Appendix K

Development and Assumptions of the Battle Creek Hydrology and Hydroelectric Power Model

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Purpose of the Monthly Hydrology and Hydroelectric Power Model

The purpose of this monthly hydrology and hydroelectric power model is to determine the relative value of the Battle Creek Hydroelectric Project to Pacific Gas & Electric Company (PG&E) under different restoration alternatives that have different stream flow targets and diversion capacities at the eight existing diversion dams. In order to identify relative hydroelectric power values, the monthly diversions must be calculated for a range of Battle Creek flows that are representative of the likely future flows. This appendix documents the hydrology and hydroelectric power diversion flow assumptions that allow the monthly flows in each reach of Battle Creek to be estimated.

Monthly Hydrology

The fist step in the monthly hydrology model is to estimate the natural or unimpaired flows (i.e., no upstream diversions) at each diversion dam location. The North Fork Battle Creek has five diversion dams. The two upstream diversions at Al Smith Dam and Keswick Dam are upstream of the potential restoration area and are considered in the model to be a single diversion located at Keswick Dam. These diversions are for the Volta power plants and have a combined capacity of 128 cubic feet per second (cfs). The existing Federal Energy Regulatory Commission (FERC) instream flow requirement below Keswick Dam is 3 cfs. Table K-1 provides a summary of the diversion dam locations (river mile) with the upstream watershed area and the approximate elevation and capacity of the diversion.

Several water stage gages are present throughout the Battle Creek watershed. Some of the gaged flow data are reported to the U.S. Geological Survey (USGS). These USGS records are available from 1983 to the present, but only relatively low flows are reported to demonstrate compliance with the FERC requirements.

Higher flows passing the diversion dams are not reported to USGS. The USGS records include flows at each of the five hydroelectric power plants (i.e., Volta 1 and Volta 2, South, Inskip, Coleman). PG&E maintains additional gages within their canal system to let them know how much water is being diverted at each of the eight diversion dams. The data from these diversion gages is proprietary information that PG&E is not required to make public. They have provided these diversion records from recent years to assist in verifying the hydrology model assumptions.

Initial efforts to model the hydrology of the watershed attempted to use data from all of the reported PG&E gauges. However, the measured flows at the USGS gage below Coleman National Fish Hatchery are the best source of flow data for the entire Battle Creek watershed. Daily measurements are available at this gauge (with no missing data) for the period from October 1, 1961, through September 30, 2002. Using the watershed area-flow method, the total flow measured at the base of the watershed is apportioned to points throughout the watershed based on the percentage of total drainage area at the point being estimated. For example, the total drainage area at the base of the watershed (Coleman National Fish Hatchery) is 357 square miles, and the total drainage area at the Eagle Canyon Diversion Dam on the North Fork is 186 square miles. Thus, under the area-flow method, 52 percent of the measured daily flow at Coleman National Fish Hatchery is the assumed flow at the Eagle Canyon Diversion Dam under natural unimpaired conditions (with no upstream diversions for hydroelectric power).

The Resource Agencies thought that the area-flow method would be appropriate for the restoration alternative assessments. The PG&E records from recent years (Water Years [WY] 1998–2002) have been used to confirm the area-flow estimates. Discussion with PG&E staff about the specific hydrology of the watershed did, however, help refine the area method modeling. In particular, the existence of volcanic soils and fractured geology throughout the watershed provides a nearly constant base flow at several major springs. The area-flow method assumes uniform runoff across the entire watershed. In order to increase the accuracy of the model, the flows from the major springs was estimated and the area-flow method used to estimate the remainder of the flow.

With the assistance of PG&E and California Department of Fish and Game staff familiar with the watershed, estimates of major spring flows were made. It was assumed that these springs had a constant flow all times of the year. The area-flow method was then used to apportion the remaining measured flows (i.e., total flow at Coleman National Fish Hatchery less the sum of all estimated spring flows) to points in the watershed that correspond to diversion facilities. Using this adjusted area-flow method, the model can estimate the monthly average unimpaired flow at each diversion point on the North Fork and South Fork of Battle Creek.

The monthly model uses the full range of measured monthly flows at the USGS gage below the Coleman Hatchery from the 1963 to 1993 period. The monthly flows are ranked from smallest to largest and the percentile values (i.e.,

minimum, 10 percent, 20 percent, 30 percent... maximum) monthly flow values are determined. Table K-2 gives the monthly flow values for Battle Creek obtained form the 1963 to 1993 flow record. The model uses the 10 percent, 30 percent, 50 percent, 70 percent, and 90 percent monthly flow values to approximate the full range of future likely flows. Each of these five flow values is assumed to be representative of flows expected in about 20 percent of the future years. The 10 percent flow values are representative of the lowest flows that would be exceeded in 80 percent of the future years. Table K-2 indicates that the 10 percent flow value for January would be 345 cfs. This value is used to represent the lowest 20 percent of the future January flows.

Calculated North Fork Battle Creek Flows and Diversions

The hydrology model calculates all flows and diversions for each month for the five representative total Battle Creek monthly flows. This provides a description of the range of flows likely in each reach or diversion canal under each of the restoration alternatives. Table K-3 shows an example of the calculations for the North Fork Battle Creek assuming the 10 percent monthly flow values under the No Action Alternative (all diversions with FERC flows). The upstream flows at Keswick are estimated as a spring flow of 20 cfs and with 22.5 percent of the non-spring Coleman National Fish Hatchery flow. The total Battle Creek Spring flow is estimated to be 65 cfs. The January flow at Keswick Dam is calculated to be 83 cfs. The minimum FERC flow at Keswick Dam is 3 cfs, and so the calculated diversion to the Volta power plants for January is 80 cfs. A portion of this would actually have been diverted at the Al Smith diversion.

The next diversion dam is the North Battle Creek Feeder Diversion Dam. There are relatively large streams (Bailey Creek and Rock Creek) that join the North Fork just upstream of the dam. The North Battle Creek Feeder diversion capacity is 50 cfs. The estimated flow at the feeder in January is 49 cfs, and the calculated diversion to the Cross Country Canal and the South Powerhouse is 46 cfs, leaving the required FERC flow of 3 cfs below North Battle Creek Feeder. Because the North Battle Creek Feeder canal and the Volta 2 tailrace (with a pipeline across the North Fork) both flow into the Cross Country Canal with a total capacity of 150 cfs, only the water needed to fill the Cross Country Canal is diverted at North Battle Creek Feeder Diversion Dam. In January, with a Volta 2 powerhouse flow of only 80 cfs, the full diversion capacity of 50 cfs would have been diverted if the flow at the diversion dam had been slightly higher. For January, the Cross Country Canal flow is calculated to be 126 cfs (i.e., 80 cfs from the Volta powerhouse plus 46 cfs from the North Battle Creek Feeder Diversion Dam).

The next diversion dam is the Eagle Canyon Diversion Dam. The diversion capacity is 64 cfs. There are 5 cfs of springs assumed between North Battle Creek Feeder and Eagle Canyon Diversion Dams. The calculated January flow is

46 cfs, largely from Digger Creek that joins North Fork Battle Creek just upstream of Eagle Canyon Diversion Dam. The Eagle Canal flows to the Inskip powerhouse, and the diversion is calculated to be 43 cfs, leaving the required FERC flow of 3 cfs below the Eagle Canyon Diversion Dam.

The last diversion dam on the North Fork Battle Creek is the Wildcat Diversion Dam. The total upstream spring flow is assumed to be 35 cfs and the watershed fraction is 53 percent of the total Battle Creek watershed flow. There are an assumed 10 cfs of springs between Eagle Canyon and Wildcat Diversion Dams. Some of this spring flow is currently flowing into the Eagle Canyon Canal, so the assumed springs at Eagle Canyon Diversion Dam should perhaps be increased to reflect this diversion under the No Action Alternative. For most of the Action Alternatives (all except the No Dam Removal Alternative), Wildcat Diversion Dam would be removed and the Wildcat diversions would be eliminated.

The calculation results shown in Table K-3 indicate that the flows in the North Fork Battle Creek would be only 3 cfs throughout the year if the 10 percent monthly values were to occur each month for the entire year. This simply indicates that the hydroelectric power diversion capacities were designed to allow the diversion of the entire North Fork flows during low flow conditions.

Calculated South Fork Battle Creek Flows and Diversions

Table K-4 gives the monthly model calculations for the South Fork Battle Creek flows and diversions for the No Action Alternative (all diversions with FERC flows) for the 10 percent monthly Battle Creek flows. The first diversion is at the South Diversion Dam. There are no upstream springs and the watershed fraction is 19 percent. The January flow at South Diversion Dam is 53 cfs. The required FERC flow is 5 cfs, so the maximum diversion in January is 48 cfs. The South Diversion Dam diversion capacity is 100 cfs, but this includes the 10 cfs assumed spring flow from Soap Creek that can be diverted into the South Canal. The South Canal and Cross Country Canal join to form Union Canal that flows to the South Powerhouse penstock with a capacity of 222 cfs. Because the Cross Country Canal flow is 125 cfs and the Soap Creek Feeder diversion is 10 cfs, the diversion at South Diversion Dam could be 87 cfs to fill the South Powerhouse capacity. But the available water at South Diversion Dam limits the January diversion to 48 cfs. The South Powerhouse flow is therefore 183 cfs in January.

The next diversion dam is Inskip Diversion Dam. The upstream watershed is 88 square miles, representing a flow of about 25% of Battle Creek non-spring flow. The calculated flow at Inskip Diversion Dam in January is 204 cfs, which includes the South Diversion Dam flow of 5 cfs, the South Powerhouse discharge of 183 cfs (entering just upstream from Inskip Dam), and 16 cfs from several creeks (including Soap Creek) that enter the South Fork between South Diversion Dam and Inskip Diversion Dam. The required FERC flow is 5 cfs and the Inskip

diversion capacity is 199 cfs. The Inskip Canal is assumed to pick up any Ripley Creek spring flow (assumed to be 5 cfs) and will join with the Eagle Canyon Canal to flow into the Inskip Powerhouse Penstock with a capacity of 283 cfs. The Eagle Canyon Canal flow for January is 43 cfs, so the possible January diversion at Inskip Diversion Dam would be 235 cfs. The available water at Inskip Diversion Dam limits the diversion to 199 cfs, so the total Inskip Powerhouse flow is 247 cfs.

The last diversion dam on South Fork Battle Creek is Coleman Diversion Dam. The upstream watershed is 102 square miles, representing about 29 percent of the non-spring Battle Creek flow. The calculated flow at the Coleman Diversion Dam is 258 cfs in January. This includes the 247 cfs discharged from Inskip Powerhouse just upstream of Coleman Diversion Dam, the 5 cfs released from Inskip Diversion Dam, and local inflows of 6 cfs. The required FERC flow is 5 cfs, and the Coleman Diversion Dam is 253 cfs.

There are two diversions on Baldwin Creek that increase the Coleman Canal flow. The Pacific Power diversion has a capacity of 15 cfs and the Asbury dam and pump has a capacity of 35 cfs. Baldwin Creek flow is estimated from the watershed to be about 4 percent of the non-spring Battle Creek Flow and includes Darrah Springs that supply the Darrah Springs Hatchery with a constant assumed flow of 15 cfs. Wildcat Canal with a capacity of 18 cfs also joins the Coleman Canal. The Coleman powerhouse flow in January is therefore 291 cfs, including the 253 cfs diversion at Coleman Diversion Dam, 26 cfs from Baldwin Creek, and 12 cfs from Wildcat Diversion Dam on the North Fork Battle Creek.

The calculated January flow below the confluence of North Fork and South Fork is 8 cfs, representing the required FERC flows from Wildcat and Coleman Diversion Dams. The Coleman Powerhouse flow increases Battle Creek flow to 299 cfs. The Battle Creek flow at the Coleman National Fish Hatchery was 345 cfs in January. The missing flow is about 14 percent of the non-spring Battle Creek flow that is not accounted for by the 53 percent of the watershed at Wildcat Diversion Dam, the 29 percent of the watershed at Coleman Diversion Dam and the 4 percent of the watershed in Baldwin Creek. It is possible that slightly more of the watershed flow enters Battle Creek upstream of the confluence, but this area-flow method with a constant spring flow of 65 cfs provides a reasonable method for estimating the likely flows at each upstream dam.

Estimating Hydroelectric Power Production

Monthly diversions at each diversion dam are calculated from the total available flow at that diversion, the required in stream flow below the diversion, and the capacity of the conveyance and generation facilities that the diversion must pass through. The upstream diversions on the North Fork Battle Creek (Al Smith and Keswick) are assumed to be operated to capacity. The sequential diversions on the North Fork are also maximized subject to available water and canal

capacities. The South Fork diversions are then limited by available water or remaining powerhouse capacities.

The Battle Creek power plants are operated as run-of-the-river facilities generating electricity 24 hours per day because there are no storage facilities available for peaking power generation. Each hydroelectric powerhouse has an assumed capacity. The energy production is calculated with the simple equation that estimates the daily energy:

Energy (KWh) = 2.0 x flow (cfs) x Head (feet) x Efficiency

The head and efficiency at each powerhouse can be multiplied together to give the effective head. The efficiencies are generally about 80 percent. The Volta 1 and Volta 2 powerhouses are operated in series and the total effective head is used. The Volta powerhouses have a combined effective head of 1,100 feet. The megawatt hours (MWh) production at each plant for each month is calculated from the number of days in the month. For example, for the No Action Alternative at 10 percent flows, the January production at the Volta powerhouses was 5,441 MWh, South Powerhouse produced 4,145 MWh, Inskip Powerhouse produced 4,728 MWh and Coleman Powerhouse produced 7,226 MWh. The combined January energy production was 21,345 MWh, which, with an assumed price of $35/MWh, would represent an energy value of about $750,000 for the month.

Conclusions

The monthly flow and diversion model is an important tool for evaluating the flows and energy production for the alternative restoration water management actions. The results for each restoration alternative can be reviewed in Appendix L, “Results from the Monthly Flow and Diversion Model.”

Table K-1. Battle Creek Stream and Diversion Data

Battle Creek Location	Battle Creek Reach	River Mile	Elevation (feet)	Diversion Capacity (cfs)
Confluence with Sacramento River	BC	0.0		--
Coleman National Fish Hatchery Weir	BC	7.5		--
Coleman Powerhouse Tailrace	BC	8.0	490	--
North Fork and South Fork Confluence	BC	17.1	830	--
Wildcat Diversion Dam	NFBC	2.8	1070	18
Eagle Canyon Diversion Dam	NFBC	5.4		64
Digger Creek	NFBC	5.5	1470	--
North Battle Creek Feeder Diversion Dam	NFBC	9.6		50
Bailey Creek	NFBC	9.8	2110	--
Fish Blockage	NFBC	14.5		--
Keswick Diversion Dam	NFBC	15.1	3650	128 (with Al Smith Diversion)
Coleman Diversion Dam	SFBC	2.5	1000	340
Ripley Creek	SFBC			--
Inskip Diversion Dam	SFBC	8.0	1415	220
Soap Creek	SFBC			--
South Diversion Dam	SFBC	14.4	2030	100
Fish Blockage	SFBC			--

Notes:

BC Mainstem Battle Creek

NFBC North Fork Battle Creek

SFBC South Fork Battle Creek

Table K-2. Cumulative Percentiles of Historic Monthly Flow in Battle Creek below Coleman National Fish Hatchery (cfs) for the 1963–1993 Period of Record

Percentile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TAF/yr
0%	234	260	266	231	266	207	168	160	154	139	205	224	173
10%	345	340	345	343	331	292	220	191	203	205	255	259	223
20%	399	391	441	436	375	300	224	210	216	222	263	311	253
30%	445	508	529	476	396	317	250	229	231	250	295	344	273
40%	458	538	593	515	462	367	265	238	245	275	339	405	292
50%	579	635	676	605	595	448	305	248	252	296	366	462	380
60%	788	708	741	659	651	489	346	253	276	318	415	538	405
70%	864	845	833	729	744	521	384	291	279	327	438	583	415
80%	983	939	879	894	799	641	404	295	294	362	467	792	465
90%	1,187	1,072	1,301	1,020	851	739	438	325	322	391	765	1,041	517
100%	2,434	1,919	1,802	1,135	1,070	1,074	666	461	423	589	1,058	1,602	629

Note: Average Flow = 501 cfs

Table K-3. Example Monthly Calculations of North Fork Battle Creek Flows and Diversions for No Action Alternative for 10% Monthly Flows (cfs)

		Location on Battle Creek	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Watershed (mile^2)	357	Battle Creek at Coleman National Fish Hatchery Flow	345	340	345	343	331	292	220	191	203	205	255	259
		Total Springs	65	65	65	65	65	65	65	65	65	65	65	65
Watershed (mile^2)	80	Keswick Springs	20	20	20	20	20	20	20	20	20	20	20	20
Fraction of Watershed	0.224	Estimate of Flow at Keswick Diversion Dam	83	82	83	82	80	71	55	48	51	51	62	63
Diversion Capacity	128	Estimate of Volta Diversions	80	79	80	79	77	68	52	45	48	48	59	60
		Instream Flow Target	3	3	3	3	3	3	3	3	3	3	3	3
		Flow Below Keswick Dam	3	3	3	3	3	3	3	3	3	3	3	3
Watershed (mile^2)	133	Upstream Springs	20	20	20	20	20	20	20	20	20	20	20	20
Fraction of Watershed	0.372	Estimate of Flow at North Battle Creek Feeder Diversion Dam	49	48	49	48	47	41	30	26	28	24	35	36
Diversion Capacity	50	Estimate of North Battle Creek Feeder Diversion	46	45	46	45	44	38	27	23	25	21	32	33
		Instream Flow Target	3	3	3	3	3	3	3	3	3	3	3	3
		Flow Below North Battle Creek Feeder Diversion Dam	3	3	3	3	3	3	3	3	3	3	3	3
Watershed (mile^2)	186	Upstream Springs	25	25	25	25	25	25	25	25	25	25	25	25

		Location on Battle Creek	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fraction of Watershed	0.521	Estimate of Flow at Eagle Canyon Diversion Dam	46	45	45	45	43	38	27	23	24	29	32	33
Diversion Capacity	64	Estimate of Eagle Canyon Diversion	43	42	42	42	40	35	24	20	21	26	29	30
		Instream Flow Target	3	3	3	3	3	3	3	3	3	3	3	3
		Flow Below Eagle Canyon Diversion Dam	3	3	3	3	3	3	3	3	3	3	3	3
Watershed (mile^2)	189	Upstream Springs	35	35	35	35	35	35	35	35	35	35	35	35
Fraction of Watershed	0.529	Estimate of Flow at Wildcat Diversion Dam	15	15	15	15	15	15	14	14	14	14	15	15
Diversion Capacity	18	Estimate of Wildcat Diversion	12	12	12	12	12	12	11	11	11	11	12	12
		Instream Flow Target	3	3	3	3	3	3	3	3	3	3	3	3
		Flow Below Wildcat Diversion Dam	3	3	3	3	3	3	3	3	3	3	3	3

Table K-4. Example Monthly Calculations of South Fork Battle Creek Flows and Diversions for No Action Alternative for 10% Monthly Flows (cfs)

		Location on Battle Creek	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Watershed (mile^2)	67													
Fraction of Watershed	0.188	Estimate of Flow at South Diversion Dam	53	52	53	52	50	43	29	24	26	26	36	36
Diversion Capacity	100	Estimate of South Dam Diversion	48	47	48	47	45	38	24	19	21	21	31	31
		Instream Flow Target	5	5	5	5	5	5	5	5	5	5	5	5
		Flow Below South Diversion Dam	5	5	5	5	5	5	5	5	5	5	5	5
		Estimate of Flow at Soap Creek Feeder	10	10	10	10	10	10	10	10	10	10	10	10
Diversion Capacity	10	Estimate of Soap Creek Feeder Diversion	10	10	10	10	10	10	10	10	10	10	10	10
		Instream Flow Target	0	0	0	0	0	0	0	0	0	0	0	0
		Flow Below Soap Creek Feeder	0	0	0	0	0	0	0	0	0	0	0	0
Diversion Capacity	150	Estimate of Cross-Country Canal Flow	125	123	125	125	120	106	79	68	73	69	92	93
Diversion Capacity	120	Estimate of South Canal Flow	58	57	58	57	55	48	34	29	31	31	41	41
Diversion Capacity	222	Estimate of South Powerhouse Flow	183	180	183	182	175	153	113	97	104	100	132	135
Diversion Capacity	0	South Powerhouse Connector	0	0	0	0	0	0	0	0	0	0	0	0

		Location on Battle Creek	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Watershed (mile^2)	88													
Fraction of Watershed	0.284	Estimate of Flow at Inskip Diversion Dam	204	201	204	203	195	171	127	109	117	113	148	151
Diversion Capacity	220	Estimate of Inskip Diversion	199	196	199	198	190	166	122	104	112	108	143	146
		Instream Flow Target	5	5	5	5	5	5	5	5	5	5	5	5
		Flow Below Inskip Diversion Dam	5	5	5	5	5	5	5	5	5	5	5	5
		Estimate of Flow at Ripley Creek Feeder	5	5	5	5	5	5	5	5	5	5	5	5
Diversion Capacity	5	Estimate of Lower Ripley Creek Feeder Diversion	5	5	5	5	5	5	5	5	5	5	5	5
		Instream Flow Target	0	0	0	0	0	0	0	0	0	0	0	0
		Flow Below Ripley Creek Feeder	0	0	0	0	0	0	0	0	0	0	0	0
Diversion Capacity	283	Estimate of Inskip Powerhouse Flow	247	243	246	245	236	206	151	129	138	139	177	180
Diversion Capacity	0	Inskip Powerhouse Connector	0	0	0	0	0	0	0	0	0	0	0	0
Watershed (mile^2)	102													
Fraction of Watershed	0.286	Estimate of Flow at Coleman Diversion Dam	258	254	258	256	246	215	157	134	144	145	185	188
Diversion Capacity	340	Estimate of Coleman Diversion	253	249	253	251	241	210	152	129	139	140	180	183

		Location on Battle Creek	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Instream Flow Target	5	5	5	5	5	5	5	5	5	5	5	5
		Flow Below Coleman Diversion Dam	5	5	5	5	5	5	5	5	5	5	5	5
Watershed ($mile^2$)	14	Upstream Springs	15	15	15	15	15	15	15	15	15	15	15	15
Fraction of Watershed	0.039	Estimate of Baldwin Creek Flow	26	26	26	26	25	24	21	20	20	20	22	23
Diversion Capacity	15	Estimate of Pacific Power Diversion	15	15	15	15	15	15	15	15	15	15	15	15
Diversion Capacity	35	Asbury Pipe Pumping	11	11	11	11	10	9	6	5	5	5	7	8
		Instream Flow Target	0	0	0	0	0	0	0	0	0	0	0	0
		Baldwin Creek Flow	0	0	0	0	0	0	0	0	0	0	0	0
		Flow Below Confluence	8	8	8	8	8	8	8	8	8	8	8	8
Diversion Capacity	380	Estimate of Coleman Powerhouse Flow	291	287	291	289	279	246	185	160	170	171	214	217