4. Existing Hydraulic Conditions

A one-dimensional hydraulic model was developed in HEC-RAS 4.1 to simulate the hydraulic conditions of the Klamath River from upstream of J.C. Boyle (RM 230) to downstream of Indian Creek near Happy Camp (RM 105). The model is used to calculate the hydraulic condition before and after dam removal and the areas inundated by flood flows before and after dam removal. The model also serves as the basis for the sediment transport model used to calculate sediment transport under the No Action and Dam Removal Alternatives (Section 9).

This section describes the data necessary to build the model and a description of the current hydraulic conditions downstream of Iron Gate.

4.1. Development of Hydraulic Model

Woolpert, Inc obtained airborne LiDAR in February and March of 2010 for the Klamath River from Link Dam to approximately Happy Camp, CA. The LiDAR data was presented as full LAS data as well as a 3ft grid derived from the LAS. For the purposes of this study, the 3ft grid elevation data was used. LiDAR does not penetrate water, so the data representing the water surface was clipped so that the bathymetric data could be combined with the portion of the data representing the above-water land surface. This 3-ft grid, excluding the water surface data, was converted to points so that it could be used in developing the elevation model.

The 2001 bathymetric survey of the upstream reservoirs was used for generation of the cross sections in the reservoir pool (JC Headwaters, Inc., 2003). A 2009 bathymetry survey of the Klamath River from Iron Gate Dam to Happy Camp, CA was used for generation of the downstream cross sections. The downstream bathymetry survey was conducted in October, 2009 by Reclamation, with support from the USGS. The survey was conducted from two boats, each using a multi-beam ADCP interfaced with GPS. Data gaps exist in this dataset due to gaps in GPS coverage and/or data collection issues for the ADCP (aeration, shallow depth, etc.). One significant gap occurred within the 10 miles downstream of Iron Gate Dam. Woolpert was contracted to conduct a series of bathymetric cross sections to mitigate for a 3-mile gap in the reach from I-5 (near Hornbrook, CA) to the Shasta River confluence. In addition, a bathymetric survey was conducted by USGS for Happy Camp, CA, that included the Klamath River, Indian Creek, and the local confluence. This data was collected on April 21 – 22, 2009 and is part of an ongoing USGS water temperature study (pers. comm. Paul J. Kinzel).

A Geographic Information System (GIS) Triangulated Irregular Network (TIN) terrain model was used to create the surface elevation model. During triangulation of a TIN or terrain, a common misrepresentation of geometry can occur when relatively high land surface elevations on opposite sides of the river are “connected,” essentially crafting a dam across the channel geometry. To avoid

this, bank toes were developed by shifting the previously digitized bank lines toward the channel centerline by 15 feet. Elevation data from the three bathymetric data sources (Reclamation, USGS, Woolpert) were stationed along these channel centerline and two bank toe lines to represent locations of known bed topography. From this, a series of interpolated channel points were developed to represent the below-water bank toes and the channel center, placed at 3-foot intervals to match the frequency of the terrestrial elevation data. Elevations were assigned to these interpolation points as a linear function between points of known bed elevation.

4.1.1. HYDRAULIC MODEL UPSTREAM OF IRON GATE DAM

This section discusses the data and information used for the cross section setup of the 1D HEC-RAS model and the Sedimentation and River Hydraulics – One Dimensional model (SRH-1D) (Huang and Greimann, 2010) for analysis upstream of Iron Gate Dam.

The 2001 bathymetric survey of the reservoirs was used for generation of the cross sections in the reservoir pool (JC Headwaters, Inc., 2003). The 2010 LiDAR data was used for the generation of the cross sections between the reservoirs. An ArcGIS (ESRI, Inc) TIN terrain model was used to generate a three dimensional surface for each reservoir and the LiDAR. The LiDAR data were not manipulated to account for the flow in the channel at the time of the flight.

Banklines, a centerline, and 493 cross-sections were delineated in GIS for 45.9 river miles. Figure 4-1 shows a portion of the cross sections delineated in the reservoir. Figure 4-2 shows a portion of the cross section delineated in the river reaches. The GIS data was processed using HEC-GeoRAS, an interface that provides tools in ArcGIS to process geospatial data for import into HEC-RAS. Banklines were manually adjusted where necessary in HEC-RAS to ensure that the top of bank was captured.

The Mannings roughnesses were set to 0.04 for the main channel and 0.06 for the overbanks.

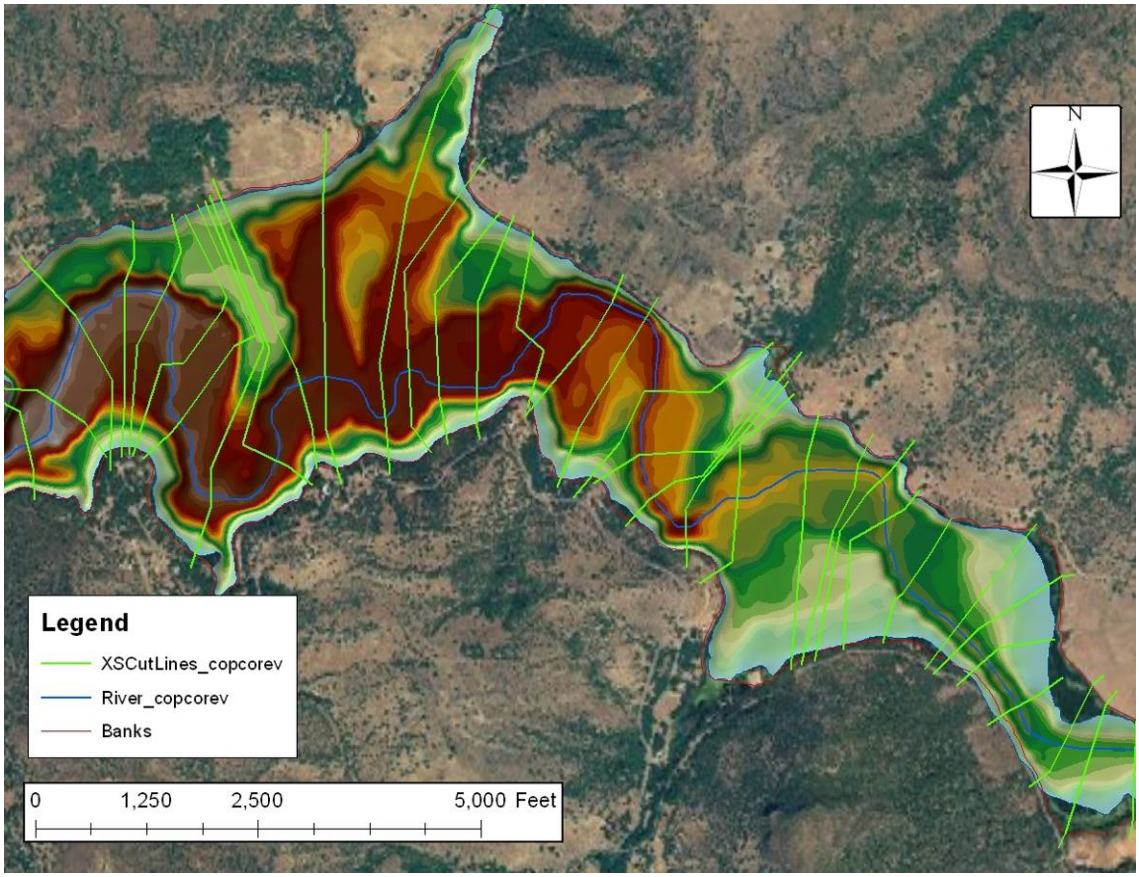

Figure 4-1. Cross sections in Copco Reservoir shown with bathymetric survey TIN and 2009 aerial photograph as background.

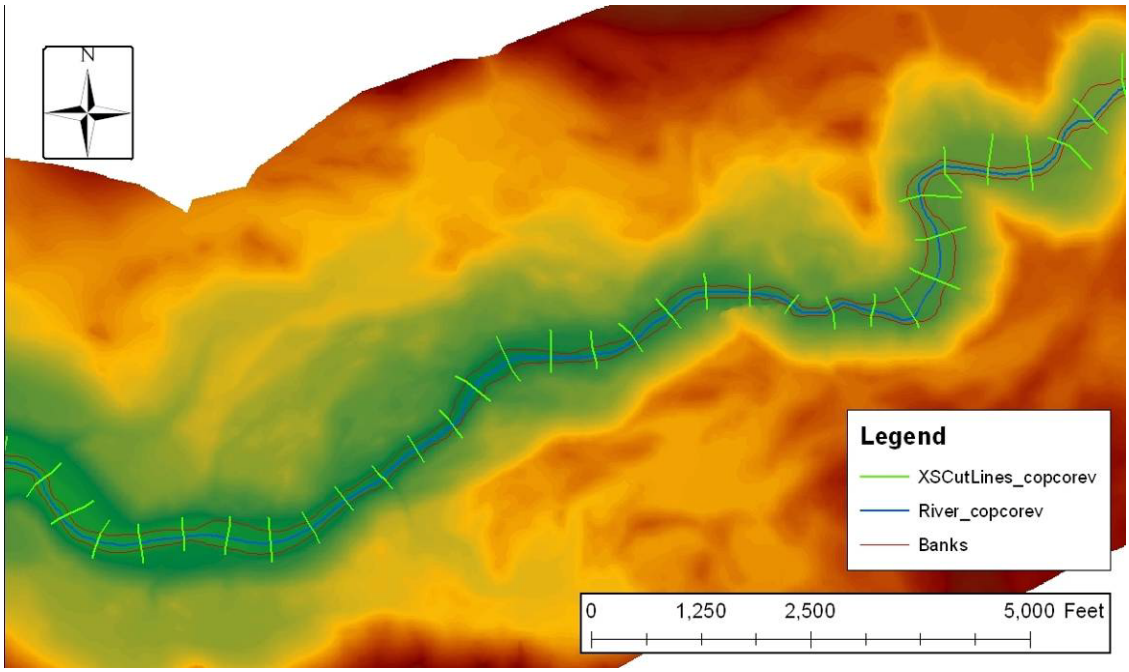

Figure 4-2. Cross sections in a river reach upstream of Copco Reservoir shown with LiDAR data TIN.

4.1.2. HYDRAULIC MODEL DOWNSTREAM OF IRON GATE

Bathymetric data was available from Iron Gate Dam to Happy Camp (RM 190 to 105) and this was merged with the 2010 LiDAR data. The wetting portion of the channel was eliminated from the LiDAR data and replace with the bathymetric data. A GIS TIN terrain model was then used to generate a three dimensional surface of the channel. Banklines, a centerline, and 692 cross sections, were delineated in GIS for 85 river miles. The terrain model was used to extract cross section elevations. The GIS data was processed using HEC-GeoRAS, an interface that provides tools in ArcGIS to process geospatial data for import into HEC-RAS. Banklines were manually adjusted where necessary in HEC-RAS to ensure that the top of bank was captured. The channel centerline and overbank flowpaths were digitized, and cross sections were automatically generated using HEC-GeoRAS at 1000 foot intervals along the digitized centerline. These cross sections were then modified in terms of spacing or extent to capture hydraulic controls and as well as to capture possible extent of inundation. In addition, cross sections were located more frequently in the reach from Iron Gate Dam to the Shasta River at approximately 500-ft spacing. This data was exported to HEC-RAS from HEC Geo-RAS where further model refinement could be conducted.

Ineffective flow areas and levees were added to cross sections where appropriate. A one-dimensional flow model such as HEC-RAS applies an averaged velocity to the entire wetted portion of a cross section. A reduced velocity can occur in a cross section if portions of a cross section are represented as providing conveyance where in reality little or no conveyance is provided by that portion of the cross section. In areas where no surface water connection will occur between two relatively low areas of a cross section until the intermediary high point is inundated (such as a much of the roadway in the valley) a levee was assigned. In areas where a cross section may get inundated from backwater, but where no surface connection exists from upstream (such as downstream of a bridge), an ineffective flow area was assigned.

Channel and overbank roughness was calibrated to two different datasets. Channel roughness was calibrated to longitudinal profile data, and the overbank roughness was calibrated to gage data.

Of the three bathymetric datasets (BOR, Woolpert, USGS), only the BOR dataset included water surface elevations along with the ground elevations. Daily flow data from the USGS gages (11516530, 11520500, 11517500, 11519500) corresponding to the data collection period (10/11/09 – 10/18/09) were run in the HEC-RAS model. A range of channel roughness values were applied to the geometry and the resulting water surface elevations were compared to the measured water surfaces from the survey. One value for channel roughness from Iron Gate Dam to Happy Camp was unable to match the surveyed water surfaces. A relationship between reach-average bed slope and roughness was developed

such that the modeled water surface elevations matched the surveyed water surface elevations to an acceptable level. Figure 4-3 presents the reach averaged slopes and the resulting roughness values. Tributaries are shown for reference and not necessarily used to distinguish reaches used for slope averaging. Reaches were based on generic changes in geomorphology, typically changes between alluvial reaches and narrow bedrock reaches.

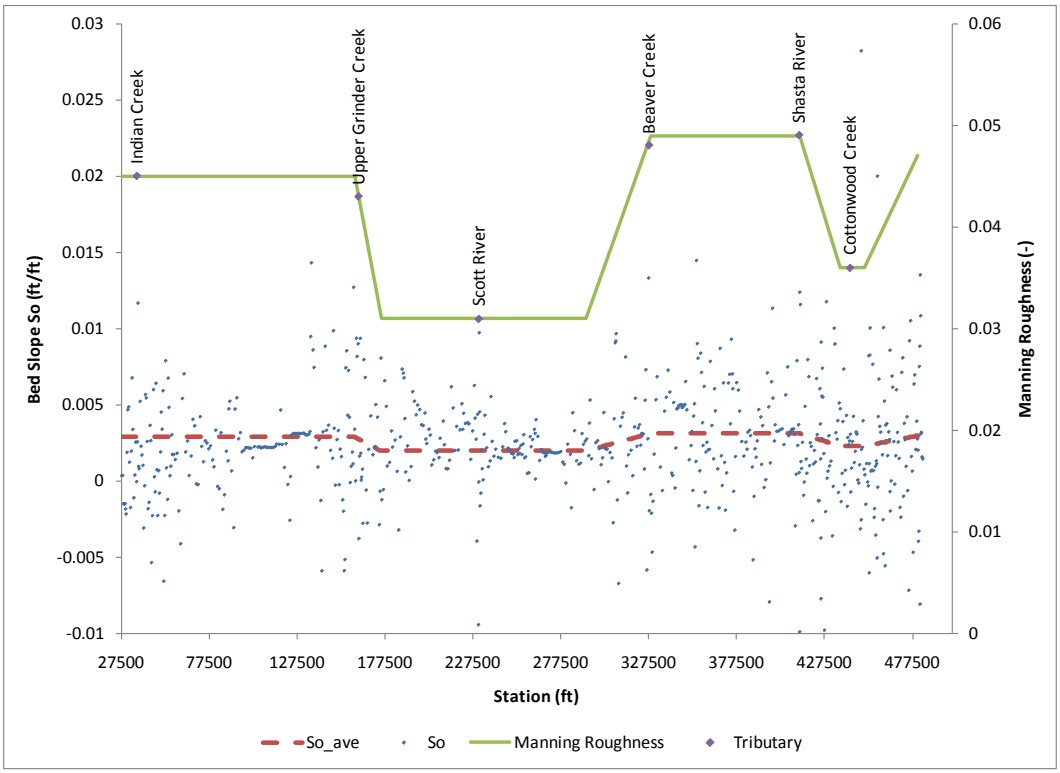

Figure 4-3. Calibrated Manning's Roughness for the main channel of the Klamath River.

Figure 4-4 presents the error in modeled water surface elevation relative to measured water surface for the data collected in October of 2009 by Reclamation. The measured water surface elevations were developed by locating all of the surveyed data that were within 5 ft of the model cross sections. Of the 792 cross sections used for the model from Iron Gate Dam to Happy Camp, 540 cross sections had data within 5 ft, giving 540 water surface elevations to be matched. The computed water surface elevations for the majority of the cross sections were within 1 foot of the measured and within 2 feet for most all of the cross sections.

The overbank roughness was calibrated by comparing modeled water surfaces to gage heights at Iron Gate Dam and at Seiad Valley (USGS 11516530, 11520500). A range of overbank roughness values from 0.055 to 0.08 were run in the model (with channel roughness as described above). Water surface elevations at the cross sections nearest the USGS gages were used for comparison. As can be seen in Figure 4-5 and Figure 4-6, the spread in measured values is on the order of, if not greater than, the spread in the modeled values based on varying overbank

roughness. However, the lower roughness of 0.055 for the overbank areas more closely matches the high flow measured values.

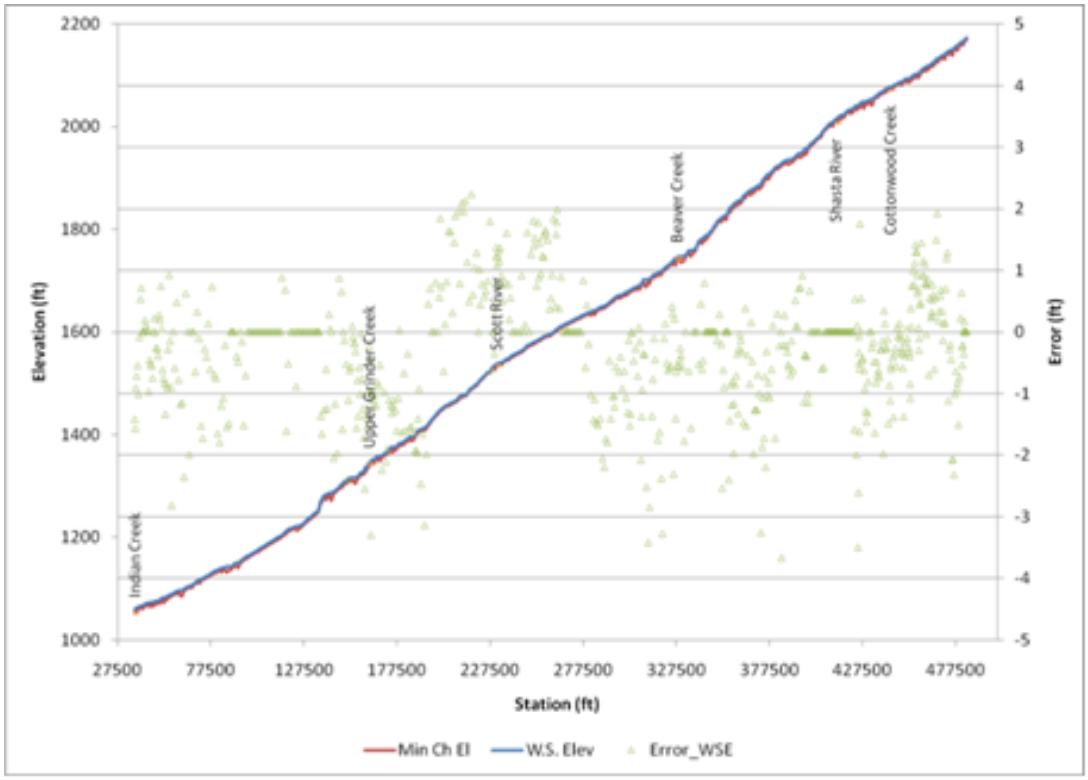

Figure 4-4. Comparison between measured and computed water surface elevations for the survey performed in October 2009.

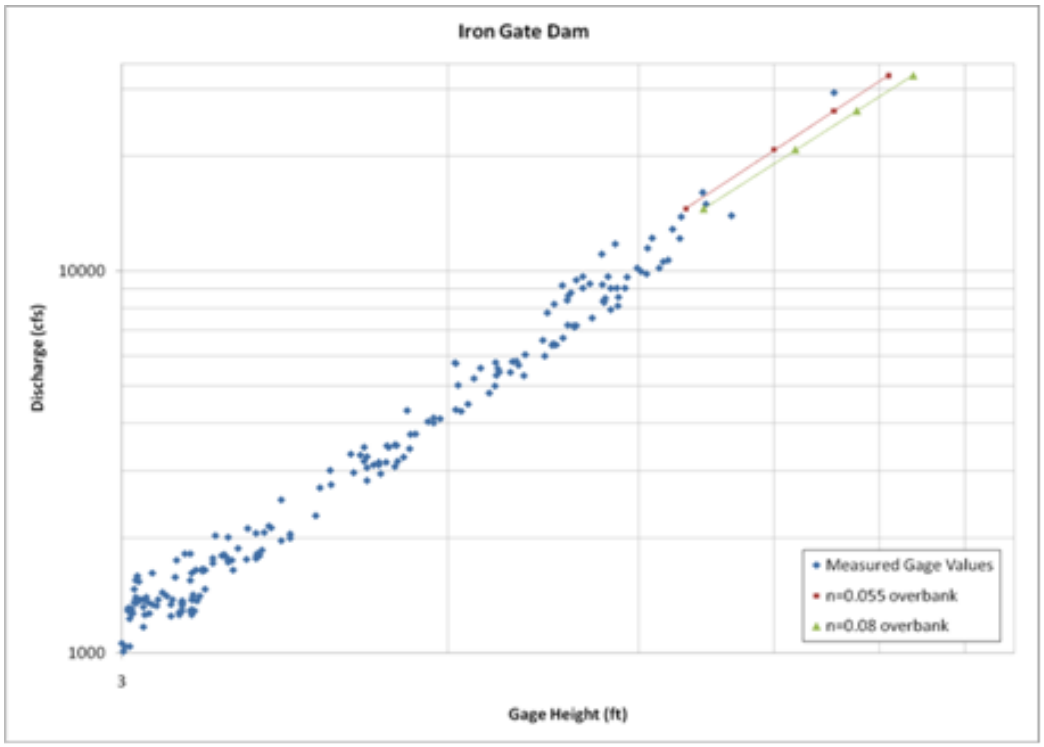

Figure 4-5. Calibration of HEC-RAS model to measurements at USGS gage below Iron Gate.

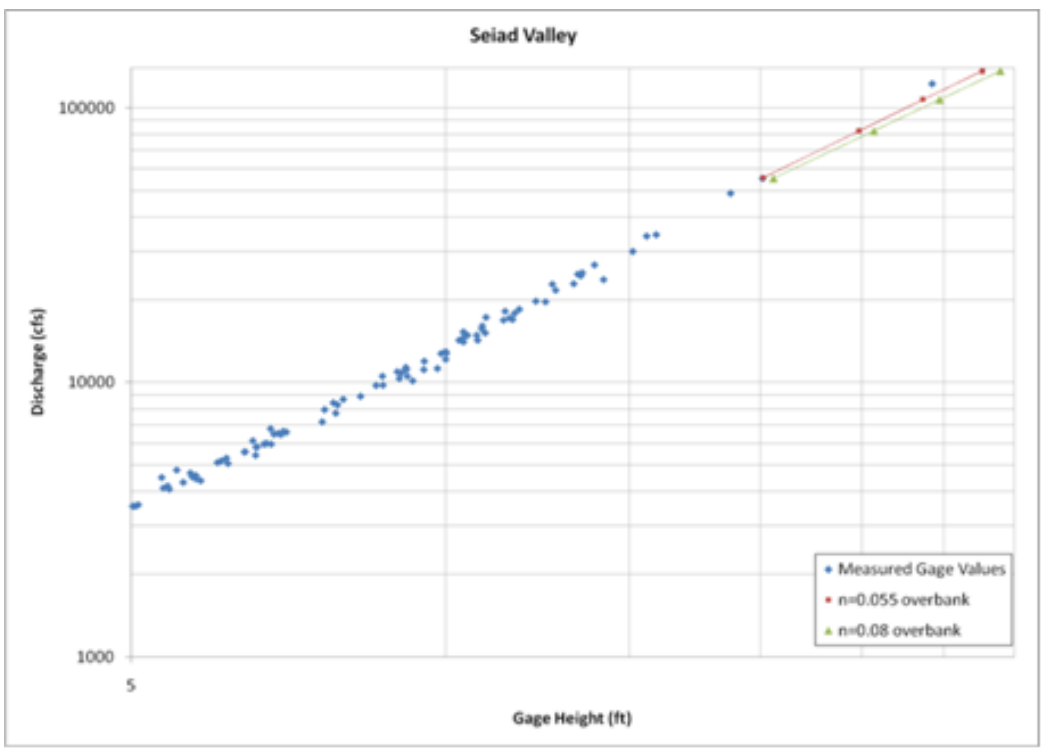

Figure 4-6. Calibration of HEC-RAS model to measurements at USGS gage near Seiad Valley.

4.2. Current Hydraulic Conditions

The bed profile and average water surface slope for the Reach from Keno Dam to Happy Camp, CA is shown in Figure 1-6. The HEC-RAS model was used to estimate reach average conditions from Iron Gate Dam to Indian Creek. The reaches are defined in Table 4-1. Results are limited to the reach from Iron Gate Dam to Indian Creek because this is the only reach where bathymetric data was collected to develop underwater cross sections. The average hydraulic properties for various stream flows are given in "Appendix B. Hydraulic Conditions Downstream of Iron Gate Dam". The reach averaged hydraulic conditions are given in Figure 4-7 and Figure 4-8 for 2-year flood conditions. The properties for the median stream flow are given in Figure 4-9. Stream power is defined as γQS, where γ is the unit weight of water, Q is the flow rate, and S is the energy slope.

Table 4-1. Reaches for hydraulic and sediment analyses.

Reach	**Approx Length (miles)**	**Upstream USGS RM**
Iron Gate to Bogus Creek	0.5	190.1
Bogus Creek to Willow Creek	4.6	189.6
Willow Creek to Cottonwood Creek	2.7	185.0
Cottonwood Creek to Shasta River	5.4	182.1
Shasta River to Humbug Creek	5.5	176.7
Humbug Creek to Beaver Creek	10.5	171.5
Beaver Creek to Dona Creek	8.2	161.0
Dona Creek to Horse Creek	5.5	152.8
Horse Creek to Scott River	4.4	147.3
Scott River to Indian Creek	36.7	143.0
Indian Creek to Elk Creek	1.1	106.8
Elk Creek to Clear Creek	7.0	105.5
Clear Creek to Salmon River	33.5	98.6
Salmon River to Red Cap Creek	13.0	66.0
Red Cap Creek to Bluff Creek	3.2	53.6
Bluff Creek to Trinity River	6.0	49.5
Trinity River to Blue Creek	26.7	43.4
Blue Creek to Mouth	15.7	16.3

The reach averaged depth, channel velocity, and stream power decrease from Iron Gate Dam to Cottonwood Creek are given in Figure 4-7. The reach immediately downstream of Iron Gate Dam has a higher energy slope and narrower top width which increases the velocity relative to the next downstream reach. From Iron Gate Dam to Cottonwood Creek, the depth and velocity decrease as the top width increases and energy slope decreases. Depth, velocity, and stream power increase downstream of Cottonwood Creek as the flow and slope increases. There is another increase in velocity and stream power downstream of Shasta River caused by the increase in slope and stream flow rate. Downstream of the Shasta River to Beaver Creek, the channel is more confined and has a steeper slope than the

reaches upstream or downstream of it. Downstream of Beaver Creek to Horse Creek, the energy slope decreases and top width increases causing a decrease in stream power. From Horse Creek to the Scott River, the energy slope stays relatively small and there is a slight decrease in top width which causes an increase in hydraulic depth and stream power. Downstream of Scott River, the flow and energy slope increase significantly causing an increase in stream power.

The results for the median flow show similar trends to the 2-year flood analysis, but the magnitude of the stream power is significantly less (Figure 4-9). The 2-year flood values are taken from Table 2-5.

The 100-year floodplain for the current conditions for the reach downstream of Iron Gate Dam to Happy Camp, CA is given in "Appendix G. Mapping of 100-year Flood Plain under No Action and Dam Removal Alternatives". Based upon an analysis of the aerial photographs, there are several hundred structures within current 100-year floodplain downstream of Iron Gate Dam to Happy Camp.

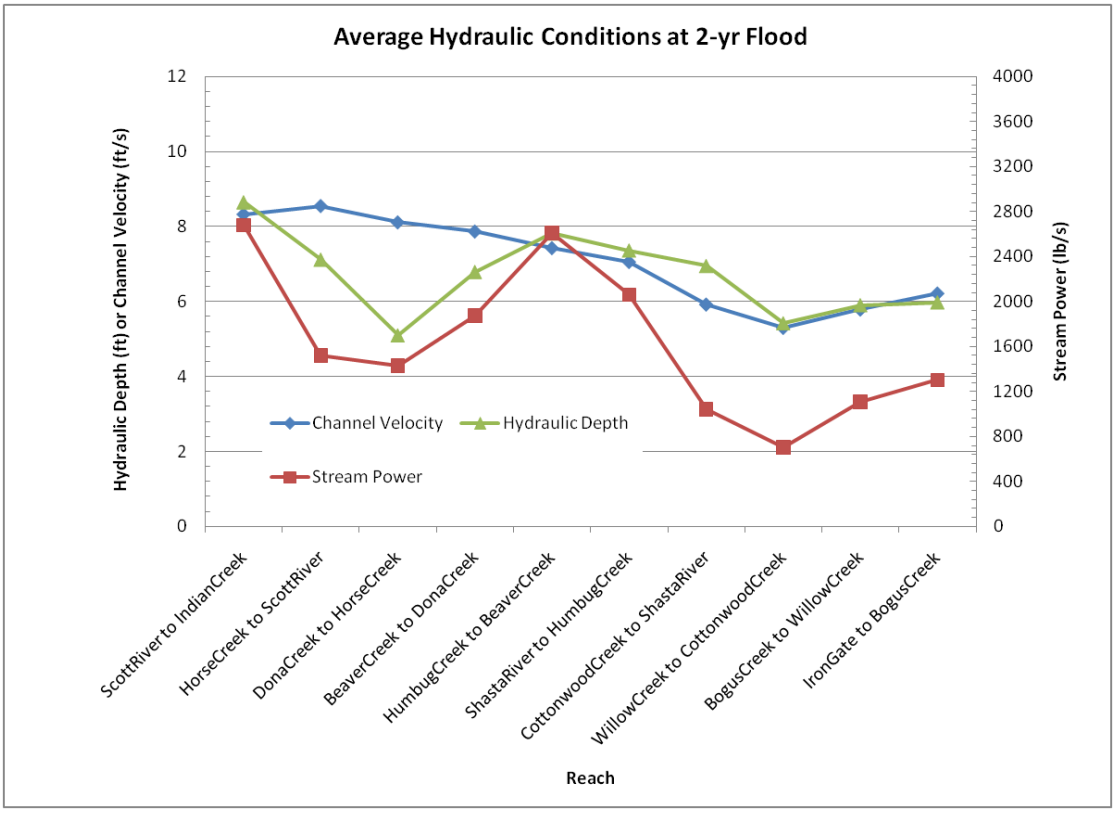

Figure 4-7. Reach averaged channel velocity, depth and stream power at 2-year flood conditions.

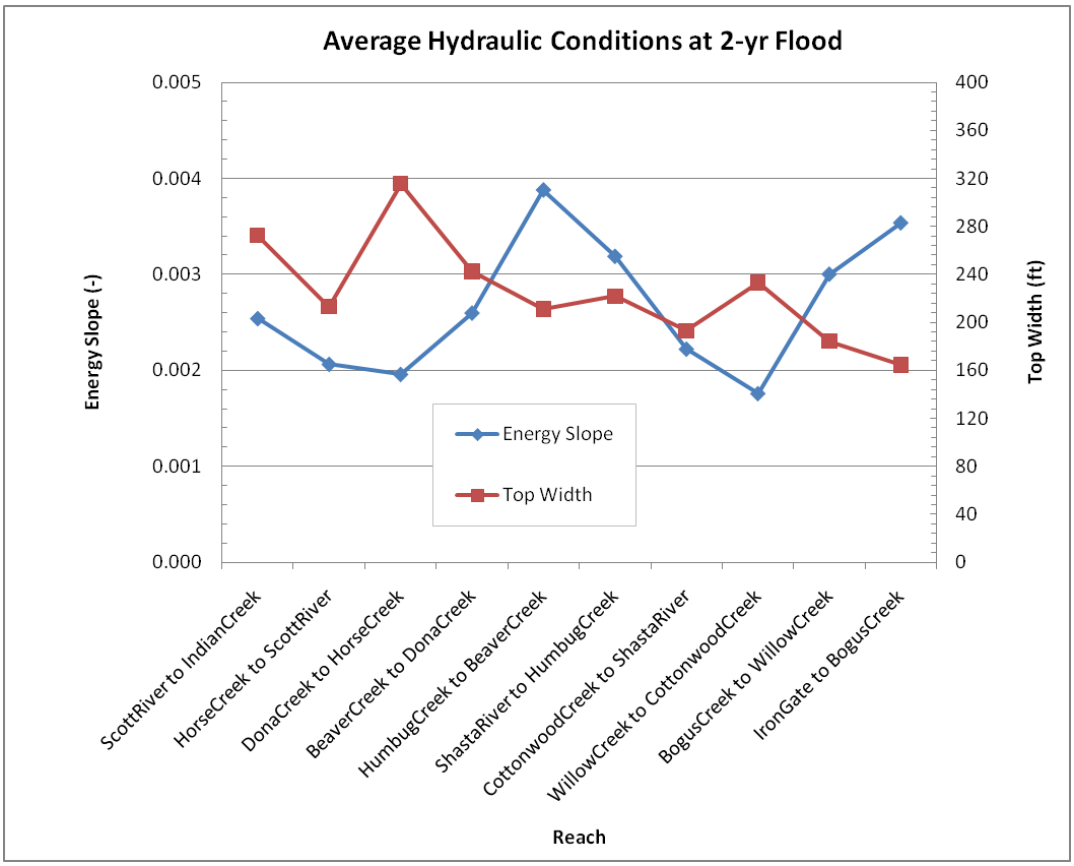

Figure 4-8. Reach averaged energy slope and top width at 2-year flood conditions.

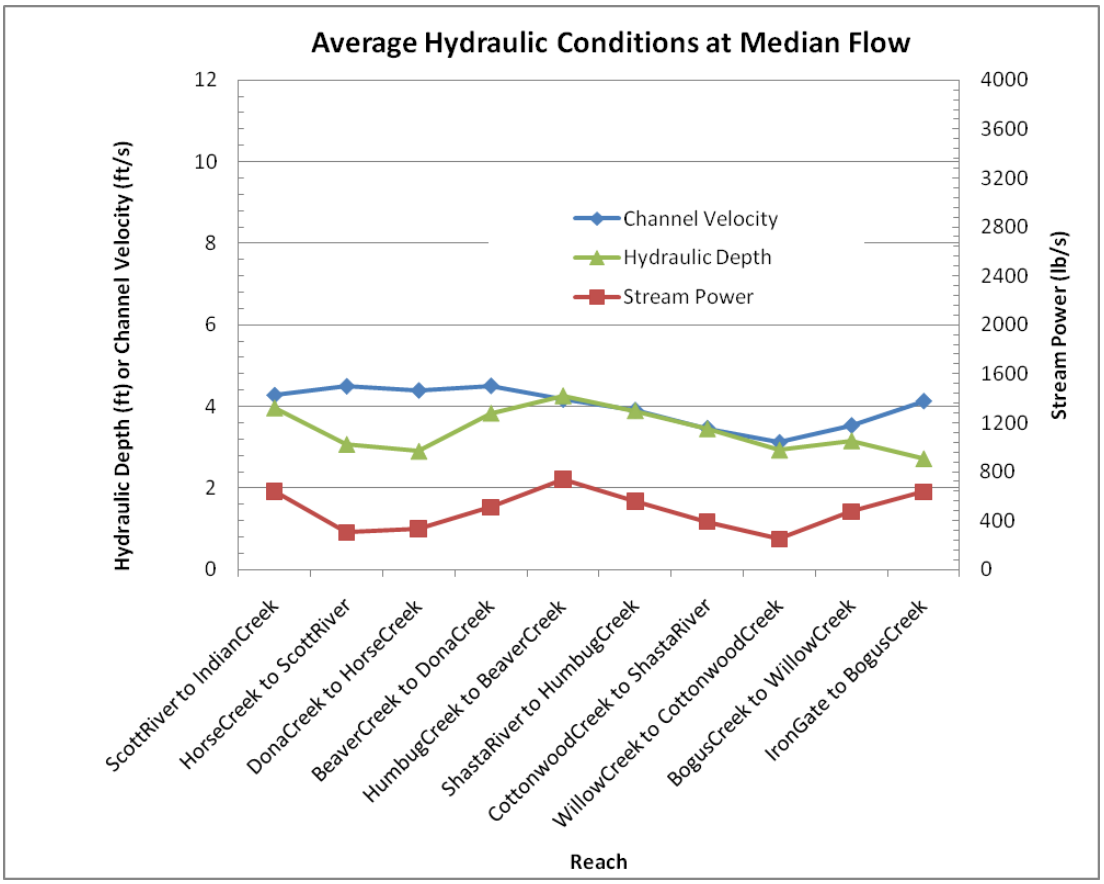

Figure 4-9. Reach averaged channel velocity, depth and stream power at median flow.