Appendix M

Copper Analysis

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Draft Technical Memo

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From: Sally Schoemann, ENTRIX

RE: **Evaluation of Potential Copper Concentrations in Old Cow Creek as a result of Kilarc Diversion Dam Removal (Draft for Review)**

As part of the decommissioning of Pacific Gas and Electric Company's (PG&E) Kilarc-Cow project (FERC Project No. 606), PG&E is proposing removing the Kilarc Main Diversion Dam and allowing the sediments to naturally attenuate downstream. As part of the decommissioning, studies were conducted to determine the concentrations of mercury (Hg), methylmercury (MeHg), copper (Cu), Silver (Ag), and arsenic (As) within sediments behind the diversion dam. This results of the study indicated the levels of Cu behind the diversion dam were elevated. This technical memo presents calculations performed to evaluate the potential environmental impact of the copper concentrations in Old Cow Creek under various hydrodynamic scenarios following removal of the Kilarc Diversion Dam. The model that is presented is designed to determine streamflow copper concentrations, given flow conditions over a period of time. The model is applied to reasonable hydrologic scenarios, resulting in copper concentrations that may be compared to relevant freshwater aquatic toxicity criteria. Similarly, the model may be used to evaluate hydrologic conditions that result in copper concentrations equal to or above aquatic toxicity criteria. The practicality of these conditions occurring may then be evaluated.

Background

The sediments behind the Kilarc Main Canal Diversion Dam were found to potentially have copper present above sediment screening levels established for possible effects to aquatic life.[1]

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[1] U.S. Environmental Protection Agency, Federal Register, Volume 65, No. 97 (Thursday, 18 May 2000), pp. 31682-31719; and Federal Register, Volume 66, No. 30 (Tuesday, 13 February 2001), pp. 9960-9962 [California Toxics Rule and Correction], http://www.gpoaccess.gov/fr/.. Central Valley Regional Water Quality Control Board. 1998. As Amended 2007. Water Quality

Control Plan (Basin Plan) for the California Regional Water Quality Control Board, Central Valley Region.. Sacramento, CA.

Further evaluation and analysis of the copper data, including leachability testing, and evaluation of particle size fractioning data indicated that the silt fraction of the sediments had higher copper concentrations than the sand/silt/clay fractions.

The copper found within the fine silt and clay-sized sediments behind the Kilarc Main Canal Diversion Dam is believed to be a result of natural weathering processes. The source of the copper is from within naturally occurring soils and rock within the watershed and not from anthropogenic sources. The release of these sediments after dam removal would be similar to the ongoing mass-wasting failures of hillslopes that directly deliver large amounts of sediment to the channel on both Old Cow and South Cow creeks (See Section E.2.3, Geomorphology).

The sediments when transported downstream would be redistributed and some copper could become desorbed from the sediments, dissolving in the stream flow. The neutral to basic pH of the stream would minimize the desorption, and the natural hardness and alkalinity would serve to complex copper after desorption with formation of copper carbonate (CuCO3), which would minimize the amount of the ionic form of copper.

Although the volume of fine sediments which contain most of the copper is very low (estimated to be less than 1 percent by dry weight of total material, representing a volume of about 6 cubic feet [0.22 cubic yard]), further analysis was conducted to evaluate the probability of these sediments to degrade water quality to a level where adverse impact would occur.

Approach

The copper concentration in Old Cow Creek after the dam is removed may be calculated as the sum of the copper naturally occurring in the stream and the copper desorbed from sediment stored behind the Kilarc Diversion Dam. The amount of copper available to the water column due to the sediments is dependent on numerous factors including:

- The quantity of sediment
- The mass of copper within the sediment
- The particle size fractioning of the sediment, (because decreasing particle size increases the aqueous phase partitioning of copper)
- The period of time over which the sediments are transported and redistributed throughout the stream (because maximum copper concentrations will be found during storm events when the sediments are in flux), and
- The flow rate in the stream during the period of sediment flux

Several scenarios are evaluated to quantitatively bracket potential streamflow concentrations of copper. For each case, the contribution from sediment to the copper concentration (C_s) was calculated as the mass of copper (M), divided by various streamflows, Q, and various durations of time, t , such that:

$$C_s = M / (Q * t)$$

Adding this concentration to the background copper concentration in the stream, $C_{bg,,}$ results in a total copper concentration in the stream, C_t, of,

$$C_t = C_s + C_{bg}$$

For this model, we assume that the mass of copper is equally distributed throughout the length of the streamflow over the entire time period. The approach is analogous to a plug-flow model, where the mass of sediments is added to a bottle of water filled up over a period of time, and shaken until the copper is desorbed, resulting in a dissolved concentration of copper in the water. This represents a conservative approach to determine if the sediment concentrations could result in streamflow concentrations above water quality levels under reasonable hydrologic scenarios.

Model Input

Copper Mass, M. The mass of copper behind the dam was estimated based on particle size fractioning data for the sediments (Table E.2.3.6-6, attached). An estimated 200 tons of sand-sized sediments (between 0.063 mm and 2 mm) are deposited behind the dam. The weight of sediments of silt and clay size (less than 0.063mm diameter) is estimated at between 0.5 and 1 ton.

The copper concentration within the sand and silt/clay fractions was determined by analytical testing of sediment samples, as shown in Table E.2.4-12 (attached). Only sample K-1 tested the silt/clay fraction of the sediments. In the calculations for all scenarios, the mass of copper was calculated as the mass-weighted concentration of the sand (200 tons) plus the silt/clay (1 ton). The average copper concentration from samples K-II and K-IIb (55 ug/l) was selected as a conservative estimate of copper in the sand fraction (i.e. samples from K-III and K-IV were lower). The K-1 total copper concentration of 819 ug/l was assumed for the silt/clay fraction.

The leachability of Cu from these two sediment groups was determined to be an average of 24 percent and 100 percent, respectively for the sand and silt/clay fractions, based on a weak acid leachability test. This test does not simulate stream water quality conditions (which are basic and well buffered), but assumes that weakly acidic conditions extract copper from the soil, resulting in a high estimate of copper available to the water column.

Table 1 summarizes the particle-size weighted estimate of copper in sediments behind the Kilarc Diversion Dam. Although the copper concentration and leachability are greater within the silt/clay sized particles, the sand-sized sediments contain the large majority of copper, resulting in a total estimate of between 2.8 and 3.1 kilograms of leachable copper in the sediments.

Table 1. Copper Flux Input Data to Estimate Streamflow Concentrations

		Particle Size				
	Units	Silt/Clay (<.063mm)		Sand (>.063mm and <2mm)	Total	
		Low	High		Low	High
Mass Sediments	**Tons**	0.5	1	200	200.5	201
Soil Weight	**Pounds**	1,000	2,000	400,000	401,000	402,000
Soil Mass	**kg**	455	909	181,818	182,273	182,727
Copper Concentration	**mg/kg (dry)**	819	819	55	56.9	58.8
Total Mass Copper	**mg**	372,000	745,000	10,000,000	10,372,000	10,745,000
Percent Leachable	**percent**	100	100	24	--	
Leachable Copper	**mg**	372,000	745,000	2,400,000	2,772,000	3,145,000

The background concentration of copper was assumed to be equal to the copper concentration measured in samples collected in May and October 2003, as summarized in Table E.2.4.5-5 and Table E.3.4-1 (attached). The latter table presents a comparison of measured background water quality with hardness-adjusted regulatory criteria.

Streamflow Conditions

Hydrologic conditions in Old Cow Creek after removal of the Kilarc Diversion Dam were estimated in Section E.2.2.4 of the Draft License Surrender Application. The results are summarized in Tables E.2.2-2 and E.2.2-3 (attached).

A range of hydrologic scenarios was considered for evaluation of copper concentration in the stream, given practical consideration of sediment transport. Quoting from Section E.2.2 of the Draft License Surrender Application,

The magnitude of change in the flow and sediment regime under regulated conditions, and back to unregulated conditions for Project decommissioning, was in part evaluated by assessing the change in the magnitude of geomorphically significant streamflow. The geomorphically significant streamflow is approximated as the bankfull discharge, or the 1.5-year recurrence interval flow (Section E.2.2, Hydrology and Water Resources).

The stream gradient above the Kilarc Main Canal Diversion Dam is very steep, approximately 6.7 percent, and below the Kilarc Main Canal Diversion Dam the gradient is approximately 5.3 percent... These steep gradients would promote very high sediment transport rates during high flow events. Therefore, it is expected that most of the finer matierial (cobble sized and smaller) will be readily mobilized and the larger boulder sized material will only be mobilized during extreme flood events.

It is unknown how long it would take for Old Cow Creek to naturally mobilize and transport this volume of sediment since it would be dependent upon the frequency and magnitude of flood events following dam removal.

Recognizing that the fine sediments buried deep in the thalweg may not be mobilized under low or even moderate flow conditions, a low, medium and high flow event were selected for further analysis. The low flow event was selected as the 90th percentile estimate of the average January flowrate. The medium event is the bankful discharge, or the 1.5 year flow. The high flow event is the peak flow for the five-year return period.

Table 2. Selected Unimpaired Flowrates in Old Cow Creek at the Kilarc Main Canal Diversion Dam for Further Analysis

Units	**Flowrate**		
	Low (January, 90th Percentile)	**Medium (1.5 yr Peak Event)**	**High (5 yr Peak Event)**
cfs	293	1,047	1,848
m3/s	8.3	29.6	52.3
liters/s	8,297	29,648	52,330

Results

The high flow case assumed a 5-year return period storm event that mobilized 100 percent of the copper within sediments within one 24-hour period . Recognizing that this is very unlikely to happen, the assumption of 100 percent mobilization emphasizes the low probability of the results. Applying the simple mass balance model, the maximum copper concentration due to sediments would be between 0.6 and 0.7 μg/l. When added to the background copper concentration in the water, 0.16 μg/l, the total copper concentration is estimated to be between 0.8 and 0.9 μg/l. This range is well below the 4.10 μg/l criteria specified by California Toxics Rule and the 5.60 μg/l standard of the Basin Plan, established at a hardness of 40 mg/l. If the duration of time for mobilization is doubled, i.e. peak flows continuing for a 48 hour period, the estimated concentration would be halved.

The low flow case assumed the (90th percentile) mean January flow for 14 days and resulted in a sediment contribution to the copper concentration in the stream of between 0.36 and 0.41μg/l. Adding this to the background copper concentration, the total copper concentration is estimated to be between 0.44 and 0.48 μg/l, which is less than the CA Toxics Rule standard (4.1 μg/l).

The medium flow condition was the bankfull flow estimated as a 1.5 year unimpaired flow event at Old Cow Creek occurring over a 3-day period. This case resulted in a copper concentration between 0.36 and 0.41µg/l from the sediments, and a total copper concentration between 0.52 and 0.57 µg/l, which is lower than the CA Toxics Rule standard.

Table 3 summarizes these results.

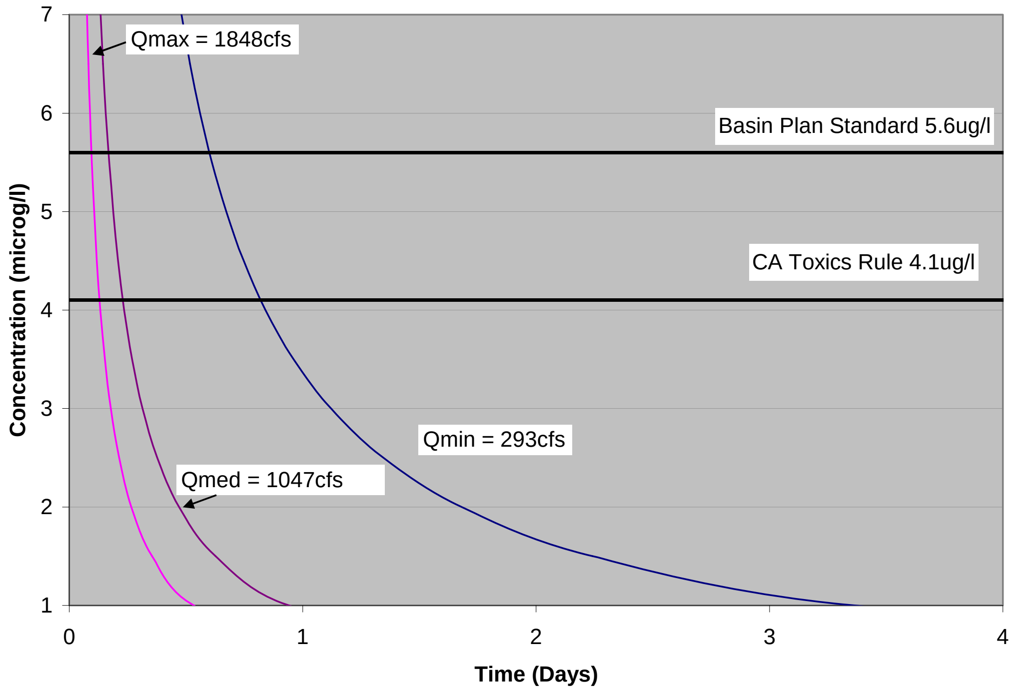
Table 3. Results of Estimated Copper Concentration in Old Cow Creek for Flow Scenarios (All Units µg/l).

Scenarios		Copper Concentration (Sediment Source)		Background Copper Concentration	Total Estimated Copper Concentration	
		Low	**High**		**Low**	**High**
Minimum	Minimum Flow 14 days	0.276	0.313	0.162	0.44	0.48
Medium	1.5yr Peak Flow 3 days	0.361	0.409	0.162	0.52	0.57
Maximum	5yr Peak flow for 24 hour	0.613	0.696	0.162	0.78	0.86

NOTE: California Toxic Rule Criteria at 40 mg/l hardness is 4.1 µg/l.

Based on the model input parameters, the results may also be viewed in terms of concentration versus the duration of a storm event, for specific flow scenarios. Figure 1 presents a graph of different streamflow and duration scenarios compared to the California Toxics Rule and the Sacramento River Basin Plan Standards, respectively. In Figure 1, the curves, bounded by the maximum and minimum streamflows, demonstrate different streamflow and time combinations that would meet the given criteria for aqueous copper concentration. The graph shows that the estimated leachable mass of copper behind the dam would need to be 100 percent dissolved into the streamflow in less than one day for the water quality criteria to be exceeded. The lower the flowrate (less total volume over a period of time), the longer time estimated for the criteria to be exceeded.

Figure 1
Estimated Copper Conc. Vs Time: Old Cow Creek at Kilarc Diversion Dam



These results indicate that there is a very low probability of exceeding freshwater aquatic toxicity criteria in Old Cow Creek as a result of the release of sediments behind the dam. The calculations are based on conservative assumptions, such as a high estimate of fine-sized sediments, a high estimate of leachability (100% for silt/clay sized particles), and conservative flow assumptions.

Table E.2.3-6. Percentage of Particle Sizes by Class, Kilarc Main Canal Diversion Dam

	Cobble and Coarser (>64mm, >2.52in)	Gravel (64mm-2mm, 2.52in-0.08in)	Sand (2mm-.063mm, 0.08in-0.002in)	Silt (<.063mm, <0.002in)
K-I	5%	71%	24%	1%
K-II	9%	79%	11%	0%
K-III	52%	41%	6%	0%
K-IV	65%	34%	1%	0%

NOTE: K-I through K-IV indicates the sampling location identifier.

Table E.2.4-12. Kilarc Main Canal Diversion Dam Bulk Sediment Sample Total Copper (Cu) and Leachable Copper Results

Sample ID	% Total Solids	Total Cu (mg/kg dry)	Leachable Cu (mg/kg dry)	% Leachable Cu	TEL	PEL
K-I	6.8	819	1120	100	35.7	197.0
K-II		51.2				
K-IIb	75.4	58.3	19.1	33	35.7	197.0
K-III		34.2				
K-IIIb	76.1	37.5	7.24	19	35.7	197.0
K-IV	77.2	43.5	8.1	19	35.7	197.0

NOTE:
1. Sample K-1 was composed of silt and clay fractions of sediment only. All other samples were made up of the sand, silt, and clay fractions of the collected sediment.
2. Testing was performed using EPA Methods 1638 (Total) or Method 1638 (mod) – leachable. The leachable copper test extracts the Cu that is weakly adsorbed to the sediment surface by running a weak hydrochloric acid over the sample for a fixed amount of time and measuring the resulting dissolved Cu concentration (Giddings et al, 1991).
3. TEL and PEL levels derived for freshwater sediment from Buchman (2004). The levels are not criteria or clean-up levels, and are published as screening values to aid in interpretation of sediment quality data.
4. "Background" levels established for Cu by Buchman (2004) are estimated to be 10 to 75 mg/kg.

Table E.2.4.5-5 (partial) **Summary of Water Quality Data for Metals, Kilarc Development, May and October 2003**

Constituent	Range of Concentrations (µg/L)	CA Primary Drinking Water MCL (µg/L)	CA Secondary Drinking Water MCL (µg/L)	Basin Plan Standards (µg/L)	California Toxics Rule Criteria (µg/L)
Total Metals					
Copper	<0.003 – 0.077	1,300	1,000	-	4.1
Dissolved Metals					
Copper	<0.003 – 0.162	-	-	5.6	-

Table E.2.2-2. Estimated Peak Flow (cfs) for Old Cow Creek and South Cow Creek

	1.5 Year	2-Year	5-Year	10-Year	25-Year	Drainage Area (square miles)	Drainage Area as Percent of Gage No. 11374000
Cow Creek near Millville (gage No. 11374000), measured flow	18,700	22,600	33,000	37,700	45,000	425	---
Old Cow Creek at Kilarc Main Canal Diversion Dam	1,047	1,256	1,848	2,111	2,520	23.8	5.6%
South Cow Creek at South Cow Creek Diversion Dam	2,057	2,486	3,630	4,147	4,950	47.0	11%

Table E.2.2-3. Summary of Average Monthly Unimpaired Flow (cfs) for Old Cow Creek

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Maximum	98	180	270	379	381	361	221	281	181	87	62	37
Minimum	22	17	17	17	18	22	42	41	39	42	42	23
Average	30	45	86	127	123	106	90	93	62	51	47	28
Median	28	32	70	101	101	91	75	80	54	48	46	28
10^{th} Percentile	23	20	20	32	37	45	56	54	44	43	42	24
20^{th} Percentile	24	21	30	51	50	57	61	59	45	44	43	25
80^{th} Percentile	32	60	146	205	176	144	132	127	71	58	51	30
90^{th} Percentile	37	91	183	293	232	194	154	152	102	62	52	33

Table E.3.4-1. Summary of Copper Water Quality in the Kilarc Development

Sample	2003 Sample Date	Measured Values[1]		Water Quality Objectives for Cu[2]			Related Water Quality Measurements[3]		
		Total Copper (mg/L)	Dissolved Copper (mg/L)	Basin Plan Objective (mg/L)	Acute Concentration (mg/L)	Chronic Concentration (mg/L)	Hardness (mg/L)	pH	Alkalinity (mg/L)
NC1	March	0.11	0.07	3.25	3.3	2.5	21.8	7.98	21
	October	<0.003	<0.003	7.11	7.5	5.3	51.9	8.10	54.4
CC1	March	0.09	0.06	6.82	7.2	5.1	49.5	7.79	57.8
	October	<0.003	<0.003	6.93	7.3	5.2	50.4	7.92	52.1
CC2	March	0.62	0.05	4.62	4.8	3.5	32.2	7.85	37
	October	<0.003	<0.003	4.40	4.6	3.4	30.5	7.80	29.8
OC1	March	0.077	0.044	3.61	3.7	2.8	24.5	7.89	30
	October	<0.003	<0.003	6.82	7.2	5.1	49.5	8.06	44.8
OC3	March	0.384	0.162	3.99	4.1	3.1	27.4	7.75	33
	October	0.174	0.23	6.82	7.2	5.1	49.5	8.07	48.7
KF1	March	0.088	0.088	3.34	3.4	2.6	22.5	8.00	28
	October	<0.003	0.047	6.75	7.1	5.1	49.0	8.28	58.8
OC4	March	0.158	0.077	3.61	3.7	2.8	24.5	7.95	27
	October	<0.003	0.037	6.88	7.3	5.2	50.0	8.24	46.5
MC1	March	0.706	0.451	7.36	7.8	5.5	53.9	7.27	61
	October	0.13	0.095	11.35	12.3	8.3	87.0	8.10	80.5
SC1	March	0.309	0.187	3.99	4.1	3.1	27.4	7.55	32
	October	0.068	0.18	7.00	7.4	5.2	51.0	7.88	48.1
SC4	March	0.457	0.238	4.89	5.1	3.7	34.3	7.77	38
	October	0.056	0.163	9.04	9.7	6.7	67.6	7.89	63.2
SC5	March	0.478	0.248	5.02	5.2	3.8	35.3	7.65	42
	October	0.093	0.191	9.04	9.7	6.7	67.6	7.85	65
CCF1	March	0.309	0.275	4.12	4.3	3.2	28.4	7.23	34
	October	0.056	0.116	8.09	8.6	6.0	59.8	7.82	58

NOTE:
1. Samples collected in March and October 2003.
2. Calculated values. Copper water quality objective varies based on an empirical formula that takes hardness of the water into account. Therefore, Basin Plan objectives for copper vary based on hardness. (California Regional Water Quality Control Board (CRWQCB, 2007)).
3. Calculated values. Similar to the Basin Plan, NOAA provides a formula for calculation of criterion based on variability of hardness. (Buchman 2004).