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September 21, 2006

Michael Bowen
California State Coastal Conservancy
1330 Broadway, 11th Floor
Oakland, CA 94612

Re: Klamath River Sediment Study

Dear Michael,

At your request, I have compiled a brief summary of the preliminary results of the Klamath River sediment investigation. These results include the following: 1) a summary of the analysis of sediment volume, 2) a description of sediment grain size distribution, and 3) a preliminary estimate of the volume and type of sediment that would be eroded by dam removal. This information is based on 45 sediment samples taken at 26 locations by Shannon and Wilson, Inc. from Iron Gate, Copco I, and J.C. Boyle reservoirs during their 2006 field season, and under a contract with the Coastal Conservancy.

The results of our analysis of sediment volume indicate that the three reservoirs have trapped approximately 21 million cubic yards (mcy) of material. However, our preliminary analysis concludes that less than 4 mcy of this material would erode as a result of dam removal activities. Previously G&G Associates[1] investigated the feasibility of removing the four lower dams and allowing sediment behind the dams to erode downstream. Stillwater Sciences[2] analyzed the effects that eroding sediments would have downstream of Iron Gate Dam. The results of our analysis of the volume and grain size of eroded sediment compares well with assumptions made by Stillwater. We, therefore, believe that erosion is a feasible method of removing sediment in the river channel as discussed in the G&G Associates and Stillwater reports.

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[1] *Klamath River Dam Removal Investigation, J.C. Boyle Dam Copco I Copco 2 Dam and Iron Gate Dam*, G&G Associates, July 2003

[2] *A Preliminary Evaluation of the Potential Downstream Sediment Deposition Following the Removal of Iron Gate, Copco, and J.C. Boyle Dams, Klamath River, CA*, Stillwater Sciences 2855 Telegraph Avenue Berkeley, CA 94705, May 2004

Discussion of Results

Additional investigation of removal of the four lower dams on the Klamath River was conducted on behalf of the California State Coastal Conservancy and Ocean Protection Council. This investigation was prompted by questions regarding the feasibility of dam decommissioning as a future project management alternative. The current study includes collecting and analyzing sediment from the reservoirs of these dams to provide a basis for dam removal studies. Shannon and Wilson, Inc. utilized over water boring and grab sampling to collect sediment samples at 26 different locations in three of the reservoirs. One reservoir, Copco II, did not have sufficient sediment to allow sample collection. The location of the samples is discussed in *Sediment Sampling Plan Klamath River Sediment Study*, June 2006, Gathard Engineering Consultants (Appendix A, "Sampling Plan").

Estimated sediment thickness provided in the Sampling Plan was based on elevations shown on contour lines on predam and post dam reservoir surveys. Results of the borings provided a comparison of actual sediment thickness to sediment thickness calculated from survey information. Comparison of the estimated thickness, based on pre and post dam surveys, with the measured thickness based on borings did not always provide a high correlation. Table 1 shows both estimated and measured sediment thickness.

The difference between estimated and measured sediment thickness may result from numerous extrapolations of known information as discussed below.

- The accuracy of drill rig location was limited to the accuracy of the rig location system used. Slight variation in the location of the rig could result in large variation in sediment thickness, for instance at locations near or at predam canyon walls.
- The predam and post dam survey contour lines were based on extrapolation of spot elevation information. The accuracy of contour lines used to estimate sediment thickness was limited by the accuracy and amount of information used to create predam survey contour lines.
- Side slopes along the predam river were very steep. Contour lines of pre and post dam surveys were overlaid to estimate sediment thickness. Slight variations in the horizontal alignment of the surveys could result in large thickness estimate changes, and possible inaccuracies, in the estimated sediment thickness.
- Estimates in the Sampling Plan were conservative (towards larger thickness) to ensure that drill rig operators provided sufficient drilling equipment length to access the full depth of sediment. Extrapolation of sediment elevations from predam and post dam elevations was required. Accuracy of the information is limited by extrapolation from 10-foot interval contour lines.

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Table 1 Estimated and Measured Sediment Thickness

Coring Location	Measured Sediment Thickness - feet	Estimated Sediment Thickness - feet
Copco I Reservoir		
C-1	5.8	20
C-2	4.4	10
C-3	5.7	10
C-4	7.7	10
C-5	5.8	7
C-6	10	10
C-7	0.4	15
C-8	3.6	8
C-9	3.5	12
C-10	9.4	10
C-11	4	10
C-12	6	--
Iron Gate Reservoir		
Coring Location	Measured Sediment Thickness - feet	Estimated Sediment Thickness - feet
IG-1	7	15
IG-2	1.9	12
IG-3	2	10
IG-4	2.5	2
IG-5	0.5	2
IG-6	2	20
IG-7	5	20
IG-8	4.3	5
IG-9	6.5	10
J.C. Boyle Reservoir		
Coring Location	Measured Sediment Thickness - feet	Estimated Sediment Thickness - feet
J-1	13.2	15
J-2	0	2
J-3	0.5	2
J-4	0.3	2
J-5	0.3	2

1. Sediment Volume

In April 2003 JC Headwaters, Inc. issued a report, conducted for PacifiCorp, investigating sediment characteristics in several reservoirs on the Klamath River. The report included bathymetric surveys, analysis of the trapped sediment volume in the reservoirs, and provided information on the nature and distribution of the sediments in the impoundments. Iron Gate, Copco I, and J.C. Boyle reservoirs were included in that investigation.

The report, entitled *Bathymetry and Sediment Classification of the Klamath Hydropower Project Impoundments*, J. M. Eilers and C.P Gubala, JC Headwaters, Inc., April 2003 (JC Headwaters Report), included figures showing bathymetric contour lines for the three reservoirs. PacifiCorp presented the results of the bathymetric survey by JC Headwaters as part of the dam licensing proceedings. Bathymetric contour lines provided in electronic format were received from PacifiCorp for predam and JC Headwaters surveys.

These files were used to compare the water volume of the predam and current reservoirs. Contour line information in a digital format compatible with AutoCAD software was taken from the data provided by PacifiCorp. AutoCAD was used to calculate the area contained inside each contour line. The volume of water contained in the reservoir, for both predam and the JC Headwaters surveys, was determined by multiplying the area inside each contour line by the difference in elevation between adjacent contour lines for all the contour lines in the reservoir. Volumes of the predam and JC Headwaters survey were calculated using identical water surface elevations. The estimated volume of sediment contained in the reservoir was calculated as the difference between the water volume of the predam and JC Headwaters surveys. Table 2 shows the sediment volumes calculated using this approach. It also provides volumes from the JC Headwaters Report.

To develop bathymetry the JC Headwaters investigation sampled water depths at cross section lines located at approximately 50-meter intervals. The method for developing predam contour lines is unknown but each approach involves extrapolation of information. The Copco I predam survey was particularly rough. On the south side of the reservoir some contour lines were not shown at all. Both Iron Gate and J.C. Boyle predam surveys appear to have been conducted after cofferdams, used to divert the river for dam construction, were in place. The lowest contour line for each was the elevation of the top of the cofferdam although other information shows lower river elevations. This discrepancy inherently limited the accuracy of sediment volume calculations.

Using the techniques described above, both Iron Gate and J.C. Boyle reservoirs appear to have significantly more sediment in them than the previous the JC Headwaters Report indicated. At this point in time no explanation for the large discrepancy in the volume of sediment in Iron Gate Reservoir is available. However, analyzing sediment volume involves comparing the difference between two very large numbers to determine the remaining sediment volume. Small errors in the survey can result in a large difference in the calculated volume of sediment and may be the reason for differences in calculated sediment volume. Comparison of bathymetry from the JC Headwaters Report to the predam survey at J.C. Boyle reservoir clearly shows a large volume of sediment near the dam that would account for most of the larger volume for the AutoCAD analysis shown in Table 2. Investigation of these issues is ongoing.

Table 2 Sediment Volume

Comparison of Reservoir Sediment Volume Cubic Yards of Sediment				
	J.C. Boyle	Copco1	Copco 2	Iron Gate
AutoCAD analysis	636,000	10,870,000	No sediment	8,767,000
JC Headwaters Report	22,222	9,629,00		4,818,000

2. Sediment Grain Size Analysis

The JC Headwaters Report also included an analysis of the sediment grain sizes and locations within the reservoirs. Hydroacoustic echo techniques were used to define bathymetry and grain size. JC Headwaters analysis of the sediment also included cores from the top four inches and visual observation of sediment using an under water camera.

These techniques provide only limited information regarding the grain size of reservoir sediments. Reservoir sediments tend to be layered with varying grain sizes. Analyzing sediment from only the top four inches does not provide a thorough analysis of sediment grain sizes. Accurate knowledge of grain size distribution is necessary to conduct analysis of sediment transport and erosion behavior.

To provide a more accurate determination of the distribution and location of sediment grain size, samples of reservoir sediment were extracted using boring techniques at 21 locations and 5 grab samples locations. Locations of sample extraction are described in the Sampling Plan (Appendix A). An additional boring was located in Copco between C1 and C7. From the 26 sample locations 45 individual grain size analyses were conducted. The grain size characteristics at boring locations were used to extrapolate the material size distribution and location for each reservoir. This information was used to develop an estimate of the grain size of sediment that would be eroded from the reservoir if dams were removed.

Table 3 shows the grain size distribution analysis results.

Table 3 Grain Size Distribution

Material Size Analysis Results Cubic Yards			
Reservoir	Iron Gate	Copco I	J.C, Boyle
Clay and Silt	7,249,132	8,972,039	450,043
Sand	1,092,064	1,794,856	128,922
Gravel	425,808	102,462	25,765

3. Sediment Eroded past Iron Gate Dam

Sediment eroded from J.C. Boyle would be trapped in Copco I Reservoir. Copco I sediment would flow into and be partially trapped in Iron Gate Reservoir. Sediment eroded past Iron Gate Dam would eventually be transported to the Pacific Ocean. The method, sequence, and timing of breaching the reservoirs to erode sediment are still under investigation. The following erosion assessment assumes the minimum duration of downstream water quality impacts would occur by first removing Copco II dam followed by simultaneously breaching the three remaining dams.

Table 4 shows the estimated sediment volume eroded past Iron Gate Dam assuming simultaneous removal of J.C. Boyle, Copco I, and Iron Gate reservoirs. The volume of sediment eroded and released was based on the following conservative preliminary assumptions. Analysis of the sediment release is ongoing and may result in reduced estimates of sediment releases.

- The new eroded river channel would follow the pre dam river channel. The channel width would be 200 feet wide at the bottom with side slopes at 10 horizontal to 1 vertical through Iron Gate and Copco I reservoirs

- All material would be eroded simultaneously. No time lag for larger particles would occur.

- Material from J.C. Boyle would resettle in Copco I. That material would be eroded out of Copco I reservoir in the same proportion as Copco I sediments. The same process would occur in Iron Gate. Approximately 2.2 mcy of sediment in Copco I would erode into Iron Gate Reservoir, which includes 23% of the sediment eroded from J.C. Boyle and 23% of Copco I sediment.

- Sediment eroded from Copco I would be partially trapped in Iron Gate reservoir. Approximately 34% of the sediment arriving in Iron Gate Reservoir from Copco I would be eroded with Iron Gate sediment erosion.

Table 4 Sediment Eroded Past Iron Gate Dam (thousand cubic yards)

Condition	Gravel	Sand	Silt/Clay	Total
Sediment released to Iron Gate Reservoir from the removal of Copco I	98	419	1,717	2,234
Copco I sediment eroded past Iron Gate Dam following Iron Gate Dam removal (34% of Total Copco I sediment eroded)	33	142	584	759
Iron Gate Reservoir sediment only from Iron Gate Dam removal	220	451	2,340	3,011
Total sediment released downstream of Iron Gate Dam	**253**	**593**	**2,924**	**3,770**

The information presented in this memorandum represents preliminary results of analysis of sediment sampling activities. The ongoing work awaits final results from sediment boring activities. We anticipate that some of the data and results presented may be revised when analysis and reports are complete.

Sincerely,

Dennis Gathard, P.E.

Appendix A

Sediment Sampling Plan

Klamath River Sediment Study