed area algorithm with 30-m Digital Elevation Model data from the USGS National Elevation Dataset. The total watershed area calculated from the various sources above is within 30 square miles of the published USGS watershed area for the Klamath River near the Klamath, California, USGS gauge (No. 11530500), which is located approximately 5 river miles from the mouth of the river. The cumulative watershed area was calculated for the entire watershed and from Iron Gate dam to the mouth.

Sediment yields were applied to the delineated watersheds below Iron Gate dam to approximate the Project impact on the sediment supply. Sediment yields from tributary delta surveys were applied to the watersheds upstream of Cottonwood Creek (191.7 tons/mi^2/yr), and a sediment yield from the Salmon River (450 tons/mi^2/yr) (de la Fuente and Haessig, 1993) was applied to watersheds downstream of Cottonwood Creek. Cumulative sediment yield by river mile was plotted to illustrate the Project impact downstream of Iron Gate dam. The resulting cumulative sediment yield was developed using limited data and is, therefore, a very coarse estimate of the sediment yield for the watershed.

The average annual discharge and average annual peak discharge data from USGS gauges downstream of Iron Gate dam were compared to illustrate the Project impact on flows in the Klamath River basin downstream of Iron Gate dam.

6.4.17 Geomorphology Assessment of Project Impacts on Cultural Resources Sites Methods

Project geomorphologists and cultural resources consultants participated in a 3-day site visit to the Klamath River with representatives of the Klamath, Shasta, Karuk, and Yurok tribes. The objectives of the trip included:

1. Information-sharing with members of the Cultural Resources Working Group to provide a general overview of the goals, objectives, methods, and results of the geomorphology studies

2. Information-sharing with Project geomorphologists regarding locations, characteristics, and extent of sensitive cultural resources sites

3. Information-sharing with Klamath River cultural resources consultants, stakeholders, and tribal representatives regarding hydrology, geomorphology, and potential impacts of Project facilities and operations on hydrologic and geomorphic processes

4. Semiquantitative assessment of potential Project impacts at several specific cultural resources sites of concern

5. Discussion of additional studies required to more accurately characterize potential Project impacts on cultural resources areas

The first day of the trip included mostly qualitative investigations upstream of Iron Gate dam. Specific sites visited on the first day included Lake Ewauna near Washburn Road, J.C. Boyle reservoir at the Spencer Creek confluence, and two sites in the J.C. Boyle peaking reach. The second day of the trip included similar investigations, primarily between Iron Gate dam and the Shasta River confluence. Specific sites on the second day included the Osburger Site downstream of Iron Gate dam, the USGS flow gauge at the Iron Gate fish hatchery, the confluence of the Shasta and the Klamath rivers, and the confluence of Ash Creek with the Klamath River. The final day of the trip included purely qualitative investigations of sites between 50 to 100 miles downstream of Iron Gate dam. Specific sites on the final day of these investigations included the Ukanom Creek confluence, the Rock Creek confluence, the Ishi Pishi Falls area, and the Fish Camp area. The results of these site investigations are summarized in section 6.7.17.

6.4.18 Linkage of Data Collection and Analysis Tasks

The linkages between various data collection and analysis tasks described in this section are outlined in the following flow diagram (Figure 6.4-2). The intended results and outcomes of the analyses include an assessment of potential Project effects on channel sediments and channel form and development of PM&E measures (such as gravel augmentation) for recommendation in PacifiCorp's license application.

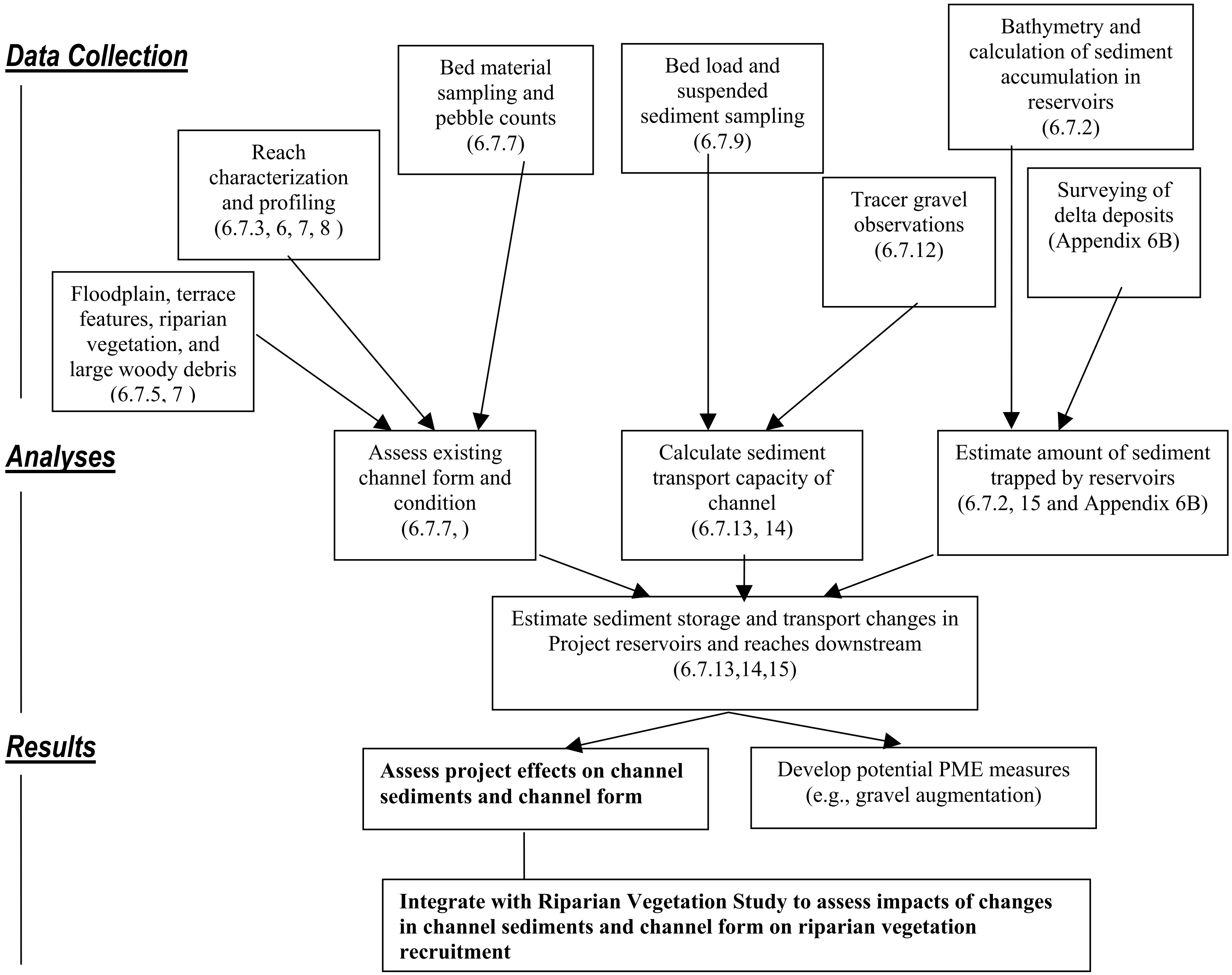

Figure 6.4-2. Flow diagram showing links between data collection and analyses tasks in this technical report.

6.5 RELATIONSHIP TO REGULATORY REQUIREMENTS AND PLANS

This study helps PacifiCorp address certain regulatory requirements and planning objectives related to Project effects on sediment transport and river geomorphology. The information derived from this study is used to address FERC requirements (18 CFR 4.51 and 16.8) for information on water uses in the Project area. It also provides geomorphology information as needed to support analyses of water quality, riparian vegetation, and fisheries resources.

The information in this study is used as necessary to address compliance with management objectives from various resource agencies, tribes, and other stakeholders. Such objectives relate to flow and channel protection and to the flows needed to support water quality, fisheries, and riparian resources. This information also will help PacifiCorp and stakeholders develop PM&E, measures to meet the intention of these regulations and management objectives.

6.6 TECHNICAL WORK GROUP COLLABORATION

This study was developed through a collaborative process between PacifiCorp and interested stakeholders. Several meetings and conference calls with stakeholders have been held to discuss various elements of this study. At the general recommendation of GSG participants, PacifiCorp agreed to engage the GSG for review and comment at key points during this study, including the selection of study reaches for field data collection and field data collection methods. In addition, PacifiCorp agreed to seek review and comment on geomorphic analyses, particularly sediment budget development and the linkage between geomorphology and riparian vegetation effects (such as riparian vegetation encroachment and recruitment).

PacifiCorp has worked with stakeholders to establish a more collaborative process for planning and conducting studies needed to support Project relicensing documentation. As part of this collaborative process, an Aquatic Resources Work Group was formed and meets approximately monthly to plan and discuss aquatic resources studies and results, including this study on geomorphology and sediment transport. The Aquatic Resources Work Group provides a logical continuation of the GSG process being conducted and planned to discuss and review specific aspects of this study on geomorphology and sediment transport.

6.7 RESULTS AND DISCUSSION

6.7.1 Geomorphic Setting

The Klamath River begins in Upper Klamath Lake, flows down a steep bedrock reach into the basin occupied by Lower Klamath Lake, and from there through the Cascade and Klamath Mountains to the Pacific Ocean. Prior to 1900, when the upper Klamath River flooded, it flowed into Lower Klamath Lake and inundated (shallowly) large areas. As floodwater receded, much of this stored floodwater would drain back into the Klamath River channel. Overflow into Lower Klamath Lake is now prevented, and the Lower Klamath Lake bed has been mostly converted into agricultural lands. The principal tributaries to the Upper Klamath River are the Williamson, Wood, Sprague, and Lost rivers. Principal tributaries to the Lower Klamath River are Shasta, Scott, Salmon, and Trinity rivers.

The geology of the Klamath River basin is varied and complex, and geology exerts a strong influence on channel form and process at large and small scales. At the large scale, the Upper

Klamath River drains a region of volcanic rocks and passes through large tectonically down-dropped valleys with relatively low relief in the Basin and Range Province, then cuts westward through volcanic rocks of the rugged Cascades Province, then through mostly metamorphic rocks of the Klamath Mountains, and finally through the Coast Range, with a broad range of rock types, many metamorphic.

The Basin and Range Province (or Modoc Province, as the California portion is termed) is a region of crustal extension via normal faulting, which has produced a series of parallel ridges and valleys, formed by uplifted and down-dropped fault blocks. The province consists mostly of basalts, which have been undergoing faulting since Miocene time. The vertical displacements are more rapid than the rate of surface erosion and deposition, so that the region is poorly drained, and much of the land area is internally drained. The valley fills consist of interfingering alluvial fan deposits, lake sediments, and young basalt flows. The Cascades Province lies to the west of the Modoc Province and consists of composite volcanoes (largely andesitic volcanic lithologies instead of the dominantly basalts of the Modoc), which reach much higher elevations. The boundary between the Modoc and Cascade Provinces is not clear, as the Basin and Range faulting extends into the Cascade lithologies, and the lithologies interfinger. Near Hornbrook, along the axis of Cottonwood Creek, there is a sharp contact between the volcanic Cascades Province and the Klamath Province. This area includes a wide range of rock types, including some highly resistant units, which are important in understanding historical land use impacts, as well as ores of gold and other precious metals. Numerous mining claims (that sought to follow mineralized veins) are visible on hillslopes, and accumulation of gold in alluvial deposits led to extensive placer mining along the river in the 19th and early 20th centuries. The lowermost 40 miles of the Klamath River (Weitchpec to the mouth) traverse the Coast Range geologic province, dominated by subduction zone lithologies, notably the Franciscan Formation.

The Klamath River channel changes character as it passes from one geologic province to the next. The channel has a low gradient in its upper reaches passing through the Basin and Range Province, with the mostly alluvial bed alternating with bedrock outcrops (such as the outcropping in the Link River channel). From Keno downstream, the Klamath River flows in a steep bedrock channel to approximately the California line, interrupted only by a short alluvial reach above J.C. Boyle dam. In the California reach above Copco reservoir, the Klamath River is alluvial, though with occasional bedrock controls. The short reach of river between Copco and Iron Gate reservoirs is steep and bedrock-controlled. Below Iron Gate, the river has alluvial features, but with frequent bedrock outcrops in the bed, and it flows through a narrow valley cut into the Cascade volcanics. The valley widens near Hornbrook and the Cottonwood Creek confluence, then narrows again as it flows along the boundary between the Cascade and Klamath Provinces. From I-5 downstream, the river cuts across the Klamath Province, and the channel is steep and bedrock-controlled, with limited accumulations of alluvium. The alluvial accumulations increase in extent with distance downstream, and they are more abundant in reaches with locally wider valley bottoms. Near Seaid Valley, the valley is considerably wider than elsewhere, and the alluvial character is most pronounced.

Thus, the Klamath River does not follow the classic concave upward longitudinal profile seen in many rivers. Instead, its headwater reaches are relatively flat (Upper Klamath Lake basin, Lake Ewauna), and its middle and lower reaches (starting at Keno) are much steeper. Likewise, the Shasta and Scott rivers, important tributaries below Iron Gate dam, have low gradient upper reaches and steep canyon-like lower reaches.

The hydrologic implications of this geologic setting are profound. The upper basin lies in the rain shadow of the Klamath Mountains and Cascade Range, and most runoff comes from the east slope of the Cascades. The basaltic volcanic rocks of the Modoc Province (and to a lesser extent lithologies of the Cascades) are highly permeable, resulting in low drainage density (i.e, much of the available water infiltrates to groundwater, the basalts and basin fills constituting a large aquifer rather than following the surficial stream network). Consequently, runoff is largely from groundwater and relatively steady. The low gradients and surface runoff contribute to a low sediment yield and thus to low sediment loads. The part of the Cascades Province traversed by the Klamath River does not include a large volcano and thus lies in the rain shadow of the Klamath Mountains. As a result of these characteristics, the Klamath River down to Iron Gate dam does not experience very large floods. The Project facilities are all located from Iron Gate dam upstream, in the Modoc and Cascades Provinces.

Once the river enters the Klamath terrain, its character begins to change noticeably, as the Klamath River receives flashy runoff and high sediment loads from tributaries. As a result, with distance downstream of Iron Gate dam, the low sediment yield and relatively steady hydrologic signature of the upstream reach is progressively “drowned out” by the flashy runoff and high sediment loads of the tributaries. For example, the Q10 (the flood occurring as an annual maximum once per decade on average) is less than 13,000 cfs at Iron Gate dam but over 60,000 cfs at Seaid Valley. The characteristics of the river downstream of Iron Gate dam are discussed in more detail in section 6.4.15.

In general, the scientific literature reports that dams can affect spawning gravels in one of two ways. When reservoirs are large enough to reduce floods, fine sediment from tributaries (and from bank erosion and other sources) can accumulate on the bed downstream because it is no longer flushed away by high flows. This fine sediment can infiltrate salmonid spawning gravels and reduce incubation success (for sediments finer than about 1 mm) or affect the ability of fry to emerge from the gravel (for sediments about 1- to 10-mm in size) (Kondolf, 2000a). This effect has been documented in many rivers, including the Trinity River below Lewiston Dam, which is notable for the present study because it is one of the best documented examples of this impact and is a downstream tributary to the Klamath (Milhous, 1982). Reservoirs whose capacity is relatively small in relation to river flow typically allow high flows to pass, while still trapping gravels supplied from upstream. Downstream of such reservoirs, the bed may progressively coarsen as smaller gravels are transported downstream without being replaced (as previously) by gravels supplied from upstream. As a result, the bed may become dominated by larger gravels and cobbles that are unsuitable for use by spawning fish (Kondolf and Matthews, 1993).

Another downstream effect of reservoirs can be changes in the distribution of riparian vegetation resulting from changes in hydrology and the availability of sediments. Reduced flood flows can result in less active bed scour, erosion, deposition, and channel migration, thereby resulting in smaller areas of fresh sediment surfaces available for colonization by seedlings of woody riparian species, but also less frequent scour and removal of seedlings from the active channel. Thus, riparian vegetation can invade formerly scoured areas of the channel bed, but over time the riparian community may tend toward older individuals and later successional stage species with less diversity of species and structure (Johnson, 1992). Even if reservoirs do not significantly affect the high flows that erode and deposit sediment, they may affect the shape of the hydrograph during the seasons that riparian seedlings would normally establish, resulting in changes in the extent of riparian vegetation establishment (Rood and Mahoney, 1990). Moreover, changes in water quality (from upstream land uses and/or transformations within reservoirs) can potentially affect the growth of riparian vegetation through supply of nutrients for plant growth. Riparian vegetation is important as a resource in its own right, especially as it can provide important habitat to terrestrial and aquatic species. It can also affect geomorphic channel processes by increasing hydraulic roughness, by inducing deposition on bars and along channel margins, and by changing the direction of flow.

Because the Project's reservoirs are relatively small compared with the river's annual runoff (e.g., Iron Gate reservoir impounds only 4 percent of annual runoff, and Copco reservoir only 5 percent,) and because the Project reservoirs are *not* operated for flood control, it is unlikely that the Project's reservoirs significantly affect high flows, except in bypassed reaches, (i.e., reaches in which flows are reduced by diversion through penstocks for hydroelectric generation, such as the J.C. Boyle bypass reach and the Copco No. 2 bypass reach). Moreover, there were significant changes in how floods were routed between Upper and Lower Klamath Lakes a century ago that are unrelated to Project operations. For example, construction of the railroad embankment (and USBR control gates) blocked flood overflow into Lower Klamath Lake, as had occurred formerly. Current USBR irrigation facilities are managed so that in a flood situation Upper Klamath Lake water can be moved to the Lost River system. Water can also be evacuated from Keno reservoir to the Klamath Irrigation Project via ADY canal. Elimination of flood overflow into Lower Klamath Lake should have *increased* the magnitude of flood flows in the Klamath River below Keno over that of conditions prevailing before the late 19th century. All these considerations suggest that coarsening of the bed has been a much more likely Project effect than accumulation of fine sediments. In bypassed reaches, the net effects of the dams would depend upon the degree to which floods of various magnitudes have been reduced, and to the base flow conditions in the reach. For example, the relatively low (10 cfs) base flow maintained in the Copco No. 2 bypass reach, combined with changes to relatively short return-interval flood flows, has resulted in significant riparian vegetation encroachment. Any such effects in the J.C. Boyle bypass reach, where the base flow is higher (100 to 300 cfs) and flood flow conditions are similar, are much more subtle.

The ongoing hydrologic analysis will provide a better basis for determining the degree to which the Project reservoirs have reduced flood peaks. However, no analyses of the effects of blocking overflow into Lower Klamath Lake on the hydrology of the Klamath River have been discovered. The initial hypothesis is that the peak-flow-related effects of the dams would be minor (except in the bypassed reaches), and therefore data collection efforts have focused on information that has helped evaluate potential sediment supply reduction and coarsening of the bed below Project facilities.

To understand the possible direct effects of the Project on sediment supply, sediment transport, and channel form, it is also necessary to understand geologic controls and the effects of other historical human influences on channel form and processes, both present and past. The Klamath River has an unusual geologic setting, with strong geologic controls on channel form, and thus the channel does not fit conventional assumptions about longitudinal profiles or downstream changes in alluvial channel form. Reflecting the geology of the reaches through which it flows, the Klamath River alternates from low gradient reaches above bedrock controls (such as near Keno dam) and steep bedrock reaches (such as Keno reach). Examples of important human effects unrelated to the Project include the diversion of flood flows from Lower Klamath Lake into the Klamath River at Keno mentioned above, the use of the river channel to float logs downstream, and the blasting of rocks from the channel to facilitate log flotation.

The conceptual model of sediment transport and channel geomorphology in the Project vicinity in depicted in Figure 6.7-1. The sediment budget results are presented in detail in section 6.7.15.

6.7.2 Reservoir Sedimentation Study

Bathymetric surveys were conducted on Lake Ewauna, Keno reservoir, J.C. Boyle reservoir, Copco reservoir, and Iron Gate reservoir in fall 2001. Additional bathymetric survey work in Keno reservoir was conducted in August 2003. A supervised sediment classification was also conducted on each of these impoundments during the fall 2001 surveys. A general assessment of the magnitude of accumulated sediment in the impoundments was conducted by comparing the current bathymetry of the impoundments with available information on pre-impoundment topography. Bathymetry study results are detailed in Bathymetry and Sediment Classification of the Klamath Hydropower Project Impoundments (Eilers and Gubala, 2003). Those results are summarized in the following subsections.

6.7.2.1 Bathymetry of Project Reservoirs

Figure 6.7-2 depicts the overall Lake Ewauna/Keno reservoir area. Bathymetric maps for the Project area are presented in Figures 6.7-3 to 6.7-7.

6.7.2.2 Unsupervised Sediment Classification

The hydroacoustic signature produces two echoes that can be analyzed separately to yield information on sediment regularity (E1:bottom smoothness) and reflectivity (E2: bottom hardness). Detailed hydroacoustic signature images of sediment regularity and reflectivity are provided in Eilers and Gubala (2003). The images for Lake Ewauna illustrate obvious differences in sediment composition in the original thalweg compared to the shallows extending up to the northeastern portion of the impoundment. The surprisingly high degree of reflectivity for much of the shallow area in Lake Ewauna may be associated with the high incident of wood fiber observed in these sediments.

In Keno reservoir, much of the impoundment was characterized by reflective, irregular substrate which is indicative of rock, possibly interspersed with some depositional material. Only in the forebay was there any indication of significant quantities of a high percentage of soft, flocculent material.

The hydroacoustic signals in J.C. Boyle reservoir indicated the presence of a high percentage of rock substrate. However, this does not include the very shallow material in the upper half of the reservoir that was not navigable during the survey work. Thus, much of the deeper portions of the impoundment comprise the original river channel that has retained much of its recognizable shape.

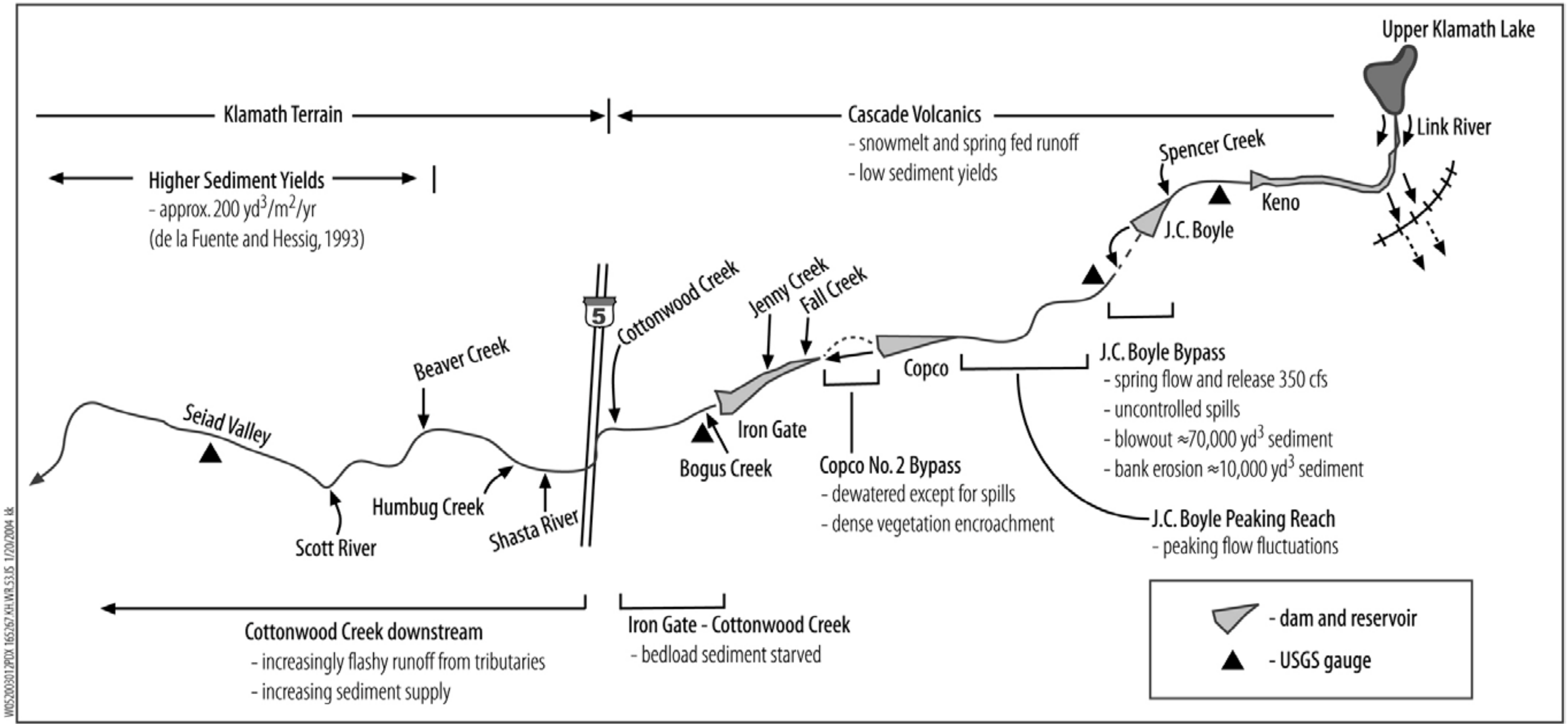

Figure 6.7-1. Conceptual model of sediment transport and channel geomorphology in the Project vicinity.

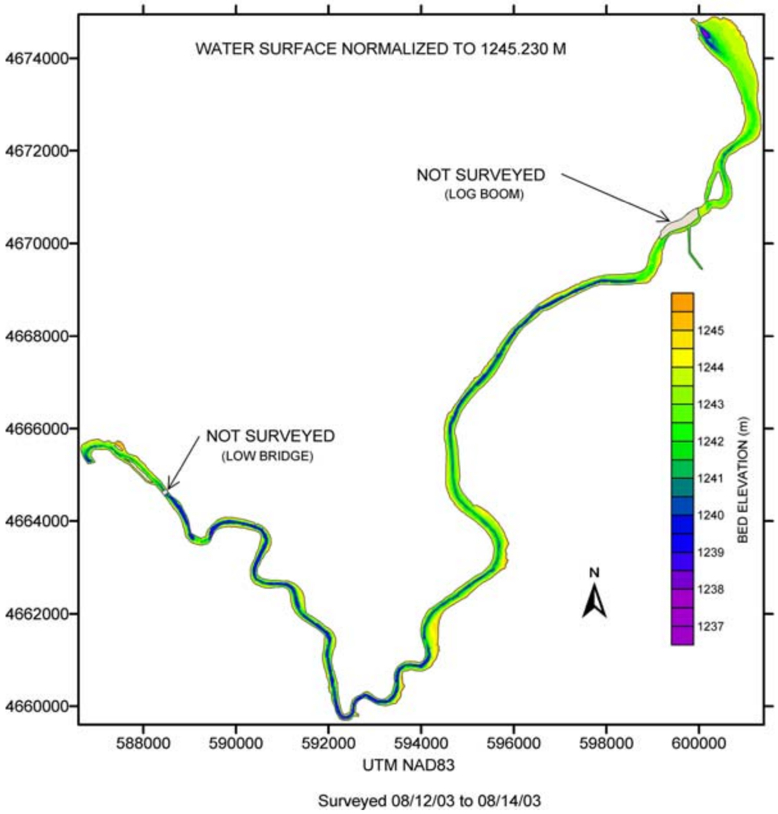

Figure 6.7-2. Bathymetric map of entire Lake Ewauna/Keno reservoir.

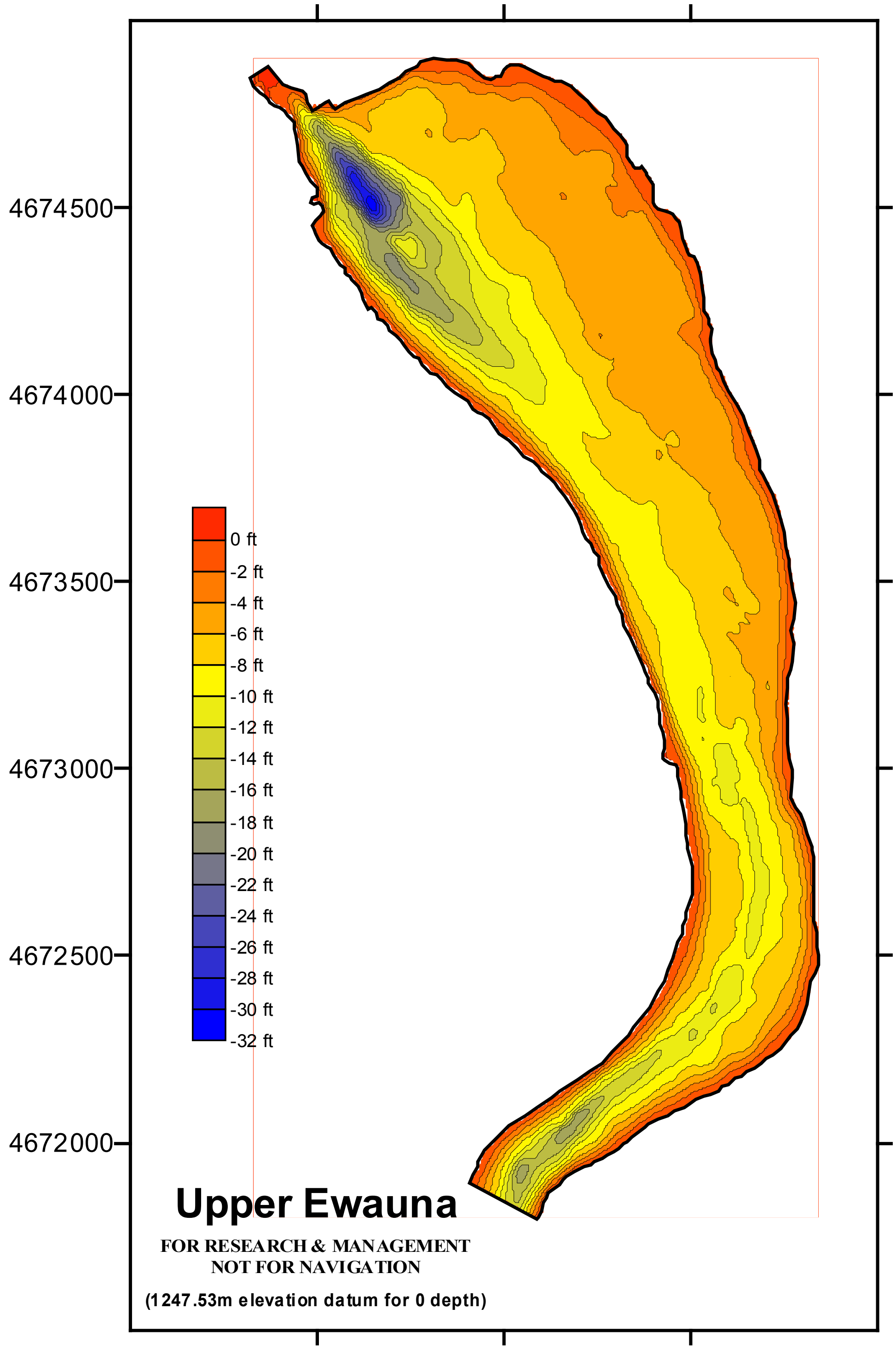

Figure 6.7-3. Bathymetric map of Lake Ewauna, Oregon.

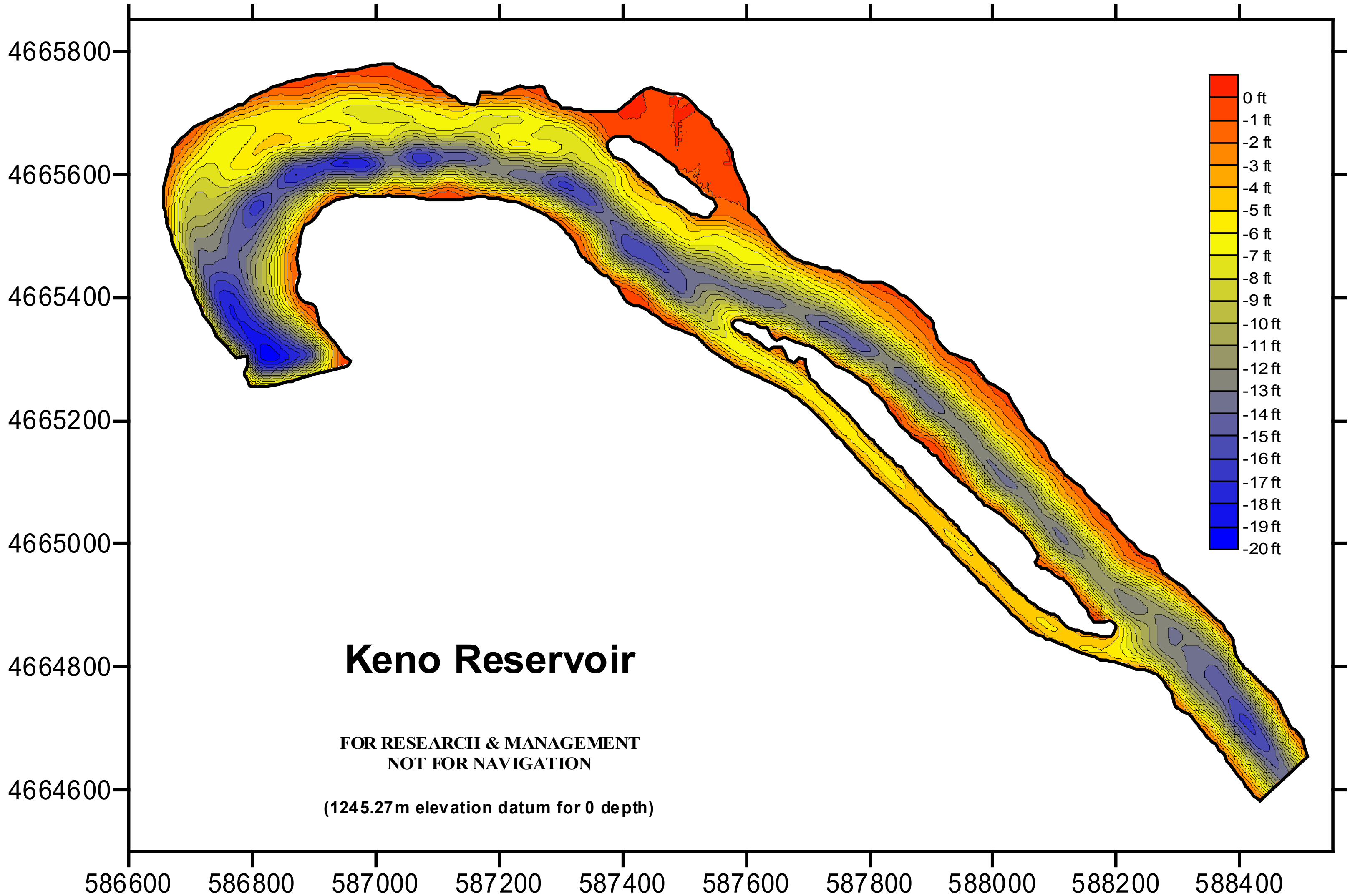

Figure 6.7-4. Bathymetric map of Keno Lake, Oregon up to the bridge at Highway 66.

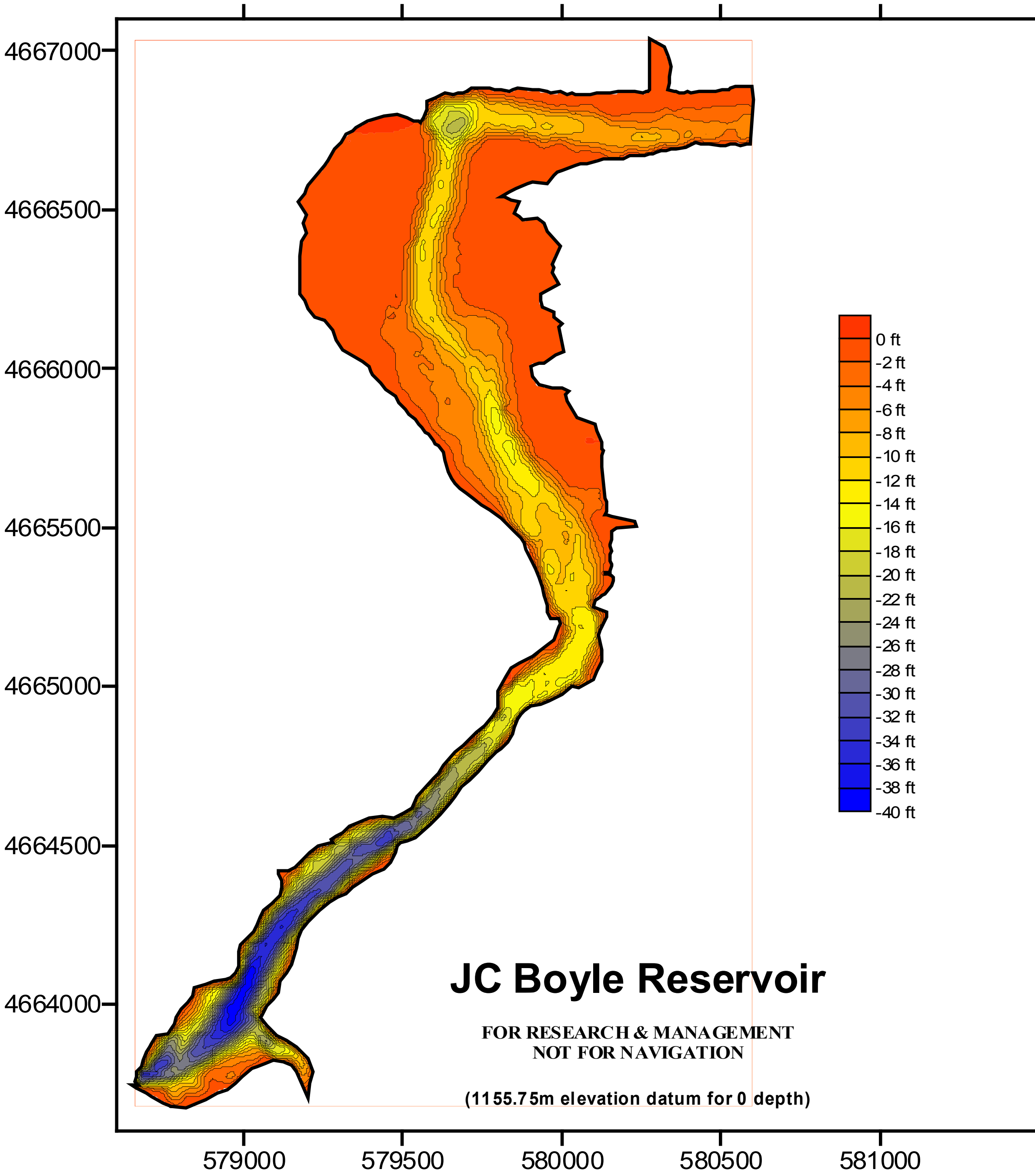

Figure 6.7-5. Bathymetric map of J.C. Boyle reservoir. The shallow areas in the north half of the lake were not navigable during the survey, and the depth in this region is estimated between zero and 2 feet.

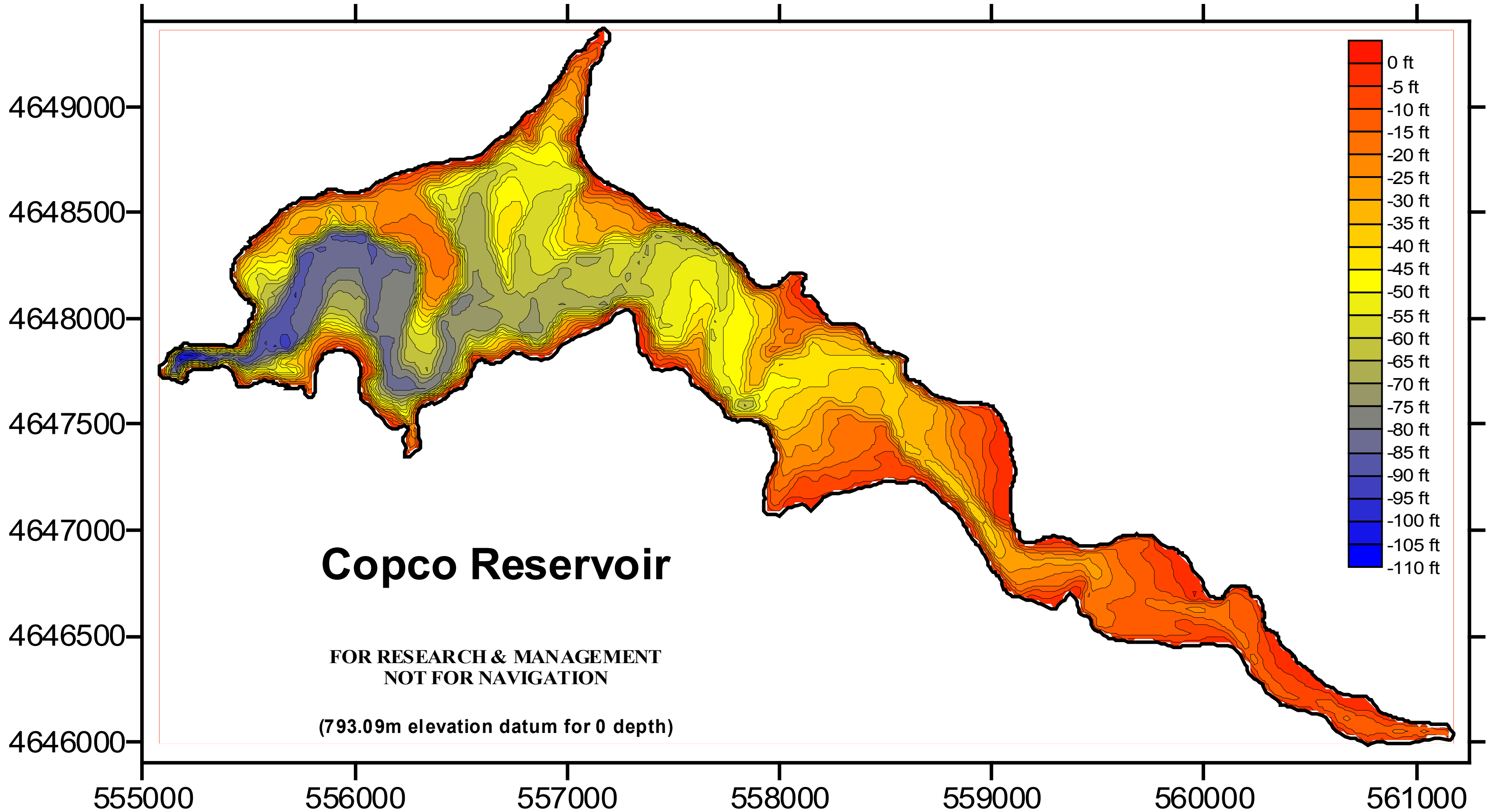

Figure 6.7-6. Bathymetric map of Copco No. 1 reservoir up to bridge crossing.

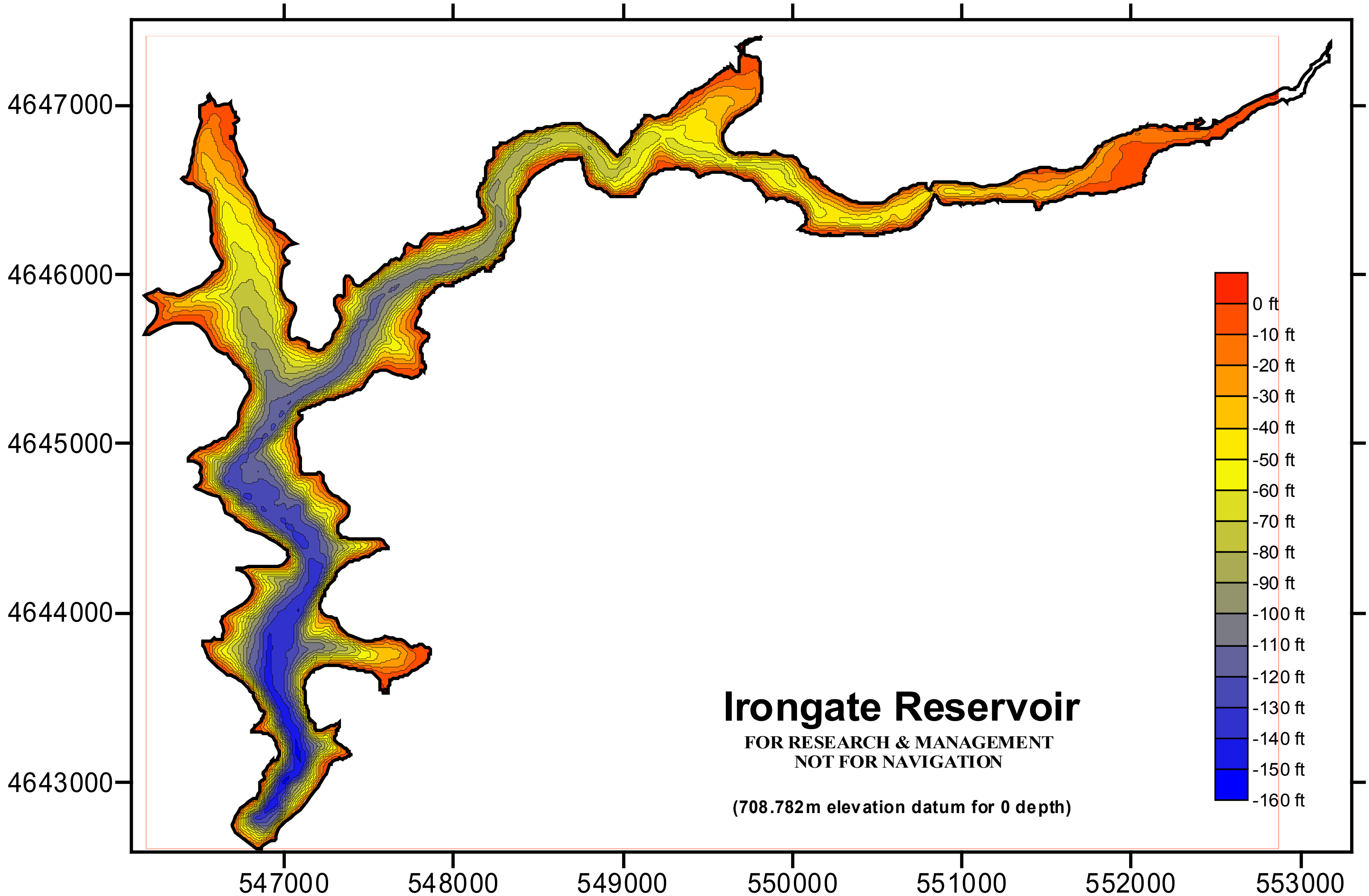

Figure 6.7-7. Bathymetric map of Iron Gate reservoir.

Copco reservoir shows considerable contrasts in substrate types, ranging from highly reflective materials on the upper portion (indicative of exposed rock) to dispersive material in the deep areas (indicative of soft sediment). This is a typical pattern observed in many reservoirs where higher velocities in the upper areas associated with inflows and exposed shorelines during lake-stage fluctuations provide little opportunity for deposition of fine particles. However, the deep, lower ends of elongate impoundments provide considerable opportunity for deposition of all but the smallest particles. A somewhat similar pattern is achieved in Iron Gate reservoir, although the bend in the upper northeast arm of the impoundment appears to offer an intermediate depositional zone prior to the main deep basin approaching the forebay.

6.7.2.3 Sediment Composition

Details on sediment sample sites and sample disposition are described in Eilers and Gubala (2003). Analytical results for all 39 sediment samples collected are presented in Table 6.7-1. The water content of the sediment samples ranged from 68 to 90 percent, with a median value of 82 percent. The water content of the sediments in these impoundments is considerably lower than those in Upper Klamath Lake (Eilers et al. 2003, in review). Low water content is indicative of a higher proportion of inorganic material in the sediments.

Table 6.7-1. Analytical results for sediment samples collected from Project reservoirs.

Lake/ Reservoir	Sample Number	TP (ppm)	C (%)	N (%)	Water (%)	C:N	N:P
Ewauna	EWA-04	734	10.6	0.95	88.3	11.13	12.96
Ewauna	EWA-05	754	8.2	0.90	90.2	9.15	11.90
Ewauna	EWA-05 bottom	269	4.8	0.52	86.7	9.38	19.17
Ewauna	EWA-07	846	10.5	0.74	87.7	14.11	8.78
Ewauna	EWA-09	815	11.2	0.95	89.1	11.73	11.71
Ewauna	EWA-09 bottom	379	7.4	0.64	87.2	11.71	16.76
Ewauna	EWA-05 anchor	349	6.6	0.56	82.0	11.92	15.94
Ewauna	EWA-07 anchor	542	13.6	0.76	84.2	17.97	14.02
Ewauna	EWA-09 anchor	534	13.5	0.75	80.4	17.92	14.05
Keno	Keno-04	639	5.6	0.56	80.5	10.14	8.70
J.C. Boyle	JCB-03	1042	9.6	1.16	87.4	8.30	11.16
J.C. Boyle	JCB-04	604	4.3	0.46	73.6	9.35	7.57
J.C. Boyle	JCB-07	686	6.8	0.72	81.7	9.42	10.50
J.C. Boyle	JCB-08	902	8.1	0.97	88.3	8.40	10.71
Copco	Copco-01	615	5.3	0.62	82.7	8.57	10.00
Copco	Copco-01 bottom	605	5.6	0.68	78.6	8.21	11.21
Copco	Copco-02 duplicate	645	5.5	0.63	83.7	8.72	9.74
Copco	Copco-01 bottom	663	5.4	0.60	79.0	9.00	9.08
Copco	Copco-04	989	6.1	0.67	85.6	9.02	6.81
Copco	Copco-04 bottom	778	6.0	0.66	80.4	9.08	8.43
Copco	Copco-05	787	6.7	0.75	85.2	8.98	9.52
Copco	Copco-05 bottom	705	6.4	0.71	80.2	9.08	10.02

Table 6.7-1. Analytical results for sediment samples collected from Project reservoirs.

Lake/ Reservoir	Sample Number	TP (ppm)	C (%)	N (%)	Water (%)	C:N	N:P
Copco	Copco-06	733	6.6	0.69	83.8	9.60	9.35
Copco	Copco-06 bottom	774	6.2	0.65	77.5	9.51	8.36
Copco	Copco-06 duplicate	738	6.8	0.72	85.0	9.43	9.77
Copco	Copco-06 duplicate bottom	696	6.7	0.73	80.5	9.26	10.47
Copco	Copco-07	665	5.6	0.60	84.2	9.31	8.98
Copco	Copco-07 bottom	637	5.7	0.63	79.8	9.09	9.88
Copco	Copco-08	899	6.9	0.76	84.1	9.17	8.40
Copco	Copco-08 bottom	723	6.3	0.62	76.8	10.08	8.60
Copco	Copco-09	825	5.9	0.59	78.9	9.92	7.15
Copco	Copco-09 bottom	690	5.0	0.48	67.9	10.39	6.95
Iron Gate	Iron-01	730	6.6	0.55	69.7	11.97	7.52
Iron Gate	Iron-02	1039	6.1	0.64	83.6	9.47	6.18
Iron Gate	Iron-02 bottom	712	4.5	0.44	73.7	10.21	6.20
Iron Gate	Iron-06	875	5.2	0.64	80.3	8.20	7.29
Iron Gate	Iron-06 bottom	822	5.8	0.71	78.5	8.19	8.64
Iron Gate	Iron-01 anchor	915	16.9	1.46	74.3	11.60	15.94
Iron Gate	Iron-03	970	4.6	0.39	75.8	11.84	3.98

TP = total phosphorus, C = carbon, N = nitrogen, C:N = ratio of carbon to nitrogen, N:P = ratio of nitrogen to phosphorus

The carbon content for the sediments ranged from 4.3 to 16.9 percent, with a median of 6.3 percent. The highest values were associated with samples obtained in Lake Ewauna that had large wood chips imbedded in the sediment. Excluding these wood-fiber samples, the sediments had relatively low carbon content, which is consistent with a higher proportion of inorganic inputs or high rates of decomposition and loss of carbon through sediment diagenesis.

The samples with low concentrations of nutrients were associated with sediment samples with a high percentage of sand. Nitrogen (N) and phosphorus (P) concentrations in the sediment are also comparatively low even when compared to carbon (C) concentrations. The ratio of carbon to nitrogen (C:N) on a percentage basis averaged 10.2 (SD 2.2), which is almost twice as great as the Redfield ratio (5.56) expected for phytoplankton (Chapra, 1997). The ratio of nitrogen to phosphorus (N:P) averaged 10.1 (SD 3.2), which is also considerably greater than the Redfield ratio of 7.2 percent.

The textural analysis of the samples illustrates that the sediment in the upper impoundments (Lake Ewauna through J.C. Boyle reservoir) typically have a greater percentage of sand based on the sites sampled (Figure 6.7-8). This spatial trend is reversed somewhat in Iron Gate reservoir where percentages of sand again increase over those found in Copco reservoir. Percentages of clay are greatest in the samples from Copco and Iron Gate reservoirs. A comparison of sediment samples from the upper 10 cm with those below 10 cm shows that the upper sediments have higher values of nutrients and water content (Eilers and Gubala, 2003, Table 4).

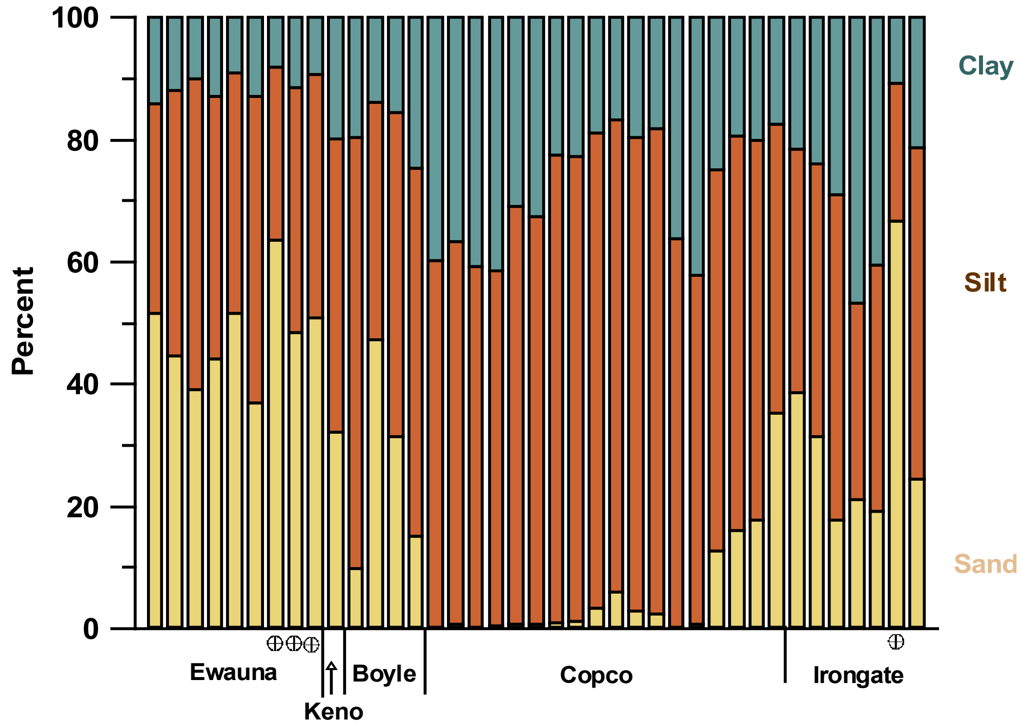

Figure 6.7-8. Textural classes of sediment samples from the Project area. The samples are arranged in the same order as shown in Table 6.7-1. Samples identified with a cross-filled circle were collected with an anchor.

6.7.2.4 Classification of Sediments in Project Reservoirs

Supervised sediment classifications were derived by integrating the hydroacoustic signals (E1 and E2) with the sediment sampling results. The resulting maps for the 50-m grid nodes illustrate major differences in sediment composition of the upper impoundments (Lake Ewauna, Keno reservoir, J.C. Boyle reservoir) with the lower impoundments (Copco and Iron Gate reservoirs). The upper systems are characterized by higher proportions of rock, sand, and silt, whereas the lower impoundments have higher proportions of silt and clay (Figures 6.7-9 to 6.7-13).

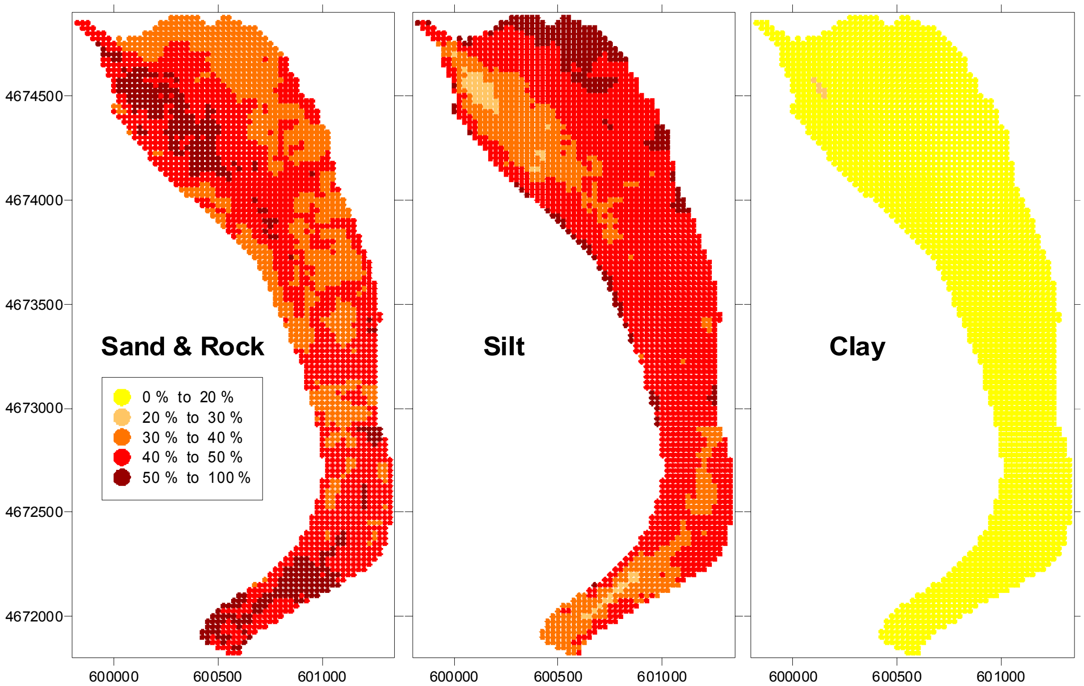

Figure 6.7-9. Acoustically classed sediments for Lake Ewauna.

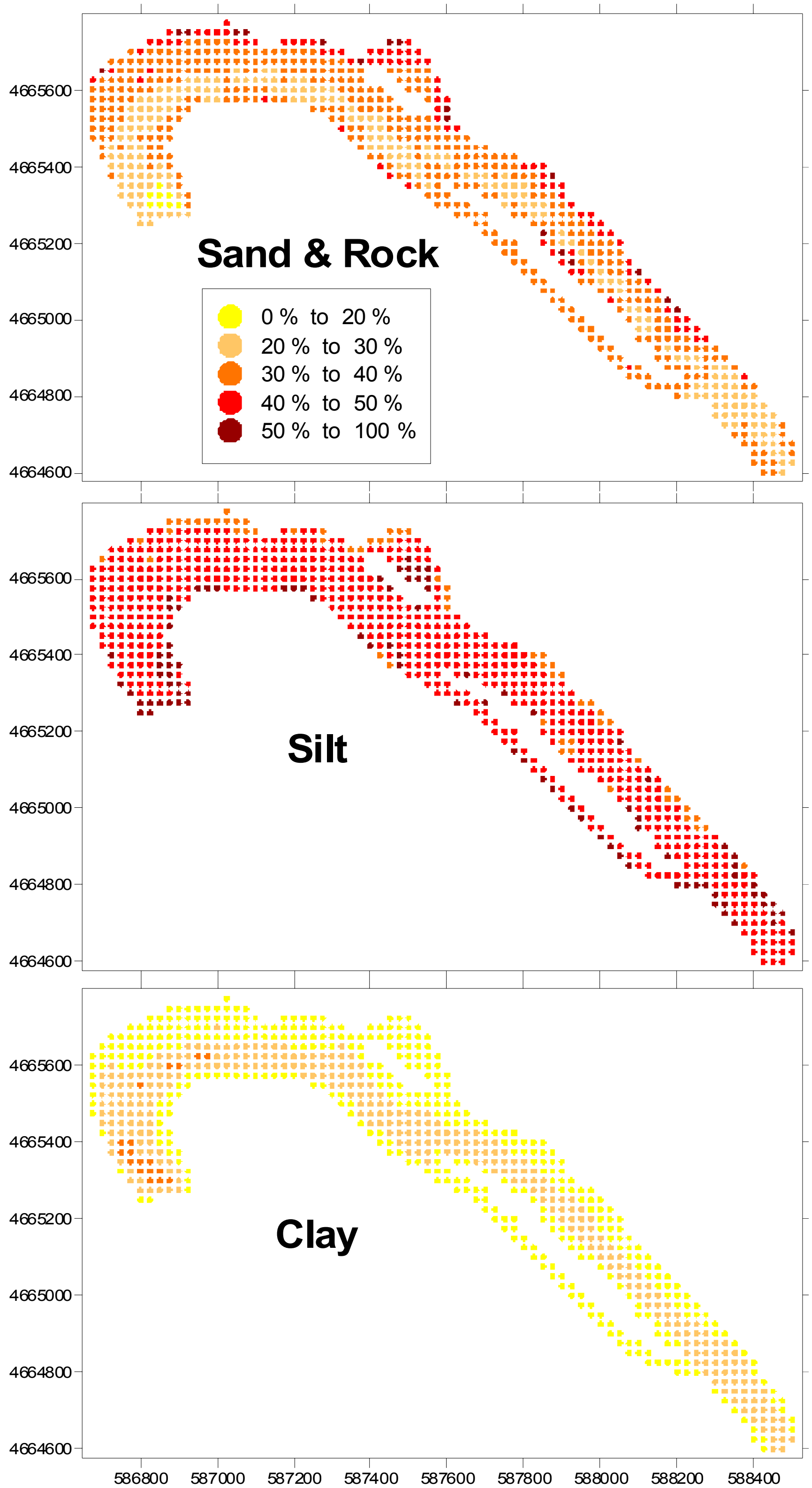

Figure 6.7-10. Acoustically classed sediments for Keno reservoir.

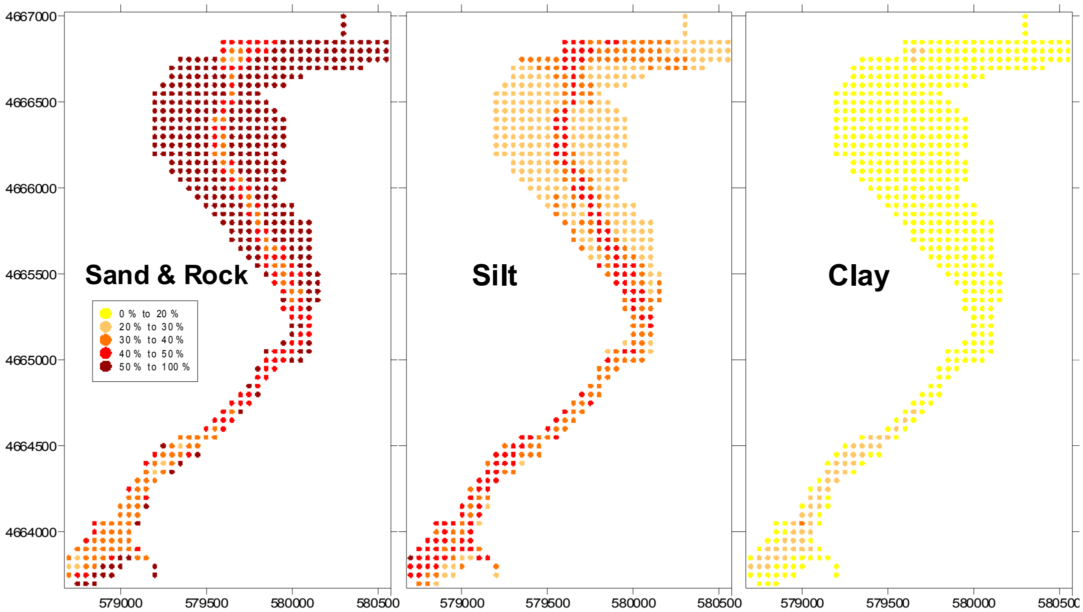

Figure 6.7-11. Acoustically classed sediments for J.C. Boyle reservoir.

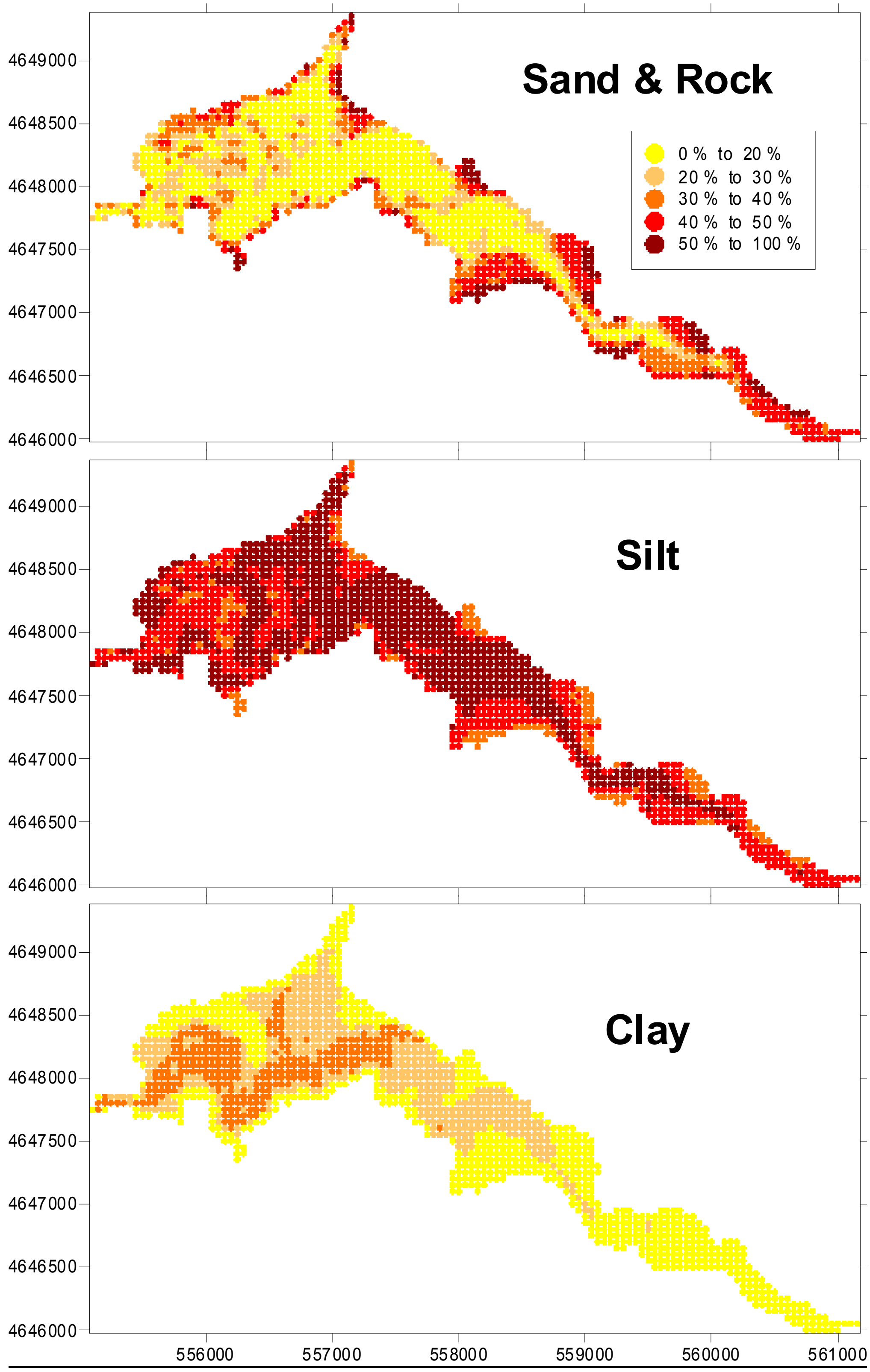

Figure 6.7-12. Acoustically classed sediments for Copco No. 1 reservoir.

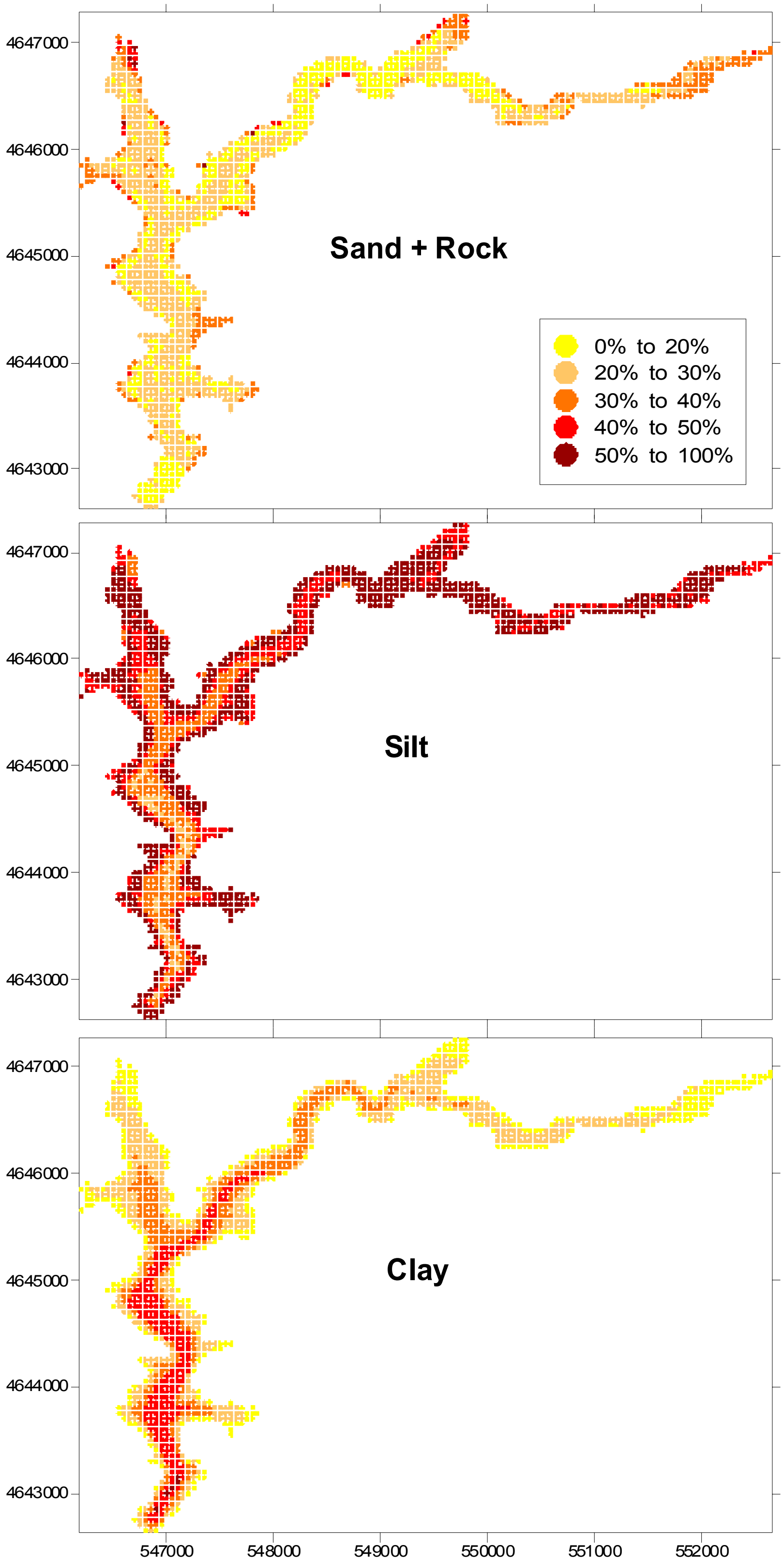

Figure 6.7-13. Acoustically classed sediments for Iron Gate reservoir.

6.7.2.5 Comparison of Bathymetry with Historical Topography

An indication of the amount of sediment accumulated in the impoundments was derived by comparing the current bathymetry with the pre-dam topography of the study sites. Pre-construction topography of the study sites was used to generate a surface that was compared with the current bathymetry. No historical topographic map was provided for Lake Ewauna, and therefore this site was not included in the historical comparison.

The estimates for loss of lake volume calculated using historical topography for the four impoundments is presented in Figure 6.7-14. The hypsographic curves of the lakes and the historic volumes for the same area were plotted and compared (Figures 6.7-15 to 6.7-18).

There is a considerable disparity in the estimates for volume loss, ranging from 0.6 percent in J.C. Boyle reservoir to 14.6 percent in Copco No. 1 reservoir. The greatest loss in volume—that calculated for Copco No. 1 reservoir—appears realistic considering that this is the oldest impoundment in the system (constructed in 1918), it is deep and has a high trapping efficiency, and it is situated in a portion of the study area with considerable topographic relief. Iron Gate reservoir would be expected to have a considerably lower degree of infilling because it is relatively recent (constructed in 1962) and is located immediately below Copco reservoir.

The values computed for Keno reservoir are also consistent with a shallow, narrow system that would likely have comparatively low trapping efficiency. The values computed for Keno reservoir are based on the bathymetry of the impoundment before dredging in the forebay began in 2002. The change in volume estimates for J.C. Boyle reservoir is low. The reason for the low infilling calculated for J.C. Boyle reservoir may be related to the nature of the historical topography, which does not show a deep channel in the northern portion of the reservoir.

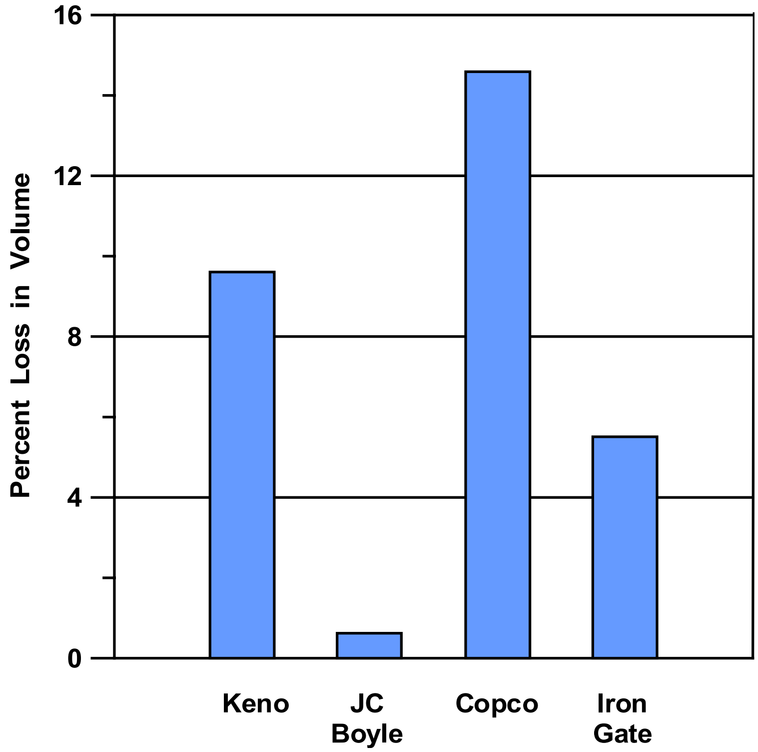

Figure 6.7-14. Estimates of loss in reservoir volume based on comparison of current bathymetry with historical topography for four of the five impoundments.

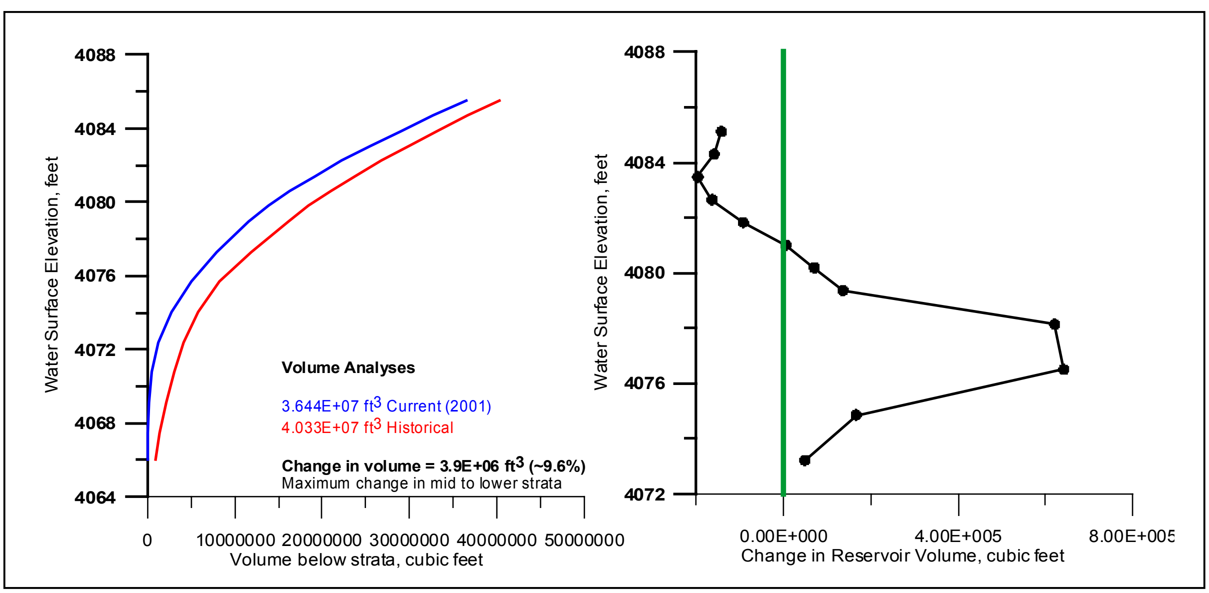

Figure 6.7-15. Current and historical hypsographic curves for Keno reservoir and an estimate of the distribution of the change in lake volume as a function of lake depth.

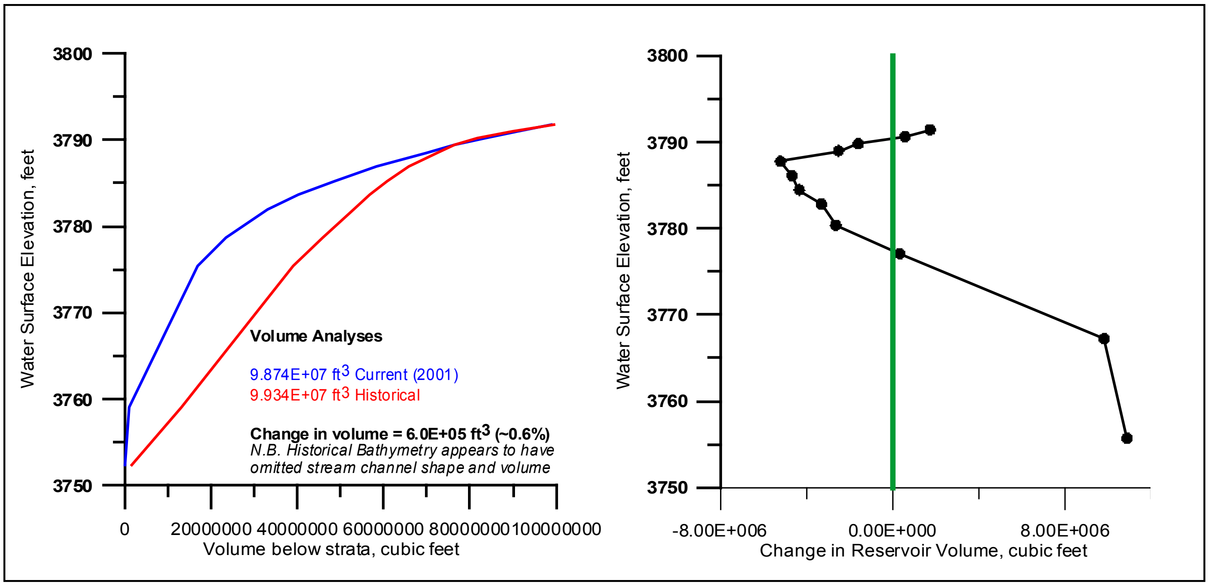

Figure 6.7-16. Current and historical hypsographic curves for J.C. Boyle reservoir and an estimate of the change in lake volume as a function of depth.

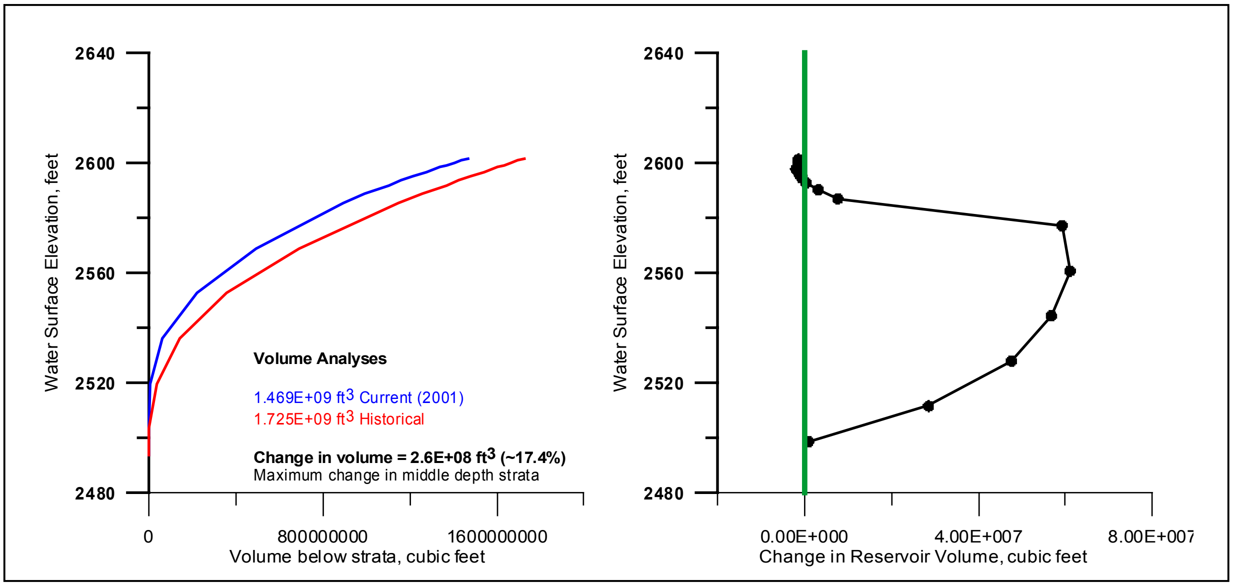

Figure 6.7-17. Current and historical hypsographic curves for Copco No. 1 reservoir and an estimate of the change in lake volume as a function of depth.

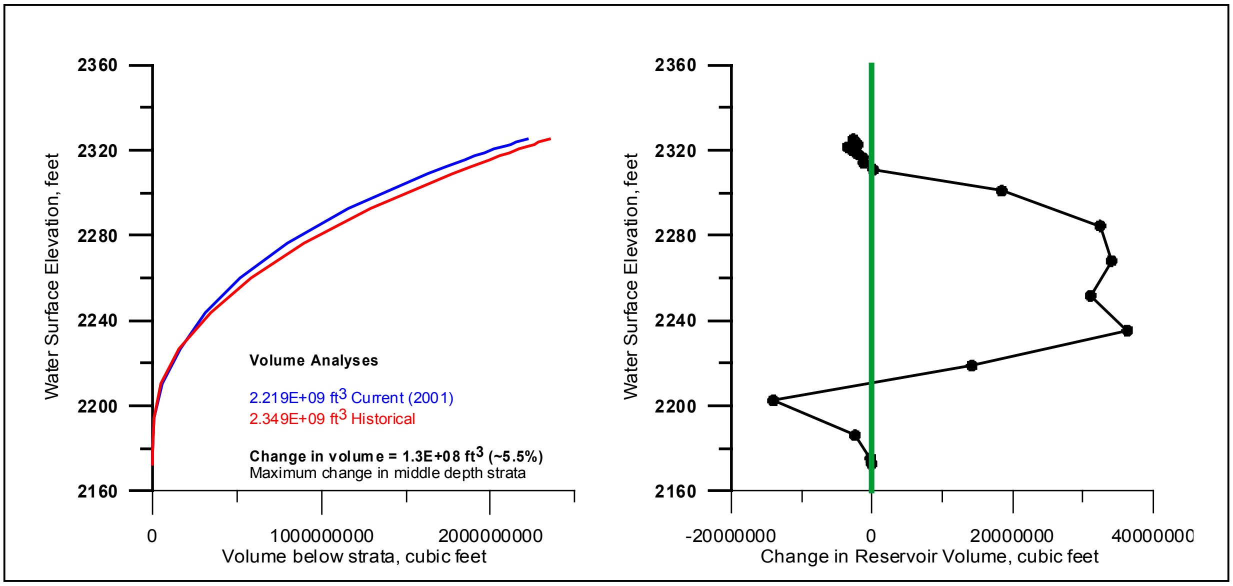

Figure 6.7-18. Current and historical hypsographic curves for Iron Gate reservoir and an estimate of the change in lake volume as a function of depth.

6.7.3 Qualitative Geomorphic Characterization and Initial Delineation of Reaches

The qualitative geomorphic characterization and initial delineation of reaches resulted in a broad set of preliminary study reaches that basically correspond to the Project reaches (i.e., Link River, Keno reach, J.C. Boyle bypass reach, J.C. Boyle peaking reach, Copco bypass reach, downstream of Iron Gate dam, downstream of Iron Gate dam near Seiad Valley). Figure 6.7-19 shows the longitudinal profile of the Klamath River throughout the Project area. Significant changes in slope, channel width, and confinement, along with other major channel features, were used in the reach selection. Table 6.7-2 summarizes the characteristics used to qualitatively separate the Project area in these initial reaches.

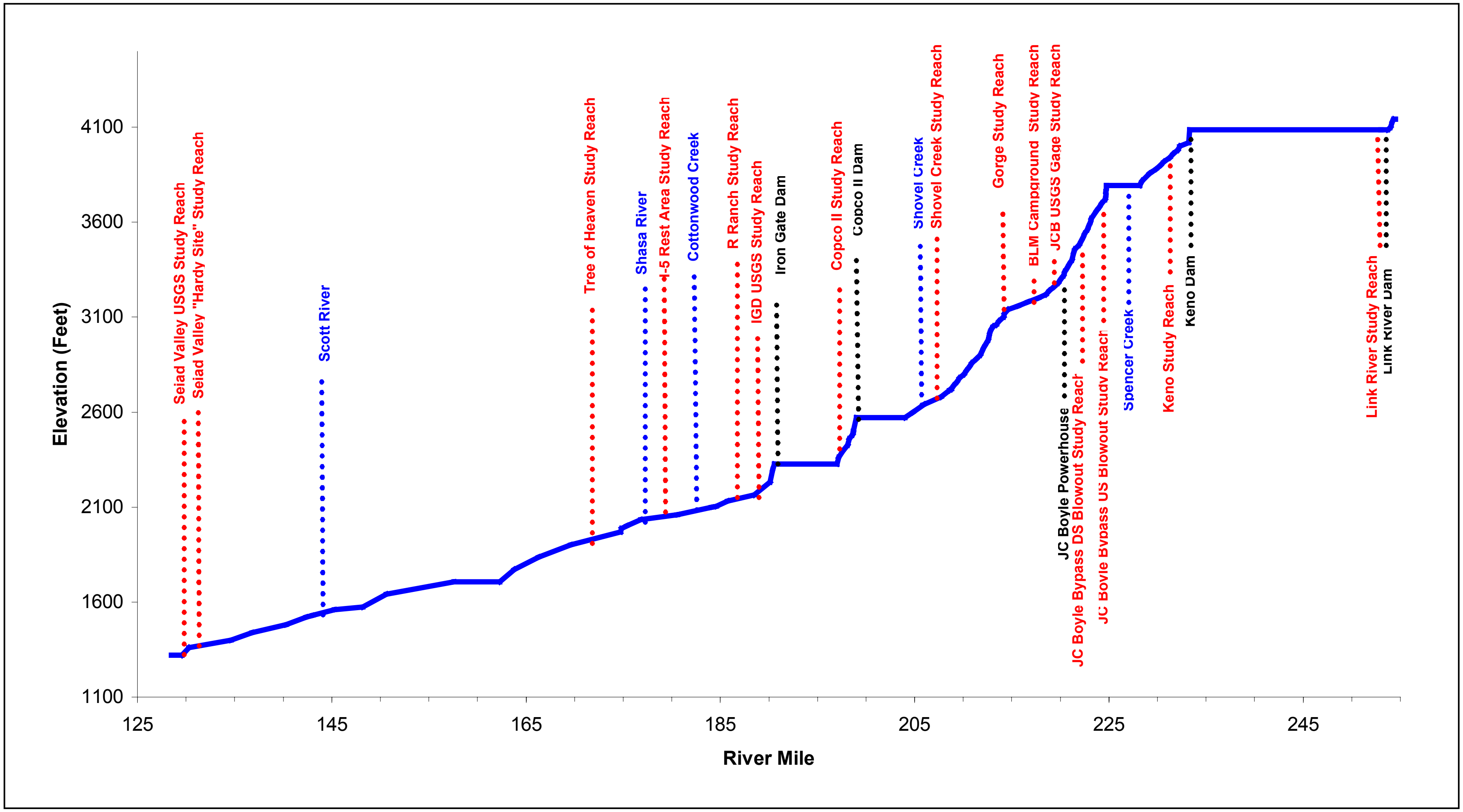

Figure 6.7-19. Klamath River profile showing major tributaries and study reaches.

Table 6.7-2. Characteristics used to qualitatively separate the Project area in geomorphic reaches.

Reach	River Miles	Average Gradient	Defining geomorphic characteristics	Riparian Vegetation
Link River	254.5-253	0.007	Plane bedrock bed with bedrock ledges and some boulders and cobble. Bedrock-cored mid-channel island, low terraces. Very limited sediment storage, historically sediment-starved by Upper Klamath Lake.	Limited to channel margins and upper extent of bedrock-cored mid-channel island. Extensive blackberry growth on both banks.
Keno	233.3-229.3	0.011	Plane bedrock bed, confined channel. Very limited sediment storage, alternating bedrock terraces and marginal islands.	Mostly reed canarygrass and shrubby willows limited to channel margins, pines and oaks on higher terraces.
J.C. Boyle Bypass	224.7-220.9	0.019	Confined V-shaped bedrock channel, many boulders. Very limited sediment storage. Boulders sidecast from canal construction encroach on right bank channel margin but extend across channel at only one site. Significant sediment source at emergency overflow spillway.	Reed canarygrass and low shrubby willows limited to channel margins and rare terraces.
J.C. Boyle USGS Gauge /Frain Ranch Reach	220.9-214.5	0.007	Channel flanked by floodplain/ terrace surfaces, with two levels distinguishable. Cored by boulders with finer sediment on surface. Channel bed dominated by boulders and cobbles and long pools alternating with riffles.	Reed canarygrass along channel margins, willow on low floodplain, pines and oaks on higher terraces.
J.C. Boyle Gorge Reach	214.5-208.7	0.014	Steep bedrock and boulder cascades, large boulders at channel margins. Minimal sediment storage downstream of margin boulders	Steep drop from oak-covered terraces to largely unvegetated boulder channel margins.
J.C. Boyle Shovel Creek Reach	208.7-204	0.006	Alluvial channel flanked by broad floodplain with well developed alternating bars and pool-riffle morphology. Locally multiple channels. Bed material decreases in size downstream from large cobble to coarse gravel.	Floodplain primarily irrigated pasture with riparian corridor of varying width. Riparian corridor composed of mature willow, alder, cottonwood, oak, ash, and box elder.
Copco No. 2 Bypass	198.7-197	0.019	Steep, confined boulder and bedrock-dominated channel with fossilized boulder-cobble bars.	Fossilized bars dominated by mature (old growth) alders. Individual sycamore and maple trees also on fossilized bars.

Table 6.7-2. Characteristics used to qualitatively separate the Project area in geomorphic reaches.

Reach	River Miles	Average Gradient	Defining geomorphic characteristics	Riparian Vegetation
Iron Gate Dam to Cottonwood Creek	190.1-182.1	0.003	Directly downstream of Iron Gate dam, coarse cobble-boulder bars. Further downstream, cobble bed with well-developed pool-riffle morphology flanked by discontinuous floodplain and extensive high terraces. Discrete delta deposits and downstream bars at tributary confluences.	Discontinuous grasses, emergent wetland, and shrubby willows at channel margins. Discontinuous band of alder near active channel. Upper terraces dominated by oak.
Cottonwood Creek to Scott River	182.1-143	0.003	Channel confined between canyon walls, cobble-gravel bed with well-developed pool-riffle morphology flanked by discontinuous floodplain and terraces, no extensive high terrace. Discrete delta deposits and downstream bars at tributary confluences. Significant gravel/cobble bars at Scott River confluence.	Discontinuous grasses, emergent wetland, and shrubby willows at channel margins. Discontinuous band of alder near active channel. Upper terraces dominated by oak.
Downstream of Scott River (includes Seiad Valley)	143-129.6	0.003	Channel confined between canyon walls, cobble-gravel bed with well-developed pool-riffle morphology flanked by discontinuous floodplain and terraces, no extensive high terrace. Discrete delta deposits and downstream bars at tributary confluences. Increasing quantities of sand and fine gravel with distance downstream.	Discontinuous grasses, emergent wetland, and shrubby willows at channel margins. Discontinuous band of alder near active channel. Upper terraces dominated by oak.

6.7.4 Review of Previous Studies

6.7.4.1 Klamath and Shasta Rivers Spawning Gravel Enhancement Study (Buer, 1981)

Buer (1981) was concerned largely with finding sites for gravel enhancement projects. (All direct quotations in this subject are from Buer, 1981, unless otherwise noted). The report objectives were to “(1) determine the effects of watershed and hydrologic changes on the gravel budget and the distribution of gravel in the study area; (2) locate areas suitable for artificial gravel placement; and (3) develop management alternatives for enhancement of spawning areas”(p. 1).

The report's thesis was that, “Few salmon now spawn in the reach below Iron Gate Dam because the riffles are now armored by cobbles too large for salmon to move” (p. 2). The report concluded that “reduction of spawning gravel within the study reach” was “one of the chief causes of the decline” in salmon populations, and that “The reach below Iron Gate was a prime spawning area; it now produces few salmon” (p. 17).

The study involved collection of 17 bulk samples and 51 surficial pebble counts (Wolman, 1954) along the Klamath River from Iron Gate dam downstream to Humbug Creek. The report concluded that the bed was “armored by cobbles too large for spawning over nearly its entire length” (p. 99). However, of the 51 median grain sizes reported for pebble counts, 14 were smaller than 40 mm and 22 were smaller than 50 mm. Chinook salmon that are 90 cm long can use a range of gravel sizes for spawning, with median sizes reported in the literature centering around 35 mm, but going up to about 80 mm (Kondolf, 2000a). Thus, strictly based on the sizes reported, it may be argued that these gravels are not necessarily too coarse for spawning. Buer (p. 86) implies that the pebble counts were conducted at sites with suitable gravel and would thus not be representative of the channel as a whole, noting that “half the samples appear suitable. However, the channel bottom is armored in most places, and large sections of river channel have little, if any, gravel deposits. Redd counts, carcass counts, and visual observations confirm that little spawning habitat remains in the reach.” Unfortunately, the tables reporting the gravel size distributions did not include river miles for the sample sites (nor were sample sites shown on a map), so it has not been possible for the study team to reoccupy the Buer sediment sampling sites in the present study, nor to compare the team’s results on a site-specific basis.

Buer also estimated bed load transport capacity in the reach by applying the Schoklitsch and Meyer Peter-Muller equations (Vanoni, 1975) and concluded that “...with the present bed composition, no bed load transport will take place. The bed is now armored with cobbles, requiring flows in excess of the December 1964 flood to move” (p. 101). The analysis indicated that the smaller gravels entering from Bogus Creek (sizes not indicated) would be quickly transported downstream from the reach. Buer noted that only the Shasta River, Bogus, Little Bogus, and Cottonwood creeks had gravel streambeds (in the reach from Iron Gate to the Humbug Creek confluence) and that these streams contribute relatively little gravel. Also, Cottonwood Creek was heavily mined for gravel to construct I-5 (further reducing its potential gravel contribution to the mainstem).

The second half of the Buer report addressed potential gravel enhancement methods and sites.

6.7.4.2 Initial Assessment of Pre- and Post-Klamath Project Hydrology on the Klamath River and Impacts of the Project on Instream Flows and Fishery Habitat (Balance Hydrologics, 1996)

The objectives of the Balance Hydrologics (1996) study were to determine how USBR’s Klamath Irrigation Project has changed flow downstream of Iron Gate dam, characterize and quantify pre-Project flows in the Upper Klamath River basin, develop understanding of the long-term hydrologic patterns in the basin, characterize importance of sustaining flows emanating from the upper basin during summers and dry years, identify and describe how Project operations have changed and will change flows, assess water quality considerations, and identify approaches to physical solutions for anadromous fish problems.

Balance Hydrologics analyzed available hydrologic records, using the Keno gauge record for 1905-1912 as best available data on pre-Project flow, preceding the Lost River diversion in 1912.

The Balance Hydrologics report concluded that fall/winter flows had increased and late-spring and summer flows had decreased, with a slight increase in October and November flows, since the Project. Prior to the project, the Klamath River basin above Keno appears to have provided 30 to 40 percent of late-spring and summer flows at the mouth of the Klamath. Balance

Hydrologics concluded that the differences between pre-and post-Project flows have increased over the past 30 to 50 years, with Project facilities reducing sub-1,000 cfs flows (minimum monthly) by an order of magnitude and change seasonal pattern at Keno. Balance also concluded that annual runoff depends on precipitation of prior several years. The report found that pre-Project flows were less variable, that the timing of peak flows changed with the Project, and that current peak flows were higher than unimpaired. Pre-Project Klamath hydrographs had more gradual rising and falling limbs. Balance also noted the expanding agricultural use of water from 1929-1989 (190,000 to 290,000 ac-ft).

Balance (1996) included no discussion of sediment transport or resulting channel changes, although the report did state that the post-project channel was wider, shallower, and less stable, with negative impacts on salmon egg incubation. However, the basis for the stated channel change was not clear.

6.7.4.3 Geomorphic and Sediment Evaluation of the Klamath River, California, Below Iron Gate Dam (Ayres Associates, 1999)

The objectives of the Ayres Associates (1999) study were "(1) to provide a comprehensive understanding of the Klamath River geomorphology; (2) to determine if the channel geometry is changing; and (3) to address questions related to sediment changes, including gradation changes and filling of pools." These sediment-related objectives were developed to "test" six hypotheses, as paraphrased below:

1. Channel morphology is different than under natural conditions because of mining operations.
2. Channel morphology is different since the close of Iron Gate dam.
3. Channel exhibits some degree of paving.
4. Substrate below Iron Gate dam has been altered.
5. Substrates have been fouled by fines.
6. Changing Iron Gate dam operation could improve fishery conditions.

Thus, the purpose of the Ayres report was largely to document possible downstream effects of Iron Gate dam (and upstream dams) on flow regime and spawning gravel supply. However, the report covered the entire 189 miles of the Klamath River from Iron Gate dam to the mouth, and most of the study focused on lower reaches of the river. To characterize this vast reach, Ayres plotted a longitudinal profile from the USGS 7.5-minute topographic maps, examined a limited number of historical aerial photographs (100 prints in total), conducted pebble counts on 20 bars downstream of RM 133, and surveyed six study sites, only two of which were upstream of Seiad Valley. Thus, relatively little of the field work was conducted within the first 50 miles of Iron Gate dam, in the reach of the river more likely to have experienced changes in hydrology and sediment transport related to Project operations. The report presented (in a 79-page chapter) standard hydrologic analyses on flow records (e.g., flood frequency analyses and flow duration curves) for mainstem gauges below Iron Gate dam, Seaid Valley, Orleans, and Klamath (of which the lower two were unlikely to reflect effects of Iron Gate dam) and on five tributaries: Trinity at Hoopa, Salmon River at Somes bar, Scott River near Fort Jones, Shasta River near Yreka, and Indian Creek near Happy Camp. These tributaries influence the river flow downstream but, except for the Shasta and Scott rivers, would not affect the 50 miles of river below Iron Gate dam, the reach most likely affected by the dam. The report was mostly descriptive.

The Ayres report was critical of the Balance Hydrologics (1996) hydrologic analysis for not including the Klamath River at Fall Creek near Copco gauge data in its analysis, and for using precipitation at Yreka instead of Klamath Falls as a predictor of runoff from the basin. Ayres questioned the Balance Hydrologics conclusion that the volcanic basin aquifer was the principal source of flow during droughts under pre-Project conditions.

The Ayres report argued that the Klamath River downstream of Iron Gate dam has already adjusted to and is not adversely affected by the changes in channel morphology created by past in-channel and channel margin mining activities, or by increased sediment contributions from tributaries with extensive logging activities. The report concluded that fines were regularly flushed from pools and riffles under normal flow conditions, and that a release of approximately 2,500 cfs from Iron Gate dam was required to mobilize fines. In contrast, the report estimated that 13,200 cfs were required to mobilize riffles near the Beaver Creek confluence (RM 161) and 9,800 cfs at the Little Bogus Creek confluence (RM 187). Based on this, the Ayres report concluded that the study riffles from Iron Gate dam down to Seiad Valley are rarely mobilized. Over the period 1962-1997, Ayres concluded that the riffle at RM 161 was mobile in only 14 of the 35 years and the riffle at RM 187 was mobile only 12 of the 35 years. The report also concluded that riparian vegetation encroachment downstream of Iron Gate dam is not a problem because the river is naturally “confined” and vegetation is limited by inundation, margin mobilization, and scour.

The Ayres report disagreed with the conclusion of Buer (1981) that the bed below Iron Gate dam was armored. Ayres argued that a wide range of grain sizes were present in the bed, that the deposits were loose, and that salmon use the gravels to spawn. Field observations and measurements conducted for the present study would also indicate that the bed has not armored to the extent that the bed is immobile and that spawning cannot occur. However, the fact that the bed is still mobile and some areas are suitable for spawning does not necessarily imply that there has been no change in bed material size. It is still possible that the bed has become coarser since construction of Iron Gate dam, and that this has had a negative impact on spawning.

The Ayres report also concluded that urban development in “tributary watersheds immediately downstream of IGD has resulted in increased erosion and sediment and water runoff in these watersheds. This increasing sediment erosion has revived sediment input to the river immediately below IGD.” It is certainly reasonable to expect increased runoff and erosion from urbanizing watersheds, but the report did not present evidence specifically indicating these effects, and urbanization has not been extensive below Iron Gate dam. More fundamentally, the statement that the urbanization-related erosion has “revived sediment input” might be taken to imply that this sediment somehow compensates for sediment trapping by Iron Gate dam and, before that, by Copco dam. However, sediment derived from urbanization effects is likely to be mostly fine-grained, and thus the statement by Ayres that these tributaries are supplying “significant quantities of gravel to the river...[as] a result of the increased development in the area...since the early 1970s” would seem unlikely, and to be accepted would need to be supported by direct physical evidence, which was not provided in the report. In any event, the magnitude (and grain sizes) of any such sediment contributions would need to be compared with that of the sediment starvation resulting from Iron Gate dam to evaluate the importance of this potential contribution.

The Ayres study relied heavily on application of tractive force calculations on a small number of sites (only two sites within the 50 miles below Iron Gate dam, at RM 161 and 187) and concluded that riffles were infrequently mobilized. While the riffles in the reach below Iron Gate dam typically contain large cobbles that are infrequently mobile, they also contain smaller gravels that are probably mobile much more frequently. Thus, the riffles are probably not immobile 2 years out of 3, as implied by the Ayres report.

6.7.4.4 River Channel Morphological and Sediment Changes in the Klamath Basin, Oregon and California (McBain and Trush, 1995)

The McBain and Trush (1995) report was quite different from the other three described above in that its objectives were to compile available information sources, summarized in a bibliographic format by river segment, and to list potential information sources and data gaps. After a short text section discussing data gaps, recommended data collection priorities, and data analysis, the bulk of this report consisted of entries for various historical data sources. In the present study, this document helped identify potential data sources.

6.7.4.5 Evaluation of Interim Instream Flow Needs in the Klamath River: Phase II Final Report (Hardy and Addley, 2001)

The objectives of the Hardy and Addley (2001) study were to develop flow recommendations for fish in the Klamath River below Iron Gate dam based on different water year types. At seven study sites (each 0.6 to 1.0 mile long) detailed topographic, substrate, and vegetation maps were developed, and water depths and velocities, through these study reaches at a range of flows were modeled. Habitat suitability curves were developed from site-specific data where possible. The study developed unimpaired hydrographs, simulated to remove the effects of regulation of Upper Klamath Lake outflow and regulation by reservoirs. The unimpaired hydrographs were used to assess habitat conditions prior to effects of the USBR and PacifiCorp projects. Habitat modeling coupled two-dimensional hydraulic modeling with three-dimensional habitat models. Flow recommendations were developed for five water year types (from critically dry to extremely wet). When coupled with the USBR's Klamath Project Simulation Model, the Hardy and Addley model indicated that the Project could be operated to meet the recommended flow levels in 449 out of 468 simulated months.

Of the seven study sites, four were within 50 miles of Iron Gate dam: R-Ranch, Trees of Heaven, Brown Bear, and Seiad. The data collection was state-of-the-art, yielding detailed topographic maps and modeling. For the present study, detailed study sites and tracer gravel sites were located at three of the Hardy and Addley sites—R Ranch, Tree of Heaven Campground, and Seiad Valley—to take advantage of that report's detailed site information.

6.7.5 Review of Historical Aerial Photographs

A comprehensive review of historical aerial photographs revealed very little systematic change in the geomorphic character and features (e.g., channel planform or bedforms) of Project reaches upstream of Iron Gate dam. Significant local changes were observed in the aerial photographs and are summarized by geomorphic reach in the following subsections. The Link River and Keno reaches, being bedrock-controlled, appeared especially resistant to changes in channel form over the period covered by available aerial photographs. Reaches that were more alluvial in nature (e.g., Shovel Creek reach in the J.C. Boyle peaking reach) showed minor changes in channel form over the period covered by available aerial photographs (approximately 1940 to 2000). Local changes to channel features were also visible in the J.C. Boyle bypass and peaking reaches, the Copco No. 2 bypass reach, and reaches downstream of Iron Gate dam. The most significant channel morphology changes in the Project area upstream of Iron Gate dam were observed in the J.C. Boyle bypass reach. The most significant channel changes in the vicinity of the Project were observed downstream of Iron Gate dam, associated with tributary and in-channel mining activities. The results of the aerial photograph analysis are summarized by geomorphic reach in Table 6.7-3.

Table 6.7-3. Summary of geomorphic changes identified through analysis of historical aerial photographs.

Geomorphic Reach	River Miles	Photo Years	Systematic Change Throughout Geomorphic Reach	Local Change
Link River	254.5 – 253	1979 1988 1994 2000	No major changes to location and orientation of reach bedforms. No major changes to reach planform.	Some maturation of vegetation along terraces and on bedrock-cored island.
Keno	233.3 – 229.3	1952 1960 1968 1979 1994 2000	No major changes to location and orientation of reach bedforms. No major changes to reach planform.	Some channel geometry change and bedform change immediately downstream of Keno dam after dam construction in 1968. Minor changes to alluvial features (e.g., islands, bars, terraces). Minor vegetation change associated with changes to alluvial features.
J.C. Boyle Bypass	224.7 – 220.9	1952 1955 1957 1965 1979 1986 1988 1993 1994 2000	Significant change to right bank associated with sidecast material from road and canal construction. Riparian vegetation affected by sidecast. Change in location of bedforms downstream of emergency overflow spillway (new bedforms develop over observed period).	Channel confinement and associated erosion on opposite bank due to encroaching sidecast material.
J.C. Boyle USGS Gauge/ Frain Ranch	220.9 – 214.5	1952 1955 1957 1965 1979 1986 1988 1993 1994 2000	No major changes to location and orientation of reach bedforms. No major changes to reach planform.	Minor changes to alluvial features and associated riparian vegetation.

Table 6.7-3. Summary of geomorphic changes identified through analysis of historical aerial photographs.

Geomorphic Reach	River Miles	Photo Years	Systematic Change Throughout Geomorphic Reach	Local Change
J.C. Boyle Gorge	214.5 – 208.7	1952 1955 1957 1965 1979 1986 1988 1993 1994 2000	No major changes to location and orientation of reach bedforms. No major changes to reach planform.	Minor changes to some depositional areas/pools between steep gradient cascades/rapids.
J.C. Boyle Shovel Creek	208.7 – 204	1952 1955 1957 1965 1979 1986 1988 1993 1994 2000	No major changes to reach planform. Some minor changes to alluvial features, especially downstream of Shovel Creek confluence.	Local changes in vegetation primarily associated with changes to alluvial features. Also agriculture-related riparian vegetation changes.
Copco No. 2 Bypass	198.7 – 197	1955 1964 1971 1979 1989 1993 1994 2000	No significant channel planform change. Difficult to detect bedform change at scale of photographs.	Riparian vegetation in reach already encroached in 1955. Increased encroachment difficult to detect in subsequent photographs.
Iron Gate Dam to Cottonwood Creek	190.1 – 182.1	1955 1965 1971 1979 1988 1993 1994 2001	No significant channel planform change. Minor changes to alluvial bedforms; however, most bedforms maintain general size and configuration and remain in same location.	Riparian zone vegetation and morphology change immediately downstream of Iron Gate dam.
Cottonwood Creek to Scott River	182.1 – 143	1955 1965 1971 1979 1988 1993 1994 2001	In general, no significant channel planform change. Minor changes to alluvial bedforms; however, most bedforms maintain general size and configuration and remain in same location.	Major channel morphology and riparian vegetation change associated with tributary and in-channel mining.

Table 6.7-3. Summary of geomorphic changes identified through analysis of historical aerial photographs.

Geomorphic Reach	River Miles	Photo Years	Systematic Change Throughout Geomorphic Reach	Local Change
Scott River to Seiad Valley	143 – 129.6	1955 1965 1971 1979 1988 1993 1994 2001	In general, no significant channel planform change. Minor changes to alluvial bedforms, however, most bedforms maintain general size and configuration and remain in same location.	Major channel morphology and riparian vegetation change associated with tributary and in-channel mining.

6.7.5.1 Link River Geomorphic Reach

The significant bedrock control throughout most of the Link River reach is apparent in the historical aerial photographs. Figures 6.7-20 and 6.7-21 show that, as expected for a bedrock-controlled reach, no significant change to channel planform or bedforms was visible for the period in available aerial photographs. Minor changes in the appearance of riparian vegetation were apparent; however, these appeared to be associated with normal succession and growth. As with most of the photographs used in this analysis, the scale of the photographs makes identification of small-scale changes in geomorphology and vegetation difficult and in some cases impossible. This reconnaissance-level investigation of aerial photographs provides no evidence of changes to the underlying geomorphic processes in the Link River reach.

Figure 6.7-20. Link River reach (RM 254) 1979, Q = 1,220 cfs.

Figure 6.7-21. Link River reach (RM 254) 1994, Q = 1,090 cfs.

6.7.5.2 Keno Geomorphic Reach

The Keno reach is similar to the Link River reach. Because of its similar bedrock channel control, significant secular channel changes would not be expected. This is borne out in the photographs from 1960 and 1994 (Figures 6.7-22 and 6.7-23), which show no significant visible changes in channel form in the Keno study reach area despite the completion of Keno dam between the time these two photographs were taken. These photographs also show that there has clearly been no large-scale encroachment or decline in the initially sparse riparian vegetation. It is possible that the sun angles and resolution of the aerial photographs could have impaired the detection of minor channel or vegetation changes. The difference in flow at the time of these two photographs (680 cfs in 1960 and 342 cfs in 1994) could also impair detection of changes. Still, this reconnaissance level investigation of aerial photographs provides no evidence of changes to the underlying geomorphic processes in this reach.

Figure 6.7-22. Klamath River Keno reach (RM 233) 1960, Q = 680 cfs.

Figure 6.7-23. Keno reach (RM 233) 1994, Q = 342 cfs.

6.7.5.3 J.C. Boyle Bypass Geomorphic Reach

Significant changes to geomorphology and riparian vegetation were observed in this reach. Figures 6.7-24 and 6.7-25 show some of the changes that have occurred in this reach between 1952 and 1994. Major changes appear to be a result of the sidecast material generated from canal and road construction along this reach and erosion associated with the emergency overflow spillway. While the narrow canyon in this reach limits potential change to the channel planform, significant changes were observed in the location and configuration of bedforms. Channel confinement due to encroaching sidecast material near RM 223 has altered the large terrace on river-right just upstream of the encroaching material. There has also been significant erosion on river-left just downstream of the encroaching material. Perhaps the most visible geomorphic change in this reach is in the section downstream of the emergency overflow spillway near RM 222. Erosion at the spillway has significantly increased the rate of fine and coarse sediment delivery in this area, and bedforms have developed and changed through time as a result of this change in sediment supply. Project facilities and operations in this reach may have significantly affected underlying geomorphic processes in this reach.

Figure 6.7-24. J.C. Boyle bypass reach (RM 222) 1952,
Q = 1,550 cfs.

Figure 6.7-25. J.C. Boyle bypass reach (RM 222) 1994,
Q = 300 cfs (approximate release plus spring inflow)

6.7.5.4 J.C. Boyle USGS Gauge / Frain Ranch Geomorphic Reach

While changes in the vegetation on the broad, flat terraces in this reach were observed in the historical aerial photographs, the channel planform did not appear to change significantly from 1955 to 2000. Figures 6.7-26 and 6.7-27 show a section of this geomorphic reach in 1968 and 1993. Minor changes were observed on some alluvial features; however, for the most part bedforms remained in the same locations along this reach. This reconnaissance level investigation of aerial photographs provides no evidence of significant changes to the underlying geomorphic processes in this reach.

Figure 6.7-26. USGS/Frain Ranch reach (near RM 215)
1968, Q = 779 cfs.

Figure 6.7-27. USGS/Frain Ranch reach (near RM 215)
1993, Q =895 cfs

6.7.5.5 J.C. Boyle Gorge Geomorphic Reach

Given the steep gradient and tight canyon that characterize this reach, significant shifts in channel planform or bedforms was not expected. Figures 6.7-28 and 6.7-29 show a section of this geomorphic reach in 1968 and 1993. Some very minor changes were observed in depositional areas between the steep cascade/rapid sections throughout this reach. Changes in riparian vegetation in this reach appeared to be very limited. As expected, this reconnaissance level investigation of aerial photographs provides no evidence of changes to the underlying geomorphic processes in this reach.

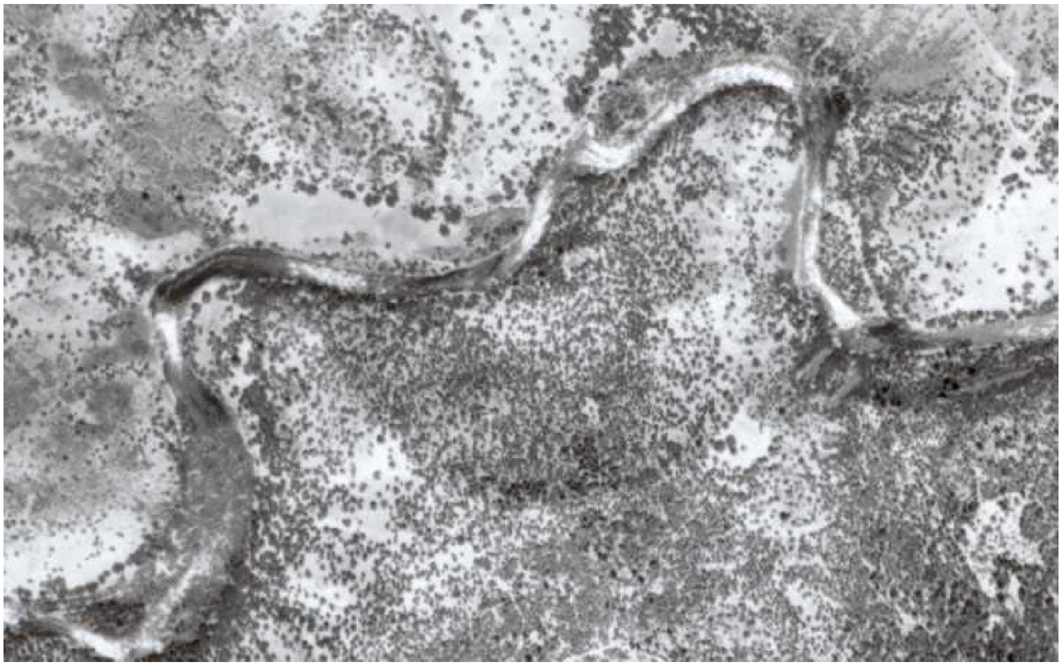

Figure 6.7-28. Gorge reach (near RM 213) 1968, Q = 779 cfs.

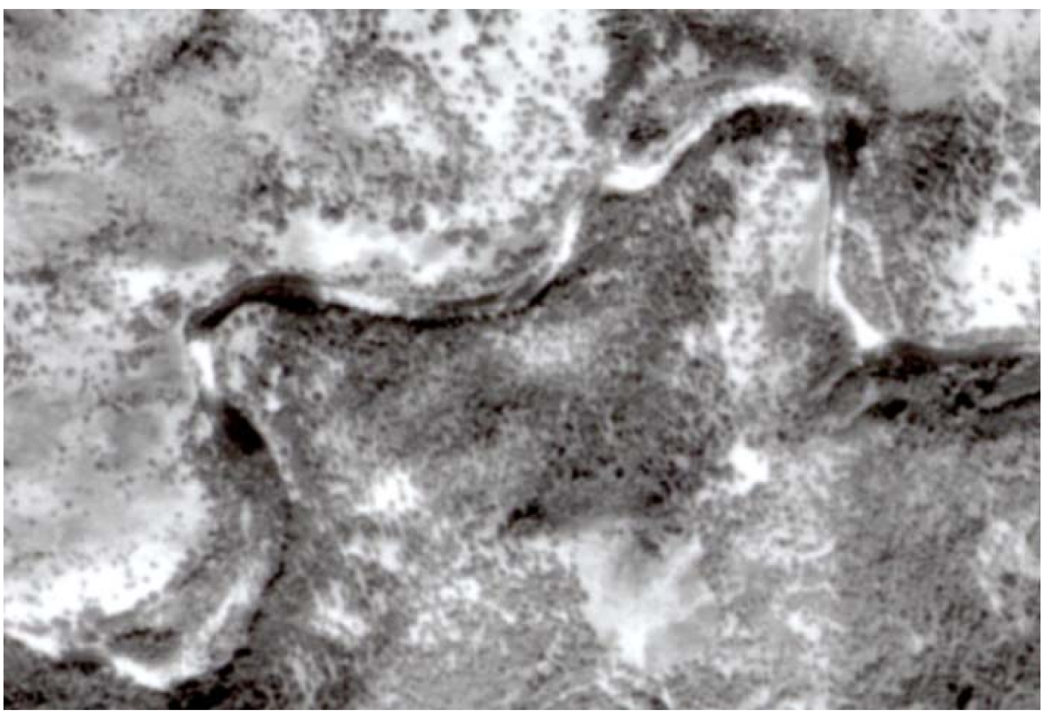

Figure 6.7-29. USGS/Frain Ranch reach (near RM 213) 1993, Q = 895 cfs.

6.7.5.6 J.C. Boyle Shovel Creek Geomorphic Reach

The Shovel Creek study reach in the J.C. Boyle peaking reach is an example of readily apparent local changes in channel form and associated riparian vegetation. In this reach, the mid-channel island and small side channel just downstream of the bridge at Shovel Creek changes significantly between 1955 and 2000 (Figures 6.7-30 and 6.7-31). The mid-channel island increases in area while the side channel appears to decrease in length. Also, the outside bend just downstream of the "Miller Bridge" appears to be more undercut in 2000 than in 1955. Distribution and density of riparian vegetation does not appear to have changed significantly from 1955 to 2000, except where new surfaces associated with channel form changes have been colonized. The flow was approximately the same at the time these two photographs were taken (874 cfs in 1955 and 830 cfs in 2000), and the scales of the two photographs were similar. Therefore, the apparent changes are not likely the product of differences in the photographs. The patterns of erosion, deposition, and consequent vegetation recruitment and establishment appear to be typical of what would be expected in a naturally migrating river. Thus, while large-scale changes are not evident, more detailed mapping of patterns of change may be required to test specific effects of Project operations, such as the peaking that occurs in this reach.

Figure 6.7-30. J.C. Boyle peaking reach at the Shovel Creek study site (RM 206) 1955, Q = 1,530 cfs.

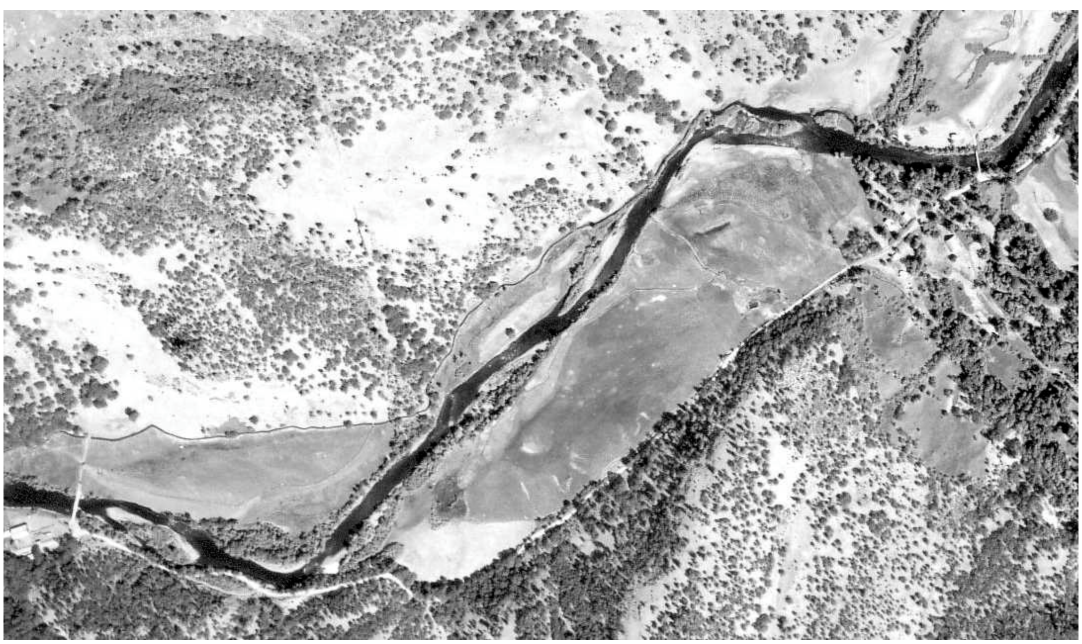

Figure 6.7-31. J.C. Boyle peaking reach at the Shovel Creek study site (RM 206) 2000, Q = 1,110 cfs.

6.7.5.7 Copco No. 2 Bypass Geomorphic Reach

Copco dam predates the first available aerial photographs for this reach (1955) by approximately 30 years. Therefore, it is likely that the riparian vegetation encroachment observed in this reach today was already fairly well developed by 1955. Still, some additional encroachment was observed between 1955 and 1993 (Figures 6.7-32 and 6.7-33). Extremely low base flows in this reach have allowed the encroachment of mature trees into the active channel. Therefore, Project facilities and operations appear to have a significant impact on the underlying natural geomorphic processes in this geomorphic reach.

Figure 6.7-32. Copco No. 2 bypass (near RM 197) 1955, Q = 1,320 cfs.

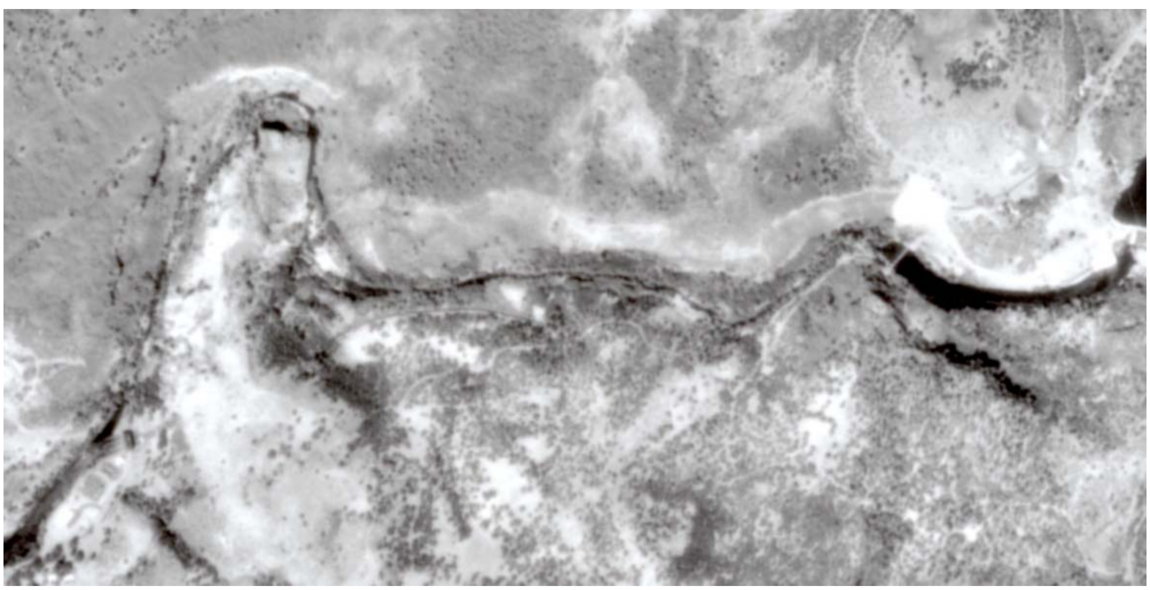

Figure 6.7-33. Copco No. 2 bypass (near RM 197) 1993, Q = 10 cfs.

6.7.5.8 Iron Gate Dam to Cottonwood Creek Geomorphic Reach

Downstream of Iron Gate dam (the farthest downstream Project facility), the most significant channel changes were observed immediately downstream of the dam, and also in the vicinity of tributary and mainstem mining sites. Figures 6.7-34 and 6.7-35 show the area near Iron Gate dam before (1955) and more than 30 years after the dam was constructed (2001), respectively. While the planform of the river immediately downstream of the dam does not appear to shift significantly, some alluvial features (especially at tributary confluences and immediately downstream of the dam) were formed, removed, and altered between 1955 and 2001. Many of the most significant changes appear to be associated with the construction of the fish hatchery on the alluvial fan of Little Bogus Creek on river left just downstream of the dam. Some minor local channel changes were apparent in a reach near Klamathon between 1944 and 1994 (Figures 6.7-36 and 6.7-37). In this reach, the fringe of bank vegetation appears to be better developed in 1994 than in 1944. Also, a bar upstream of the railroad bridge appears large and more densely vegetated in 1994 than in 1944. In addition, approximately 15 small, mid-channel features (possibly piers associated with the old Klamathon mill) visible in the 1944 are not visible in 1994. It is possible that these apparent changes could be artifacts of the different scales or format (color versus black and white) of the two photographs, or related to the difference in flow at the time of the two photographs (2,190 cfs in 1944 and 570 cfs in 1994). Based on this reconnaissance-level review of these aerial photographs, the Project geomorphologists cannot conclude whether the apparent changes described above reflect Project-induced impacts or effects or other changes to underlying geomorphic processes. Changes in underlying processes become less likely with distance downstream of Iron Gate dam.

Figure 6.7-34. Downstream of Iron Gate dam (near RM 190) 1955, Q = 852 cfs.

Figure 6.7-35. Downstream of Iron Gate dam (near RM 190) 2001, Q = 1,010 cfs.

Figure 6.7-36. Downstream of Iron Gate dam near Klamathon 1944, Q = 1,280 cfs.

Figure 6.7-37. Downstream of Iron Gate dam near Klamathon 1994, Q = 572 cfs.

6.7.5.9 Cottonwood Creek to Scott River Confluence Geomorphic Reach

In general, the pattern observed in the upstream reaches of limited changes to channel planform was repeated in this reach. Minor changes to alluvial features were observed in some locations, but most bedforms remained in the same location and maintained similar dimensions. However, extremely large changes in channel form were observed near former tributary and mainstem mining sites. Figures 6.7-38 and 6.7-39 provide an example of this type of change near Humbug Creek and the Tree of Heaven Campground in 1955 and 1999. The direct manipulation of the channel and the redistribution of large amounts of sediment in the river corridor appear to have significantly altered the planform and bedform of the Klamath River in this location. It is possible that impacts from this material are still occurring downstream of this area. From this reconnaissance-level aerial photograph analysis, it seems likely that channel geomorphology changes this far downstream of Iron Gate dam are due in large part to past mining activities.

Figure 6.7-38. Downstream of Iron Gate dam (near RM 170) 1955, Q = 1,540 cfs.

Figure 6.7-39. Downstream of Iron Gate dam (near RM 170) 1999, Q = 1,130 cfs.

6.7.5.10 Scott River to Seiad Valley Geomorphic Reach

Observations in this geomorphic reach were very similar to those in the Cottonwood Creek to Scott River reach. No significant reach-wide changes to channel planform were observed in this reach, while minor changes to alluvial features were observed in some locations. Again, most bedforms remained in the same location and maintained similar dimensions. Figures 6.7-40 and 6.7-41 show the major local impacts on channel geomorphology associated with past mining activities near Seiad Valley. Here again, direct manipulation of the channel and the redistribution of large amounts of sediment in the river corridor appear to have significantly altered the planform and bedform of the Klamath River. From this reconnaissance-level aerial photograph analysis, it seems likely that channel geomorphology changes in this reach are due in large part to past mining activities.

Figure 6.7-40. Downstream of Iron Gate dam (near RM 140) 1955, Q = 1,280 cfs.

Figure 6.7-41. Downstream of Iron Gate dam (near RM 140) 1999, Q = 1,130 cfs.

6.7.6 Selection of Representative Study Reaches

As described in the study plan, the Project geomorphologists selected 14 study sites: one in the Link River reach, one in the Keno reach, two in the J.C. Boyle bypass reach, four in the J.C. Boyle peaking reach, one in the Copco No. 2 bypass reach, and five downstream of Iron Gate dam. Specific information about each study site is presented in Table 6.7-4.

6.7.7 Measurements and Observations at Representative Reaches

Figure 6.7-42 shows the locations of the 14 study sites. Individual measurements and observations at each study site are presented in figures and tables in Appendix 6A.

6.7.7.1 Cross-Section and Long Profile Surveys

Graphs and figures generated from the cross section and long profile surveys for each cross section at each study reach are presented in Appendix 6A. The most upstream reach within the Project area, the Link River reach (RM 254), is characterized by a predominantly bedrock channel with a relatively low average gradient (0.011). The dominant bedforms in this reach include bedrock runs and pools, a bedrock-cored island, and bedrock ledge “cascades.” Narrow boulder and cobble terraces border the channel on river-right, with steep banks present just beyond the terraces. A significantly wider terrace borders the channel on river-right. It appears that this terrace would be inundated only during major floods.

Table 6.7-4. Klamath River geomorphology – final study sites.

Project Reach	River Mile	Site Location*	Study Reach Gradient	Bed Type	Study Site Characteristics and Justification of Site Selection
Link River	254	Downstream end of island just downstream of Link dam	0.011	Bedrock at island with plane bed downstream of island	Presence of diverse riparian vegetation on island. Geomorphic features downstream of island are typical of this Project reach. The habitat and geomorphic features on the island at the midpoint of the study site are atypical, but potentially important riparian and aquatic habitat.
Keno	232	At USGS gauge	0.013	Bedrock and large boulders at gauge site with coarse riffles upstream and downstream of gauge	Gauge records available to link local hydrology to local geomorphic features. Geomorphic features upstream and downstream of gauge are typical of most of this Project reach. The island at RM 232 is a geomorphic feature that is repeated throughout the Project reach. Potential to include upstream and downstream islands which are a repeated feature throughout this Project reach.
J.C. Boyle Bypass	224	At the silty terrace just upstream of encroaching sidecast material	0.014	Coarse plane bed with large boulders and sidecast material in some areas	Presence of sidecast material that has affected geomorphic features, as well as sidecast material that does not appear to have affected geomorphic features. Also, the large silt terrace at the midpoint of the study site is an important geomorphic feature in the study reach. Presence of tracer gravel site to provide calibration information for bed load transport estimates.
J.C. Boyle Bypass	221	At island just downstream of emergency spillway	0.023	Coarse plane bed with some large boulders; gravel and cobble on small bars and in pockets created by coarse material.	Geomorphic features downstream of the emergency spillway are significantly different than the features upstream of the spillway. Presence of gravel bars and more frequent riffles in this section of the study reach. Also, the large sediment source created by the emergency spillway washout provides an opportunity to investigate storage and transport of fine sediment in this reach.

Table 6.7-4. Klamath River geomorphology – final study sites.

Project Reach	River Mile	Site Location*	Study Reach Gradient	Bed Type	Study Site Characteristics and Justification of Site Selection
J.C. Boyle Peaking	219.5	At USGS gauge	0.017	Coarse plane bed with some large boulders . Gravel and cobble on small bars and in pockets created by coarse material.	Gauge records available to link local hydrology to local geomorphic features.
J.C. Boyle Peaking	217	At BLM camp-ground near Frain Ranch	0.003	Coarse plane bed with flood terraces at different elevations above the bed	Presence of geomorphic features repeated in the Frain Ranch section of this Project reach.
J.C. Boyle Peaking	214	In the Klamath Gorge upstream of Rock Creek	0.02	Very large boulders with islands and terraces	Presence of geomorphic features repeated in the gorge section of this Project reach.
J.C. Boyle Peaking	207	At tracer gravel site near Shovel Creek confluence	0.008	Medium and large cobble riffles and alternating bars with wide alluvial floodplain	Presence of tracer gravel site to provide calibration information for bed load transport estimates. The geomorphic features at this site are representative of the features present in this section of this Project reach.
Copco No. 2	197.7	Near access point for Copco penstock	0.016	Coarse cascade (with more water) bed with many large boulders, bedrock, and significant vegetation encroachment	Geomorphic features representative of this Project reach.
Downstream of Iron Gate Reservoir	189.6	At USGS gauge near Bogus Creek confluence	0.0016	Coarse plane bed with cobble riffles upstream and downstream of gauge	Gauge records available to link local hydrology to local geomorphic features. Geomorphic features at this study site are typical of most of this Project reach. The sediment delivered by Bogus Creek provides an opportunity to investigate storage and transport of fine sediment in this reach.

Table 6.7-4. Klamath River geomorphology – final study sites.

Project Reach	River Mile	Site Location*	Study Reach Gradient	Bed Type	Study Site Characteristics and Justification of Site Selection
Downstream of Iron Gate Reservoir	186.7	At Tracer gravel site near R-Ranch	0.004	Plane with island and side channel with cobble bed material	Presence of tracer gravel site to provide calibration information for bed load transport estimates. The geomorphic features at this site are representative of the features present in this section of this Project reach. Also, the island and side channel are potentially important riparian and aquatic habitats.
Downstream of Iron Gate Reservoir	179	At Tracer site near I-5 rest area	0.005	Plane bed with cobble and small alluvial terrace	Presence of tracer gravel site to provide calibration information for bed load transport estimates. The geomorphic features at this site are representative of the features present in the canyon section of this Project reach.
Downstream of Iron Gate Reservoir	172	At Tree of Heaven Campground	0.0008	Plane bed with large active gravel/cobble bars	Location of Hardy site and site of potential salmon spawning activity. Large gravel /cobble point bar at upstream end of study reach. Mature willows in riparian corridor.
Downstream of Iron Gate Reservoir	128.5/ 131	Seiad Valley	0.0001-0.002	At Seiad Valley USGS gauge/At Hardy study site	At USGS site, gauge records available to link local hydrology to local geomorphic features. At Hardy site, significant gravel deposits and large cobble bar at upstream end of study reach.

* Site location given for the midpoint of study site. Actual study site extends upstream and downstream from this location

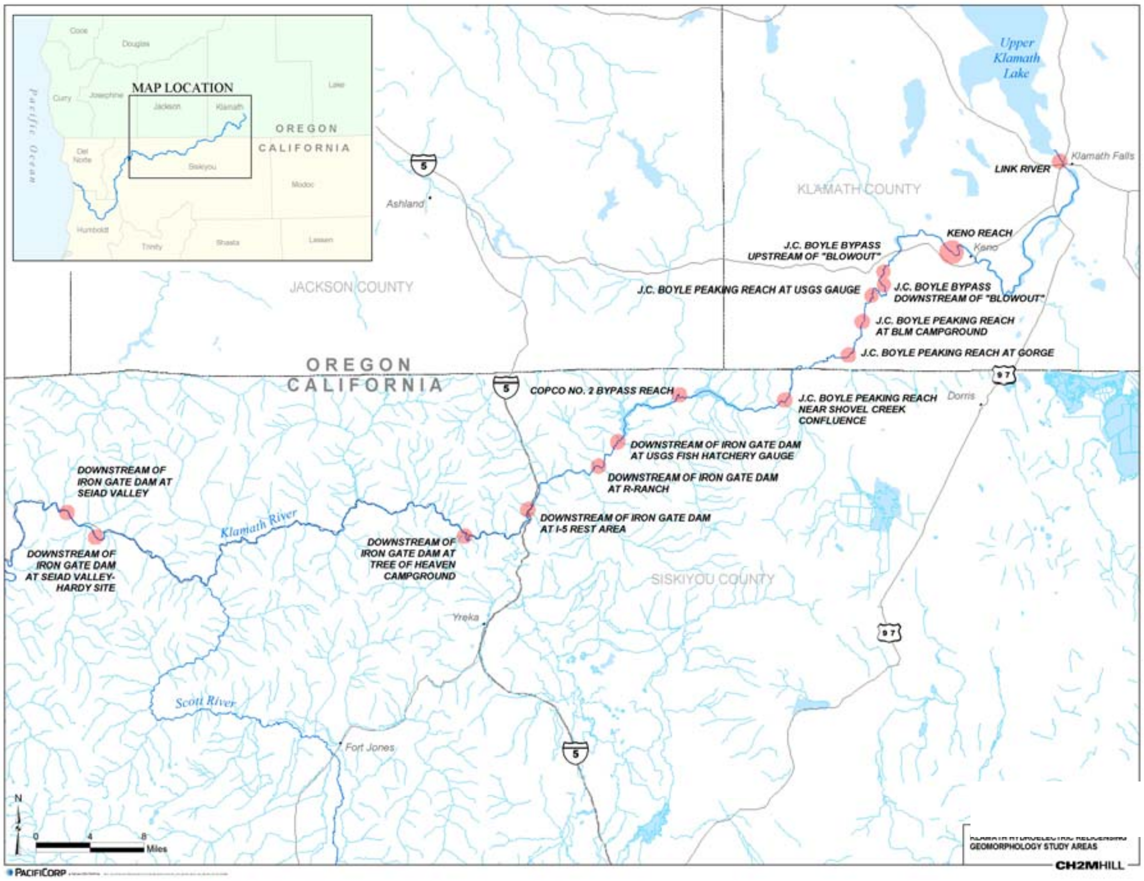

Figure 6.7-42. Geomorphology study sites in Project area.

The Keno reach (RM 232) begins approximately 20 miles downstream of Link River. The Keno reach is characterized by a predominantly bedrock channel with a slightly greater gradient than the Link River reach (0.013 versus 0.011). The channel morphology consists of sequences of boulder/bedrock cascades and deep bedrock runs. Steep banks and alternating bedrock terraces confine the channel.

The channel features that characterized the upstream reaches also occur in the J.C. Boyle bypass reach, located approximately 5 miles downstream of the Keno reach. The channel consists of a confined, V-shaped, boulder and bedrock channel. Two study sites are present within this reach: one site is located upstream of the emergency spillway (RM 224), and one is located downstream of the spillway (RM 221). Large colluvial boulders border the left bank, and boulder sidecast material from canal construction encroaches on the right bank of the channel, crossing the channel at one location. The channel morphology of the study site upstream of the emergency spillway consists of alternating pools and boulder cascades. An exposed boulder bar and a vegetated boulder bar covered with fines is present near the middle of this study site. The gradient of the J.C. Boyle bypass reach downstream of the spillway is one of the highest in the Project area (0.023). This could be due to the significant input of coarse sediment from the large eroded area at the base of the emergency overflow spillway. The river in this reach may be adjusting to the increased sediment input by increasing in slope (effectively increasing the local sediment transport capacity).

The channel morphology of this study site is significantly different from the features upstream of the emergency spillway. Boulder runs contain pockets of fine sediment, and boulder and coarse cobble riffles exist. The study site also includes an island of small boulders near the center of the channel and a lower-gradient side channel characterized by riffles and pools with substantial quantities of gravel-sized sediments. At the downstream end of the study reach, large quantities of fine sediment (sand to gravel) surround the coarse framework materials of the bed.

The general channel form common to the upstream reaches of the J.C. Boyle reach begins to evolve in the J.C. Boyle peaking reach near the USGS gauge (RM 219.5) located just downstream of the J.C. Boyle bypass reach. The channel is characterized by alternating cobble riffles and runs, with cobble bar and pool morphology. Here, the channel is flanked by relatively wide terraces at multiple levels. The gradient of the reach is still high (0.017) in this region. However, local areas of sediment deposition (e.g., bars, terraces) are present.

The channel at the BLM campground study site (RM 217) within the J.C. Boyle peaking reach is similar to the USGS gauge study site. Here, the channel is still characterized by pools, cobble bars, and cobble riffles and runs. The channel is also bordered by relatively wide terraces. The channel gradient at this site is significantly less than at the USGS gauge study site (0.003). This is consistent with the increased frequency of depositional areas through this area and into the Frain Ranch area upstream of Caldera.

The river becomes extremely confined and the channel gradient increases to 0.02 as it enters the J.C. Boyle peaking gorge reach (RM 214). The reach is characterized by steep bedrock and boulder cascades. The channel bed, channel margins, and steep banks consist of large boulders, which are mostly unvegetated.

The channel has transitioned into an unconfined, alluvial channel flanked by wide, multilevel terraces by the time it reaches the J.C. Boyle Shovel Creek reach (RM 207). Alternating pools, bars, runs, and riffles characterize this reach, which has a relatively low gradient (0.008). A terrace that supports a riparian corridor of varying width borders the channel, beyond which there is a floodplain that supports mostly irrigated pastureland.

The channel becomes a confined, boulder- and bedrock-dominated channel once again in the Copco No. 2 bypass reach (RM 197.7), located approximately 9 miles downstream of the J.C. Boyle Shovel Creek reach. Fossilized boulder-cobble bars colonized by mature (old growth) alders dominate the channel cross section. Mature alders are also located along the steep boulder banks of the channel. The average gradient of the reach is 0.019.

The Iron Gate dam reach at the USGS gauge (RM 189.6) is located approximately 7 miles downstream of the Copco No. 2 bypass reach. The reach is characterized by alternating coarse cobble-boulder bars and cobble runs. The average gradient at this study site is 0.016. A discontinuous floodplain and extensive high terraces border the channel.

The Iron Gate dam reach near R-Ranch (RM 186.7) is characterized by cascades, cobble and gravel bars and riffles and pools, bedrock runs and pools, and a large mid-channel island. A terrace that supports a riparian corridor of varying width borders the channel on both sides. This terrace on river-right is occupied by a recreational vehicle park. Relatively wide floodplains exist on alternate sides of the channel through this study reach. The average gradient of the reach is 0.004.

The Iron Gate dam reach near the I-5 rest area (RM 179) is characterized by gravel/cobble riffles, runs, and bars. A large mid-stream island is located in this reach. The channel is bordered in this study reach by a discontinuous floodplain and terraces. The channel is confined by steep canyon walls in the vicinity of this study reach. The average gradient of this reach is 0.005.

The Tree of Heaven Campground study reach (RM 172) is characterized by deep runs and an extensive cobble point bar. Similar to the I-5 rest area study site, the Tree of Heaven Campground study site is confined within canyon walls. Discontinuous terraces and floodplains border the channel throughout this study reach. The average gradient of this reach is 0.0008.

The Seiad Valley study sites (RM 131 and RM 128.5) are the most downstream sites within the Project area. Both sites are characterized by gravel/cobble bars, riffles, and runs. These sites are also confined within canyon walls and have discontinuous terraces and floodplains on alternating sides of the channel. The average gradient in these two study reaches ranges from 0.0001 to 0.002.

Throughout the study area, the morphology of the Klamath River is largely defined by local geologic controls. The presence of depositional areas is closely associated with wide valley bottom widths that allow the energy of high flows to be spread across a larger cross-sectional area, thus reducing shear stress and facilitating deposition. Conversely, steep channel sections are primarily located in confined settings. The Klamath River does not exhibit the consistent, longitudinal changes in gradient and morphology that are typical of many river systems. Rather, the local morphology is largely determined by local geologic controls. This is an important consideration when attempting to assess the impacts of Project facilities on sediment transport and fluvial geomorphology.

6.7.7.2 Reach Maps and Photo Points

Photographs and reach maps for each study reach are also presented in Appendix 6A. These photographs and maps illustrate the morphology described in the preceding section.

6.7.7.3 Bed Material Sampling

Table 6.7-5 summarizes the results of the pebble counts conducted throughout the Project reaches for this study. Figures 6.7-43 to 6.7-48 show pebble count D_{50} and D_{84} values in relation to important Project facilities and potential sediment sources (e.g., tributaries). The pebble count results show broad variation and generally suggest strong local control on sediment particle size distributions throughout the Project study area. A discussion of the pebble count results follows for each of the study reaches in the Project area. This discussion includes pebble counts described in sections 6.4.7.3 and 6.4.7.5.

The Link River reach is characterized by a bedrock channel and is considered a sediment transport reach. Pebble counts were conducted on two depositional gravel bars. The D_{50} of the pebble count taken at cross section 253.9 was 52 mm, and the D_{50} of the second pebble count 50 feet downstream of the cross section was 32 mm. The relative lack of suitable substrates for surface pebble counts in this reach confirms the assessment of this reach as primarily a transport reach. Very few patches of apparently mobile fine or coarse sediment were present.

Table 6.7-5. Summary of pebble counts conducted throughout the Project reaches for this study.

Reach Name	River Mile	D_{50}	D_{84}	Geomorphic Feature	Location
Link River	254	52.9	118.2	Bar	On bar (perpendicular to flow near cross section 1)
Link River	254	32.4	121.1	Bar	On bar (parallel to flow 50 feet above and 50 feet below cross section 1)
Keno	232	336.1	717.4	Bar	Keno Bar at cross section 2
Keno	229.8	129.8	219.5	Toe of slope	Cobble margin at edge of water
Keno	229.8	9.3	14.6	Pocket gravel	Pocket gravel behind boulder river right
Keno	228.3	145.2	298.6	Bank	J.C. Boyle reservoir head
J.C. Boyle Bypass – Above Blowout	224.4	172.5	314	Terrace	100 feet across cross section 2 parallel to flow
J.C. Boyle Bypass – Above Blowout	224.3	55	81.8	Pocket gravel	Downstream of cross section 3; near right bank in water, just downstream of large boulders in riffle
Below J.C. Boyle Blowout	222.5	474.6	1111.4	Sidecast	On sidecast below blowout
Below J.C. Boyle Blowout	222.4	128	313.4	Island/Mid-channel bar	Top of island, parallel to flow, upstream and downstream of cross section 1
Below J.C. Boyle Blowout	222.4	19.7	43.6	Bar	On fine sediment bar on right bank, downstream end of island, parallel to flow
J.C. Boyle Downstream of Power Plant at USGS Gauge	219.7	100.8	163	Pool	At cross section 2 (at USGS gauge), approximately 50 feet upstream and downstream of cable way
J.C. Boyle Downstream of Power Plant at USGS Gauge	219.6	136.2	219.5	Point bar	On a point bar downstream of USGS gauge, at head of riffle
BLM Campground	217.8	141.1	281	Bar	At cross section 1, closer to right bank
BLM Campground	217.8	153.6	254.9	Bar	At cross section 1, closer to channel
BLM Campground	217.5	24.4	116.2	Bar	Across cross section 2 at bar, closer to right bank
BLM Campground	217.5	122	228.6	Bar	Across cross section 2 at bar
BLM Campground	217.2	131.5	234	Bar	At cross section 3 on bar
Gorge Reach	214.4	41.2	71.5	Point bar	Point bar downstream of Frain Ranch, upstream of gorge
Gorge Reach	214.4	40.2	80.34	Point bar	Point bar below Frain Ranch, upstream of gorge – higher on bar, at stream confluence
Gorge Reach	214.2	13.7	27.7	Pocket gravel	In gorge, in boulder pocket on left bank approximately 75 feet downstream of cross section 1

Table 6.7-5. Summary of pebble counts conducted throughout the Project reaches for this study.

Reach Name	River Mile	D_{50}	D_{84}	Geomorphic Feature	Location
Shovel Creek	207.8	187.1	313.1	Bar	Bar length, 26.3 m; located next to large island; particles loose, slightly embarkated; bar half exposed, half submerged; rocky riffle just upstream; most particles subrounded, some well rounded, some subangular
Shovel Creek	207.6	119.3	190.8	Bar	Bar length 30.2 m; next large bar downstream from pebble count A; bar separates side channel from mainstem at low flow; material loose; same shapes as in pebble count A; material appears finer downstream
Shovel Creek	207.4	131.6	247.4	Bar	Bar length > 100 feet; rocks very greasy; water not moving interstitially; fine gravel under boulders; rocks same shape as pebble counts A and B
Shovel Creek	206.5	64.4	107.8	Bar	On bar at tracer transect
Shovel Creek	206.5	121.5	183.6	Channel	In channel just upstream of tracer transect
Shovel Creek	206.5	122.56	184.15	Bar	At tracer transect
Shovel Creek	206.5	64.43	107.67	Bar	At tracer transect
Shovel Creek	206.5	49.64	85.48	Bar	
Shovel Creek	206.3	138	225.1	Bar	“Model T Bar” – recent bulldozer action building up control at irrigation return flow; cut bank at left bank across from bar is cobble and boulders, 2 m high and 6 m long
Shovel Creek	206.2	108.5	216.4	Bar	Downstream of island of pebble count D
Shovel Creek	205.7	56.5	95.7	Bar	Left-bank bar downstream and opposite of eroding right bank; bar composed of material from eroding right bank
Copco No. 2 Bypass	197.7	132	344.9	Channel	On right bank near cross section 1
Copco No. 2 Bypass	197.7	175.6	344.4	Channel	In main channel near cross section 1
Copco No. 2 Bypass	197.7	252.3	548.3	Fossilized bar	On bar near cross section 1
Copco No. 2 Bypass	197.2	85.7	148.2	Currently mobile bar	Currently mobile bar approximately 0.5 mile downstream of Copco No. 2 bypass site
Downstream of Iron Gate dam	189.9	101.6	209.8	Bar	Downstream of Iron Gate dam on exposed gravel bar
Downstream of Iron Gate dam	189.9	113.8	220.8	Bar	Downstream of Iron Gate dam on exposed gravel bar
Downstream of Iron Gate dam	189.9	97.2	158.9	Bar	Left-bank bar below Iron Gate dam just upstream of hatchery bridge
Downstream of Iron Gate dam	189.6	47.1	81.2	Tributary delta deposit	Bogus Creek delta deposit
Downstream of Iron Gate dam	189.6	47.3	85.3	Channel	In main channel flow adjacent to Bogus Creek Delta

Table 6.7-5. Summary of pebble counts conducted throughout the Project reaches for this study.

Reach Name	River Mile	D_{50}	D_{84}	Geomorphic Feature	Location
Downstream of Iron Gate dam	189.4	52.9	105.4	Bar	Bar downstream of USGS gauge
Downstream of Iron Gate dam	189.2	96.8	141.7	Point bar	DWR Site 43. Upstream of end bend point bar
Downstream of Iron Gate dam	188.8	96.8	147	Submerged bar	DWR Site 42. Submerged bar, left side
R-Ranch	188.3	90	130.4	Bar	Pebble count on bar at downstream end of bend with new construction
R-Ranch	187.8	59.5	83.9	Bar	Pebble count along left bank exposed bar, upstream of tributary confluence
R-Ranch	187.2	72.6	110.7	Bar at head of island	Head of island opposite R-Ranch, upstream from gravel bar head of island.
R-Ranch	187	35.9	76.3	Tributary delta deposit	Delta of Little Bogus Creek, in channel
R-Ranch	186.9	107.6	162.2	Bar	Bar downstream of Little Bogus Creek
R-Ranch	186.9	41.5	100	Channel	Upstream of island at arroyo mouth, Upstream from constriction on left bank
R-Ranch	186.8	37.1	71.9	Bar	Head of bar/island at gravel bar
R-Ranch	186.7	67.45	106.44	Channel	Tracer gravel, across channel
R-Ranch	186.7	50.9	71.6	Riffle	Right channel next to island
R-Ranch	186.6	41.7	86.1	Bar	Downstream end of bar/island
R-Ranch	186.6	87.9	151.4	Channel	In main channel downstream of island
Cottonwood Creek	182.2	51.67	81.75	Channel	Cottonwood Creek tracer site
Cottonwood Creek	182.2	67.35	104.55	Channel	Cottonwood Creek tracer site
Cottonwood Creek	182.2	68	91.14	Channel	Cottonwood Creek tracer site
Cottonwood Creek	182.1	50.9	71.6	Bar	Left bank opposite Cottonwood Creek confluence
I-5 Rest Area	179.2	45.3	77.8	Riffle	Riffle upstream of I-5 overpass
I-5 Rest Area	179.1	49.4	93.5	Bar	Bar at cross section
I-5 Rest Area	179.1	100	161	Pool	Pool at cross section
I-5 Rest Area		76.43	116.53	Channel	I-5 tracer gravel site at cross section
I-5 Rest Area	179.1	30.3	56.3	Channel	Side channel near cross section
Tree of Heaven	172.4	23.4	43.9	Bar	Cross section 1 on bar
Tree of Heaven	172.2	41.7	63	Channel	Cross section 2
Tree of Heaven	171.9	43.6	67.8	Bar	Near Tree of Heaven Campground on right bank bar cross section 3
Seiad Valley	163.5	19.6	37.7	Bar	Bar river access
Seiad Valley	159.3	17.5	32.5	Riffle	Top of Eagles Nest river access
Seiad Valley	149.8	27.8	55.8	Bar	RM 149.8 shallow channel reach, approx-imately 150 feet long bar 1 foot high
Seiad Valley	145.3	50	97.4	Riffle	Downstream of Horse Creek at riffle

Table 6.7-5. Summary of pebble counts conducted throughout the Project reaches for this study.

Reach Name	River Mile	D_{50}	D_{84}	Geomorphic Feature	Location
Seiad Valley	145.3	25.3	41.8	Bar	Downstream Horse Creek on bar approximately 8 feet above water surface
Seiad Valley	142.6	20.2	74.3	Riffle	Approximately 1 mile downstream of Scott River – through top of riffle
Seiad Valley	142.2	76.1	140.4	Bar	RM 142.2, Sarah Tottan campground, downstream of Scott River
Seiad Valley	139.8	70.1	132.5	Bar	Approximately RM 139.8 downstream of Hamburg
Seiad Valley	131	56	169.5	Bar	Hardy site on bar upstream of cross section
Seiad Valley	130.5	43.2	127.1	Riffle	Hardy site in riffle in main channel near downstream end of bar
Seiad Valley	130.5	33.1	60.9	Bar	Hardy site on exposed bar near downstream end of bar
Seiad Valley	130.5	14.5	36.8	Riffle	Hardy site in riffle near left bank side channel near upstream end of bar
Seiad Valley	129.8	43	81.5	Bar	Sluice box river access
Seiad Valley	128.5	43.5	79.4	Channel	USGS gauge station

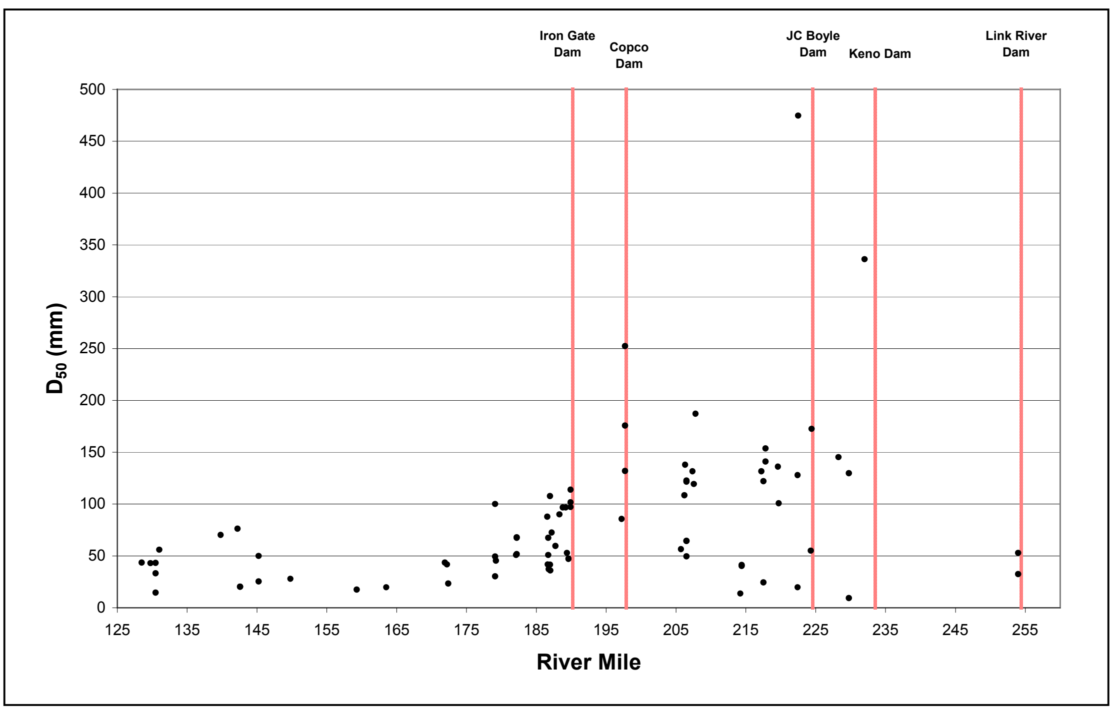

Figure 6.7-43. Klamath River pebble count D_{50} particle size longitudinal distribution.

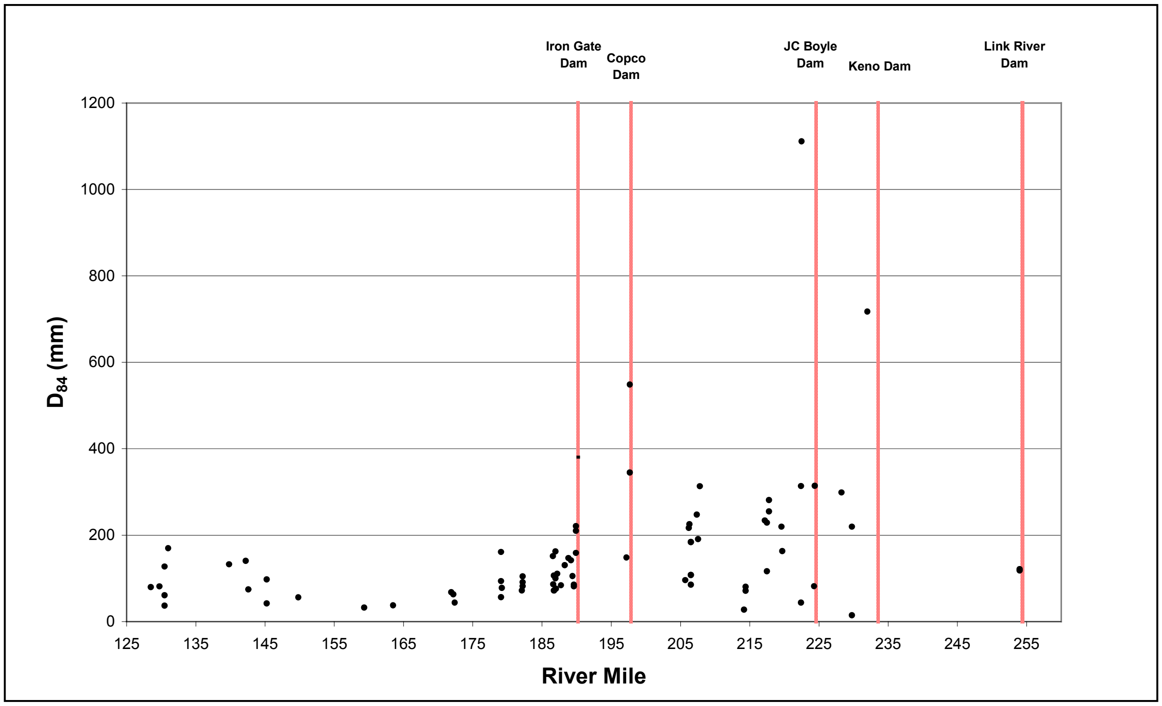

Figure 6.7-44. Klamath River pebble count D_{84} particle size longitudinal distribution.

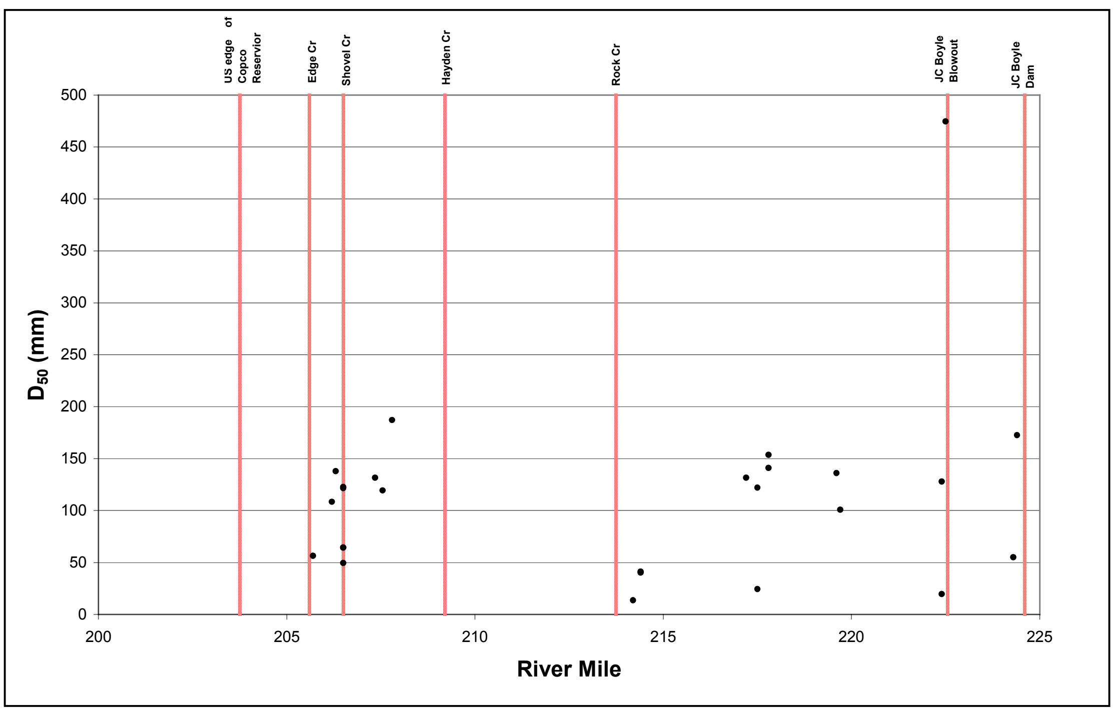

Figure 6.7-45. Klamath River pebble count D_{50} particle size longitudinal distribution, RM 200 – 225.

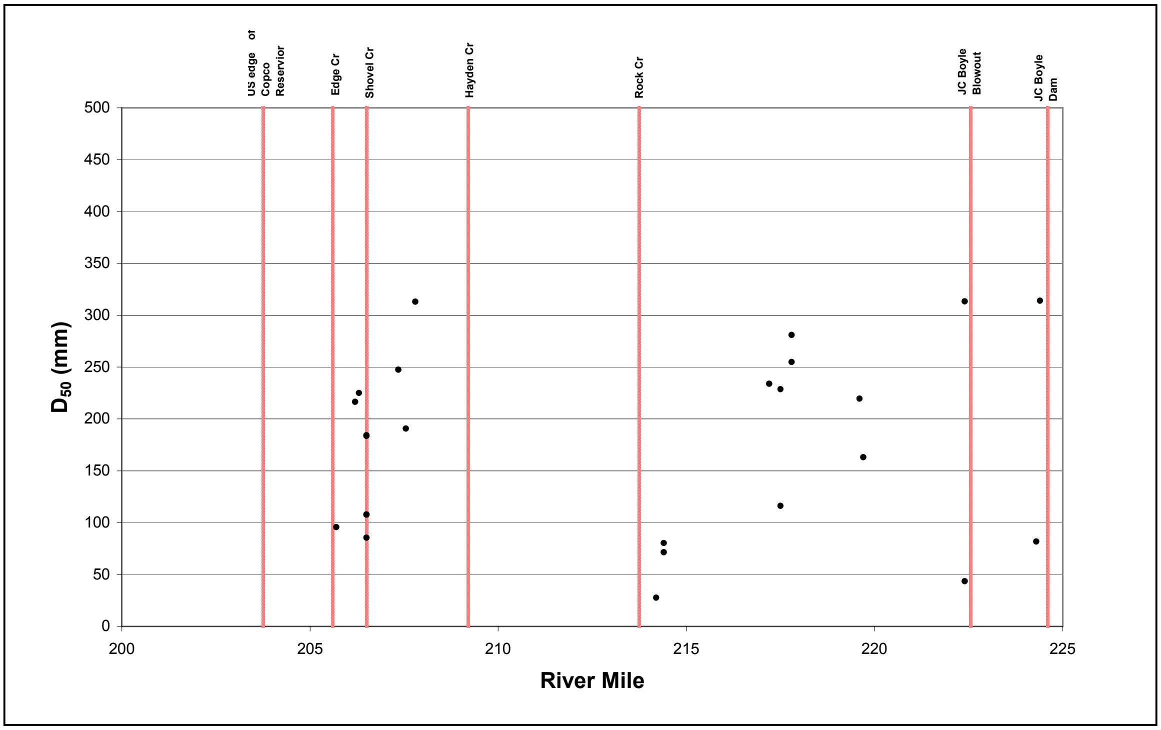

Figure 6.7-46. Klamath River pebble count D_{84} particle size longitudinal distribution, RM 200 – 225.

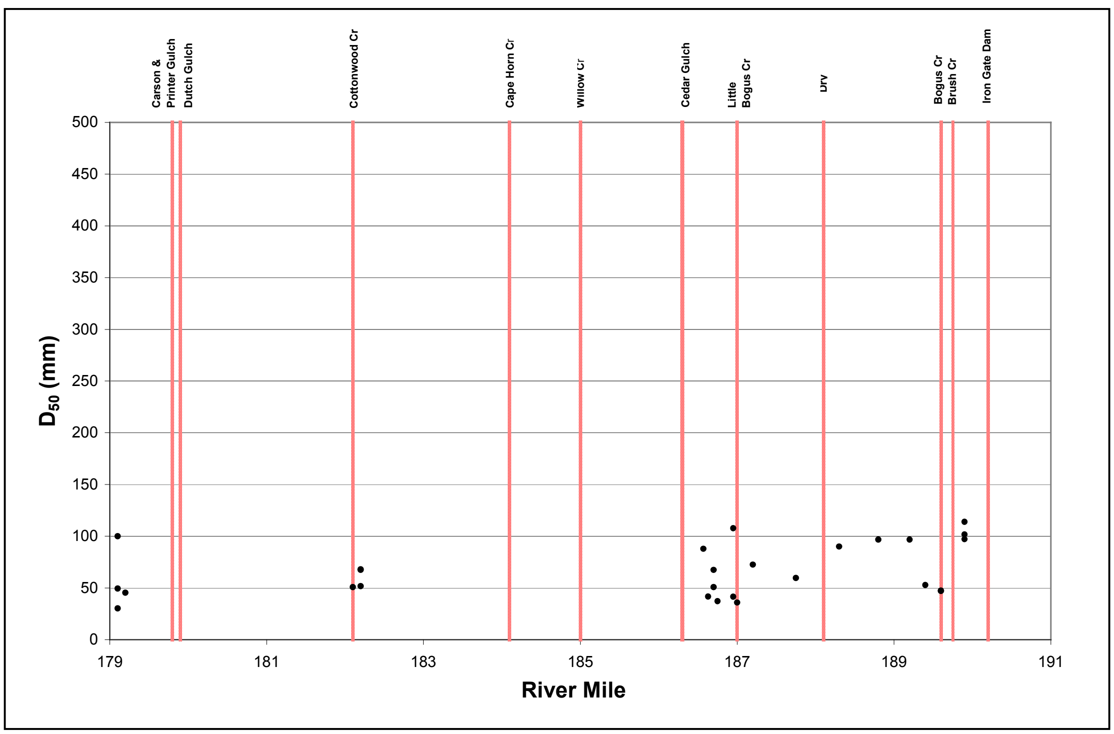

Figure 6.7-47. Klamath River pebble count D_{50} particle size longitudinal distribution, RM 179-191.

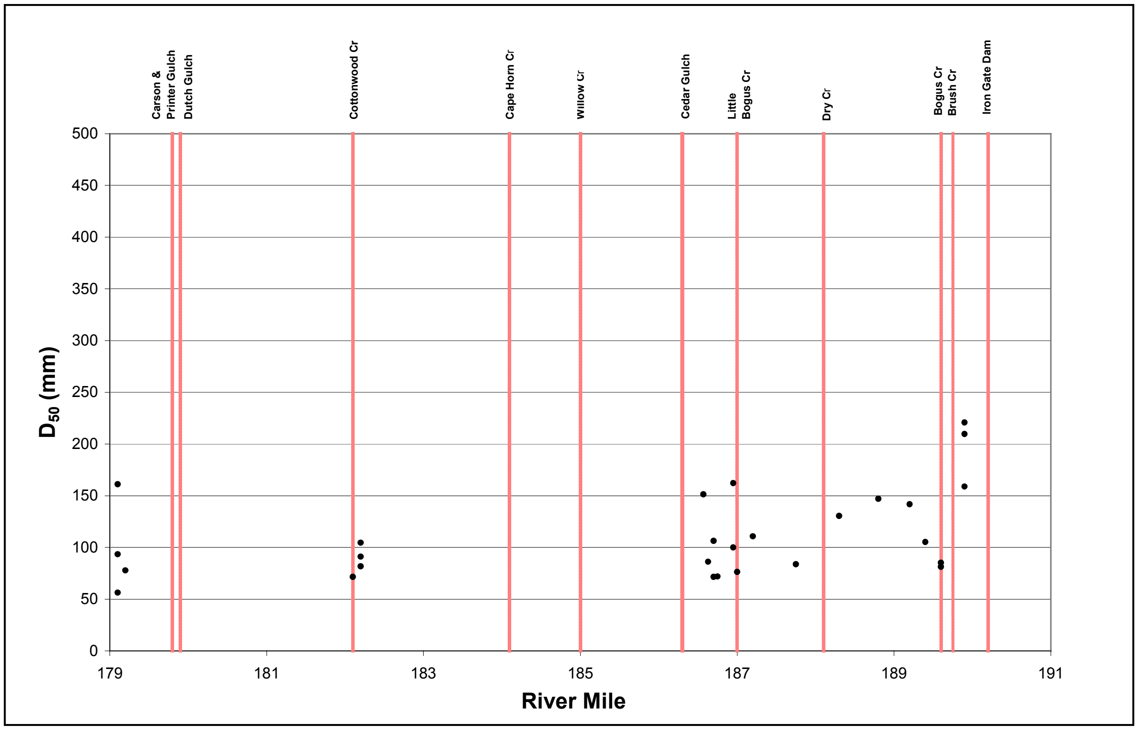

Figure 6.7-48. Klamath River pebble count D_{84} particle size longitudinal distribution, RM 179-191.

The Keno reach is characterized by a predominantly bedrock channel consisting of bedrock-boulder cascades and deep bedrock runs. Four pebble counts were conducted in the Keno reach on different geomorphic features. The pebble count at cross section 233.1 was taken on a cobble bar in a deep bedrock run and the D_{50} was 336 mm. Two pebble counts were taken at RM 229.75 the first at the toe of the bank at the cobble margin of the channel (D_{50} 130 mm) and the second on a depositional patch of gravel directly behind a boulder (D_{50} 9 mm). The last pebble count was conducted on the cobble bank of the channel at the head of J.C. Boyle reservoir (D_{50} 145 mm). The bed material in this transport reach is predominantly coarse, but fine material has deposited behind larger clasts, resulting in two thresholds for mobility. The fine material most likely is mobilized at flows expected every 1 to 2 years (bankfull flow) while the larger clasts are only mobilized during rare, high flow events. Here again, the pebble counts confirm this reach as primarily a transport reach. However, local geologic controls did provide sheltered depositional areas where relatively fine sediment was deposited and temporarily stored in the channel.

The J.C. Boyle reach upstream of the emergency spillway is characterized as a V-shaped boulder and bedrock channel. The channel is confined by the large colluvial boulders on the left bank and boulder sidecast material from canal construction on the right bank. Two pebble counts were taken in this reach. The first pebble count was taken on a terrace at cross section 224.4 and the D_{50} was 173 mm. The second pebble count was taken in a depositional patch of gravel downstream of a large boulders downstream of cross section 223.2 (D_{50} 55 mm). Local geologic controls were associated with deposits of relatively fine sediments in this reach.

Downstream of the emergency spillway, the channel appears to be adjusting to the sediment input from the blowout. The boulder runs below the blowout contain substantial pockets of fine sediment. Three pebble counts were taken in this reach. The pebble count taken farthest upstream was conducted on the boulder sidecast that has a D_{50} of 475 mm. The two remaining pebble counts were taken below cross section 222.5 at the upstream extent of an island/mid-channel bar (D_{50} 128 mm) and on a fine gravel depositional bar downstream of the island/mid-channel bar (D_{50} 20 mm). Although the transport capacity is high for the reach (due to the high local slope), sediment is added frequently to the channel from operation of the canal spillway. The gravel and fine cobble deposits in this reach, while apparently good for spawning resident rainbow trout, reflect an unnaturally high local sediment yield.

The J.C. Boyle peaking reach downstream of the USGS gauge is characterized by alternating cobble riffles, runs, and pools lined by cobble bars. Boulders and cobbles dominate the channel bed. Seven pebble counts were taken in this reach. The pebble count conducted farthest upstream in this reach was taken at the USGS gauge in a cobble pool (D_{50} 101 mm). The second pebble count was taken at a point bar at the head of a fine cobble riffle (D_{50} 136 mm). The remaining five pebble counts were taken on bars at three different cross sections at the BLM campground. Four of the pebble counts are similar in D_{50}, and the average D_{50} is 137 mm. At cross section 219.6, a bar was sampled near the right bank with a D_{50} of 24 mm.

The J.C. Boyle Gorge reach is characterized by confined canyon with steep bedrock and cascades with large boulders at the channel margins. Three pebble counts were conducted in this reach. Two pebble counts were taken on a point bar downstream of Frain Ranch, and the D_{50} was 41 mm and 40 mm, respectively. The third pebble count was taken in a patch of pocket gravel downstream of a group of boulders, and the D_{50} was 14 mm. The pebble counts in this area highlight the storage of relatively fine sediments (gravel and fine cobble) just upstream of the transition from the Frain Ranch area into the gorge at Caldera. While small patches of fine gravel were identified behind boulders at the margin of the gorge itself, the gorge is primarily characterized by very coarse boulders.

The J.C. Boyle Shovel Creek reach is characterized as an alluvial channel flanked by broad floodplains with well-developed alternating bars and pool-riffle morphology. The pebble counts in this reach (specifically the number of pebble counts possible on bars and other alluvial features) illustrate the difference between this alluvial reach and the more confined, steeper gorge reach upstream. Ten of the 11 pebble counts were conducted in this reach on bars. One pebble count was conducted on the channel bed and had a D_{50} of 122 mm. Of the ten pebbles counts taken on bars in the reach, five had a D_{50} greater than 120 mm, with an average D_{50} of 140 mm. The average D_{50} for the remaining five pebble counts was 71 mm. Although field observations note that the bed material fines downstream in this reach from cobbles to fine gravel, the pebble counts do not quantitatively reflect this perceived fining.

The Copco No. 2 bypass reach is characterized as a steep, confined boulder and bedrock-dominated channel with fossilized bars consisting of boulders and cobbles. Pebble counts taken at cross section 197.7 in this reach were coarser in the channel than on the right bank, with a D_{50} of 176 mm and 132, respectively. Pebble counts were conducted on a fossilized and active bar to quantify the difference in surface particle size distributions. The D_{50} of the fossilized bar was 252 mm compared to 86 mm at the active bar. The fossilized conditions captured in the pebble counts at this reach highlight the long-term effects of the elimination of upstream coarse sediment supply combined with relatively unaltered peak flood flows.

The reach from Iron Gate dam to Cottonwood Creek is characterized by coarse cobble-boulder bars below the dam and by a cobbled bedded channel with defined pool-riffle morphology farther downstream. Tributary deltas have formed at the confluence with tributaries that are composed of finer-grained material than the mainstem. Fine-grained sediment inputs from the tributaries initially decrease the size distribution of surface clasts in the mainstem, but the bed typically coarsens by the next tributary. The D_{50} of bars in this reach average 104 mm. The D_{50} of the Bogus Creek tributary delta is 47 mm, and the D_{50} of the channel at the tributary is 47 mm. Before the next downstream tributary, the channel coarsens and the D_{50} increases to 96 mm. This pattern continues throughout the reach and is documented by 23 pebble counts conducted in this reach.

The reach from Cottonwood Creek to Scott River is characterized by a confined channel with a cobble-gravel bed and well-developed pool-riffle morphology. Bars along this reach appear to fine with distance downstream. The D_{50} at a bar at the upstream extent of the reach is 49 mm, compared to 25 mm at the downstream extent of the reach. This perceived fining could be due to the continual increase in fine sediment supplies with distance downstream. Unlike the bars, the D_{50} of riffles at the upstream and downstream extent of this geomorphic reach remained consistent at 45 mm and 50 mm, respectively.

The reach downstream of Scott River (including Seiad Valley) is characterized by a confined, cobble-gravel bedded channel with well-developed pool-riffle morphology. The channel has significantly fined at the farthest downstream study reach compared with the upper reaches. The average D_{50} for the five pebble counts conducted on bars is 56 mm, and the average D_{50} for the three riffles where pebble counts were conducted in this reach is 26 mm. Further, increasing quantities of sand and very fine gravel were noted in the pebble counts conducted in this reach. These pebble counts indicate that the impact of the Project on fine sediment supply is largely undetectable by the time the Klamath River reaches Seiad Valley.

A qualitative comparison of pebble counts conducted on similar geomorphic features suggests a trend of fining downstream. Tributary inputs to the mainstem add fine sediments to the channel and appear to provide sediment of suitable size for salmonid spawning (Kondolf, 2000a). In reaches below Project reservoirs, the channel tends to be coarser immediately downstream of the dam and tends to fine relatively rapidly with distance downstream. This is one indication that the Project dams have trapped fine sediment and the channel has coarsened downstream of Project dams.

Ten percent of the pebble count D_{50} and D_{84} values computed with a spreadsheet algorithm were compared to values from hand-plotted pebble count data on probability paper. This comparison showed that both methods produced similar D_{50} and D_{84} values from the pebble count data. On average, the D_{50} values determined with the spreadsheet algorithm were only 3.2 percent different from the values calculated with the hand-plot method. D_{84} values calculated with the spreadsheet algorithm were an average of 4.1 percent different from the values calculated with the hand-plot method. Given the uncertainty associated with determining D_{50} and D_{84} values from hand-plots, the difference between the two estimates was deemed acceptable for comparisons of sediment size distribution data collected in this study to data from prior studies.

6.7.7.4 Floodplain and Riparian Terrace Features, Large Woody Debris Survey, and Riparian Vegetation Study Integration

This section presents results and discussion regarding the geomorphology of the riparian corridor in the Project area. The existing characteristics of and potential Project impacts to riparian vegetation are dealt with in significantly greater detail in the riparian vegetation study in the Terrestrial Resources FTR. The intent of this section is to identify key relationships between riparian vegetation and underlying geomorphic processes in the Project area. The results of the large woody debris (LWD) surveys are presented first, followed by a qualitative discussion of observed floodplain and riparian terrace features and associated riparian vegetation. The final part of this section summarizes the results of an investigation of potential bar fossilization by willows downstream of Iron Gate dam.

A summary of the LWD survey is provided in Table 6.7-6. The average length, diameter, and spacing of LWD within the Project area varies from site to site. For example, the average length ranges from 1 to 10 m; the average diameter ranges from less than 0.025 to 0.61 m; and the average spacing ranges from 5 to 100 m. Although the LWD attributes differ from site to site, the accessibility of the material to flows generally is comparable throughout the Project area. The elevation of the LWD along the banks indicates that the material typically is not accessible until periods of high flows. At several study sites, the LWD includes colluvial wood from the banks. The elevation of this material along the banks indicates that the colluvial wood generally is not accessible by the channel. While significant deposits of LWD were observed in most Project reaches and may provide temporary aquatic and riparian habitat, nowhere did they appear to strongly influence underlying geomorphic processes. In most cases, the conditions were maintained primarily by interactions of flow and local geology appeared to control the recruitment and growth of riparian vegetation, and therefore the locations of LWD in the system.

Table 6.7-6. Summary of large woody debris.

Study Site	Average Length (m)	Average Diameter (m)	Spacing (m)	Availability to Channel
Link River	Mixed < 1 and 5-10	< 0.08-0.3	5-15	Accessible by channel during high flows, some LWD accessible at normal flows.
Keno	1-4	< 0.15-0.3	10-50	Accessible by channel during high flows.
J.C. Boyle Bypass, Upstream of Blowout	1-2	< 0.15	Some areas of close spacing, mainly on right-bank terrace, otherwise every 100 m	Accessible by channel during high flows (~1,500 cfs).
J.C. Boyle Bypass, Downstream of Blowout	1-2	< 0.15	100	Primarily wood from colluvial banks, which is not accessible by channel. Limited LWD accessible by channel during high flows.
J.C. Boyle USGS Gauge	10	0.3-0.61	50-100	Accessible by channel during high flows (~1,500 and 3,000 cfs).

Table 6.7-6. Summary of large woody debris.

Study Site	Average Length (m)	Average Diameter (m)	Spacing (m)	Availability to Channel
J.C. Boyle Peaking, BLM Campground	3-5	< 0.15 to 0.46	100-150	Accessible by channel during high flows (> 3,000 cfs).
J.C. Boyle Peaking, Gorge	3-6.5	< 0.15 to 0.46	23	Accessible by channel during high flows.
J.C. Boyle Peaking, Shovel Creek	1-3	0.025 to 0.15	20-50	Accessible by channel during high flows (~1,500 to 3,000 cfs).
Copco No. 2	2-3	< 0.15	Closely spaced	Accessible by channel during high flows. Some LWD from colluvial banks, which is not accessible by channel.
Downstream of Iron Gate Reservoir, USGS Gauge	1-2	< 0.15	50-100	Accessible by channel during high flows.
Downstream of Iron Gate Reservoir, R-Ranch	1-2	< 0.15	50-100	Accessible by channel during high flows.
Downstream of Iron Gate Reservoir, I-5 Rest Area*	--	--	--	--
Downstream of Iron Gate Reservoir, Tree of Heaven Campground*	--	--	--	--
Downstream of Iron Gate Reservoir, Seiad Valley-Hardy Site	3-5	0.3	10-20	Accessible by channel during high flows. Access to channel limited by thick vegetation around the LWD.
Downstream of Iron Gate Reservoir, Seiad Valley at USGS Gauge	3	0.3	15-30	Accessible by channel during high flows.

*No significant amounts of large woody debris present.

Table 6.7-7 summarizes tree age data collected during the riparian vegetation study throughout the Project area. The following discussion of floodplain and riparian terrace features by geomorphic reach integrates this data with observations from the geomorphology study and the riparian vegetation study.

Table 6.7-7 Riparian tree age summary.

Geomorphic Reach	River Mile	Location	Species	Age
Link	No tree ages collected in this geomorphic reach			
Keno	232.4	RB narrow terrace	*Salix lucida*	119
	232	RB narrow terrace	*Fraxinus latifolia*	n/a
J.C. Boyle Bypass	No tree ages collected in this geomorphic reach			
J.C. Boyle USGS Gauge/Frain Ranch	219.7	RB terrace	*Quercus kelloggii*	153
	219.7	RB terrace	*Calocedrus decurrens*	83
	219.7	RB terrace	*Quercus garryana*	131
	219.7	RB terrace	*Quercus kelloggii*	130
	219.7	RB terrace	*Calocedrus decurrens*	65
	219.7	RB terrace	*Quercus garryana*	52
	219.7	RB terrace	*Quercus garryana*	20
	219.7	RB terrace	*Calocedrus decurrens*	64
	215.63	RB low terrace	*Quercus garryana*	55
	215.63	RB low terrace	*Quercus garryana*	92
	215.63	RB low terrace	*Quercus garryana*	107
	215.63	RB low terrace	*Salix exigua*	19
	215.63	RB low terrace	*Salix exigua*	24
	215.63	RB low terrace	*Salix exigua*	15
	215.63	RB low terrace	*Salix exigua*	13
	215.63	RB low terrace	*Salix exigua*	13
	215.63	RB low terrace	*Salix exigua*	5
	215.63	RB low terrace	*Salix exigua*	4
	215.63	RB low terrace	*Salix exigua*	5
J.C. Boyle Gorge	No tree ages collected in this geomorphic reach			
J.C. Boyle Shovel Creek	206.5	LB terrace	*Fraxinus latifolia*	86
	206.5	LB terrace	*Salix lasiolepis*	13
	206.5	LB terrace	*Salix exigua*	50
	206.5	LB terrace	*Salix exigua*	46
Copco No. 2 Bypass	197	Island	*Alnus rhombifolia*	54
	197	Island	*Alnus rhombifolia*	52
	197	LB terrace	*Alnus rhombifolia*	0
	197	LB terrace	*Alnus rhombifolia*	66
	197	US island margin	*Alnus rhombifolia*	32
	197	US island margin	*Alnus rhombifolia*	62

Table 6.7-7 Riparian tree age summary.

Geomorphic Reach	River Mile	Location	Species	Age
Iron Gate Dam to Cottonwood Creek	189.6	LB terrace	*Salix exigua*	11
	189.6	LB terrace	*Salix exigua*	5
	189.6	LB terrace	*Salix exigua*	6
	189.6	LB terrace	*Fraxinus latifolia*	74
	189.6	LB terrace	*Fraxinus latifolia*	n/a
	189.6	LB terrace	*Salix exigua*	11
	189.41	RB bar	*Salix exigua*	13
	189.41	RB bar	*Salix exigua*	11
	189.41	RB bar	*Salix exigua*	24
	189.41	RB bar	*Salix exigua*	20
	189.41	RB bar	*Salix exigua*	14
	189.4	RB bar	*Salix exigua*	25
	189.4	RB bar	*Salix exigua*	8
	189.4	RB bar	*Salix exigua*	10
	189.4	RB bar	*Salix exigua*	14
	189.4	RB bar	*Salix exigua*	17
	186.7	R-Ranch island	*Fraxinus latifolia*	102
	186.7	R-Ranch island	*Quercus garryana*	129
	186.7	R-Ranch island	*Juniperus occidentalis*	119
Cottonwood Creek to Scott River	179	LB terrace	Salix exigua	11
	179	LB terrace	Salix exigua	11
	179	LB terrace	Salix exigua	5
	179	LB terrace	Salix exigua	7
	179	LB terrace	Salix exigua	4
	179	Island margin	Salix exigua	21
	179	Island margin	Salix exigua	21
	179	Island margin	Salix exigua	7
	179	Middle island	Salix exigua	22
	179	Middle island	Salix exigua	36
Downstream of Scott River to Seiad Valley	No tree ages collected in this geomorphic reach			

RB = right bank, LB = left bank, US = upstream.

Link River

Because it is primarily a bedrock reach, channel morphology did not appear to be significantly controlled by riparian vegetation conditions. As discussed in the riparian vegetation study, riparian vegetation at Link River was influenced by river hydrology and by seepage from the West Side canal and the East Side canal and penstock. Seepage, especially from the West Side canal, has created many perched wetland habitats well away from the hydrological influence of normal river flows in the reach. The riparian vegetation at Link River was unique compared to other Project river reaches because of the presence and abundance of introduced woody species. Apple (*Mauls* sp.), plum (*Prunes* sp.), and elm (*Umlauts* sp.) were commonly the dominant species in the tree layer. A non-native species of rose (*Rosa* sp.) was uncommon, but locally abundant. Reed canarygrass (*Phalaris arundinacea*), a species of questionable origin in the region (Merigliano and Lesica, 1998), was also abundant close to the active channel and in seepage areas. Vegetation types identified in this reach included hardstem bulrush (*Scirpus acutus*), reed canarygrass, red osier dogwood (*Cornus sericeus*), apple, elm, Himalayan blackberry (*Rubus discolor*), Scouler's willow (*Salix scouleriana*), arroyo willow (*Salix lasiolepis*), and shining willow (*Salix lucida* ssp. *lasiandra*). No tree ages were recorded in the Link River reach, so it is difficult to link vegetation conditions to specific hydrologic events or changes in river management.

<u>Keno</u>

The Keno reach also exhibits significant bedrock control, and the influence of riparian vegetation on channel forms is only slightly more significant than in the Link River reach. Fluctuating flows may limit vegetation growth to some extent at channel margins and therefore lead to increased erosion of fines from these areas. In addition, marginal islands (usually associated with bedrock protrusions or accumulations of coarse cobble and boulders) may be stabilized to some extent by vigorous growth of emergent vegetation. This material is flattened during high flows and may protect underlying fine sediment within the coarse island matrices from shear stresses generated during periods of high flow. The active channel in the Keno reach comprises a relatively large proportion of the valley bottom, and therefore surfaces for colonization by riparian vegetation (e.g., bars, terraces, islands) are relatively small and limited in extent. Total tree and shrub cover estimates were both low in Keno Canyon, averaging less than 4 percent. The riparian vegetation study identified nine vegetation types in the Keno reach. Reed canarygrass, hardstem bulrush, and river bulrush (*Scirpus fluvitialis*) were the most frequently occurring riparian plant species growing in Keno Canyon, and they appeared to be well suited to the coarse bed materials at the margins of the active channel. Other riparian plant species were scarce by comparison and were restricted primarily to narrow benches or terraces. Shining willow, Douglas' spiraea (*Spiraea douglasii*), brown dogwood (*Cornus glabrata*), and arroyo willow were among the few woody species captured in the plot data and occupy various positions along the sampled profiles. One very old (approximately 119 years) willow was aged on a right-bank terrace in this reach. This suggests that conditions suitable to the recruitment and growth of woody vegetation have persisted over the life of the Project in some locations in this reach.

<u>J.C. Boyle (includes Bypass, USGS Gauge/Frain Ranch Peaking, Gorge Peaking, and Shovel Creek Peaking Geomorphic Reaches)</u>

Geomorphic characteristics vary considerably throughout the J.C. Boyle peaking and bypass reaches. Still, riparian vegetation does not appear to significantly affect the formation and persistence of bedforms in the active channel or riparian zones. Even in alluvial reaches downstream of the gorge, channel-forming processes did not appear to be strongly linked to riparian vegetation. However, bars in the alluvial reaches of this reach did appear to be affected with respect to riparian vegetation by the hydroperiod on those surfaces resulting from peaking operations. The sediment composition of most alluvial bars appeared amenable to riparian vegetation recruitment and growth, but the bars were unvegetated to the margin of inundation during peaking.

Riparian vegetation in the J.C. Boyle bypass showed clear evidence of past Project impacts (specifically from sidecast material). Tree cover in the bypass reach averaged less than 1 percent, while shrub cover averaged 63 percent. In the riparian zone of the peaking reach, tree cover averaged approximately 33 percent, while shrub cover was 10 percent. Reed canarygrass, colonial bentgrass, Oregon ash, Kentucky bluegrass, Himalayan blackberry, woolly sedge, coyote willow, western goldenrod, perennial ryegrass, and devil's beggarstick were the most frequently occurring riparian plant species growing in J.C. Boyle peaking and bypass reaches, and in various combinations form the dominant vegetation types. Tree ages in this reach ranged from 5 to 135 years, indicating the presence of surfaces suitable for a range of riparian vegetation recruitment and growth.

Copco No. 2 Bypass

Project impacts on riparian vegetation and geomorphology are most apparent in the Copco No. 2 bypass reach. The base flow in this reach has been reduced to approximately 10 cfs for a long period of time. This low base flow has allowed mature trees to persist in the active channel. Large flood flows have continued to pass through this reach. These floods have progressively coarsened the bed of the active channel because supplies of fine sediment from upstream have been eliminated by Copco dam. This has created a reach where mature alders have rooted in and fossilized large cobbles and boulders in the active channel. The ages of the alders in the active channel (up to 66 years) suggest that this encroachment was already well established prior to the 1964 flood.

Downstream of Iron Gate Dam (includes Iron Gate Dam to Cottonwood Creek, Cottonwood Creek to Scott River, and Scott River to Seiad Valley Geomorphic Reaches)

Geomorphic conditions vary considerably throughout these geomorphic reaches, and the influence of riparian vegetation on channel morphology varies accordingly. Throughout most of this reach, however, the primary bedforms and riparian features are most often controlled by local geologic controls, and in some cases by the presence of mine tailings. Tree cover in the Iron Gate reach averaged 37.3 percent, and shrub cover averaged 18.3 percent. The riparian vegetation study identified 12 vegetation types. Coyote willow, colonial bentgrass, Oregon ash, rice cutgrass, Himalayan blackberry, western goldenrod, curly pondweed, teasel, duckweed, and knotgrass were the most frequently occurring riparian plant species growing in the Iron Gate reach and in various combinations form the dominant vegetation types. Woody vegetation ages in these reaches ranged from 4 to 129 years, suggesting a wide range of geomorphic surfaces for vegetation recruitment and growth. The 129-year old tree on the island near R-Ranch indicates that this island has been a persistent feature in the Klamath River since before the initiation of the Project.

Potential Gravel/Cobble Bar Fossilization Downstream of Iron Gate Dam

Recent field observations of the Blue Heron bar near RM 145 on the Klamath River indicated that bar may have become fossilized as a result of excessive willow growth (Belchik, pers. comm., 2003) and its value as salmonid spawning habitat subsequently reduced. An aerial photograph analysis and a field investigation (see section 6.4.7.4) were performed to test this hypothesis. Figure 6.7-49 presents the annual flood peaks recorded at the Seiad Valley USGS gauge from 1951 to 2001 and the condition of the Blue Heron bar as observed in aerial photographs. The aerial photographs are reproduced in Figures 6.7-50 to 6.7-54.

For the 1955-1980 period, Blue Heron bar seems to be cleared of most vegetation after flood peaks greater than the 10-year return interval peak. However, this trend appears to change from 1989 to the present, when a significant flood peak in 1997 (16-year flood) did not result in bar clearing that was visible in either the 1998 or 1999 aerial photographs. There are several potential explanations for this phenomenon. The hydrology data show a relatively long period (1983-1997) without any annual flood peaks above the 10-year flood. This dry period could have allowed vegetation to become more strongly established and therefore more resistant to subsequent large flood flows. The field investigation of Blue Heron bar in October 2003 confirmed that the gravel and cobble on the bar are fossilized by vegetation (primarily willows). Dense willow growth extended from approximately 3 feet into the active channel to 17 feet away from the active channel. However, the largest, oldest-looking willows on the bar (most in a longitudinal band approximately 3 to 9 feet from the active channel) ranged in age from 5 to 7 years (determined from cores and cuttings), which would put their date of establishment around the time of the 1997 flood.

Therefore, the growth of vegetation between the 1997 flood and the 1998 photograph may have been very rapid, making any clearing of the bar undetectable in this analysis. A reconnaissance-level search in 2003 did not reveal other similarly fossilized bars in this region of the year Klamath River. A comprehensive analysis of Blue Heron and other potentially fossilized bars would be required to determine the mechanisms responsible for fossilization. At this time it is not possible to directly link the fossilization of Blue Heron bar to Project impacts on geomorphology and sediment transport.

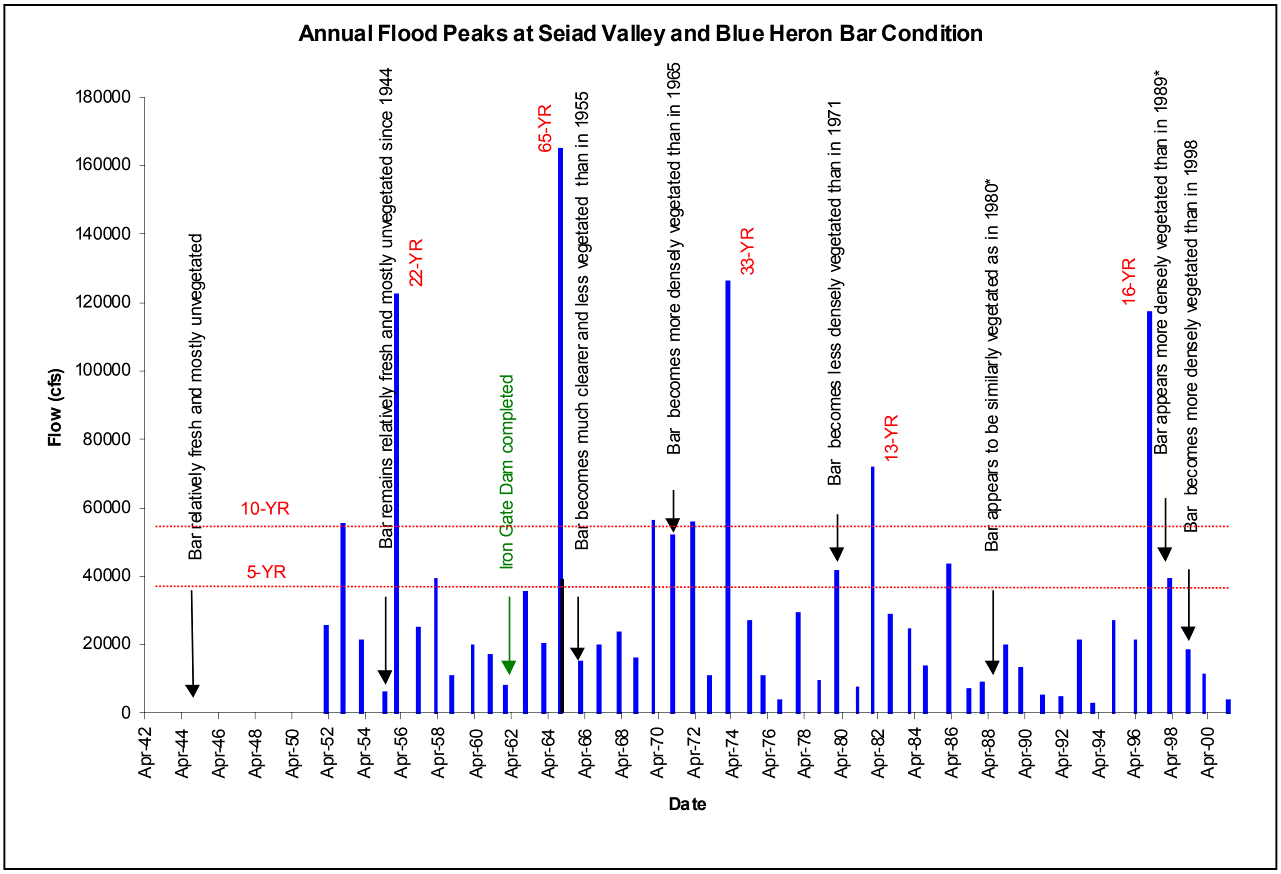

Figure 6.7-49. Annual flood peaks (in blue) with aerial photograph observations (in black) for the Blue Heron bar near RM 145.

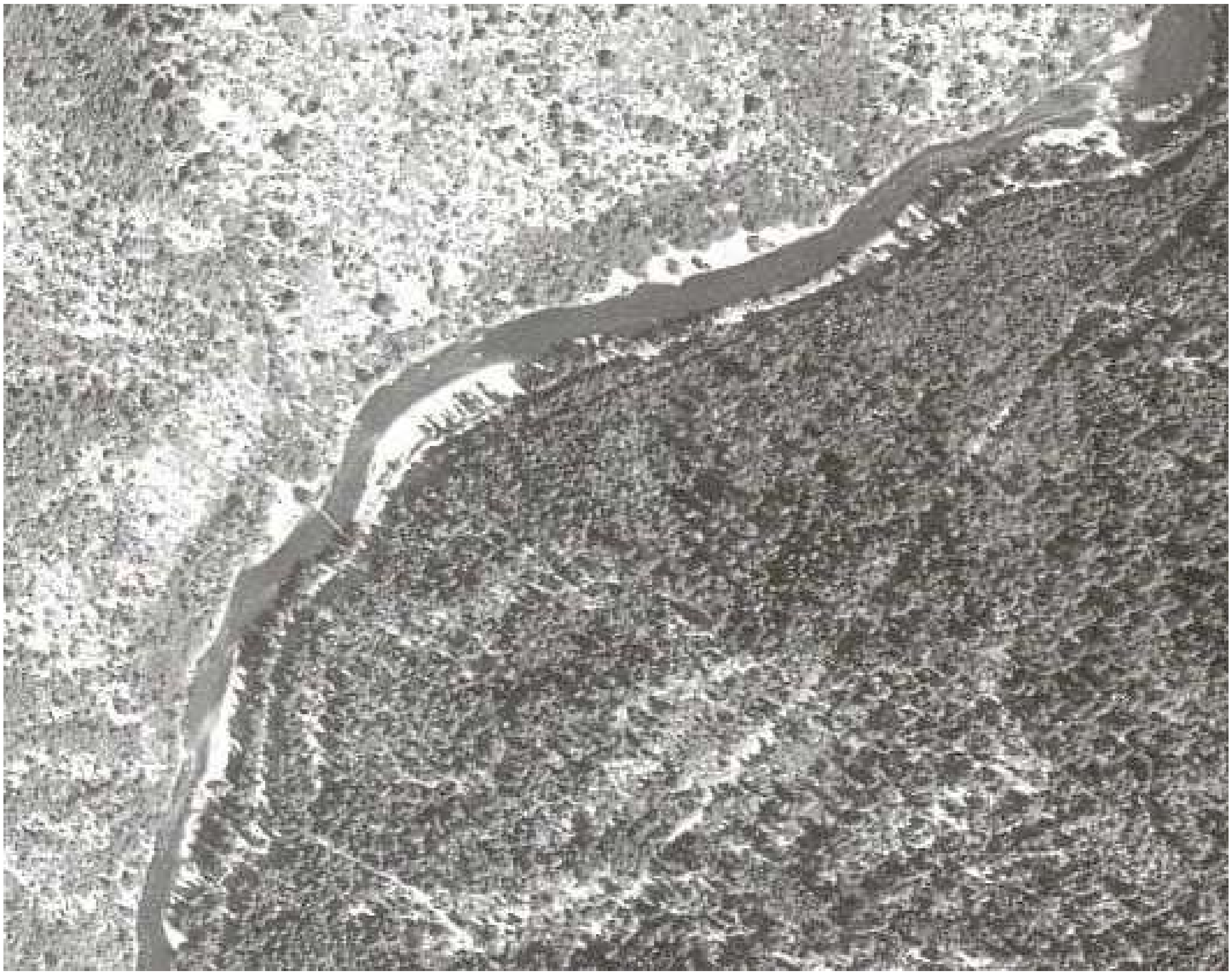

Figure 6.7-50. Blue Heron bar (relatively clear, white point bar on river left) on August 17, 1955. Mean daily discharge was 817 cfs.

Figure 6.7-51. Blue Heron bar on August 14, 1965. Mean daily discharge was 1,020 cfs.

Figure 6.7-52. Blue Heron bar on August 12, 1971. Mean daily discharge was 1,020 cfs.

Figure 6.7-53. Blue Heron bar on August 14, 1980. Mean daily discharge was 1,050 cfs.

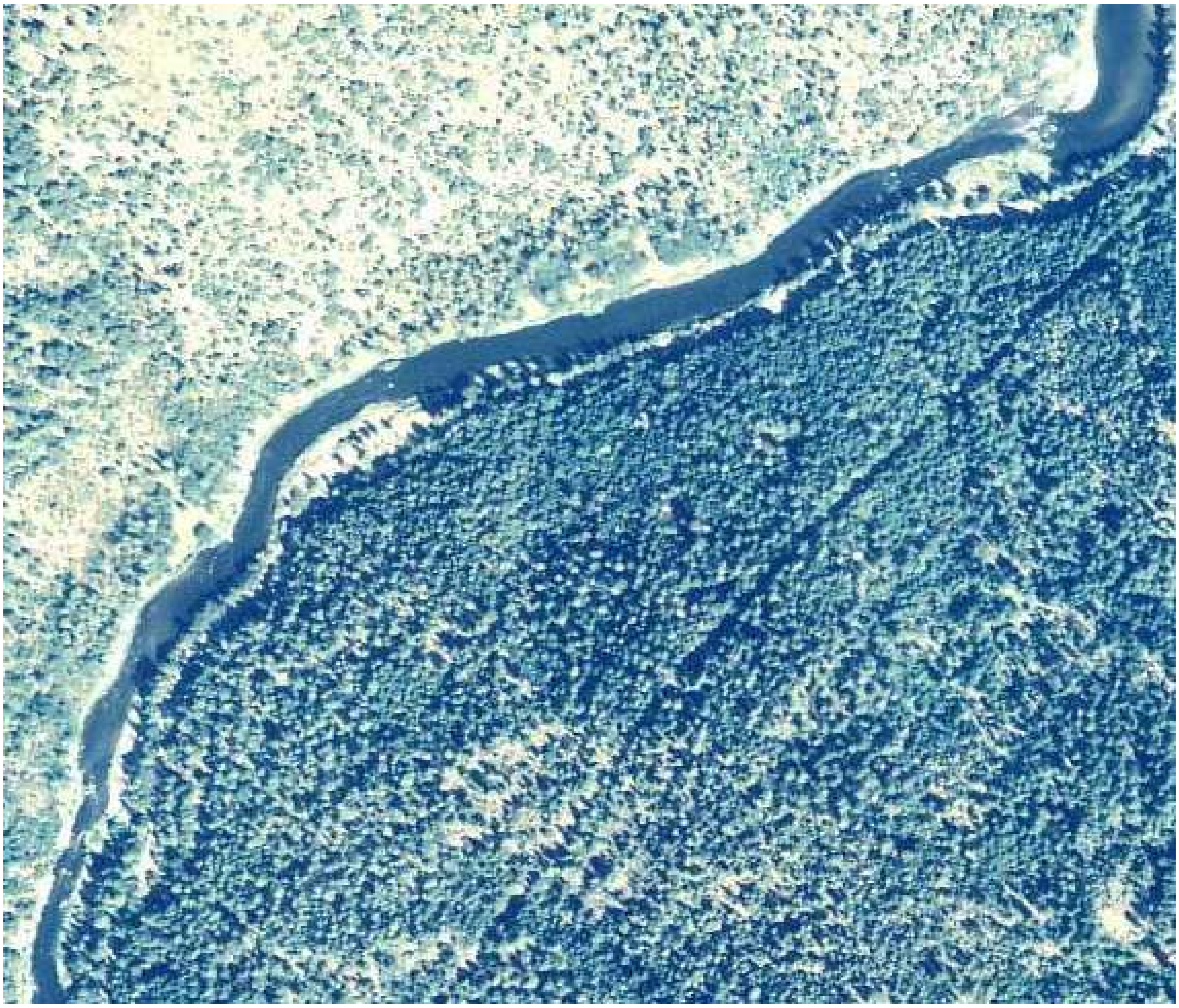

Figure 6.7-54: Blue Heron bar on August 16, 1999. Mean daily discharge was 1,130 cfs.

6.7.8 Fitting Channel Classification Systems to Klamath River Channels

6.7.8.1 Rosgen Classification System

The Rosgen channel types for each cross section in each study reach of the Klamath River are summarized in Table 6.7-8. Most channels fit the C or F Level 1 classification best. However, many of the sites did not fit all the criteria of the assigned Rosgen classification. The following discussion summarizes Rosgen channel types throughout the Project area, presents the range of morphological parameters used to develop the Level 2 classifications, and finally identifies potential Project impacts as they relate to these classifications.

Throughout the study reach, the channel is characterized as Bc, C, or F in the Rosgen classification scheme. Although B channels are typically associated with higher channel slopes than those found in the study reaches, the subscript “c” refers to lower gradient channels that maintain the B channel type of form. B channels in the study reach are characterized as having gentle slopes, low meander widths, and a moderately entrenched active channel. Controlling valley slopes tend to limit floodplain development in Bc-type channels. C channels are typically slightly entrenched in well-developed floodplains with pool-riffle bedform morphology. C channels tend to develop point bars in the active channel as the channel laterally migrates. C channels are easily altered by changes in the watershed condition or flow regime. F channels are characterized as entrenched, meandering channels and are typically deeply incised in valleys of relatively low relief containing highly erodible materials. F channels are characterized by very high width-to-depth ratios and have high sediment inputs.

Throughout most of the Project area, the Klamath River channel is relatively straight with low sinuosity (generally under 1.2). However, the J.C. Boyle peaking reach at the USGS gauge has moderate sinuosity. Further, the Copco No. 2 reach, R-Ranch reach, and downstream of Iron Gate dam at Tree of Heaven Campground have moderate to high sinuosity. Local slopes throughout much of the Project area are relatively gentle, ranging from about 0.013 to 0.0001. In some reaches, however, local slopes were as high as 0.023 a relatively steep gradient for a river as large as the Klamath. In general, channel slopes decrease with river mile throughout the Project area. The steepest slopes are found in the J.C. Boyle bypass reach, the J.C Boyle peaking reach at the USGS gauge, and the Copco No. 2 reach, which range from about 0.023 to 0.016.

Entrenchment throughout the study area varies from entrenched to slightly entrenched. Low entrenchment in the upper reaches of the study reach appears to be controlled by bedrock outcrops and valley walls. The width-to-depth ratio throughout the Project reach is relatively high, except for two study sites in the Keno and J.C. Boyle bypass reaches upstream of the “blowout” (a large canyon-like feature in the side of the hill), where the width-to-depth ratio is moderate to low, respectively. For the most part, the dominant bed material size becomes finer with river mile. The Link and Keno reaches have bedrock channel beds. The J.C. Boyle bypass and peaking reaches have beds primarily dominated by boulders and coarse cobble. Below Iron Gate dam, the channel bed is composed of cobble and coarse gravel. By Seiad Valley, the bed has transitioned to gravel and sand.

Project dams have trapped significant quantities of bed load sediment over the course of Project operations. This has resulted in some coarsening of the bed downstream of Project dams. As a result, the channel classifications presented in this report may indicate that in certain reaches (e.g., the J.C. Boyle peaking reach at the USGS gauge, and downstream of Iron Gate dam at the fish hatchery), the channel is in the process of adjusting to a reduced sediment supply from upstream reaches.

Table 6.7-8. Rosgen channel types for each cross section in each study reach.

Site	Cross Section	Entrench-ment Ratio	Width/ Depth Ratio	Sinuosity	Reach Water Surface Slope	Channel Materials	Level 1 Stream Type	Level 2 Stream Type	Notes
Link River	RM 254	2.5	23.3	1.00	0.007	Bedrock	C	C1	Exact fit not possible, two channels present and slope not within given ranges
	RM 253.9	1.9	51.8	1.00	0.007	Bedrock	C	C1	Exact fit not possible, slope not within given ranges
Keno Reach	RM 232.4	1.4	33.3	1.00	0.013	Bedrock	B	B1c	Exact fit not possible, sinuosity not within given ranges
	RM 232.1	1.1	311	1.00	0.013	Bedrock	F	F1	Exact fit not possible, sinuosity not within given ranges
	RM 231.9	2.2	11.1	1.04	0.013	Bedrock	B	B1c	Exact fit not possible, sinuosity and width-to-depth ratio not within given ranges
J.C. Boyle Bypass Upstream of Blowout	RM 223.5	2.1	4.0	1.16	0.014	Boulder	B	B2c	Exact fit not possible, sinuosity and width-to-depth ratio not within given ranges
	RM 223.3	1.2	32.9	1.16	0.014	Boulder	F	F2	Exact fit not possible, sinuosity and width-to-depth ratio not within given ranges
	RM 223.25	1.3	23.5	1.16	0.014	Boulder	F	F2	Exact fit not possible, sinuosity and width to depth ratio not within given ranges
J.C. Boyle Bypass Downstream of Blowout	RM 222.55	1.0	44.8	1.16	0.023	Boulder/ cobble	F	F2b/F3b	
	RM 222.4	1.2	74.4	1.16	0.023	Boulder/ cobble	F	F2b/F3b	
	RM 222.3	1.1	56.5	1.16	0.023	Boulder/ cobble	F	F2b/F3b	
J.C. Boyle Peaking at USGS Gauge	RM 219.9	0.5	50.6	1.28	0.017	Boulder/ cobble	B	B2c/B3c	
	RM 219.7	1.9	37.4	1.28	0.017	Boulder/ cobble	B	B2c/B3c	

Table 6.7-8. Rosgen channel types for each cross section in each study reach.

Site	Cross Section	Entrench-ment Ratio	Width/ Depth Ratio	Sinuosity	Reach Water Surface Slope	Channel Materials	Level 1 Stream Type	Level 2 Stream Type	Notes
J.C. Boyle Peaking at BLM Camp-ground	RM 217.8	1.2	108.3	1.08	0.003	Boulder/ cobble	F	F2/F3	Exact fit not possible, sinuosity not within given ranges
	RM 217.5	1.1	109.5	1.08	0.003	Boulder/ cobble	F	F2/F3	Exact fit not possible, sinuosity not within given ranges
	RM 217.2	2.3	100.3	1.08	0.003	Boulder/ cobble	C	C2/C3	Exact fit not possible, sinuosity not within given ranges
J.C. Boyle Peaking at Gorge	RM 214.4	1.1	34.3	1.11	0.020	Boulder	F	F2b	Exact fit not possible, sinuosity not within given ranges
J.C. Boyle Peaking near Shovel Creek Confluence	RM 206.5	1.4	71.9	1.03	0.007	Boulder/ cobble	B	B2c/B3c	Exact fit not possible, sinuosity not within given ranges
	RM 206.4	1.8	36.0	1.03	0.007	Boulder/ cobble	B	B2c/B3c	Exact fit not possible, sinuosity not within given ranges
	RM 206.2	1.1	78.0	1.03	0.007	Boulder/ cobble	F	F2/F3	Exact fit not possible, sinuosity not within given ranges
Copco No. 2	RM 197.7	1.8	24.7	1.46	0.017	Bedrock/ boulder	B	B1c/B2c	
	RM 197.66	1.5	43.3	1.46	0.017	Bedrock/ boulder	B	B1c/B2c	
Downstream of Iron Gate Dam at USGS Fish Hatchery Gauge	RM 189.7	1.3	42.3	1.03	0.002	Cobble/ gravel	F	F3/F4	Exact fit not possible, sinuosity not within given ranges
	RM 189.6	1.3	54.2	1.03	0.002	Cobble/ gravel	F	F3/F4	Exact fit not possible, sinuosity not within given ranges
	RM 189.5	1.3	80.5	1.03	0.002	Cobble/ gravel	F	F3/F4	Exact fit not possible, sinuosity not within given ranges
	RM 189.45	1.4	43.8	1.03	0.002	Cobble/ gravel	B	B3c/B4c	Exact fit not possible, sinuosity not within given ranges
Downstream of Iron Gate Dam at R-Ranch	RM 187	1.4	86.5	1.48	0.004	Cobble/ gravel	B	B3c/B4c	
	RM 186.7	3.0	43.2	1.48	0.004	Cobble/ gravel	C	C3/C4	Exact fit not possible, two channels present
	RM 186.6	1.5	24.0	1.48	0.004	Cobble/ gravel	B	B3c/B4c	

Table 6.7-8. Rosgen channel types for each cross section in each study reach.

Site	Cross Section	Entrench-ment Ratio	Width/ Depth Ratio	Sinuosity	Reach Water Surface Slope	Channel Materials	Level 1 Stream Type	Level 2 Stream Type	Notes
Downstream of Iron Gate Dam at I-5 Rest Area	RM 179.1	1.8	54.3	1.06	0.005	Cobble/ gravel	B	B3c/B4c	Exact fit not possible, sinuosity not within given ranges
Downstream of Iron Gate Dam at Tree of Heaven Campground	RM 172.4	1.1	30.0	1.67	0.001	Cobble/ gravel	F	F3/F4	
	RM 172.2	1.6	17.8	1.67	0.001	Cobble/ gravel	B	B3c/B4c	
	RM 171.9	2.0	33.3	1.67	0.001	Cobble/ gravel	B	B3c/B4c	
Downstream of Iron Gate Dam at Seiad Valley-Hardy Site	RM 131.55	1.0	234.9	1.10	0.0001	Gravel/ sand	B	F4/F5	Exact fit not possible, sinuosity not within given ranges
Downstream of Iron Gate Dam at Seiad Valley USGS Gauge	RM 128.5	1.4	40	1.10	0.0001	Gravel/ sand	B	B4c/B5c	Exact fit not possible, sinuosity not within given ranges

6.7.8.2 Montgomery and Buffington Classification System

Table 6.7-9 summarizes the major geomorphic features of each study reach and then presents the Montgomery and Buffington (1997) channel type for each study reach. In general, the reaches in the Project area change from bedrock in the upstream reaches to plane bed in the middle reaches, to pool-riffle in the downstream reaches. Channel conditions resulting in some of the Montgomery and Buffington classifications are likely due to local project impacts (e.g., Copco No. 2 bypass reach) while others are likely the result of natural geomorphic processes (e.g., Seiad Valley).

Bedrock channels were found in the Link River reach and portions of the Keno reach, J.C. Boyle peaking reach, and Copco No. 2 reach. Bedrock channel types are defined as lacking a continuous alluvial bed and were typically confined by valley walls. Low gradient bedrock channels imply high transport capacity relative to sediment supply. Bedrock reaches are considered transport reaches and show little or only temporary response to changes in sediment supply because of their high sediment transport capacity. The results of the sediment budget (see section 6.7.15) confirm this condition for the Project reaches classified as bedrock under the Montgomery and Buffington classification scheme.

Cascade channels were identified in portions of the J.C. Boyle peaking reach and the Copco No. 2 reach. Cascade channels are characterized by tumbling flow, with laterally and longitudinally disorganized bed material typically consisting of cobbles and boulders. Finer sediment is trapped under larger clasts and deposited in low energy sites. This results in two thresholds for sediment transport. During moderate flows, fine-grained bed materials are transported downstream while larger cobble and boulder-sized clasts are transported only during rare high flow events. Similar to bedrock channels, Cascade channels are considered transport reaches. The results of the sediment budget (section 6.7.15) confirm this condition for the Project reaches classified as Cascade under the Montgomery and Buffington classification scheme.

Plane bed channels were identified in portions of the Keno reach, the J.C. Boyle bypass and peaking reaches, and several reaches downstream of Iron Gate dam. Plane bed channels refer to planar gravel and cobble bed channels typically identified as glide, run, riffle, and rapid morphologies. Plane bed channels lack rhythmic bedforms and include long stretches of featureless bedforms. The typically armored bed surface indicates transport capacity is greater than sediment supply, and plane bed channels are transitional between supply and transport limited morphologies. Plane bed channels are considered response reaches because the channel morphology adjusts with changes in sediment supply. Again, the results of the sediment budget (section 6.7.15) confirm this condition for the Project reaches classified as plane bed under the Montgomery and Buffington classification scheme.

Pool-riffle channels were identified in the J.C. Boyle reach and several reaches downstream of Iron Gate dam reach. Pool-riffle channels are characterized by an undulating bed that defines a sequence of bars, pools, and riffles, and the bed material ranges in size from sand to cobble. Pool-riffle channels have well-developed floodplains and occur in moderate to gentle slopes. Armored bed surfaces indicate supply-limited channel condition while unarmored bed material indicates a balance between sediment supply and transport. Many of the pool-riffle reaches in the Klamath River (primarily upstream of Iron Gate dam and immediately downstream of Iron Gate dam) appear to be armored to some degree. Based on the results of the sediment budget, armoring is likely due to both natural processes and Project effects in the reaches termed "response" under the Montgomery and Buffington classification scheme.

Both the Rosgen and Montgomery and Buffington classification systems yield a snapshot of existing channel conditions that facilitates some interpretation of the response of the channel to past and potential future changes in hydrology and watershed land uses. The Rosgen classification system applied here is more quantitative than the Montgomery and Buffington system, but because of the complex nature of the Klamath River and the significance of local geologic controls, many of the classifications under the Rosgen system do not fit all parameters. Because they are more qualitative in nature, the Montgomery and Buffington channel classifications are more likely accurate, and therefore provide a useful reality check against the characteristics and behaviors embodied in Rosgen channel types. Interpretations of both classification systems were considered in the assessment of sediment budget results in section 6.7.15.

Table 6.7-9. Montgomery and Buffington channel types for each study reach.

Project Reach	River Mile	Study Reach Gradient	Major Geomorphic Features	Montgomery and Buffington Channel Type
Link River	254	0.011	Bedrock at island, with plane bed downstream of island	Bedrock
Keno	232	0.013	Bedrock and large boulders at gauge site, with coarse riffles upstream and downstream of gauge	Bedrock /Plane bed
J.C. Boyle Bypass	224	0.014	Coarse plane bed with large boulders and sidecast material in some areas	Plane bed
J.C. Boyle Bypass	221	0.023	Coarse plane bed with some large boulders; gravel and cobble on small bars and in pockets created by coarse material	Plane bed
J.C. Boyle Peaking	219.5	0.017	Coarse plane bed with some large boulders; gravel and cobble on small bars and in pockets created by coarse material	Plane bed
J.C. Boyle Peaking	217	0.003	Coarse plane bed with flood terraces at different elevations above the bed	Plane bed
J.C. Boyle Peaking	214	0.02	Very large boulders with islands and terraces	Cascade/Bedrock
J.C. Boyle Peaking	207	0.008	Medium and large cobble riffles and alternating bars with wide alluvial floodplain	Pool-riffle
Copco No. 2	197.7	0.016	Coarse cascade (with more water) bed with many large boulders, bedrock, and significant vegetation encroachment	Cascade/Bedrock
Downstream of Iron Gate Reservoir	189.6	0.0016	Coarse plane bed with cobble riffles upstream and downstream of gauge	Plane bed
Downstream of Iron Gate Reservoir	186.7	0.004	Plane bed with island and side channel with cobble bed material	Plane bed
Downstream of Iron Gate Reservoir	179	0.005	Plane bed with cobble and small alluvial terrace	Plane bed/Pool-riffle
Downstream of Iron Gate Reservoir	172	0.0008	Plane bed with large active gravel/cobble bars	Plane bed/Pool-riffle
Downstream of Iron Gate Reservoir	128.5/ 131	0.0001-0.002	At Seiad Valley USGS gauge, At Hardy study site	Plane bed Pool-riffle

6.7.9 Bed load and Suspended Sediment Sampling

Bed load and suspended sediment transport sampling was planned at the following three sites on the mainstem Klamath River, but only occurred at one site.

1. In the J.C. Boyle peaking reach upstream of Copco reservoir (at the railroad boxcar bridge just upstream of the Shovel Creek confluence)
2. At the Klamathon Bridge (or from catarafts at a better section nearby but above the Cottonwood Creek confluence)
3. At the bridge at the I-5 rest area (or from catarafts at a better section nearby)

Sampling was originally planned to occur during the spring-summer 2002 snowmelt runoff, but snowmelt runoff in 2002 and subsequently in 2003 was so low that no spill occurred from the Project dams, and thus snowmelt bed load sampling did not occur. In the 2002-2003 flow season, sampling occurred only in the J.C. Boyle peaking reach upstream of the Shovel Creek confluence because the river had sufficiently high flows for only a brief period. During 2003 sampling, bed load samples in the J.C. Boyle peaking reach were obtained at flows of approximately 3,000 cfs, which is the approximate flow release when both J.C. Boyle dam generators are running. At 3,000 cfs the bed load transport rate was measured as 1.04 tons per day, and at 2,800 cfs it was measured as 0.6 ton per day. These samples support the results of the tracer gravel observations that the existing bed is not fully mobile at 3,000 cfs. The suspended load transport rate at 3,000 cfs was measured as 256 tons per day. Bed load sampling at the Klamathon Bridge and I-5 rest area sites will be conducted in 2004, depending on availability of sufficiently high flows.

6.7.10 Reconnaissance-Level Observations and Measurements of Sediment Sources and Pathways

Reconnaissance-level examination of aerial photographs and field observations yielded relatively few obviously active, measurable sources of sediment. The principal sources measured have been those associated with the J.C. Boyle canal emergency spillway, its sidecast boulders, and gullies eroded into the slope below the canal road.

The emergency spillway is located at the upstream end of the Big Bend, just above the entrance to the tunnel leading to the penstocks for the J.C. Boyle powerhouse. Spills from this spillway have eroded the side of the hill, known locally as the blowout. The survey of the blowout indicates the volume of material removed is approximately 1,856,000 cubic feet.

Construction of the canal and canal road involved considerable sidecasting of material excavated from the hillslope, and much of this sidecast material is still present as unweathered boulder-sized blocks on the north slope of the canyon. Field observation of boulder roundness suggests that these sidecast blocks have entered the channel in only a few places, and that along most of the reach the blocks have come to rest on the slope down the right margin of the channel. Historical photographs of the J.C. Boyle canal reach under construction (courtesy of ODFW) document encroachment of sidecast blocks into the channel at only one location, about 4,800 feet upstream of the emergency spillway. This is a highly visible site where the sidecast material crossed the channel, creating a dam. The dam has partially washed out but still creates a pool upstream, and the mass of material from the right bank deflects flow into the left bank. The left bank is undercut for nearly 400 feet, which has produced an estimated 276,000 cubic feet of sediment (based on downward projection of the slope angle to reconstruct the predisturbance slope). Elsewhere, the sidecast material has narrowed the channel by causing the right bank to prograde. Although not evident in ODFW's historical photographs, this is clearly shown for a reach about a mile downstream of J.C. Boyle dam in a photograph of the J.C. Boyle canal (Boyle, 1976), in which sidecast material has clearly narrowed the channel.

Another visible source of sediment in the J.C. Boyle bypass reach is rill and gully erosion on the slope below the canal road. Measurements of the dimensions of four of the larger gullies yielded a total minimum sediment volume of 40,880 cubic feet. Other observations include large earthflows, such as the one located on the left bank immediately downstream of the USGS gauge near Bogus Creek. Without a basis to infer rates of movement, however, it is difficult to turn these observations of features into sediment yield rates.

As described in Section 6.4.5, an aerial photograph analysis of landslides and other direct contributions of sediment to the Klamath River from hillslopes was completed for the entire study area. Three small landslides were identified in the J.C. Boyle bypass reach from a review of aerial photographs of the mainstem Klamath from Link River dam to Seiad Valley. All three slides were located at the downstream end of the J.C. Boyle bypass reach at Big Bend (Table 6.7-10). The identified slides were relatively small, and two were related to the presence of road cuts. Contribution of sediment to the mainstem Klamath River due to hillslope landslide processes was limited compared to the contribution from tributaries. In the J.C. Boyle bypass reach, 79 tons per year of sediment were delivered to the channel along the mainstem from landslides compared to 5,052 tons per year of sediment contributed by tributaries. This analysis confirms observations made during the geomorphic reconnaissance trips in the study area that landslides were a small source of sediment to the mainstem Klamath.

Table 6.7-10. Landslide sediment yields.

Slide location	Slide ID	Volume of Slide Accessible by Channel (yd^3)	Mass of Slide Accessible by Channel (tons)	Slide Age (years)	Slide Yield to Channel (tons/yr)
J.C. Boyle Bypass	Big Bend 1	376	558	51	11
J.C. Boyle Bypass	Big Bend 2	1510	2242	46	49
J.C. Boyle Bypass	Big Bend 3	590	876	46	19

Big Bend Slides 1 and 2 are most likely the result of a much larger slide that occurred hundreds to thousands of years ago. The channel originally meandered around a tight bend against a steep ridge. The outward migration of the channel may have destabilized the bluff above the channel and triggered a massive landslide that formed a new high terrace and diverted the channel back toward the opposite bank. The slide most likely blocked the channel until the river carved a new channel around the fringe of the slide creating an s-curve in the original single meander at Big Bend. The channel is forced by the historical landslide debris to erode the inside bank of Big Bend, which may have destabilized the slope leading to Big Bend Slide 1. This landslide is the oldest of the three and is the only one visible on the 1952 aerial photographs, which are the oldest of the available photographs. An age of 51 years was used to calculate an average annual delivery of sediment from the slide, although the slide is most likely older as vegetation has colonized the area below the slide that would have been scoured in the 1952 aerial photographs. The slide scar is approximately midway up the canyon wall, and the majority of the slide material was held in storage on the valley wall. It was estimated that 376 cubic yards of material were delivered to the channel from the slide.

Big Bend Slide 2 is located less that 0.1 mile downstream of Big Bend Slide 1. Big Bend Slides 1 and 2 are both located on river-right and both are directly across the channel from the massive landslide. This slope was most likely destabilized by the channel adjustment to the larger channel-forming slide, but only became active after the J.C. Boyle canal access road further destabilized the slope. The slide is clearly depicted in the 1957 aerial photographs, which show the canal under construction. The slide scar starts directly below the road and continues almost to the bottom of the slope. Approximately 30 percent of the slide material remained in the lower portion of the slide scar. This is the largest of the three slides, and it was estimated that 1,510 cubic yards of material were delivered to the channel from the slide.

Big Bend Slide 3 is located 0.5 mile downstream from the apex of Big Bend at the downstream end of the J.C. Boyle bypass reach. This slide may have been a result of the J.C. Boyle canal access road cutting across a steep slope. The slide is shown in the 1957 aerial photographs. Approximately 50 percent of the slide material was deposited in a debris cone at the base of the slope and is held in storage. An estimated 590 cubic yards of material were delivered to the channel.

The slides that were identified were small, and slides of similar volume could have been obscured by vegetation along the channel in other locations. Additionally, numerous debris chutes were observed in the reaches that are confined by steep canyons, but these chutes were considered too narrow to be accurately mapped. Thus, this analysis underestimates the contribution of sediment from narrow chutes along the channel, but the contribution from these chutes is assumed to be very small relative to the tributary sediment yields. Additional errors could have been introduced to this analysis from estimation of volumes for each slide, digitization of slides from the aerial photographs onto topographic base maps, estimation of the age of slides, and estimation of material delivered to the channel.

Landslide volumes were calculated as the area of slide by the average depth of the slide. Average slide depths were estimated by comparing the scar depth with surrounding vegetation using aerial photograph stereo pairs. No ground surveys were taken of any of the landslides, and the average depth and the area of the slide may have introduced errors to the estimates. Care was taken to accurately represent the area of the slide on the aerial photograph with the area digitized on the topographic base map, but some errors may have occurred. Slides were assigned an age by comparing historical time series of aerial photographs. Lastly, the volume of material delivered to the channel was estimated as the percentage of material remaining in the landslide scar. Estimates were made from aerial photograph stereo pairs, and no ground surveys were conducted. Given all of the potential errors of this analysis, they are relatively small when compared with the finding that landslides to the mainstem Klamath contribute much less sediment than do tributaries.

Sediment contribution from bank erosion, bank collapse, and treethrow were qualitatively assessed during review of the aerial photographs. The majority of the channel banks in the study area were composed of bedrock, boulders, and cobble and therefore were only subject to minor erosion. Bank collapse was noted in a few locations in the steeper canyons, but did not appear to be a significant source of sediment. Treethrow was limited along the mainstem Klamath and was not considered a significant source of sediment.

6.7.11 Tributary Delta Surveys

A complete report summarizing the results of the tributary delta surveys is presented in Appendix 6B. This section summarizes the sediment yields calculated from the tributary delta surveys. Once a delta deposit volume had been determined, as described in Appendix 6B, it was a relatively straightforward process to translate that volume into a sediment yield. Several important assumptions were required during this process. First, the deposit volume was converted from cubic yards to tons, which involved use of a bulk density factor for the deposit. Values from the literature have a fairly wide range and vary based on geology, soil types, grain sizes present in the deposit, organic matter present in the deposit, and other factors. Values in other sediment budget studies have ranged from 85 to 125 pounds per cubic foot. Second, an assumption was made regarding the percentage of wash load in the sediment supply, assuming that much or most of the washload would not have been captured in the delta surveys and instead would have been deposited throughout the reservoir; perhaps a small portion would even have completely passed through the reservoir during storm flows. Third, an assumption was made regarding the percent of coarse sediment present in the deposit (that which would be useful in the creation and maintenance of salmonid spawning gravels, generally particles greater than 8 mm).

Table 6.7-11 presents the results of the computation of sediment yields based on the field surveys and analysis conducted in this study. The table computes the Scotch and Camp/Dutch study sites both individually and combined into a single site. Jenny Creek was also computed individually and as a portion of all three Iron Gate tributaries combined. The table presents the drainage area for each study site ranging from 17.9 square miles at Scotch Creek to 209.9 square miles at Jenny Creek, then converts deposit volumes in cubic yards to tons based on a bulk density factor of 1.485 tons/cubic yard. Next, the table show the average unit yield (tons/mi^2/yr) based on the drainage area and the number of years since closure of the dam. Finally, an estimate of 20 percent washload is added to the yield to reflect very fine-grained sediments that would not likely be deposited in the delta. This percentage is simply an estimate based on limited suspended sediment size distribution data from the Shasta River (the nearest watershed with such data that drains mostly volcanic terrain) where approximately 20 to 30 percent of the suspended sediment load was in the clay and silt size classes. The only way to improve such an estimate would be to collect sediment transport data over a range of flows for the tributaries in question and perform size distribution analyses on those samples. In addition, the hydraulic roughness caused by the dense riparian vegetation on the delta deposits acts to trap some of these fine-grained sediments and would complicate any such analysis.

The computed yields range from 1.3 tons/mi^2/yr for Spencer Creek to 220 tons/mi^2/yr for Scotch Creek. It is difficult to determine why the sediment yields from Spencer Creek would be so low, and certainly that value does not seem reasonable. It is possible that other factors upstream in that watershed control sediment delivery to some extent or that much of the sediment has been trapped upstream of where the survey was conducted. The values for Jenny Creek (18 to 22 tons/mi^2/yr) also seem very low. There are several water supply reservoirs in the upper Jenny Creek watershed that undoubtedly trap some sediment, but it is also possible that inaccurate pre-dam topography is the primary reason that sediment yields in Jenny Creek are much lower than

Scotch and Camp/Dutch creeks. Scotch and Camp/Dutch creeks have generally similar yields ranging from 166 to 220 tons/mi^2/yr. As discussed earlier, combining the two sites and computing a combined sediment yield is probably the most appropriate method. Given this, a reasonable long-term sediment yield from Iron Gate tributaries is in the range of 150 to 190 tons/mi^2/yr. It probably should be weighted to the lower end as it is likely that the delta deposits incorporate a substantial amount of organic matter that will reduce the overall bulk density value. This finding is refined further and presented in the sediment budget results discussion (section 6.7.15).

Table 6.7-11. Sediment yield based on field surveys and analysis.

Site	Deposit Volume (1.485 tons/yd^3)		Area (mi^2)	Period (years)	Yield tons/year	Yield (tons/mi^2/yr)	Add 20% For Washload (tons/mi^2/yr)
	(yd^3)	(tons)					
Scotch Creek	88,500	131,423	17.94	40	3,286	183	219.8
Camp/Dutch Creek	73,500	109,148	19.72	40	2,729	138	166.1
Combined Scotch and Camp/Dutch Creeks	162,000	240,570	37.65	40	6,014	160	191.7
Jenny Creek	107,200	159,192	209.89	40	3,980	19	22.8
Combined All Iron Gate Tributaries	269,200	399,762	247.54	40	9,994	40	48.4
Spencer Creek	2,812	4,176	84.62	44	95	1	1.3

6.7.12 Tracer Gravel Study

Tracer gravel transects were resurveyed in late June 2003 using an auto-level and stadia rod at the J.C. Boyle bypass reach downstream of the emergency overflow spillway, at the J.C. Boyle peaking reach downstream of the USGS gauge, and at the J.C. Boyle peaking reach upstream of Shovel Creek confluence. Flows at the study sites were not of sufficient magnitude or duration to completely mobilize the channel bed at these tracer transect locations. However, some tracer gravels were mobilized at each of these resurveyed study sites. Because flows were high enough to make wading unsafe, only partial surveys were completed at each study site. Table 6.7-12 summarizes the study sites where tracer particles were placed, which study sites were resurveyed, high flows during the period between tracer placement and resurvey, and the size range of the tracers that moved.

Table 6.7-12 Tracer Gravel Summary of Sites, Deployment, and Recovery

Study Site	RM	Reach	Cross Section Tracers	Pocket Tracers	Date of Deployment	Size Range of Deployed Tracers (mm)	Date of Resurvey	Size Range of Particles Moved/ Not Recovered (mm)	High Flow During Tracer Deployment (cfs)
J.C. Boyle Bypass Reach Down-stream of Emergency Overflow Spillway	222.6	J.C. Boyle bypass	Approx. 30 m upstream of mid-channel bar		04/01/2003	41-115	06/25/2003	43-115	1,700
				Upstream of island near the right bank of the main channel	04/01/2003	41-92	06/25/2003	41-54	1,700
				Midway along island near the right bank of the main channel	04/01/2003	47-91	06/25/2003	47	1,700
				Downstream end of island near the right bank of the main channel	04/01/2003	49-86	06/25/2003	49	1,700
J.C. Boyle Peaking Reach Down-stream of USGS Gauge	219.7	J.C. Boyle peaking	10 ft upstream of double snag and fallen trunk on right bank to pine on left bank		11/03/2002	45-96	06/25/2003	45-94	3,850
J.C. Boyle Peaking Reach Upstream of Shovel Creek Confluence	206.5	J.C. Boyle peaking	Upstream of Shovel Creek confluence		2/14/02, additional traces placed on 04/26/2002	32-150	06/25/2003	32-84	3,988*
Shovel Creek	206.5	J.C. Boyle peaking	0.4 mi upstream of confluence with Klamath River		02/16/2002	46-87			

Table 6.7-12 Tracer Gravel Summary of Sites, Deployment, and Recovery

Study Site	RM	Reach	Cross Section Tracers	Pocket Tracers	Date of Deployment	Size Range of Deployed Tracers (mm)	Date of Resurvey	Size Range of Particles Moved/ Not Recovered (mm)	High Flow During Tracer Deployment (cfs)
Frain Ranch Area	215.0	J.C. Boyle peaking	Tracers dropped from inflatable kayak		04/02/2003	45-113			
				Approx. 35 ft from right bank of active channel	04/02/2003	33-118			
R-Ranch Area	186.7	Iron Gate	Cross section started on a side-channel and only progresses a few ft into the mainstem		02/16/2002	52-128			
Upstream of Cottonwood Creek Confluence	182.2	Iron Gate	Waypoint 31 near the Cottonwood Creek confluence		02/16/2002	45-150			
I-5 Rest Area	179.1	Iron Gate	Approx. 100 ft from sign		02/17/2002	80-160			
			At Leprechaun House		02/17/2002	90-130			
Humbug Creek	171.6	Iron Gate	0.4 mi upstream of confluence with Klamath River		04/26/2002	30-130			

* Flow was estimated by accretion from J.C. Boyle USGS gauge.

Figure 6.7-55 shows tracer movement at the J.C. Boyle bypass reach downstream of the emergency overflow spillway. The upper graph represents tracer movement downstream, with hollow dots symbolizing tracer particles that were not located during the resurvey and were assumed to have moved downstream. The lower graph (plotted on the same x-axis) shows the location of the tracer gravels along the partial cross section. Eight of the resurveyed tracer gravels moved at this study site, and the displaced tracers ranged in size from 43 to 115 mm. Two moved tracers were in the coarse gravel size class (32 to 64 mm), and the remaining six tracers were in the fine cobble size class (64 to 128 mm). The peak discharge from hourly flow records was 1,700 cfs for the period between tracer deployment and resurvey.

At the J.C. Boyle peaking reach downstream of the USGS gauge tracer study site, four of the resurveyed tracers moved. Figure 6.7-56 shows the location of the tracer gravels along the partial cross section that were not recovered. One of the moved tracer particles was in the very coarse gravel size class (32 to 64 mm), and the remaining three tracer gravels were in the fine cobble size class (64 to 128 mm). The peak hourly discharge for the period between tracer deployment and resurvey at this tracer site was 3,850 cfs.

Figure 6.7-57 shows tracer movement at the J.C. Boyle peaking reach upstream of Shovel Creek confluence. Of the resurveyed tracer gravels, eight moved downstream and only one of the tracer gravels was relocated. One moved tracer was in the coarse gravel size class (26 to 32 mm), three were in the very coarse gravel size class (32 to 64 mm), and the remainder were in the fine cobble size class (64 to 128 mm). The peak hourly discharge that occurred between deployment and re-survey of tracer gravels at this site was 3,988 cfs.

Since the critical shear stress (and therefore the critical discharge) required to mobilize a particle on a sediment surface is characterized by a probability distribution, rather than a single value (Kirchner et al. 1990), these observations of movement are likely for the most erodible grains on the bed. Therefore, it would likely take significantly higher flows to fully mobilize the bed in these locations. Further, estimates of the discharge at incipient motion calibrated with these observations (see threshold of mobility results, section 6.7.13) likely underestimate the discharge required to mobilize the bed. The bed elevation did not increase or decrease during the tracer studies. Therefore, there is no evidence of either aggradation or channel incision at these sites.

High flow conditions in 2003 prevented surveys at the remaining tracer study sites. Therefore, only the information from the tracer observations described above was applied in threshold of mobility calculations described in section 6.7.13.

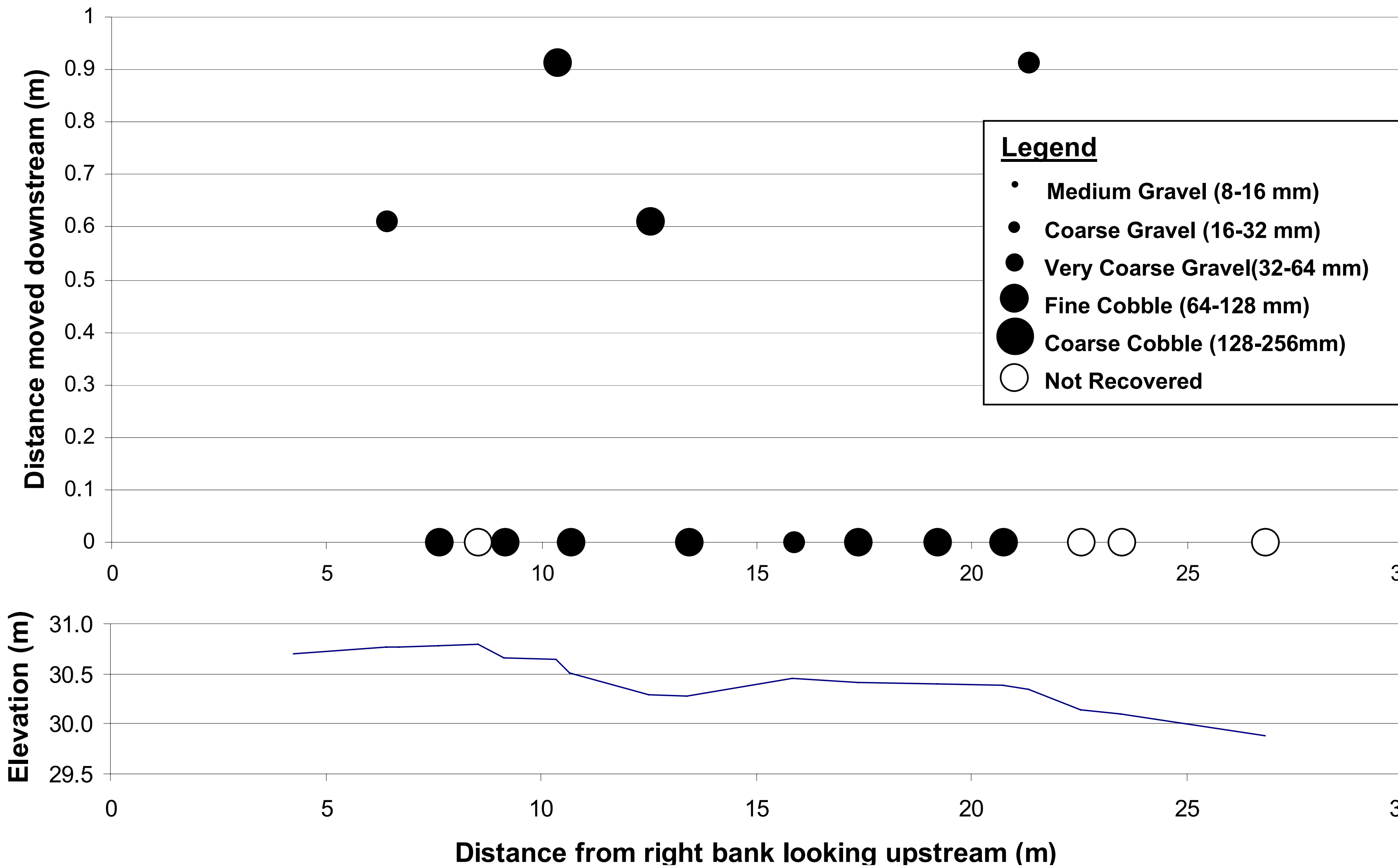

Figure 6.7-55. Tracer study results: J.C. Boyle reach downstream of emergency spillway.

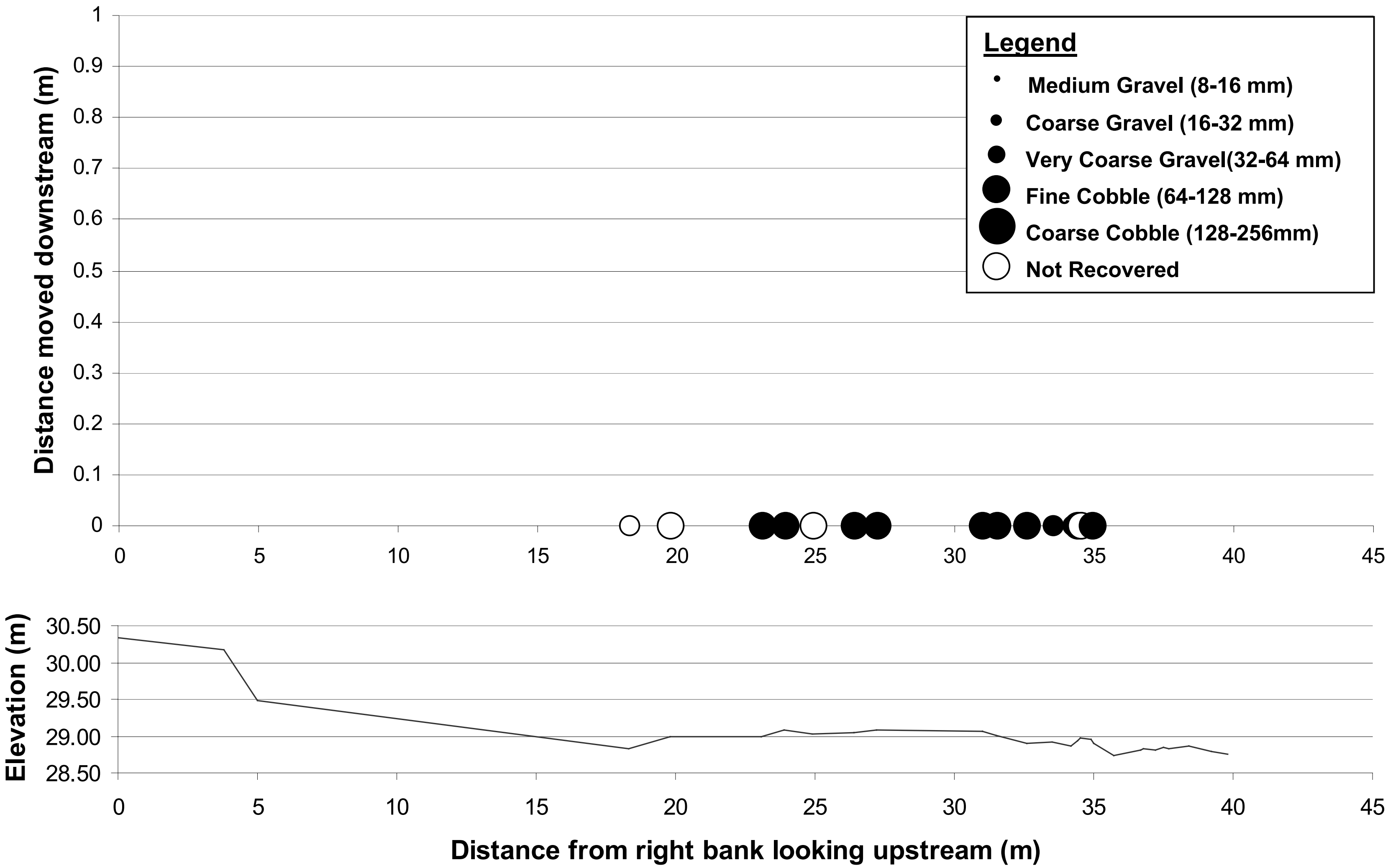

Figure 6.7-56. Tracer study results: J.C. Boyle reach downstream of USGS gauge.

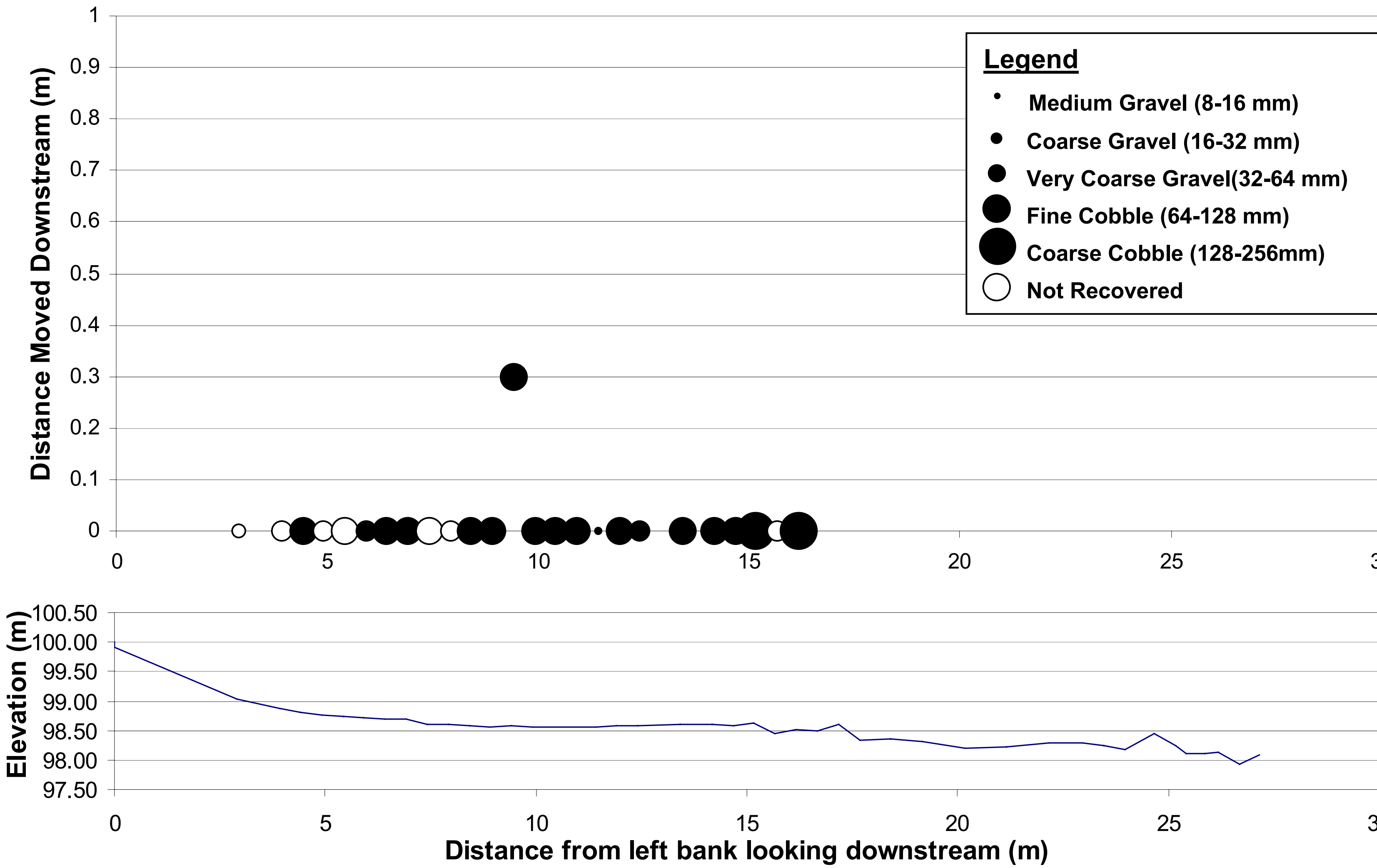

Figure 3.7-57. Tracer study results, Klamath River at Shovel Creek confluence.

6.7.13 Estimation of Threshold of Bed Mobility

The flow required to mobilize the bed was determined for both with-Project and without-Project conditions. The with-Project estimation of threshold of mobility used the median grain size of the existing mobile bed features and a calibrated Shield's number derived from tracer gravel study observations. The without-Project estimation of threshold of mobility for the Link River and Keno study sites used the same input parameters as the with-Project estimation. The remaining sites used the median grain size of surveyed tributaries (34.16 mm) to the Klamath River and a Shield's number of 0.047, which assumes a finer bed material. Table 6.7-13 summarizes the input parameters for the estimation of threshold of bed mobility for with- and without-Project conditions, the depth of water at the threshold of bed mobility, and the average flow velocity.

An additional estimation of bed mobility was developed for the sediment budget bed load transport rate. The parameters for the sediment budget threshold included the average median grain size recorded for the tributaries (34.16 mm) and the calibrated Shield's number derived from tracer gravel study observations. Table 6.7-14 summarizes the input parameters for the estimation of threshold of bed mobility developed for the sediment budget, the depth of water at the threshold of bed mobility, and the average flow velocity.

6.7.13.1 Discharge Required to Mobilize the Bed

A summary of the calculated flows at the threshold of bed mobility for each cross section at each study reach is presented in Table 6.7-15. The critical model parameters used in this analysis (i.e., Shield's number, Manning's roughness coefficient (*n*), and bed material D_{50}) are summarized in Table 6.7-14. It is important to reiterate here that the D_{50} for the with-Project condition was measured on existing bed features that appeared to be periodically mobile, while the D_{50} for the without-Project condition was assumed to be equal to the average D_{50} from the tributary delta surveys where sufficient material might have been present before the Project. The discharge required to mobilize the stream bed ranged from 180 to 390,000 cfs for the with-Project conditions and from 110 to 210,000 cfs for the without-Project conditions. The high and low values at the ends of the range of flows at the threshold of bed mobility are related to local slope and bed material conditions; they are not indicative of the values calculated for most of the study sites. The difference between the average study reach discharge at the threshold of mobility for with- and without-Project conditions varied from approximately 200 to 200,000 cfs. The with-Project conditions consistently generated higher discharges required to mobilize the bed.

It is important to note that the estimates of the discharge at the threshold of bed mobility have significant uncertainty. Sources of uncertainty included the Shield's numbers (i.e., dimensionless critical shear stress) used in the calculations for each study reach cross section, which were based on a limited set of tracer gravel movement observations. In fact, due to limitations associated with the tracer observations, the Shield's number calibrated with the tracer observations at one study reach (J.C. Boyle peaking reach at the USGS gauge) had to be applied to all study sites for the with-Project conditions. Further, the Manning's roughness coefficient used to estimate the discharge associated with the depth of flow at the threshold of bed mobility was also calibrated at a limited number of study reach cross sections and then applied to the remaining study sites.

Except for the Link River and Keno reaches, where the with- and without-Project discharge estimates at incipient motion are equal, the estimated discharge required to mobilize the bed is generally higher for the with-Project conditions than for the without-Project conditions in most Project reaches. This pattern (of increased discharge required to mobilize the existing bed throughout much of the Project area) is probably more important in the context of Project impacts and decisionmaking regarding future Project operation than the actual values estimated for discharge at incipient motion because these values are based on uncertain assumptions about the without-Project bed condition (i.e., that 10 percent of the without-Project bed would have been composed of sediment with a particle size distribution similar to that of the tributaries).

The frequency of bed mobility was determined for each study reach using with- and without-Project hydrology (described in section 6.4.13) The results of this analysis are summarized in Table 6.7-16. The frequency of bed mobilization was consistently higher for the without-Project conditions. Here again, it is the pattern of the change from with- to without-Project frequency of mobility that is most relevant to the discussion of Project impacts and future Project operations.

In general, it is likely that the active features (e.g., point bars, islands) in Klamath River reaches downstream of J.C. Boyle dam to approximately Shasta River would have been characterized by finer sediment that would have been fully mobilized more frequently than the coarse sediment that now characterizes the apparently active features in these areas. This would support the reduced frequency of bed mobilization for the with-Project condition that range from 6 percent to 91 percent of the frequencies for the without-Project condition in reaches downstream of J.C. Boyle dam. While the results for some reaches show very large reductions in the frequency of bed mobility under the with-Project conditions (e.g., with-Project frequency is only 6 percent of the without-Project frequency at RM 206.2 in the J.C. Boyle peaking reach near Shovel Creek), this may not accurately depict the physical realities of potential changes at individual sites. For example, a very low or zero frequency of mobility could be calculated for study transects with relatively narrow cross-sectional areas and coarse bed material under the with-Project conditions, while a very high frequency of mobility could be calculated for the same transect under without-Project conditions (where a finer bed particle size is assumed). Given the channel geometry constraints of such a scenario, however, it is unlikely that finer bed conditions could persist in the without-Project condition, and therefore the frequency of mobility for that transect could be significantly overestimated in this analysis. Consequently, the results of these analyses will likely be most useful in determining relative levels of change throughout the Project area and developing appropriately scaled mitigation measures to address the different levels of potential change.

Table 6.7-13. Summary of threshold of mobility input parameters for the with- to without-Project comparison.

Study Reach	Cross Section	Slope	Manning's Coefficient (n)	With Project: Median Grain Size (mm)	With Project: Shield's Number	With Project: Depth at Threshold of Mobility (m)	With Project: Total Critical Shear Stress (g/cm s^2)	With Project: Average flow velocity (m/s)	Without Project: Median Grain Size (mm)	Without Project: Shield's Number	Without Project: Depth at Threshold of Mobility (m)	Without Project: Total Critical Shear Stress (g per cm s2)	Without Project: Average flow velocity (m/s)
Link River Geomorphic Reach													
Link River	RM 254	0.01	0.06	32	0.059	0.29	309	1.7	Same	Same	Same	Same	Same
	RM 253.9	0.01	0.06	32	0.059	0.29	309	1.5	Same	Same	Same	Same	Same
	Study Reach Average	0.01	0.06	32	0.059	0.29	309	1.6	Same	Same	Same	Same	Same
Keno Geomorphic Reach													
Keno Reach	RM 232.4	0.01	0.06	130	0.059	0.97	1239	2.4	Same	Same	Same	Same	Same
	RM 232.1	0.01	0.06	130	0.059	0.97	1239	2.3	Same	Same	Same	Same	Same
	RM 231.9	0.01	0.06	130	0.059	0.97	1239	1.7	Same	Same	Same	Same	Same
	Study Reach Average	0.01	0.06	130	0.059	0.97	1239	2.1	Same	Same	Same	Same	Same
J.C. Boyle Bypass Geomorphic Reach													
J.C. Boyle Bypass Upstream of Blowout	RM 223.5	0.01	0.06	55	0.059	0.38	525	2.4	34.16	0.047	0.19	260	2.4
	RM 223.3	0.01	0.06	55	0.059	0.38	525	2.0	34.16	0.047	0.19	260	2.0
	RM 223.25	0.01	0.06	55	0.059	0.38	525	1.1	34.16	0.047	0.19	260	1.0
	Study Reach Average	0.01	0.06	55	0.059	0.38	525	1.1	34.16	0.047	0.19	260	1.0
J.C. Boyle Bypass Downstream of Blowout	RM 222.55	0.02	0.06	128	0.059	0.54	1222	2.8	34.16	0.047	0.12	260	2.2
	RM 222.4	0.02	0.06	128	0.059	0.54	1222	2.5	34.16	0.047	0.12	260	1.8
	RM 222.3	0.02	0.06	128	0.059	0.54	1222	2.9	34.16	0.047	0.12	260	2.2
	Study Reach Average	0.02	0.06	128	0.059	0.54	1222	2.7	34.16	0.047	0.12	260	2.1
J.C. Boyle Peaking at USGS Gauge	RM 219.9	0.02	0.06	101	0.059	0.57	957	2.3	34.16	0.047	0.16	260	1.9
	RM 219.7	0.02	0.06	101	0.059	0.57	957	2.7	34.16	0.047	0.16	260	2.2
	Study Reach Average	0.02	0.06	101	0.059	0.57	957	2.5	34.16	0.047	0.16	260	2.1
J.C. Boyle Peaking at BLM Campground	RM 217.8	0.003	0.06	154	0.059	5.75	1467	3.0	34.16	0.047	1.02	260	1.2
	RM 217.5	0.003	0.06	122	0.059	4.57	1165	3.0	34.16	0.047	1.02	260	1.7
	RM 217.2	0.003	0.06	131	0.059	3.92	1000	2.9	34.16	0.047	1.02	260	1.5
	Study Reach Average	0.003	0.06	136	0.059	4.75	1211	3.0	34.16	0.047	1.02	260	1.5
J.C. Boyle Peaking at Gorge Geomorphic Reach													
J.C. Boyle Peaking at Gorge	RM 214.4	0.02	0.06	41	0.059	0.20	393	4.2	34.16	0.047	0.13	260	4.1
	Study Reach Average	0.02	0.06	41	0.059	0.20	393	4.2	34.16	0.047	0.13	260	4.1
J.C. Boyle Peaking Near Shovel Creek Geomorphic Reach													
J.C. Boyle Peaking near Shovel Creek Confluence	RM 206.5	0.01	0.03	64	0.059	0.94	615	3.0	34.16	0.047	0.40	260	2.2
	RM 206.4	0.01	0.03	64	0.059	0.93	615	2.9	34.16	0.047	0.39	260	2.2
	RM 206.2	0.01	0.03	108	0.059	1.57	1036	3.2	34.16	0.047	0.39	260	1.1
	Study Reach Average	0.01	0.03	79	0.059	1.15	756	3.0	34.16	0.047	0.39	260	1.9
Copco No. 2 Geomorphic Reach													
Copco No. 2	RM 197.7	0.02	0.06	176	0.059	1.07	1677	1.8	34.16	0.047	0.17	260	0.9
	RM 197.66	0.02	0.06	176	0.059	1.07	1677	2.3	34.16	0.047	0.17	260	1.1
	Study Reach Average	0.02	0.06	176	0.059	1.07	1677	2.1	34.16	0.047	0.17	260	1.0
Downstream of Iron Gate Dam to Cottonwood Creek Geomorphic Reach													
Downstream of Iron Gate Dam at USGS Fish Hatchery Gauge	RM 189.7	0.002	0.03	102	0.059	4.30	970	3.9	34.16	0.047	1.15	260	2.0
	RM 189.6	0.002	0.03	47	0.059	2.00	452	2.3	34.16	0.047	1.15	260	2.1
	RM 189.5	0.002	0.03	53	0.059	2.24	505	2.5	34.16	0.047	1.15	260	1.9
	RM 189.45	0.002	0.03	53	0.059	2.24	505	3.1	34.16	0.047	1.15	260	2.4
	Study Reach Average	0.002	0.03	64	0.059	2.70	608	2.9	34.16	0.047	1.15	260	2.1
Downstream of Iron Gate Dam at R-Ranch	RM 187	0.004	0.03	36	0.059	1.00	342	4.2	34.16	0.047	0.76	260	3.6
	RM 186.7	0.004	0.03	51	0.059	1.42	486	2.6	34.16	0.047	0.76	260	2.1
	RM 186.6	0.004	0.03	42	0.059	1.16	398	4.1	34.16	0.047	0.76	260	3.9
	Study Reach Average	0.004	0.03	43	0.059	1.19	409	3.6	34.16	0.047	0.76	260	3.2

Table 6.7-13. Summary of threshold of mobility input parameters for the with- to without-Project comparison.

				With Project					Without Project				
Study Reach	**Cross Section**	**Slope**	**Manning's Coefficient (n)**	**Median Grain Size (mm)**	**Shield's Number**	**Depth at Threshold of Mobility (m)**	**Total Critical Shear Stress ($g/cm\ s^2$)**	**Average flow velocity (m/s)**	**Median Grain Size (mm)**	**Shield's Number**	**Depth at Threshold of Mobility (m)**	**Total Critical Shear Stress (g per cm s2)**	**Average flow velocity (m/s)**
Cottonwood Creek to Scoot River Geomorphic Reach													
Downstream of Iron Gate Dam at I-5 Rest Area	RM 179.1	0.005	0.03	49	0.059	0.96	471	4.2	34.16	0.047	0.53	260	2.6
	Study Reach Average	0.005	0.03	49	0.059	0.96	471	4.2	34.16	0.047	0.53	260	2.6
Downstream of Iron Gate Dam at Tree of Heaven Campground	RM 172.4	0.001	0.03	41	0.059	3.33	392	3.0	34.16	0.047	2.21	260	2.5
	RM 172.2	0.001	0.03	41	0.059	3.33	392	3.4	34.16	0.047	2.21	260	2.6
	RM 171.9	0.001	0.03	41	0.059	3.33	392	3.6	34.16	0.047	2.21	260	2.9
	Study Reach Average	0.001	0.03	41	0.059	3.33	392	3.3	34.16	0.047	2.21	260	2.7
Downstream of Scott River Geomorphic Reach													
Downstream of Iron Gate Dam at Seiad Valley-Hardy Site	RM 131.55	0.002	0.029	56	0.059	3.03	535	5.4	34.16	0.047	1.47	260	3.9
	Study Reach Average	0.002	0.029	56	0.059	3.03	535	5.4	34.16	0.047	1.47	260	3.9
Downstream of Iron Gate Dam at Seiad Valley USGS Gauge	RM 128.5	0.0001	0.019	41	0.059	28.51	392	3.8	34.16	0.047	18.92	260	3.2
	Study Reach Average	0.0001	0.019	41	0.059	28.51	392	3.8	34.16	0.047	18.92	260	3.2

$g/cm\ s^2$ = grams per centimeter second squared; m/s = meter per second.

Table 6.7-14. Summary of threshold of mobility input parameters for the sediment budget.

Study Reach	Cross Section	Slope	Manning's N	Threshold of Mobility Developed for the Sediment Budget: Median Grain Size (mm)	Shield's Number	Depth at Threshold of Mobility (m)	Total Critical Shear Stress (g per cm s^2)	Average Flow Velocity (m/s)
Link River Geomorphic Reach								
Link River	RM 254	0.01	0.06	34	0.059	0.30	326	1.7
	RM 253.9	0.01	0.06	34	0.059	0.30	326	1.5
	Study Reach Average	0.01	0.06	34	0.059	0.30	326	1.6
Keno Geomorphic Reach								
Keno Reach	RM 232.4	0.01	0.06	34	0.059	0.26	326	1.8
	RM 232.1	0.01	0.06	34	0.059	0.26	326	1.6
	RM 231.9	0.01	0.06	34	0.059	0.26	326	1.5
	Study Reach Average	0.01	0.06	34	0.059	0.26	326	1.6
J.C. Boyle Bypass Geomorphic Reach								
J.C. Boyle Bypass Upstream of Blowout	RM 223.5	0.01	0.06	34	0.059	0.24	326	2.4
	RM 223.3	0.01	0.06	34	0.059	0.24	326	2.0
	RM 223.25	0.01	0.06	34	0.059	0.24	326	1.1
	Study Reach Average	0.01	0.06	34	0.059	0.24	326	1.8
J.C. Boyle Bypass Downstream of Blowout	RM 222.55	0.02	0.06	34	0.059	0.14	326	2.3
	RM 222.4	0.02	0.06	34	0.059	0.14	326	1.8
	RM 222.3	0.02	0.06	34	0.059	0.14	326	2.3
	Study Reach Average	0.02	0.06	34	0.059	0.14	326	2.1
J.C. Boyle Peaking at USGS Gauge	RM 219.9	0.02	0.06	34	0.059	0.19	324	2.0
	RM 219.7	0.02	0.06	34	0.059	0.19	324	2.3
	Study Reach Average	0.02	0.06	34	0.059	0.19	324	2.1
J.C. Boyle Peaking at BLM Campground	RM 217.8	0.003	0.06	34	0.059	1.28	326	1.4
	RM 217.5	0.003	0.06	34	0.059	1.28	326	1.8
	RM 217.2	0.003	0.06	34	0.059	1.28	326	1.6
	Study Reach Average	0.003	0.06	34	0.059	1.28	326	1.6
J.C. Boyle Peaking at Gorge Geomorphic Reach								
J.C. Boyle Peaking at Gorge	RM 214.4	0.02	0.06	34	0.059	0.17	326	4.1
	Study Reach Average	0.02	0.06	34	0.059	0.17	326	4.1
J.C. Boyle Peaking Near Shovel Creek Geomorphic Reach								
J.C. Boyle Peaking near Shovel Creek Confluence	RM 206.5	0.01	0.03	34	0.059	0.50	326	2.4
	RM 206.4	0.01	0.03	34	0.059	0.49	326	2.4
	RM 206.2	0.01	0.03	34	0.059	0.49	326	1.3
	Study Reach Average	0.01	0.03	34	0.059	0.49	326	2.0

Table 6.7-14. Summary of threshold of mobility input parameters for the sediment budget.

Study Reach	Cross Section	Slope	Manning's N	Threshold of Mobility Developed for the Sediment Budget			Total Critical Shear Stress (g per cm s^2)	Average Flow Velocity (m/s)
				Median Grain Size (mm)	Shield's Number	Depth at Threshold of Mobility (m)		
Copco No. 2 Geomorphic Reach								
Copco No. 2	RM 197.7	0.02	0.06	34	0.059	0.21	326	1.0
	RM 197.66	0.02	0.06	34	0.059	0.21	326	1.2
	Study Reach Average	0.02	0.06	34	0.059	0.21	326	1.1
Downstream of Iron Gate Dam to Cottonwood Creek Geomorphic Reach								
Downstream of Iron Gate Dam at USGS Fish Hatchery Gauge	RM 189.7	0.002	0.03	34	0.059	1.45	326	2.2
	RM 189.6	0.002	0.03	34	0.059	1.45	326	2.1
	RM 189.5	0.002	0.03	34	0.059	1.45	326	2.0
	RM 189.45	0.002	0.03	34	0.059	1.45	326	2.6
	Study Reach Average	0.002	0.03	34	0.059	1.45	326	2.2
Downstream of Iron Gate Dam at R-Ranch	RM 187	0.004	0.03	34	0.059	0.95	326	4.1
	RM 186.7	0.004	0.03	34	0.059	0.95	326	2.3
	RM 186.6	0.004	0.03	34	0.059	0.95	326	4.0
	Study Reach Average	0.004	0.03	34	0.059	0.95	326	3.5
Cottonwood Creek to Scoot River Geomorphic Reach								
Downstream of Iron Gate Dam at I-5 Rest Area	RM 179.1	0.005	0.03	34	0.059	0.67	326	2.8
	Study Reach Average	0.005	0.03	34	0.059	0.67	326	2.8
Downstream of Iron Gate Dam at Tree of Heaven Campground	RM 172.4	0.001	0.03	34	0.059	2.77	326	326.2
	RM 172.2	0.001	0.03	34	0.059	2.77	326	326.2
	RM 171.9	0.001	0.03	34	0.059	2.77	326	326.2
	Study Reach Average	0.001	0.03	34	0.059	2.77	326	326.2
Downstream of Scott River Geomorphic Reach								
Downstream of Iron Gate Dam at Seiad Valley-Hardy Site	RM 131.55	0.002	0.029	34	0.059	1.85	326	4.3
	Study Reach Average	0.002	0.029	34	0.059	1.85	326	4.3
Downstream of Iron Gate Dam at Seiad Valley USGS Gauge	RM 128.5	0.0001	0.019	34	0.059	23.75	326	3.5
	Study Reach Average	0.0001	0.019	34	0.059	23.75	326	3.5

Table 6.7-15. Summary of flow at threshold of mobility for with- and without-project conditions

Study Reach	Cross Section	With-Project Flow at Threshold of Mobility (cfs)	Approximate Return Interval (years)	Without Project Flow at Threshold of Mobility (cfs)	Approximate Return Interval (years)
Link River Geomorphic Reach					
Link River	RM 254	1,346	0.7	Same	0.7
	RM 253.9	1,191	0.7	Same	0.7
	Study Reach Average	1,268	0.7	Same	0.7
Keno Geomorphic Reach					
Keno	RM 232.4	3,310	1.7	Same	1.7
	RM 232.1	4,706	2.7	Same	2.7
	RM 231.9	3,225	1.6	Same	1.6
	Study Reach Average	3,747	2.0	Same	2.0
J.C. Boyle Bypass Geomorphic Reach					
J.C. Boyle Bypass Upstream of Blowout	RM 223.5	2,251	1.0	1,968	0.9
	RM 223.3	1,921	0.9	1,604	0.9
	RM 223.25	181	0.6	112	0.6
	Study Reach Average	1,451	0.8	1,228	0.8
J.C. Boyle Bypass Downstream of Blowout	RM 222.55	4,188	1.7	2,323	1.0
	RM 222.4	3,828	1.5	1,432	0.8
	RM 222.3	3,548	1.4	1,577	0.9
	Study Reach Average	3,855	1.5	1,778	0.9
J.C. Boyle Peaking USGS Gauge / Frain Ranch Geomorphic Reach					
J.C. Boyle Peaking at USGS Gauge	RM 219.9	4,489	1.8	2,232	1.0
	RM 219.7	4,293	1.7	2,449	1.1
	Study Reach Average	4,391	1.8	2,340	1.1
J.C. Boyle Peaking at BLM Campground	RM 217.8	46,497	n/a*	2,922	1.2
	RM 217.5	40,946	n/a*	5,935	2.6
	RM 217.2	47,164	n/a*	5,502	2.4
	Study Reach Average	44,869	n/a*	4,786	2.1
J.C. Boyle Peaking at Gorge Geomorphic Reach					
J.C. Boyle Peaking at Gorge	RM 214.4	3,410	1.4	3,186	1.3
	Study Reach Average	3,410	1.4	3,186	1.3
J.C. Boyle Peaking Near Shovel Creek Geomorphic Reach					
J.C. Boyle Peaking near Shovel Creek Confluence	RM 206.5	4,849	2.0	1,931	0.9
	RM 206.4	4,320	1.7	1,753	0.9
	RM 206.2	4,887	2.0	164	0.6
	Study Reach Average	4,685	1.9	1,283	0.8

Table 6.7-15. Summary of flow at threshold of mobility for with- and without-project conditions

Study Reach	Cross Section	With-Project Flow at Threshold of Mobility (cfs)	Approximate Return Interval (years)	Without Project Flow at Threshold of Mobility (cfs)	Approximate Return Interval (years)
Copco No. 2 Geomorphic Reach					
Copco No. 2	RM 197.7	1,801	< 1	167	< 1
	RM 197.66	2,505	< 1	255	< 1
	Study Reach Average	2,153	< 1	211	< 1
Downstream of Iron Gate Dam to Cottonwood Creek Geomorphic Reach					
Downstream of Iron Gate dam at USGS Fish Hatchery Gauge	RM 189.7	27,655	24.4	3,429	1.5
	RM 189.6	8,558	2.6	4,542	1.7
	RM 189.5	11,050	3.5	4,365	1.6
	RM 189.45	12,504	4.2	5,224	1.8
	Study Reach Average	14,942	8.7	4,390	1.7
Downstream of Iron Gate dam at R-Ranch	RM 187	9,731	3.0	6,639	2.1
	RM 186.7	12,403	4.1	6,201	2.0
	RM 186.6	14,408	5.2	11,450	3.7
	Study Reach Average	12,181	4.1	8,096	2.6
Cottonwood Creek to Scott River Geomorphic Reach					
Downstream of Iron Gate dam at I-5 Rest Area	RM 179.1	6,348	2.0	3,769	1.5
	Study Reach Average	6,348	2.0	3,769	1.5
Downstream of Iron Gate dam at Tree of Heaven Campground	RM 172.4	11,819	3.9	5,891	1.9
	RM 172.2	14,172	5.1	6,627	2.1
	RM 171.9	25,994	20.1	13,654	4.8
	Study Reach Average	17,329	9.7	8,724	2.9
Downstream of Scott River Geomorphic Reach					
Downstream of Iron Gate dam at Seiad Valley-Hardy Site	RM 131.55	389,623	n/a*	210,470	n/a*
	Study Reach Average	389,623	n/a*	210,470	n/a*
Downstream of Iron Gate dam at Seiad Valley USGS Gauge	RM 128.5	67,913	10	26,658	2.9
	Study Reach Average	67,913	10	26,658	2.9

Table 6.7-16. Summary of frequency when flows exceeded the threshold of mobility.

Study Reach	Cross Section	With Project Percent of Period of Record Flows Exceeded Threshold of Mobility (%)	Without Project Percent of Period of Record Flows Exceeded Threshold of Mobility (%)	Ratio (With Project to Without Project)
Link River Geomorphic Reach				
Link River	RM 254	32	32	1
	RM 253.9	36	36	1
	Study Reach Average	33	33	1
Keno Geomorphic Reach				
Keno Reach	RM 232.4	11	11	1
	RM 232.1	6	6	1
	RM 231.9	11	11	1
	Study Reach Average	9	9	1
J.C. Boyle Bypass Geomorphic Reach				
J.C. Boyle Bypass Upstream of Blowout	RM 223.5	6	30	0.19
	RM 223.3	7	34	0.20
	RM 223.25	16	100	0.16
	Study Reach Average	9	46	0.19
J.C. Boyle Bypass Downstream of Blowout	RM 222.55	2	28	0.07
	RM 222.4	3	46	0.06
	RM 222.3	3	40	0.08
	Study Reach Average	3	35	0.07
J.C. Boyle Peaking Geomorphic Reach				
J.C. Boyle Peaking at USGS Gauge	RM 219.9	7	29	0.23
	RM 219.7	7	26	0.28
	Study Reach Average	7	27	0.26
J.C. Boyle Peaking at BLM Campground	RM 217.8	0	16	0.00
	RM 217.5	0	3	0.00
	RM 217.2	0	4	0.00
	Study Reach Average	0	6	0.00
J.C. Boyle Peaking at Gorge Geomorphic Reach				
J.C. Boyle Peaking at Gorge	RM 214.4	12	13	0.91
	Study Reach Average	12	13	0.91

Table 6.7-16. Summary of frequency when flows exceeded the threshold of mobility.

Study Reach	Cross Section	With Project: Percent of Period of Record Flows Exceeded Threshold of Mobility (%)	Without Project: Percent of Period of Record Flows Exceeded Threshold of Mobility (%)	Ratio (With Project to Without Project)
J.C. Boyle Peaking Near Shovel Creek Geomorphic Reach				
J.C. Boyle Peaking near Shovel Creek Confluence	RM 206.5	7	33	0.20
	RM 206.4	9	37	0.23
	RM 206.2	6	100	0.06
	Study Reach Average	7	54	0.13
Copco No. 2 Geomorphic Reach				
Copco No. 2	RM 197.7	7	100	0.07
	RM 197.66	5	100	0.05
	Study Reach Average	6	100	0.06
Downstream of Iron Gate Dam to Cottonwood Creek Geomorphic Reach				
Downstream of Iron Gate Dam at USGS Fish Hatchery Gauge	RM 189.7	0	16	0.00
	RM 189.6	1	10	0.13
	RM 189.5	0.2	10	0.02
	RM 189.45	0.1	7	0.01
	Study Reach Average	0.3	11	0.04
Downstream of Iron Gate Dam at R-Ranch	RM 187	1	4	0.18
	RM 186.7	0.1	5	0.02
	RM 186.6	0.03	0.2	0.16
	Study Reach Average	0.4	3	0.12
Cottonwood Creek to Scott River Geomorphic Reach				
Downstream of Iron Gate Dam at I-5 Rest Area	RM 179.1	6	17	0.33
	Study Reach Average	6	17	0.33
Downstream of Iron Gate Dam at Tree of Heaven Campground	RM 172.4	1	9	0.08
	RM 172.2	0.3	6	0.04
	RM 171.9	0.02	0.3	0.08
	Study Reach Average	0.4	5	0.07
Downstream of Scott River Geomorphic Reach				
Downstream of Iron Gate Dam at Seiad Valley-Hardy Site	RM 131.55	0	0	0
	Study Reach Average	0	0	0
Downstream of Iron Gate Dam at Seiad Valley USGS Gauge	RM 128.5	0.02	0.2	0.1
	Study Reach Average	0.02	0.2	0.1

6.7.13.2 Consideration of Hourly Data in Frequency of Mobility

Operation of J.C. Boyle power plant can cause significant fluctuations in hourly flows throughout the J.C. Boyle peaking reach. Therefore, hourly flow data were considered for the peaking reach study sites to assess the impact of these fluctuations on the analysis of the threshold of mobility. As summarized in Table 6.7-15, the threshold of mobility flows range from 3,410 to 47,164 cfs for with-Project conditions and from 164 to 5,935 cfs for without-Project conditions. Since the threshold of mobility for the with-Project condition exceeds the peaking range of operation (zero to 3,000 cfs) for all sites, no difference would exist in the frequency of mobility calculation with hourly or daily discharge data. While the threshold of mobility for without-Project conditions fell within the peaking operation range, the difference in frequency of mobility calculated with hourly and daily data was not assessed because the without-Project hydrology does not include peaking operations. The conditions considered in the sediment budget bed load transport capacity calculations (i.e., tributary size without-Project bed material and existing with-Project hydrology) yield different results, as discussed in section 6.7.24.1.

6.7.14 Bed Load Transport Rate

Because the bed load transport rates developed in this study were computed from transport equations (which assume infinite supply) rather than measured transport rates, they should be referred to as theoretical sediment transport capacities. Such theoretical capacities are always in excess of actual sediment transport rates, especially in steep channels dominated by bedrock and coarse bed material, characteristic of many reaches of the Klamath River. Theoretical bed load transport capacities by cross section and study site averages (Table 6.7-17) for with-Project conditions and hydrology show the bed load transport capacities ranged from zero, for years whose highest flow did not exceed the threshold of mobility, to 740,000 tons per year. For the without-Project conditions and hydrology, the bed load transport rate ranged from zero (for years whose flow did not exceed the mobility threshold) to 4.4 million tons per year. The large range in bed load transport capacities is caused by differences in local slope, bed material, channel geometry, and hydrology between the study sites and cross sections. Except for the study site located at Seiad Valley at the USGS gauge, which resulted in a transport capacity of zero for both with- and without-Project scenarios (discussed below), the bed load transport capacities were consistently larger for the without-Project conditions. This result can be attributed to the following two considerations in this analysis:

1. The without-Project bed was represented as significantly finer-grained than the with-Project bed for reaches downstream of J.C. Boyle reservoir. Therefore, the without-Project bed would be mobilized at lower flows (i.e., more frequently) and a greater volume of sediment would be transported over time.
2. The without-Project flows assumed no reservoir storage downstream of J.C. Boyle reservoir. Although reservoir storage is relatively minor, the hydrologic model indicated that in some cases pre-dam hydrographs would stay above the threshold of bed mobilization for longer than post-dam hydrographs, thereby resulting in a greater volume of sediment transported over time under the without-Project conditions.

Table 6.7-17. Summary of bed load transport capacity.

Study Reach	Cross Section	With Project Bed load Transport Capacity[1] (tons/yr)	Without Project Bed load Transport Capacity[1] (tons/yr)	Ratio (With Project to Without Project)
Link River Geomorphic Reach				
Link River	RM 254	322,718	Same	1.00
	RM 253.9	222,168	Same	1.00
	Study Reach Average	272,443	Same	1.00
Keno Geomorphic Reach				
Keno Reach	RM 232.4	79,874	Same	1.00
	RM 232.1	34,837	Same	1.00
	RM 231.9	192,681	Same	1.00
	Study Reach Average	102,464	Same	1.00
J.C. Boyle Bypass Geomorphic Reach				
J.C. Boyle Bypass US of Blowout	RM 223.5	93,656	506,015	0.19
	RM 223.3	149,579	939,851	0.16
	RM 223.25	739,666	4,372,619	0.17
	Study Reach Average	327,634	1,939,495	0.17
J.C. Boyle Bypass DS of Blowout	RM 222.55	15,250	94,627	0.16
	RM 222.4	22,916	839,198	0.03
	RM 222.3	37,790	803,526	0.05
	Study Reach Average	25,319	579,117	0.04
J.C. Boyle Peaking Geomorphic Reach				
J.C. Boyle Peaking Reach at USGS Gauge	RM 219.9	43,651	318,737	0.14
	RM 219.7	80,523	345,145	0.23
	Study Reach Average	62,087	331,941	0.19
J.C. Boyle Peaking Reach at BLM Campground	RM 217.8	0	787,415	0.00
	RM 217.5	0	1,807	0.00
	RM 217.2	0	3,167	0.00
	Study Reach Average	0	264,130	0.00
J.C. Boyle Peaking at Gorge Geomorphic Reach				
J.C. Boyle Peaking Reach at Gorge	RM 214.4	191,055	231,737	0.82
	Study Reach Average	191,055	231,737	0.82
J.C. Boyle Peaking Near Shovel Creek Geomorphic Reach				
J.C. Boyle Peaking Reach near Shovel Creek Confluence	RM 206.5	12,617	104,484	0.12
	RM 206.4	17,607	125,283	0.14
	RM 206.2	11,220	531,278	0.02
	Study Reach Average	13,815	253,682	0.05

Table 6.7-17. Summary of bed load transport capacity.

Study Reach	Cross Section	With Project Bed load Transport Capacity[1] (tons/yr)	Without Project Bed load Transport Capacity [1] (tons/yr)	Ratio (With Project to Without Project)
Copco No. 2 Geomorphic Reach				
Copco No. 2	RM 197.7	131,470	3,189,539	0.04
	RM 197.66	104,930	2,302,562	0.05
	Study Reach Average	118,200	2,746,050	0.04
Downstream of Iron Gate Dam to Cottonwood Creek Geomorphic Reach				
Downstream of Iron Gate dam at USGS Fish Hatchery Gauge	RM 189.7	0[2]	13,780	0.00
	RM 189.6	540	13,010	0.04
	RM 189.5	101	11,776	0.01
	RM 189.45	39	5,382	0.01
	Study Reach Average	170	10,987	0.02
Downstream of Iron Gate dam at R-Ranch	RM 187	290	1,899	0.15
	RM 186.7	128	8,458	0.02
	RM 186.6	77	176	0.44
	Study Reach Average	165	3,511	0.05
Cottonwood Creek to Scott River Geomorphic Reach				
Downstream of Iron Gate dam at I-5 Rest Area	RM 179.1	13,768	53,765	0.26
	Study Reach Average	13,768	53,765	0.26
Downstream of Iron Gate dam at Tree of Heaven Campground	RM 172.4	310	4,121	0.08
	RM 172.2	177	2,612	0.07
	RM 171.9	27	151	0.18
	Study Reach Average	171	2,295	0.07
Downstream of Scott River Geomorphic Reach				
Downstream of Iron Gate dam at Seiad Valley-Hardy Site	RM 131.55	41	441	0.09
	Study Reach Average	41	441	0.09
Downstream of Iron Gate dam at Seiad Valley USGS Gauge	RM 128.5	0[2]	0[2]	0.00
	Study Reach Average	0[2]	0[2]	0.00

[1] Transport capacities generated using available daily hydrology data, water years 1968 to 2001.
[2] Bed load transport rates of zero indicate that the flow at the threshold of mobility was greater than the highest recorded flow within the period of record.

The results indicate theoretical transport capacities 3 to 82 percent lower with-Project than without-Project, mostly due to the smaller grain sizes assumed for without-Project, which strongly affect results of the calculations. It is important to recognize the substantial uncertainty in these results and that the results are largely dependent on assumptions about pre-Project conditions, such as grain size. This is typical in such studies, especially for rivers with such strong geologic control as the Klamath, where the ideal conditions for application of theoretical equations do not exist. Moreover, the low flows experienced in 2002 and 2003 precluded implementation of the sediment sampling program, so the theoretical calculations could not be replaced or supplanted by empirical measures, except for the tracer gravel results, as calibration for the bed mobility threshold. Nonetheless, even when empirical bed load sampling has been conducted, theoretical transport functions can be used to extend empirically based rating curves because samples are typically not available for very high flows.

The only bed load transport sampling possible in the otherwise low-flow 2002 and 2003 flow season, collected at flows of 2,800 and 3,000 cfs in 2003 yielded only small quantities (0.6-1.0 ton per day) of sand transported as bed load. These results were consistent with the predicted with-project transport capacity at those flows of zero. The bed load transport capacity was calculated using a grain size reflecting the gravel bed, and thus was not intended to model transport of sand on the surface of a stable gravel bed. In any event, both the samples and calculated capacities were essentially zero, consistently indicating that the bed would be stable with the grain sizes now present on the bed and under the current flow regime.

Given this uncertainty, and similar to the threshold of mobility results, the theoretical bed load transport capacity results are best interpreted as indicators of relative change in the sediment transport dynamics in each reach. This limitation is especially important to bear in mind for the Klamath River upstream of Cottonwood Creek, where actual bed load transport rates are likely limited by naturally low sediment supply from the catchment, a condition exacerbated by the presence of the dams.

6.7.14.1 Consideration of Hourly Data in Bed Load Transport Capacity

Because the J.C. Boyle power plant produces significant fluctuations in hourly flows in the J.C. Boyle peaking reach, bed load transport capacity calculations at an hourly time step are needed to assess the influence of peaking on sediment transport. Because there are no extractions from the J.C. Boyle project facility, the total flow is unchanged, only its distribution over the course of a day or more. If the Project peaking results in more hours above the sediment transport threshold, a net increase in transport could be expected. Bed load transport capacities calculated for the sediment budget condition (i.e., without-Project sediment composition and with-Project hydrology) for hourly flow data differed from transport values calculated using mean daily flows (same values averaged by study reach in the sediment budget) from 17 percent less to 28 percent greater (Tables 6.7-18 and 6.7-19). Most of the ratios of hourly derived transport capacities to daily derived transport capacities were slightly greater than one.

Table 6.7-18. Comparison bed load transport rates calculated with daily and hourly data

Study Reach	Cross Section	Bed load Transport Capacity using Hourly Flow Data (tons/yr)	Bed load Transport Capacity using Daily Flow Data* (tons/yr)	Ratio (hourly to daily)
J.C. Boyle Peaking at USGS Gauge	RM 219.9	2.7E+05	2.5E+05	1.05
	RM 219.7	3.3E+05	3.1E+05	1.07
	Study Reach Average	3.0E+05	2.8E+05	1.06
J.C. Boyle Peaking at BLM Campground	RM 217.8	8.4E+03	7.5E+03	1.13
	RM 217.5	2.4E+02	2.6E+02	0.94
	RM 217.2	3.5E+02	3.4E+02	1.01
	Study Reach Average	3.0E+03	2.7E+03	1.03
J.C. Boyle Peaking at Gorge Geomorphic Reach				
J.C. Boyle Peaking at Gorge	RM 214.4	2.3E+05	2.1E+05	1.08
	Study Reach Average	2.3E+05	2.1E+05	1.08
J.C. Boyle Peaking Near Shovel Creek Geomorphic Reach				
J.C. Boyle Peaking near Shovel Creek Confluence	RM 206.5	9.4E+04	7.4E+04	1.28
	RM 206.4	8.2E+04	9.1E+04	0.90
	RM 206.2	3.6E+05	4.3E+05	0.83
	Study Reach Average	1.8E+05	2.0E+05	1.00

* These individual cross section values were averaged for each reach to generate the theoretical transport capacities presented in the sediment budget (Table 6.7-19).

6.7.15 Sediment Budget

Table 6.7-19 presents the results of the sediment budget by Project reach. Minimum annual, maximum annual, and average theoretical transport capacities are presented for each reach. The minimum annual value corresponds to years with the lowest total theoretical transport capacity over the analyzed period of record. The maximum annual value corresponds to the year with the highest total theoretical transport capacity over the analyzed period of record. The average annual theoretical transport capacity is used in the calculation of outputs (O) and changes in storage (Δs) because no long-term sediment transport monitoring has been conducted in the Klamath watershed. The tributary sediment yields were determined from tributary delta surveys (see section 6.7.11 and Appendix 6B) that produced an average rate of sedimentation over the life of the Project. Sediment budget schematics show the tributary sediment inputs and project features by river mile (Figures 6.7-59 through 6.7-63).

Table 6.7-19. Sediment budget results.

Project Reach	Geomorphic Reach	Theoretical Minimum Annual Transport Capacity (tons/yr)	Theoretical Maximum Annual Transport Capacity (tons/yr)	Theoretical Average Annual Transport Capacity (tons/yr)	Average Annual Tributary + Hillslope* Input (tons/yr)	Cumulative Average Annual Tributary + Hillslope Input (tons/yr)	Potential Average Annual Deficit or Surplus (tons/yr)
Link							
	Link River	0	730,000	250,000	0	0	-250,000
	Keno reservoir	0	0	0	169	169	169
Reach Total				**250,000**	**169**		**-249,831**
Keno							
	Keno reach	0	2,390,000	900,000	3,032	3,032	-896,968
	J.C. Boyle reservoir	0	0	0	3,102	6,134	6,134
Reach Total				**900,000**	**6,134**		**-893,866**
J.C. Boyle							
	J.C. Boyle bypass	0	990,000	260,000	4,105	4,105	-255,895
	J.C. Boyle USGS Gauge/Frain Ranch	0	380,000	140,000	1,798	5,839	-134,161
	J.C. Boyle gorge	0	760,000	210,000	3,421	9,260	-200,740
	J.C. Boyle Shovel Creek	20,000	450,000	200,000	2,572	11,832	-188,168
	Cocpo reservoir	0	0	0	3,522	15,354	15,354
Reach Total				**810,000**	**15,417**		**-794,583**
Copco							
	Copco No. 2 bypass	0	1,710,000	480,000	15	15	-479,985
	Iron Gate reservoir	0	0	0	10,693	10,708	10,708
Reach Total				**480,000**	**10,708**		**-469,292**
Downstream of Iron Gate Dam							
	Iron Gate dam to Cottonwood Creek	0	13,000	3,000	17,268	17,268	14,268
	Cottonwood Creek to Scott River	0	40,000	19,000	493,970	511,238	492,238
	Downstream of Scott River (includes Seiad Valley)	0	3,000	0	318,786	830,024	830,024
Reach Total				**22,000**	**830,024**		**1,336,530**

* Direct hillslope inputs, described in section 6.7.10, comprise a very small percentage (< 2%) of total inputs

The schematics also show study reaches where data were collected to estimate theoretical transport capacity. Because flows in the Klamath River during the study period were insufficient to mobilize the channel bed significantly, bed load sampling could not be completed to specify the sediment transport capacities developed by the sediment transport model. As a result, the transport component of the sediment budget is presented as a theoretical sediment transport capacity, which is an estimate of the amount of sediment with specific size characteristics the Klamath River could transport annually if sediment supply was unlimited. Because the theoretical capacities thus calculated can range over several orders of magnitude, depending on the equation selected (Vanoni, 1975), all such model results should be treated with extreme caution unless they can be calibrated with empirical data sets. For the Klamath River, the sediment transport estimates will be greatly improved when flows are sufficiently high to mobilize the bed and the bed load transport sampling described in the study plan can be conducted. The uncertainty associated with this sediment budget is assumed to be very high, but nonetheless the exercise still provides a potentially useful framework for assessing potential Project impacts on sediment transport and storage because the calculations show that in most reaches transport capacity far exceeds supply on a long-term basis, so the river is supply-limited.

The sediment budget results are most useful in assessing relative impacts in different Project reaches. The sediment budget consists of a series of cells that feed into each other in the downstream direction. Project dams act as barriers that block the sediment input cells of the upstream reaches from feeding into downstream reaches. The focus of the sediment budget was the coarser (i.e., bed load) components, because these would be more strongly influenced by Project operations, and because they are especially important for channel form and salmonid habitat (e.g., spawning gravels). However, the available data were few and direct measurements of sediment transport could not be made, so the sediment budget was based on sources of data that included not only the bed load, but also bed material load and total load. The theoretical calculations are for bed load only. The reservoir delta deposits, and thus the volcanic province tributary sediment yields based on the delta deposit data, can be considered to reflect bed material load as they include all bed load and the coarser fractions of the suspended load. The sediment yield estimates for the Salmon River watershed developed by USFS (de la Fuente and Haessig, 1993) were for total load—i.e., the sum of bed load and suspended load. However, the estimated 450 $yd^3/mi^2/y$ was not adjusted downward to convert it to an assumed bed load-only percentage (e.g., one could assume bed load to be 10 percent of the total) because the Salmon River watershed is known to have a relatively low sediment yield compared to other tributaries in the Klamath geologic province (de la Fuente, pers. comm., 2002). Thus, using the Salmon River total load as a basis for bed load in other tributaries was largely arbitrary, but it was at least based on actual sediment yield data.

Reservoirs trap 100 percent of bed load, but the percentage of suspended load trapped is a function of reservoir shape, operation, and storage capacity relative to river flow. Based on the widely applied Brune (1953) relation (as adapted by Morris and Fan, 1997), the trap efficiencies of Copco and Iron Gate reservoirs would be predicted to be around 65 to 85 percent. The volume of fine-grained (i.e., suspended) sediment accumulated in the reservoirs (from the bathymetry study, section 6.7.2.1) should represent a *minimum* value for suspended sediment. However, as the reservoir sedimentation volumes were the only suspended sediment data, the Project geomorphologists did not attempt to construct a suspended sediment budget.

When average annual suspended sediment accumulation in reservoirs (from the reservoir sedimentation study) was compared to the estimated annual delivery of bed load to each reservoir from tributaries, the volumes of suspended sediment were significantly lower than volumes of sediment in tributary deltas (which consisted of both suspended and bed load fractions), except for Keno reservoir. This is somewhat surprising, as bed load is usually less than 15 percent of suspended load. However, the delta sediments contain not only all the bed load but also part of the suspended load. Based on surficial grain sizes (which may be finer than some of the deposits at depth), less than half of the deposit is sand and gravel. One can imagine the sand and coarser silts depositing in the delta, while the finer gravel silts and clays (the “washload”) would continue out into the main body of the reservoir, to be deposited there or to be carried downstream through or over the dam. In interpreting these results, it is important to bear in mind the rough nature of the fine-sediment volumes estimated for the reservoirs, given the poor quality of pre-Project topography and unknown trap efficiencies for Project reservoirs. A suspended sediment budget could be developed by assuming that the bed load volume is some fraction of the total sediment volume (typically 5 to 15 percent), but the proposed suspended load sampling must be completed to develop a more meaningful suspended sediment budget for the Klamath River in the Project area. The bed load sediment budget discussed below is perhaps a more important tool for the assessment of Project impacts on sediment transport and geomorphology.

The Link River reach is characterized in this sediment budget as a transport reach and, because of Upper Klamath Lake, would likely have had very low sediment supply prior to the completion of the Project. Few tributaries contribute sediment directly to this reach, and relatively steep slopes result in a high theoretical transport capacity. Only tributaries to the Link River reach (Figure 6.7-59) that were determined to deliver sediment to the approximately 1-mile-long reach upstream of Lake Ewauna and the upstream end of Lake Ewauna were included in the schematic and sediment budget. Most of the tributaries to the upper portion of Keno reservoir and Lake Ewauna have very long depositional zones before joining the mainstem. For these tributaries, it was assumed that bed load material would be deposited before reaching the mainstem. The results of the sediment budget for the Link River reach and Keno reservoir indicate that Keno Dam causes a potential deficit of approximately 250,000 cubic yards per year of sediment that could be transported to the Keno reach if not for the dam. However, the actual potential deficit is determined by sediment inputs and amounts to only 169 cubic yards per year (note that this and all following tributary input values have been adjusted to remove the 20 percent washload included in the tributary volume results discussed in section 6.7.11). Further, because this sediment would have historically been deposited in Lake Ewauna, there is probably not a significant project impact on sediment transport in this reach or the Keno reach downstream.

The Keno reach is also characterized as a transport reach that has a very high transport capacity and limited sediment input. As in the Link River reach, the Keno reach was also likely relatively sediment-starved before the Project because of the presence of the low gradient areas immediately upstream, including Lake Ewauna. Although more tributaries contribute sediment in this reach, theoretical transport capacity is much higher on average than the sediment inputs (Figure 6.7-60). The results of the sediment budget for the Keno reach and J.C. Boyle reservoir indicate that J.C. Boyle dam causes a potential deficit of approximately 900,000 cubic yards per year of sediment that could be transported to the J.C. Boyle reach if not for the dam. However, the actual potential deficit is again determined by sediment inputs in this reach and amounts to

6,134 cubic yards per year. This estimate of trapped bed load sediment can be considered a Project impact on the J.C. Boyle reach downstream.

The J.C. Boyle reach has many more tributaries than the previous two reaches. However, this reach still has relatively high theoretical transport capacities that make it another supply-limited transport reach (Figure 6.7-61). The J.C. Boyle reach is divided into five subreaches to capture changes in channel morphology, Project facilities, and sediment inputs. In each subreach, the transport capacity is much greater than the sum of all sediment inputs to the reach. The results of the sediment budget for the J.C. Boyle reach and Copco reservoir indicate that Copco dam causes a potential deficit of approximately 810,000 cubic yards per year of sediment that could be transported to the Copco reach if not for the dam. However, the actual potential deficit is once again determined by sediment inputs in this reach and amounts to 15,417 cubic yards per year. This estimate of trapped bed load sediment can be considered a Project impact on the Copco reach downstream (and perhaps also on the reach between Iron Gate dam and Cottonwood Creek).

Although the transport capacity of the Copco reach is approximately half that of the previous two reaches, the reach is still supply-limited and acts as a transport reach in the sediment budget (Figure 6.7-62). The results of the sediment budget for the Copco reach and Iron Gate reservoir indicate that Iron Gate dam causes a potential deficit of approximately 480,000 cubic yards per year of sediment that could be transported to the Copco reach if not for the dam. However, the actual potential deficit is once again determined by sediment inputs in this reach and amounts to 10,708 cubic yards per year. This estimate of trapped bed load sediment can be considered a Project impact on the reach downstream between Iron Gate Dam and Cottonwood Creek.

The reach downstream of Iron Gate dam is broken into three subreaches that differ by channel morphology and sediment input from well-developed tributaries (Figure 6.7-63). The theoretical sediment transport dynamics downstream of Iron Gate dam show two significant changes, resulting in the transition from a supply-limited system to a potentially transport-limited system. First, the channel gradient decreases, which decreases the sediment transport capacity of the reaches. In addition, the geologic terrain shifts from the relatively low yield Cascade volcanics upstream to the higher yield Klamath geology downstream. These tributaries generally produce higher sediment yields than, upstream tributaries do. Although the sediment budget results indicate substantial average annual storage downstream of Cottonwood Creek, the geomorphic field investigations and historical aerial photograph analysis do not indicate any channel bed aggradation through these reaches. It is likely that the theoretical transport capacities for the study reaches downstream of Iron Gate dam were significantly underestimated because the dimensionless critical shear stress determined empirically for the J.C. Boyle reach were applied downstream of Iron Gate dam. This was done because no tracer movement observations were made downstream of Iron Gate dam during the study period. However, more of the available stream energy would likely go into sediment transport in the lower reaches, where less energy would be expended in boundary friction than in the steep boulder- and bedrock-controlled reaches upstream. Thus, the actual sediment transport capacity is almost certainly greater than is implied by these uncalibrated model results. Moreover, there is no geomorphic evidence of channel aggradation in this reach, as implied by the model results.

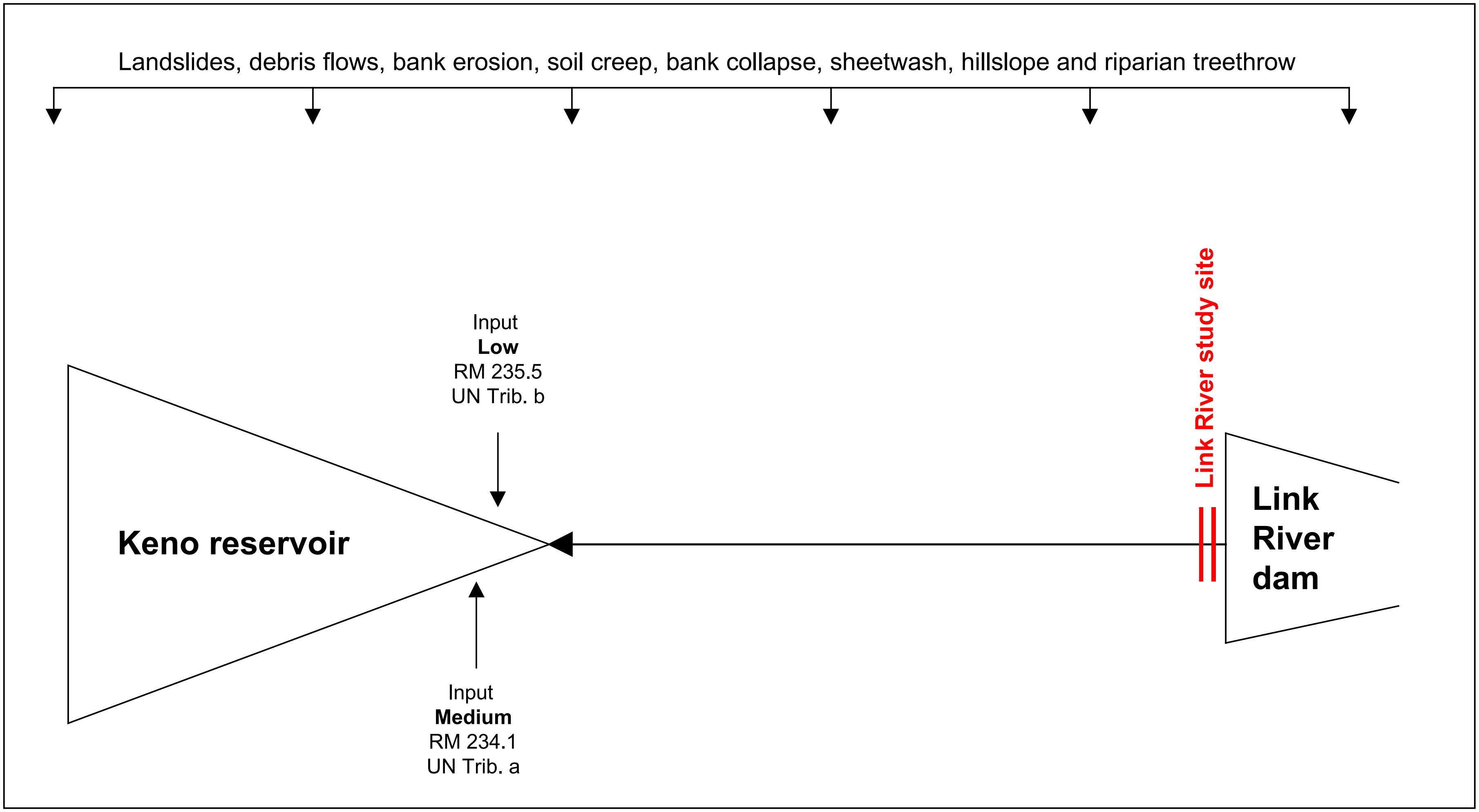

Figure 6.7-59. Link River reach sediment budget schematic.

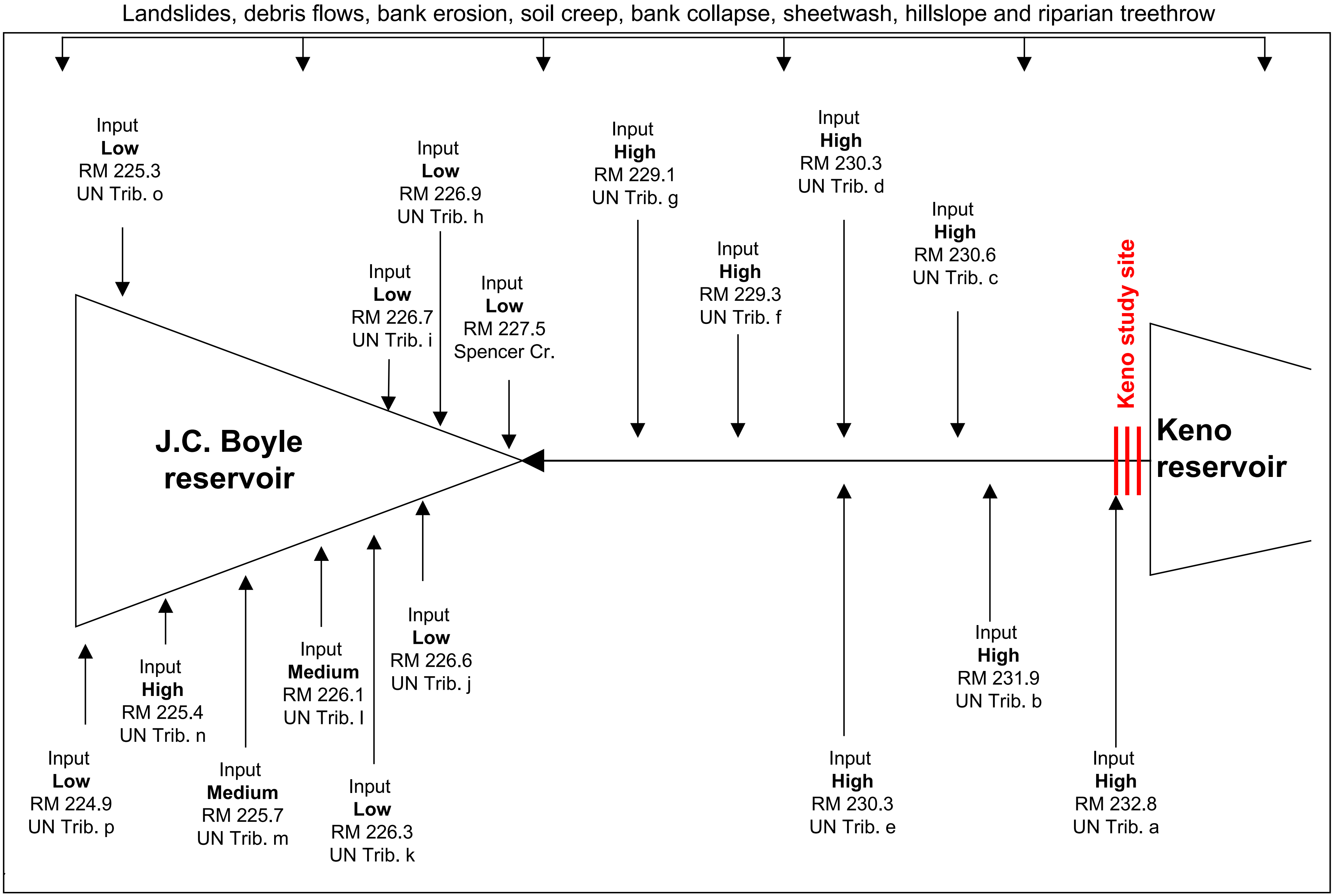

Figure 6.7-60. Keno Reach sediment budget schematic.

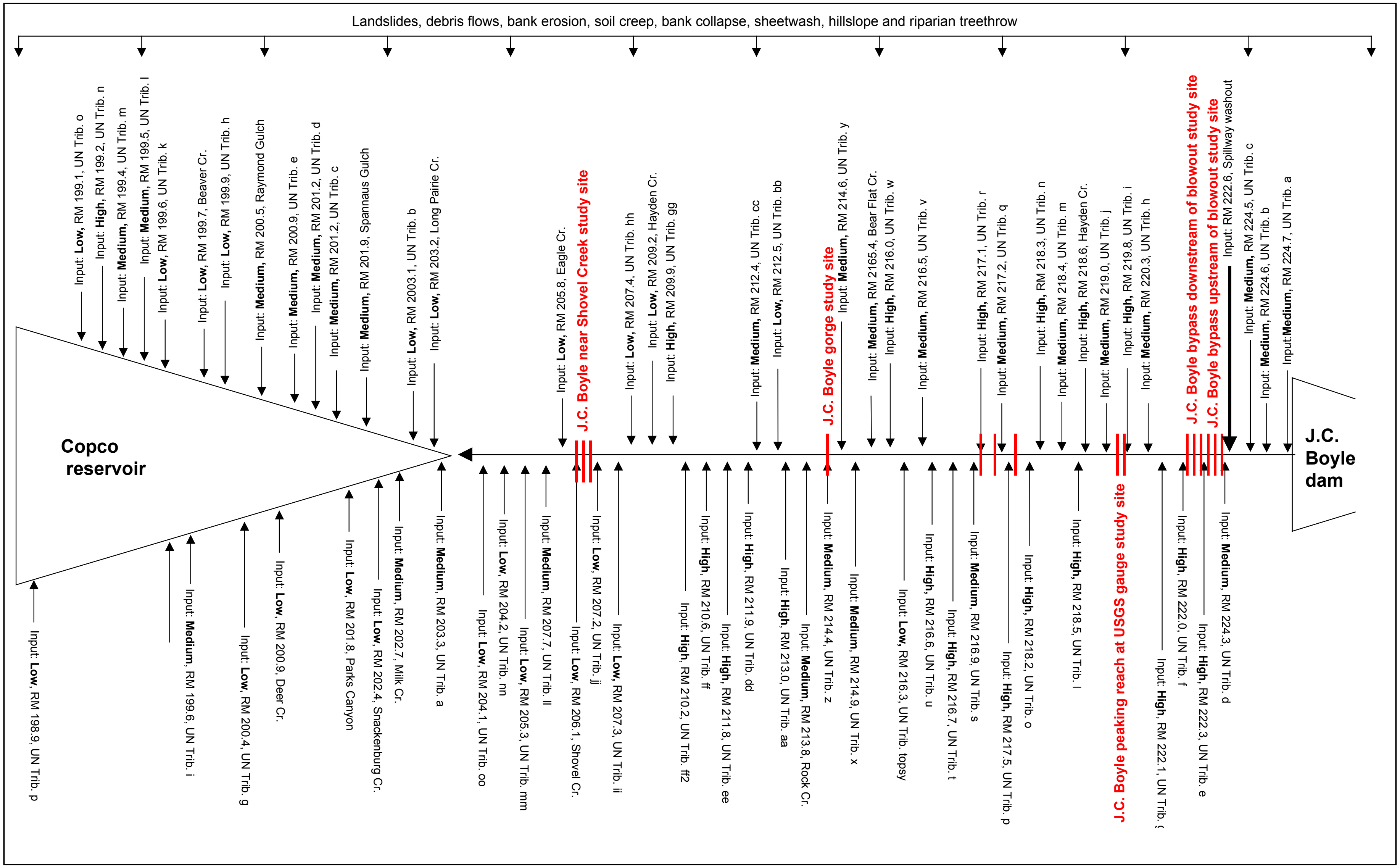

Figure 6.7-61. J.C. Boyle reach sediment budget schematic.

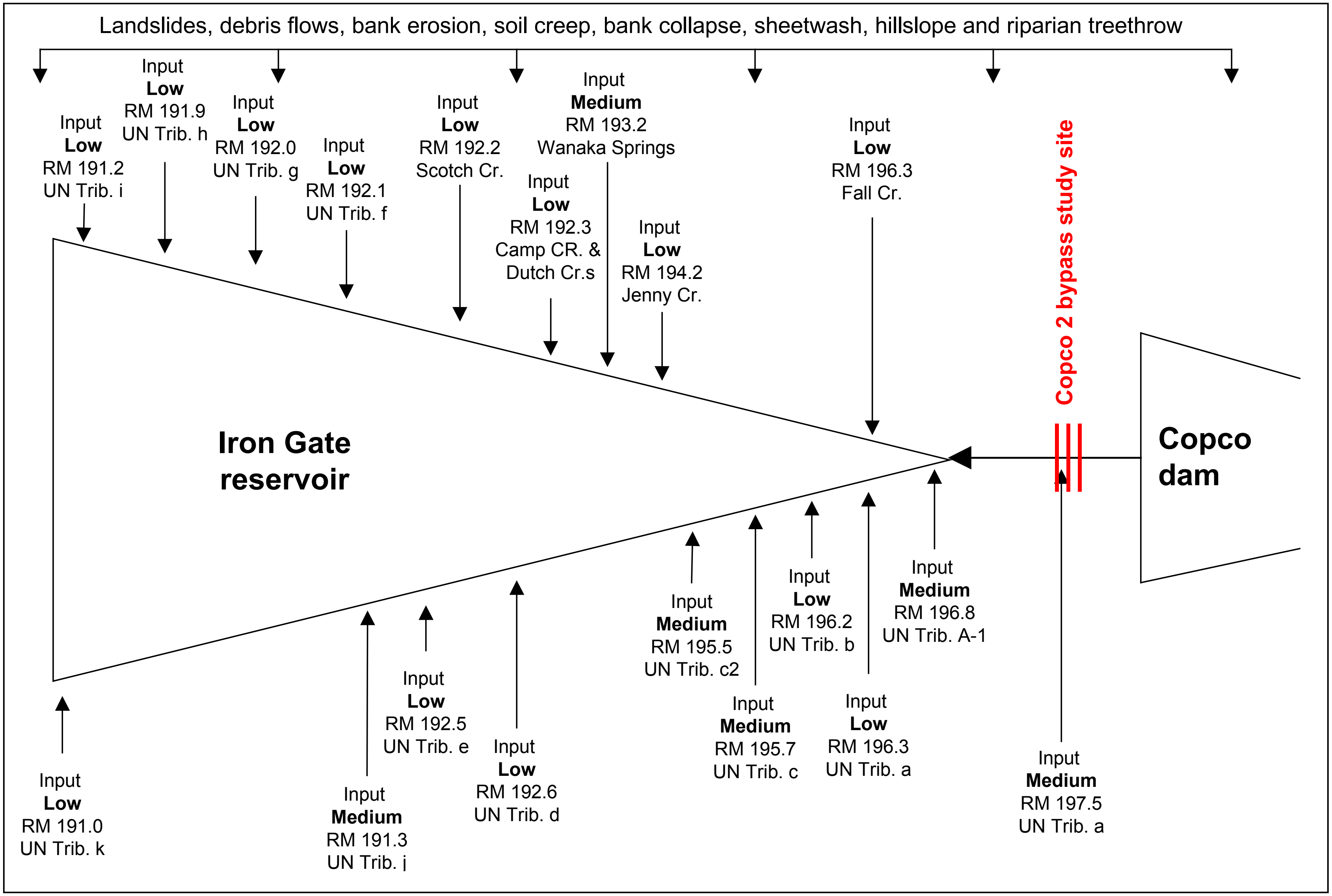

Figure 6.7-62. Copco reach sediment budget schematic.

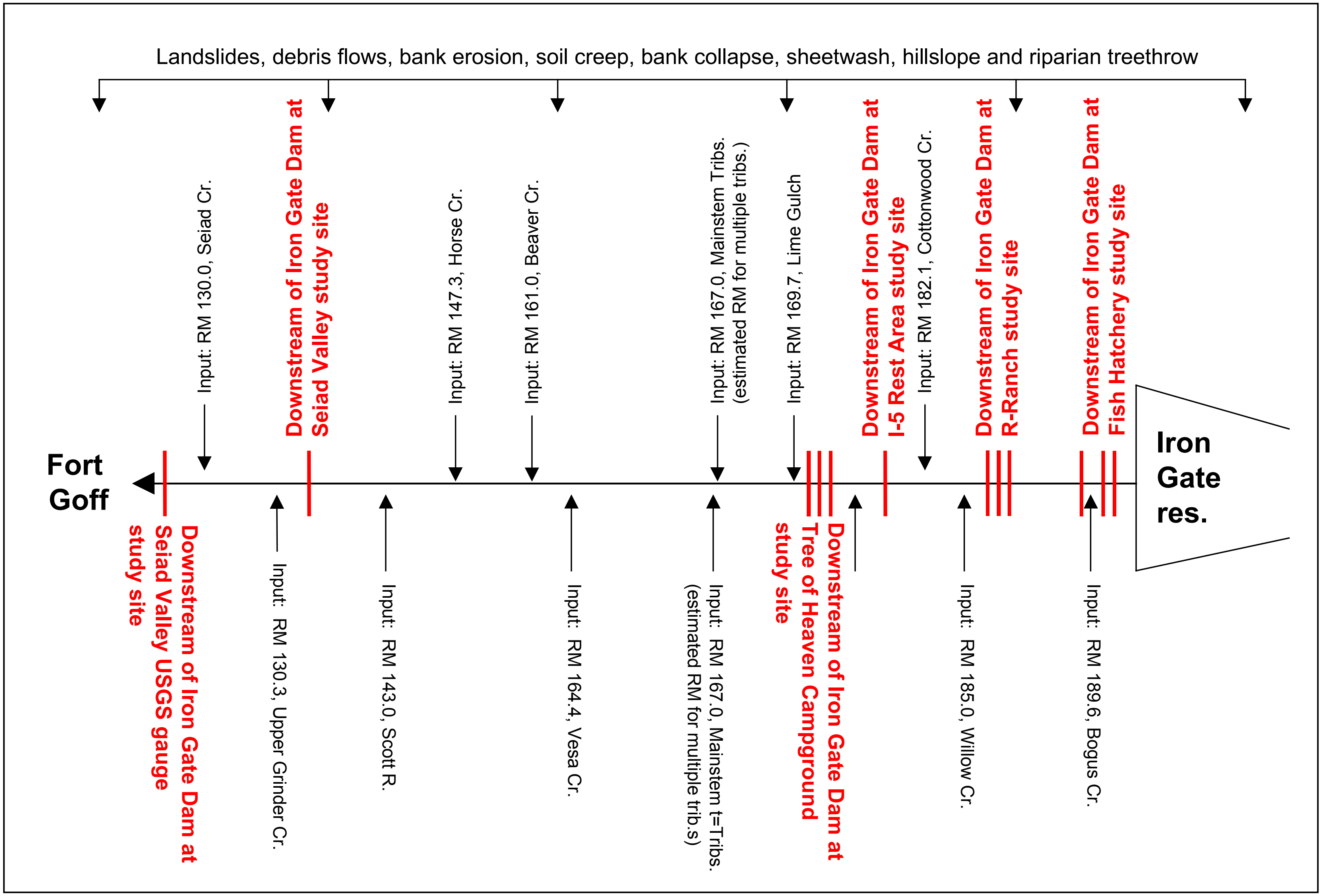

Figure 6.7-63. Downstream of Iron Gate dam sediment budget schematic.

These results also do not clearly account for differences among bed load, suspended load, bed-material load, and washload. For example, there are only limited data on the size distribution of the tributary delta deposits. The tributary delta deposits would include all bed load, but only the coarser (i.e., sand and some silt) part of the suspended load; clay and some silt sediment would tend to be carried by currents into the main body of the reservoir, where some would settle out and some would stay in suspension to be carried over or through the dam downstream, the latter being the finest fraction, termed washload. The estimated 450 $yd^3/y/mi^2$ sediment yield estimated for the Salmon River drainage is total sediment load and includes both suspended and bed load. In contrast, the theoretical transport capacities calculated were for bed load only, which would usually be less than 15 percent percent of suspended load.

This result highlights the importance of carefully considering uncertainty in applying the results of this sediment budget to future management and mitigation decisions. Perhaps the most important consideration in the upper Project reaches (considered transport reaches in the sediment budget) is the potential interannual variation that likely exists in delivery of sediment from slopes and tributaries and transport of sediment through the mainstem. It is possible that tributaries could deliver significant amounts of bed load sediment to the mainstem in a given year or series of years that is not transported immediately out of the mainstem reach (as evidenced by the theoretical minimum and maximum annual transport capacities for each reach). The fact that average annual theoretical transport rates are orders of magnitude greater than average annual sediment supply in the upper reaches does not mean that the bed load transported to the mainstem (and therefore the bed load trapped in Project reservoirs) is inconsequential in the geomorphology of Project reaches in the Klamath River.

In the reaches downstream of Iron Gate dam, though the sediment budget results are not validated by observations of aggradation, the results indicate a significant shift in sediment transport dynamics that suggests potential Project impacts downstream of Cottonwood Creek are likely much less significant than impacts upstream of the creek.

The high uncertainty associated with this sediment budget also indicates that mitigation measures proposed for the impacts associated with bed load material trapped in Project reservoirs should incorporate principles of adaptive management, whereby initial mitigation measures (e.g., gravel augmentation) are developed using the best available information (including the results of this sediment budget) and subsequently monitored and adjusted if the measures do not achieve their stated objectives. In such an approach, the highest utility of the sediment budget results will likely be in assessing relative levels of impact throughout Project reaches and identifying reasonable ranges of potential impacts for initial mitigation measures.

6.7.16 Estimating Downstream Extent of Project Impacts

In terms of geomorphology, the Project can affect both the hydrology (by regulating flows) and sediment transport (by trapping coarse sediment behind Project reservoirs). The following analyses were performed to gauge the extent of the downstream impact of the Project below Iron Gate dam:

- Assessement of the formation of alluvial features downstream of Iron Gate dam
- Comparison of the Project-impacted watershed area to the cumulative watershed area downstream of Iron Gate dam

- Comparison of sediment yields from the Project-impacted watershed area with the sediment yields of the watershed downstream of Iron Gate dam
- Comparison of the average annual peak discharge and average annual discharge of USGS gauges downstream of Iron Gate dam.

6.7.16.1 Alluvial Features Quantification

The area of alluvial feature mapped downstream of Iron Gate dam follows a bimodal distribution (Figure 6.7-64). The area of alluvial features is less than 0.2 acre for the first 9 miles downstream of Iron Gate dam. This is likely due to a combination of bed load material trapping by Project facilities (especially immediately downstream of Iron Gate dam) and the relatively low yield terrain drained by the Klamath River upstream of Cottonwood Creek. The area of alluvial features increases and peaks around RM 171 (17.2 acres) and then decreases to the second trough at RM 151 (0.2 acre). Downstream of RM 152, the area of alluvial features increases to a second and higher peak of over 28.5 acres of mapped alluvial features per river mile at RM 137. This is just a few miles downstream of the Scott River confluence and likely corresponds to the significant sediment yields from that river.

The number of alluvial features follows a similar pattern (Figure 6.7-65). There are few features directly downstream of Iron Gate dam, but the number increases and peaks at RM 158. The number of alluvial features decreases to a second trough at RM 151 and increases to a second, but lower, peak at RM 144. Of the two measurements (area of alluvial features and number of alluvial features), the area of alluvial features is probably a better indication of the impact (or lack thereof) of Project facilities downstream of Iron Gate dam.

Average valley width was also determined for each river mile downstream of Iron Gate dam and plotted alongside with channel slope by RM (Figure 6.7-66). The average valley width is approximately 570 feet and increases at RM 181, 170, 158, 149, and 138 (Figure 6.7-66). This analysis indicates that sediment yield from the more erosive Klamath Terrain is more likely to control the number and extent of alluvial features than is valley width.

This analysis suggests that the primary impact of the Project on alluvial features (and therefore on potential salmonid spawning material) is limited to the reach from Iron Gate dam downstream to the confluence with Cottonwood Creek. Because the Project traps all sediment behind Iron Gate dam and little sediment is produced from the volcanic-dominated landscape upstream of Cottonwood Creek, the Project may have significantly coarsened the channel bed to the confluence with Cottonwood Creek.

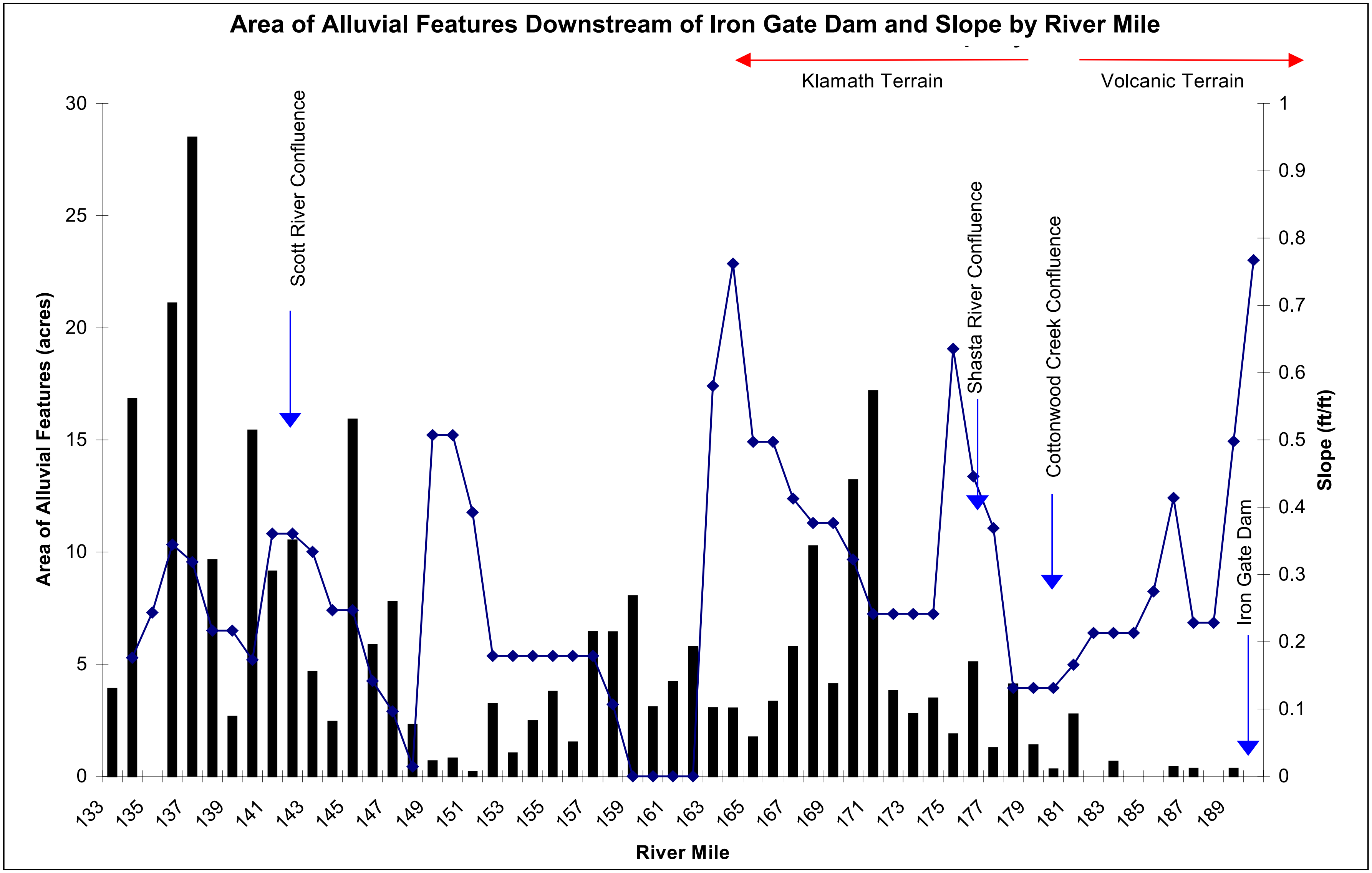

Figure 6.7-64. Area of alluvial features downstream of Iron Gate dam.

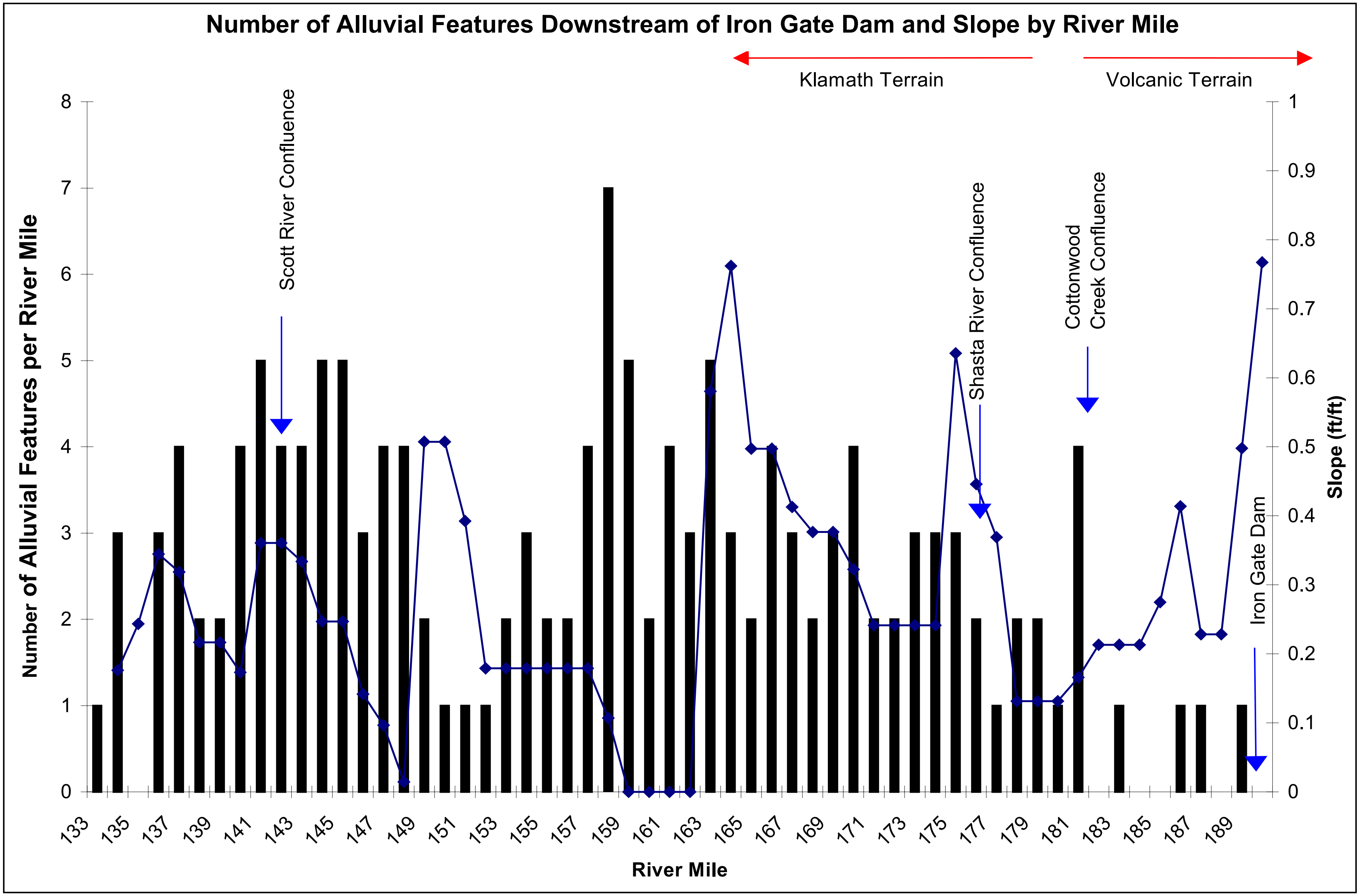

Figure 6.7-65. Number of alluvial features downstream of Iron Gate dam.

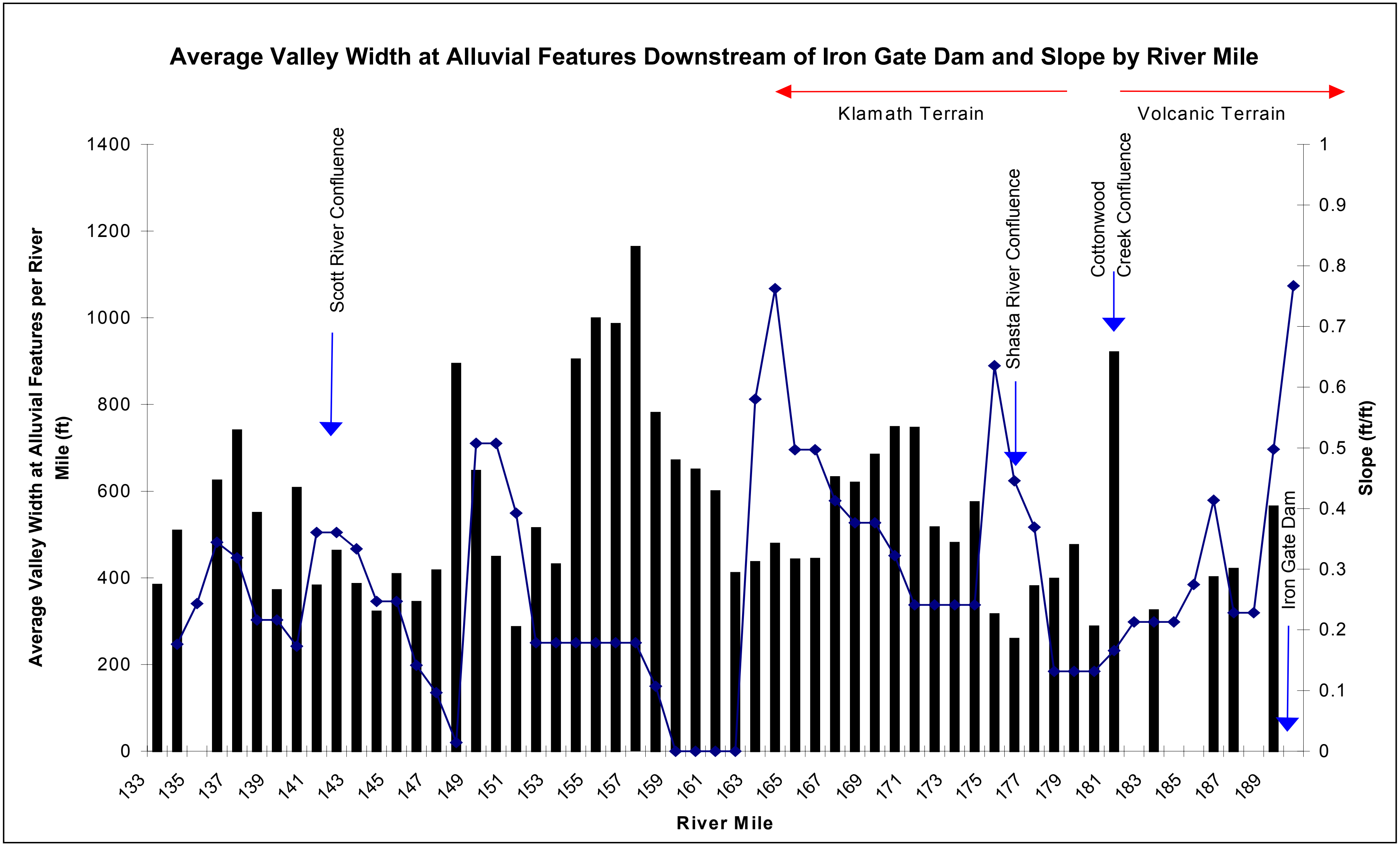

Figure 6.7-66. Valley width downstream of Iron Gate dam.

6.7.16.2 Watershed Area Quantification

Subwatershed areas within the Klamath River basin were calculated, and the cumulative watershed area was plotted (Figure 6.7-67). The watershed area between Link River dam and Iron Gate dam is approximately 820 square miles (shown as the red horizontal line in Figure 6.7-67); the total watershed area below Iron Gate dam is 7,630 square miles (shown as the blue cumulative curve in Figure 6.7-67). Before the construction of Link River dam, Upper Klamath Lake was regulated by a bedrock reef; as a result, the watershed affected by the Project was assumed to be the watershed area upstream of Iron Gate dam to Link River dam. Therefore, the Project directly impacts a watershed area that is approximately 11 percent of the total watershed area downstream of Iron Gate dam. In comparison, the Shasta River has a watershed area similar to the watershed area affected by the Project. Assuming that flow and sediment yield are related to watershed area, then the impact from the watershed area controlled by the Project is rapidly "drowned out" by downstream tributaries. Within 50 river miles downstream of Iron Gate dam, the cumulative watershed area is almost triple the watershed area directly controlled by the Project.

To quickly estimate the impact of the Project on sediment yield, sediment yields from the Salmon River (de la Fuente and Hessig, 1993) were applied to tributaries downstream of Cottonwood Creek that have similar geology. Sediment yields from this study's tributary surveys were applied to tributaries upstream of Cottonwood Creek to Keno dam to develop the cumulative sediment yield downstream of Iron Gate dam (Figure 6.7-68). Because the sediment yields are higher from the more erosive Klamath Terrain compared to the Volcanic Terrain found in the Klamath watershed above Cottonwood Creek, the Project impacts on the cumulative sediment yield are relatively small.

Because sediment historically was trapped by Upper Klamath Lake and Lake Ewauna, sediment impacts from the Project from Keno dam to the confluence with the Shasta River may be significant and have most likely resulted in local areas of bed coarsening. However, the tributaries downstream of Iron Gate dam quickly provide sediment inputs to the channel that overwhelm the Project impacts from bed load sediment trapped in Project reservoirs. Although the error associated with this limited analysis is significant, the magnitude of the difference between sediment yield affected by the Project (shown as the red horizontal line in Figure 6.7.68) compared to the cumulative sediment yield downstream of Iron Gate dam (shown as the blue cumulative curve in Figure 6.7-68) is instructive for gauging the downstream extent of the Project impact on sediment supply. From this analysis, it appears that Project impacts on river corridor geomorphology downstream of Iron Gate dam are probably no longer significant near the confluence with the Shasta River and almost certainly are no longer significant near the confluence with the Scott River.

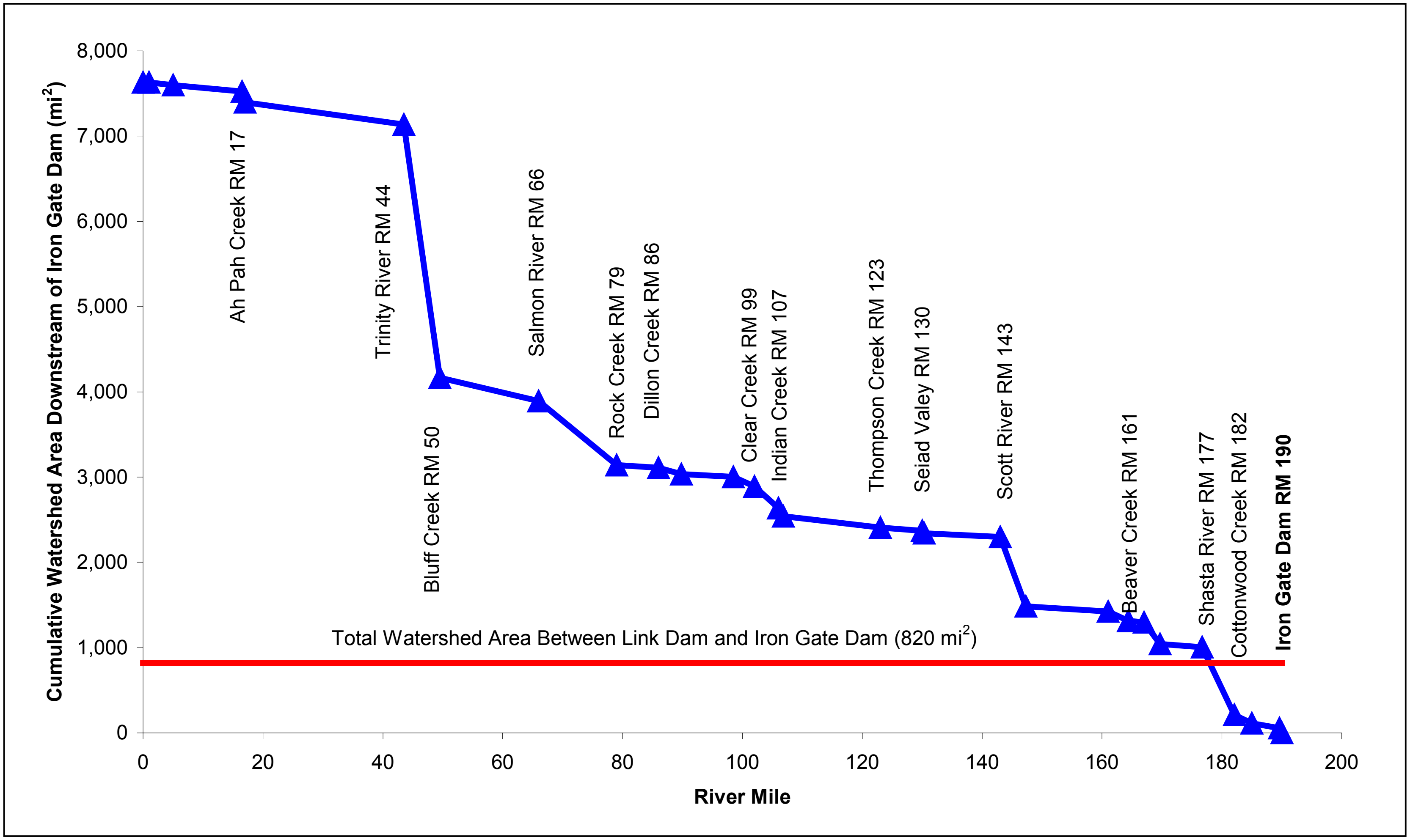

Figure 6.7-67. Comparison of Project-impacted watershed area (geomorphology) and watershed area downstream of Iron Gate dam.

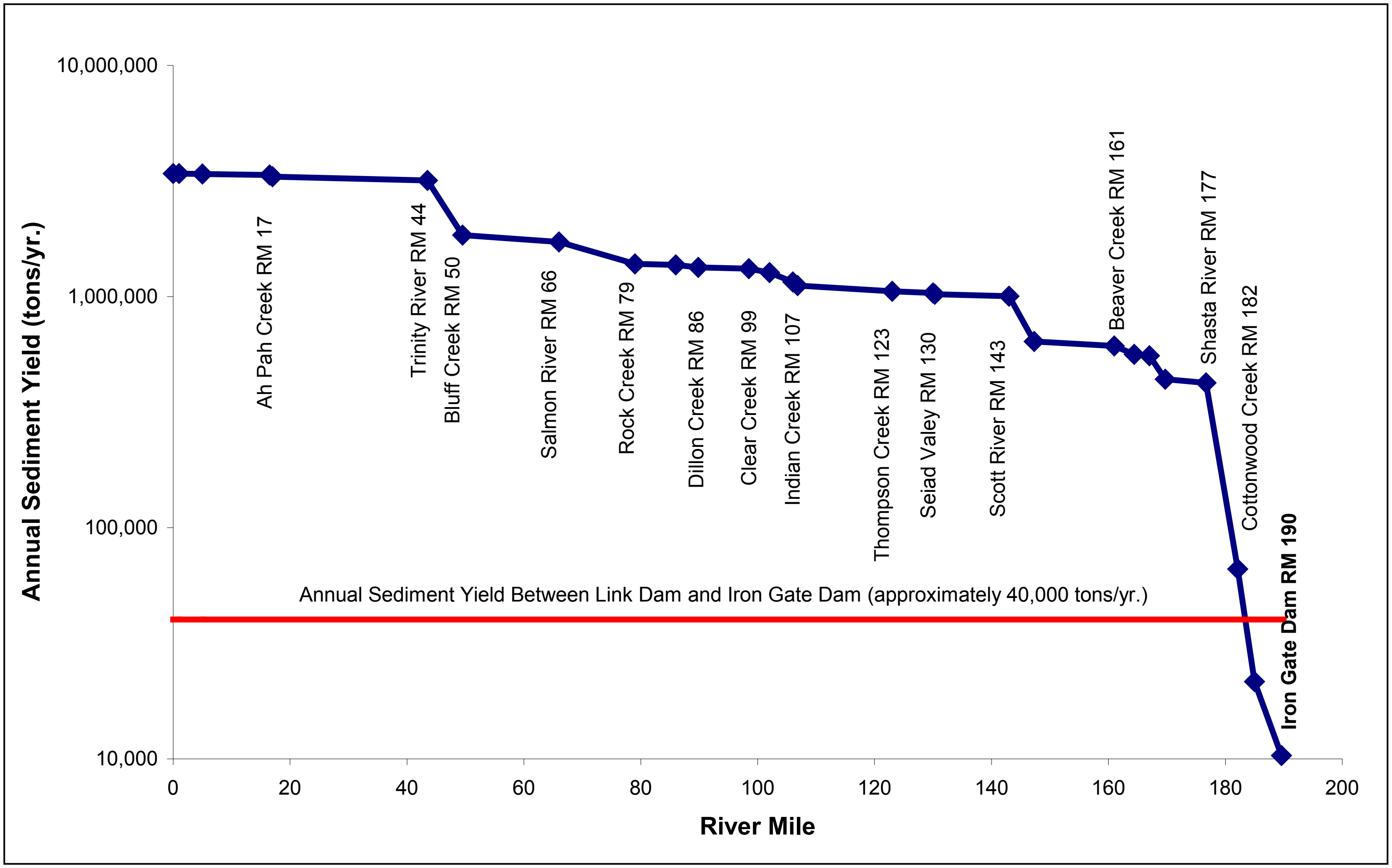

Figure 6.7-68. Comparison of Project-Impacted Sediment Yield and Sediment Yield Downstream of Iron Gate dam.

The ability of a river to transport sediment is dependent on discharge, as well as slope, channel geometry, and bed material. The average annual discharge and average annual peak discharge from the Iron Gate dam gauge was compared with downstream USGS gauges to approximate the extent of the Project impact downstream of Iron Gate dam (Figures 6.7-69 and 6.7-70). The average annual discharge and average annual peak discharge at the Seiad Valley gauge is approximately double the discharge at the Iron Gate dam gauge. Tributaries to the Klamath River contribute significant flows downstream of Iron Gate dam and reduce the extent of downstream impacts from the Project. This assessment does not show the extent of potential Project impact downstream of Iron Gate dam as clearly as the analyses discussed above.

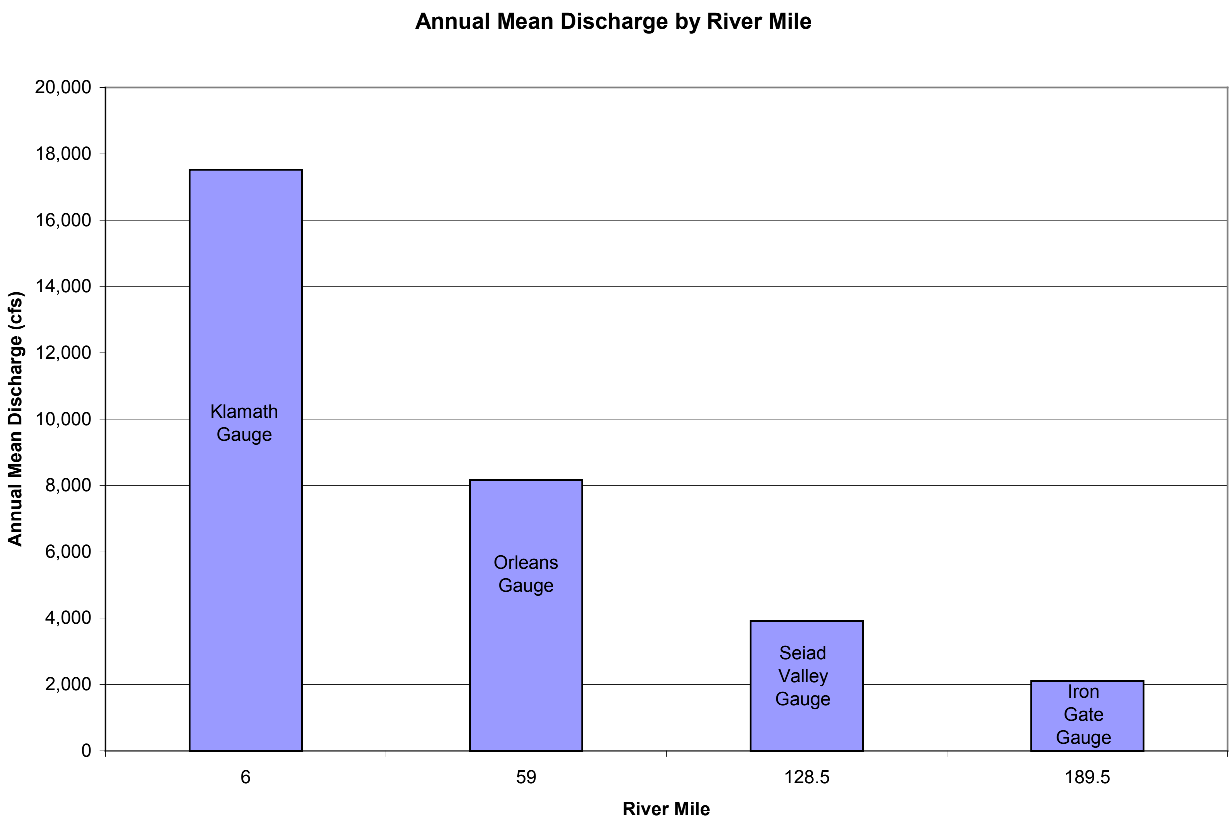

Figure 6.7-69. Average annual discharge at USGS gauges downstream of Iron Gate dam.

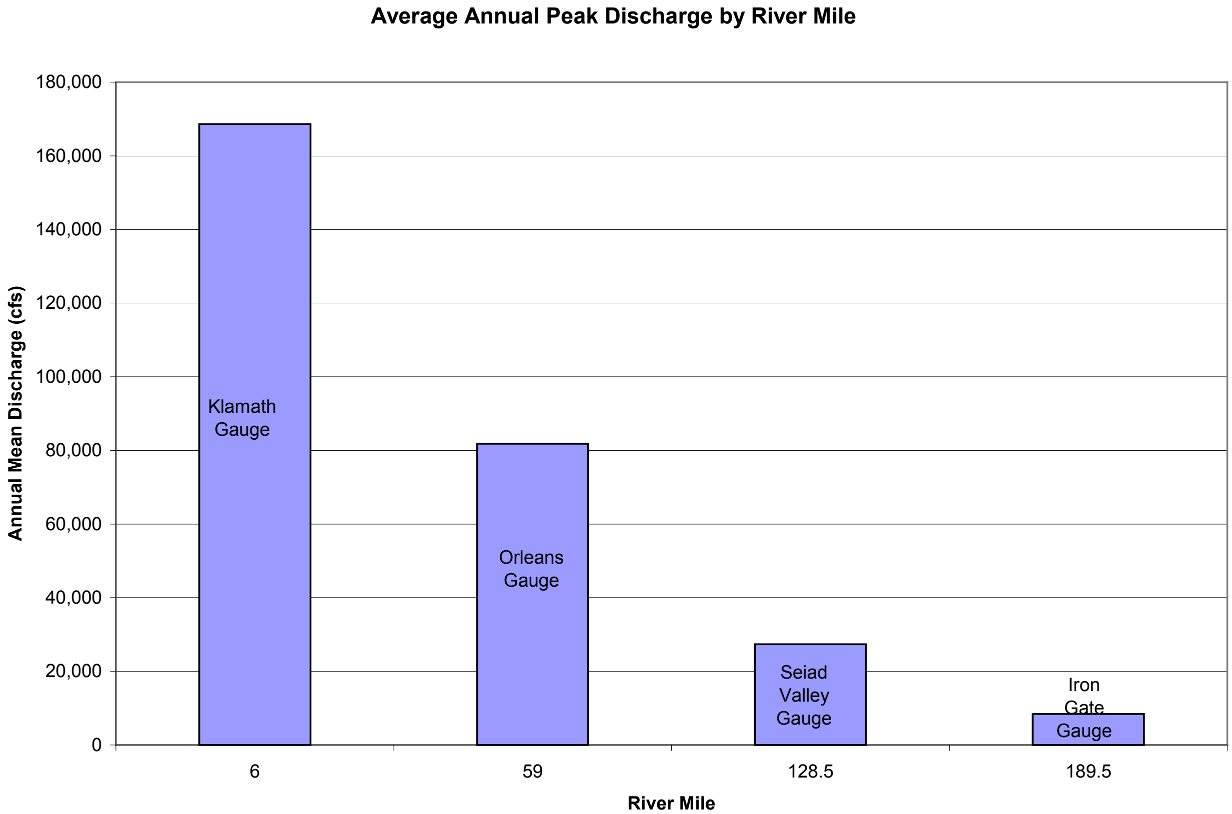

Figure 6.7-70. Average annual peak discharge at USGS gauges downstream of Iron Gate dam.

6.7.17 Geomorphology Assessment of Project Impacts on Cultural Resources Sites Results

This section summarizes the results of the investigations described in section 6.4.17. The results are organized by the day of the site visits (and therefore by the region covered each day). A brief site visit summary and a discussion of potential Project impacts on geomorphology as they relate to concerns regarding cultural sites is presented for each site visited. The major issues raised during the site visits are summarized and discussed at the end of this section.

6.7.17.1 October 20, 2003, Site Visit

Site Visit Summary – Lake Ewauna Reach near Washburn Road

The site visit group made observations and discussed geomorphic processes on river left just upstream of the Washburn Road bridge. Discussions with tribal representatives at this site indicated that the major concern in this area was exposure of sensitive cultural sites during drawdown of the Keno reservoir (these sites are inundated during normal project operations). Before the Project was completed, this area was likely a patchwork of marsh and upland. Keno dam inundated this area and eliminated a significant portion of the emergent vegetation. Therefore, when drawdowns occur, flow over unvegetated fine sediments can disturb and expose fine sediment and therefore expose sensitive cultural resources sites.

Cultural Resource Site Implications of Project Impacts on Geomorphology

Since this reach of the Klamath River had a very low gradient before the Project due to the flatness of the valley and the hydraulic control by the bedrock reef at Keno, sediment transport dynamics were not changed significantly with the completion of Keno dam. However, riparian vegetation characteristics may have significantly changed due to the inundation associated with Keno dam. Therefore, direct project impacts on geomorphology and sediment transport are not a major factor in the degradation of cultural resources sites in this reach, although project impacts on riparian vegetation, coupled with reservoir drawdowns for maintenance, appeared to be the major concern with respect to cultural resources sites.

Site Visit Summary – J.C. Boyle Reservoir at Spencer Creek Confluence

The site visit group examined the Spencer Creek delta area and the reservoir margin downstream of Spencer Creek on river right. Discussions with tribal representatives at this site indicated that the Klamath River channel was narrower before the dam inundated this area. Therefore, without the Project, sites immediately adjacent to the river bank would have been vegetated and less exposed to disturbance. Similar to the Lake Ewauna site, cultural resources sites are exposed during drawdowns of J.C. Boyle reservoir.

Cultural Resource Site Implications of Project Impacts on Geomorphology

This was a low gradient reach of river pre-Project (due to hydraulic control by the reef at the site of J.C. Boyle dam), but with conversion to a reservoir, the inundated channel has become wider, altering riparian vegetation and making more efficient the sediment trapping in this reach. All bed load and some fraction of the suspended sediment load from upstream are now stored in the reservoir. Cultural resources sites immediately adjacent to the historical channel are now inundated, unvegetated, and covered by sediment (of varying thickness). The combination of these two impacts has led to the exposure of cultural resources sites during reservoir drawdown.

Site Visit Summary – J .C. Boyle Peaking Reach near “Midden” Site and near Frain Ranch

The site visit group examined and discussed an archaeological site that was partially eroded during the 1997 flood (11,400 cfs at this location). The flow in the Klamath River at this site was approximately 1,350 cfs at the time of the site visit. This is almost half of the Project capacity to control flow in this reach (3,000 cfs with two turbines operating). The lower extent of the erosion at the site was approximately 3.5 feet above the water surface elevation. Recent high water marks indicated that even at the full Project capacity (3,000 cfs), the lower limit of the eroded site would have been approximately 2.5 feet above the water surface. It appeared that this site could have been in a back eddy during the 1997 flood and that erosion may have been exacerbated by complex, recirculating currents. The group also examined sites near the Frain Ranch area that were primarily impacted by off-road vehicle use.

Cultural Resource Site Implications of Project Impacts on Geomorphology

While there have been changes in the sediment transport dynamics in this reach (see Sections 6.7.13 through 6.7.15 for a discussion of these changes) due to Project impacts, erosion of this cultural site (and other sites similarly situated along the Klamath River) was not likely the direct result of Project impacts on geomorphology or sediment transport. This erosion occurred during a flow that was well beyond the control of Project facilities and would probably have occurred even without the Project. Given the coarse nature of the sediment immediately adjacent to the active channel at this site (boulders and coarse cobble), it is also unlikely that erosion was exaggerated by bank saturation and discharge associated with peaking operations. A tall, steep bank on river left in the vicinity of these two sites did exhibit some undercutting and erosion, perhaps accelerated by Project impacts on geomorphology and sediment transport (i.e., peaking operations). However, cultural resources consultants and tribal representatives indicated that no sites were present on this feature. Sites very close to the active channel could be affected by Project impacts on geomorphology and sediment transport, but additional study would be required to determine if such fine-scale impacts exist.

6.7.17.2 October 21, 2003, Site Visit

Site Visit Summary Downstream of Iron Gate Dam at "Osburger" Site

The site visit group explored and discussed conditions around the "Osburger" site, where two historical houses have been relocated from the town of Klamathon. The houses currently sit on a terrace approximately 30 feet above the water surface. The channel banks in this area were sandy, with a zone of angular large cobble and small boulders protruding through the fine sediments approximately 1.8 feet above the active channel water surface elevation. Evidence of erosion (and associated bank protection) was observed at the base of a steep slope below the houses and approximately 38 feet away from and 9.8 feet above the active channel edge and water surface elevation, respectively. The erosion at this site also occurred during the 1997 flood (20,500 cfs at this location). The flow at the time of the site visit was 1,350 cfs, which did not appear to be actively eroding banks or mobilizing the bed.

A scour hole was observed immediately upstream of a large boulder on a small terrace adjacent to the active channel in this area. The scour hole appeared to be from flow significantly greater than 1,800 cfs. Extensive cow hoof disturbance was observed along the terrace with the large boulder. The group discussed the fact that there is no peaking in this reach. The group also discussed ramping rates downstream of Iron Gate dam. When flow in this reach is greater than 1,750 cfs, the ramping rate must be less than 350 cfs per day. When flow is less than 1,750 cfs, the ramping rate must be less than 250 cfs per day.

Cultural Resource Site Implications of Project Impacts on Geomorphology:

While there has likely been some coarsening of bed sediments immediately downstream of Iron Gate dam, it does not seem likely that Project impacts on geomorphology and sediment transport were responsible for the erosion at these sites. Similar to the sites in the J.C. Boyle peaking reach, the erosion at this site seems to have occurred in an area that could be a back eddy during high flow. In addition, the flow during the event that caused the erosion (20,500 cfs) was well above the range of Project control (1,800 cfs maximum controlled release). It seems that the influence of natural local controls during high magnitude floods are primarily responsible for the erosion that has threatened cultural resources in this area.

Site Visit Summary – USGS Gauge Downstream of Iron Gate Fish Hatchery

This site visit was conducted to illustrate relationships between different return-period flows and geomorphic features. The group discussed return intervals, flows required to mobilize the active channel bed and generate significant erosion, and gauge data available for the Klamath River and other river systems.

Cultural Resource Site Implications of Project Impacts on Geomorphology

No cultural resources sites were assessed in this area.

Site Visit Summary – Shasta River Confluence

The site visit group observed the Shasta River confluence (on river left) from Highway 96 across the river. The primary active channel of the Shasta River enters the Klamath River at the downstream end of its delta deposit. A representative of the Yurok Tribe suggested that the primary channels of the Shasta River and other tributaries (e.g., Omagar River, Bear Creek, Pine Creek) have recently shifted downstream from the centers of the deltas. He also noted that Pine Creek was no longer directly connected to the mainstem Klamath because the bed of Pine Creek had aggraded and its base flow now infiltrates before reaching the Klamath River. This condition could be a significant barrier to fish passage.

Cultural Resource Site Implications of Project Impacts on Geomorphology

The geomorphology study did not attempt to detect historical changes in the active channel paths through confluence delta deposits. Detailed aerial photographs and field studies would be required to determine if some systematic change has occurred and to assess whether such a change was linked to Project impacts.

The Project reservoirs impound less than 10 percent of the mean annual runoff, so they have had little effect on high flows, and large floods still occur downstream of Iron Gate dam. Thus, aggradation at tributary confluences is not likely due to the Project, but more likely attributable to variations in sediment delivery from tributaries to the mainstem. While Project reservoirs trap sediment and thereby reduce sediment supply to downstream reaches, the amount of sediment naturally supplied from upstream reaches was small relative to sediment supply from tributaries downstream of Cottonwood Creek, which drain more erodible lithologies with more variable flow regimes. Based largely on these observations (and the geomorphology and sediment transport studies that confirmed them), neither tributary aggradation nor mainstem degradation downstream of Iron Gate Dam was identified as Project impacts on geomorphology and sediment transport.

Site Visit Summary – Ash Creek Confluence

The site visit group briefly observed and discussed the characteristics of the mainstem Klamath and riparian areas near the confluence with Ash Creek from an old bridge over the Klamath River off Highway 96. Ash Creek enters the Klamath River through a culvert under Highway 96 just upstream of the old bridge across the Klamath. A large embayment in the left bank was observed, and the group concurred it was most likely a relic from past gold mining, consistent with extensive tailings piles on the left bank.

Cultural Resource Site Implications of Project Impacts on Geomorphology

Observations at this site suggest that past mining impacts have had a significant impact on channel geomorphology and sediment transport and potentially on cultural resources sites. Project impacts on geomorphology and sediment transport did not appear to have major impacts at this site and were not discussed by the group.

6.7.17.3 October 22, 2003, Site Visit

Site Visit Summary – Ukonom Creek and Rock Creek Confluences

The site visit group briefly observed the Ukonom Creek confluence on river left from Highway 96 on river right. A large landslide just upstream of the confluence (in the Ukonom drainage) was observed and provided an example of a large episodic delivery of sediment from a tributary. Tribal representatives suggested that several long, deep pools downstream of this confluence have been filled by fine sediment and no longer provide cold-water habitat for migrating salmon.

The group also observed the Rock Creek confluence with the Klamath River on river right from Highway 96 on river left. Here again, it was indicated that flow through the delta formation at the confluence may have shifted recently to the downstream end of the delta. The gradient of Rock Creek appeared relatively flat near the confluence, and visible reaches were heavily forested and meandering.

Cultural Resource Site Implications of Project Impacts on Geomorphology

Project facilities have led to some sediment starvation, especially in reaches immediately downstream of Iron Gate dam. Project operations (i.e., elevated summer base flows) may have also increased fine sediment transport. Further, large winter and spring floods still occur, so it unclear why deep pools in the Klamath River in this area might be filling with fine sediment differently than before the Project. The geomorphology study results indicate that direct Project impacts are overwhelmed by tributary flows and sediment loads with distance downstream of Iron Gate dam. A more likely explanation for accumulation of fine sediments in pools in this reach (approximately 100 miles downstream of Iron Gate dam) might be sources of fine sediment in tributary watersheds, such as timber harvest and road construction. Impacts from past in-channel and tributary mining activities downstream of the Shasta River confluence may also be persistent.

Site Visit Summary – Ishi Pishi Falls

The site visit group listened to a Karuk tribal leader describe "Kutty Mene," the Karuk land around Ishi Pishi Falls. This area is the site of the Karuk World Renewal ceremony and was the largest Karuk settlement on the Klamath River. Oral histories of Karuk Tribe members suggest that floods much larger than the 1964 flood have occurred on the Klamath River in recent centuries. Despite this perceived reduction in recent flood flows, tribal representatives noted increases in the recent rate of erosion that they felt were correlated with the construction and operation of Project facilities. Specifically, a ceremonial pond in this area nearly failed and drained during the 1997 flood. Also, the erosion rate observed by tribal representatives at the "Deer Skin Dance" site has apparently increased over the past 25 to 50 years. A steep erosion face near "Little Ike's" village site on the opposite bank (river right) has also been observed by tribal representatives to be eroding at a faster rate in recent generations. The tribal leader also indicated that over a similar time frame fine sediment has filled pools throughout the area because there are no longer spring freshet flows. In addition, tribal representatives noted that fresh willow growth on gravel bars (the growth that produces the best basket materials) have become less common in this region recently. A Karuk Tribe consultant noted that the observational science of the tribes has been overlooked in assessing Project impacts.

Cultural Resource Site Implications of Project Impacts on Geomorphology

The geomorphology study results indicate that direct Project impacts are overwhelmed by tributary flows and sediment loads with distance downstream of Iron Gate dam. At this site, approximately 110 miles downstream of Iron Gate dam, the potential reduction in sediment supply due to Iron Gate dam would be only 2 percent for bed load, and therefore insignificant compared to downstream sources. Moreover, degradation of cultural sites occurred during large floods (e.g., 1997), whose magnitude would be unaffected by Project operations, and during which a wide range of other processes (natural and human-induced) occur (e.g., the massive landslide on the mountain downstream of Ishi Pishi Falls on river left). Project impacts on geomorphology are unlikely to have caused increases in erosion rates.

Site Visit Summary – Fish Camp

The site visit group explored and discussed near-channel and upland areas around the large, sandy terrace called Fish Camp on river left. The terrace was approximately 25 feet above the water surface elevation on the day of the site visit and was separated from the active channel by a line of boulders. The group observed a debris line from the 1997 flood that was at least 40 feet above the current active channel water surface elevation. A slump observed just above the debris line could have been caused by fluvial or hillslope erosion during the 1997 flood.

Cultural Resource Site Implications of Project Impacts on Geomorphology

Again, since the cultural resources site degradation was associated with flows well beyond the control of the Project, it is unlikely that direct Project impacts on geomorphology or sediment transport could be linked to the observed erosion.

6.7.17.4 Major Issues of Concern

Tribal representatives expressed concern that Project impacts on geomorphology have exacerbated degradation of cultural sites both upstream and downstream of Iron Gate dam. However, the erosion at the cultural sites visited during this effort was associated with flow events well beyond the range of control of Project facilities. While there has definitely been a change in sediment transport dynamics associated with the Project in some reaches of the Klamath River, it is unlikely that the changes observed downstream of Shasta River were caused by Project impacts. Other observed changes, such as tributary delta channel changes, are more likely attributable to changes in tributary flows or sediment loads. To assess potential dam impacts in relation to potential changes in tributary processes would require substantial, long term study to determine if systematic change has occurred, and if so, to assess probable causes of the changes.

6.7.18 Summary and Conclusions

This section summarizes the study methods and results that were developed and implemented to assess Project impacts on fluvial geomorphology and sediment transport in the Klamath River. Because of the dynamic nature of both study plan development and study implementation, there are elements of this section that can be difficult to interpret, especially to those not closely involved in efforts associated with this study from 2001 to 2004. This section briefly summarizes the results of each section and attempts to distill the most pertinent findings to the final assessment of Project impacts and the proposed mitigation and enhancement measures (see Exhibit E of the License Application).

The results presented in sections 6.7.1 to 6.7.8 document the existing conditions of the Klamath River in terms of fluvial geomorphology and sediment transport. These sections also attempt to link the observed existing conditions to the geomorphic setting of the Klamath River basin. Section 6.7.1 discusses the geology and underlying geomorphic processes that have shaped the Klamath basin and identifies some of the major natural and anthropogenic changes that have occurred in the basin over the past two centuries. As discussed throughout section 6.7, the presence of strong local geologic controls on the Klamath River in the Project area greatly complicates positive identification and accurate quantification of fine-scale changes caused by direct Project impacts. This is complicated further by the hydrologic manipulations of the Klamath Irrigation Project that are not direct Project impacts, but are nonetheless interconnected with Project facilities.

Section 6.7.2 quantifies sediment accumulation in Project reservoirs. While these results help quantify potential reductions in sediment supply to river reaches downstream of Project dams, the surveys were generally too coarse to adequately quantify trapping of bed load sediments (specifically gravel suitable for salmonid spawning). Section 6.7.3 summarizes the initial delineation of geomorphic reaches, which correspond almost directly to the reaches separated by Project dams. Section 6.7.4 reviews prior studies of the Klamath River and identifies important findings and limitations from these studies. These findings and limitations strengthened the conceptual foundation of this study and assisted in the interpretation of the analyses conducted in this study.

Section 6.7.5 documents the results of a comprehensive review of aerial photography of the Klamath River in the Project area from 1944 to 2000. This review showed no significant systemwide change to the planform, bedforms, or channel geometry of the Klamath River. However, local changes were observed and included elimination of riparian vegetation and minor channel constriction in the J.C. Boyle bypass reach (associated with canal construction), development of an island in the J.C. Boyle bypass reach (associated with erosion at the emergency overflow spillway), and significant channel planform change downstream of Iron Gate dam (associated with past mining activities). Local changes to bedforms and channel geometry were also observed in alluvial reaches (e.g., J.C. Boyle peaking reach near Shovel Creek) but did not appear to be impacts of Project facilities or operations. Section 6.7.6 refines the initial delineation of geomorphic reaches into the final set of geomorphic reaches (Link River, Keno, J.C. Boyle bypass, J.C. Boyle peaking USGS Gauge to Frain Ranch, J.C. Boyle peaking Gorge, J.C. Boyle peaking Shovel Creek, Copco No. 2 bypass, Iron Gate dam to Cottonwood Creek, Cottonwood Creek to Scott River, and Scott River to Seiad Valley) that served as the framework for the assessment of Project impacts. These reaches were identified based on data presented in section 6.7.7.

Section 6.7.7 catalogs geomorphic facies, channel geometry, long profile slope, bed material composition, and floodplain and riparian vegetation characteristics of the study sites distributed throughout the geomorphic reaches. When thoroughly reviewed, these results (presented in Section 6.7.7 and Appendix 6A) demonstrate the importance of strong geologic controls in the Klamath River and highlight the difficulty in accurately quantifying Project impacts on the without-Project geomorphology and sediment transport. Pebble count results indicate potential bed coarsening immediately downstream of Project dams and in the J.C.Boyle peaking and bypass reaches, but this impact is obscured by strong local controls that prevent the Klamath River from exhibiting a clear trend of downstream bed-sediment fining observed in most rivers. The assessment of large woody debris indicates that large wood plays a minor role in large-scale channel change but may play an important role as local aquatic and riparian habitat in some reaches. Section 6.7.8 further parses these results and classifies project reaches as bedrock, plane bed, cascade, and pool-riffle under the Montgomery and Buffington system, and as F, B, and C type channels under the Rosgen system.

In general, the results in sections 6.7.1 through 6.7.8 describe a complex system that is strongly controlled in the Project area by local geology. While local impacts of the Project have occurred, the kinds of systemwide impacts on large-scale geomorphic characteristics that have been documented in other rivers downstream of dams (e.g., Williams and Wolman, 1984) are not evident on the Klamath River. This is probably attributable to the nonalluvial (and sediment-supply-limited) nature of most of the river, which would tend to limit channel responses to Project-induced changes, and the difficulties in documenting changes that may have occurred due to the lack of detailed pre-Project data and the high local variability resulting from strong local geologic controls.

The results presented in sections 6.7.9 to 6.7.17 document the assessment of potential Project impacts on Klamath River geomorphology and sediment transport. The results presented in these sections identify the most reliable estimates of direct Project impacts. Unfortunately, the bed load and suspended load sampling program was limited by low flows during the study period. The sampling did indicate that small quantities (approximately 1 ton per day at 3,000 cfs) of sand are mobilized by flows within the range of control of the Project. Therefore, increased sand transport during peaking operations could be considered a direct Project impact. However, since gravel was not mobilized at 3,000 cfs, and sand starvation did not appear to be a major impact on geomorphology in the Project area, this result was not considered a major Project impact.

The results in section 6.7.10 confirmed that the primary sediment sources to the mainstem Klamath were from tributaries. Less than 2 percent of the total sediment inputs came from landslides directly into the channel. Important sources of fine sediment from the erosion associated with the emergency overflow spillway in the J.C. Boyle reach were quantified in this reach and included in the sediment budget for the Project area. Section 6.7.11 summarizes the results of the tributary delta survey that provided the basis for extrapolation of sediment inputs from all tributaries to the Klamath River in the Project area. The deltaic formations of several tributaries that flow directly into Iron Gate reservoir and one that flows directly into J.C. Boyle reservoir were surveyed and compared with pre-reservoir topography to estimate the volume (and mass) of bed material (includes bed load and some suspended load) delivered since the completion of the dam. This was then used to calculate an average annual sediment yield per unit area that was applied with adjustment factors to all other tributaries in the Project area. Total sediment yields estimated for each reach ranged from hundreds of tons per year in the Link River reach to tens of thousands of tons per year in the J.C. Boyle reach. Sediment yields were significantly higher downstream of Iron Gate dam.

The results of the tracer study described in section 6.7.12 suggest that the bed could be approaching the threshold of mobility at 1,500 cfs (the peak flow since the tracers were placed) in the J.C. Boyle bypass reach (RM 222), at 3,850 cfs (the peak hourly flow in 2003) near the USGS gauge (RM 219), and at 3,850 cfs near the Shovel Creek confluence (RM 206). No tracer movement was observed in 2002 when the peak hourly flow reached 3,000 cfs. The results of the tracer studies were used to calibrate the bed load transport calculations discussed below. The results of the frequency of mobility analysis presented in section 6.7.13 were based on (1) a with-Project condition with recorded hydrology and active elements of the bed characterized by their current median particle diameters, and (2) a without-Project condition with hydrology adjusted to remove reservoir storage and active elements of the bed characterized by median particle diameters characteristic of tributary sediments. The with-Project condition was mobile less frequently in all reaches downstream of J.C. Boyle dam in this analysis.

Bed load transport capacities were presented in section 6.7.14. For conditions similar to those considered in the frequency of mobility analysis, bed load transport capacities were consistently lower for the with-Project conditions. Average annual bed load transport capacities were developed for the sediment budget (using with-Project hydrology and without-Project active feature median particle sizes) and were in the hundreds of thousands of tons per year upstream of Iron Gate dam. However, transport capacities ranged from zero in dry years to millions of tons per year in wet years. Calculated bed load transport capacities were significantly lower downstream of Iron Gate dam, probably because of dimensionless critical shear stress values derived from tracer gravel observations upstream. It is likely that actual bed load transport capacities downstream of Iron Gate dam are much higher than the values presented. The important result presented in this section is that transport capacity upstream of Iron Gate dam is, on average, one to two orders of magnitude greater than the sediment yield from tributaries. This result supports the qualitative assessment of the Klamath as a historically sediment starved system.

The results in section 6.7.15 capture the primary Project impact on geomorphology and sediment transport. Specifically, the quantities of bed load material delivered from tributaries and captured in Project reservoirs. The sediment budget gives an average annual quantity of sediment that would be transported to downstream reaches (except in the Link River reach) without the Project. Mitigation measures have been developed for this impact and are presented in Exhibit E of the License Application. From a geomorphic perspective, the elimination of the upstream sediment supplies in this sediment-starved system is the primary project impact on Klamath river geomorphology and sediment transport.

Section 6.7.16 summarizes two assessments designed to identify the downstream extent of potential Project impacts on river geomorphology and sediment transport. A quantification of alluvial features and a comparison of flow and sediment inputs to flow changes and sediment capture upstream of Iron Gate dam both suggested that Project impacts are probably over-whelmed by anthropogenic impacts separate from the Project and natural processes near the Shasta River, and almost certainly by the Scott River. Finally, the results of a brief assessment of geomorphic impacts on cultural resources sites in section 6.7.17 indicate that most of the observed impacts have occurred during major flood events and therefore are not likely a direct result of Project impacts on fluvial geomorphology or sediment transport.