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Concentration of Dissolved Gases in the Willamette, Cowlitz, and Boise Rivers, 1970-72

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Concentration of Dissolved Gases in the Willamette, Cowlitz, and Boise Rivers, 1970-72

BRUCE H. MONK,[1] EARL DAWLEY,[1] and KIRK BEININGEN[2]

ABSTRACT

Data on dissolved nitrogen, dissolved oxygen, total gas pressure, and water temperatures are presented for the Willamette, Cowlitz, and Boise rivers. Water samples were taken upstream and downstream of dams and over a wide range of river and dam discharges to obtain data on the relation between river flow and dam discharges and their effect on the total gas regime of the rivers.

INTRODUCTION

In recent years fishery scientists have shown that high concentrations of dissolved atmospheric gases in the Columbia and lower Snake rivers cause gas bubble disease and, during years of high flow, can result in up to 68% mortality of juvenile and adult Pacific salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdneri* (Ebel 1971, 1973). The high concentrations occur when air is entrained in water passing over spillways and forced into solution by high pressures in the stilling basin (Ebel 1969; Beiningen and Ebel 1970).

In 1970, fishery agencies and the U.S. Army Corps of Engineers became concerned that heavy spilling of water over Lost Creek Dam (now under construction 247 km from the mouth of the Rogue River) would create supersaturated concentrations of dissolved gas harmful to native stocks of salmon and steelhead trout and to hatchery-released stocks of coho salmon, *O. kisutch*, and fall chinook salmon, *O. tshawytscha*. Hatchery stocks could also be affected by supersaturated water supplied to the hatchery by a regulating reservoir downstream from the dam. Therefore, a nitrogen monitoring program was established at various hydroelectric projects which would be pertinent to spillway design modifications at Lost Creek Dam. The program included many projects on the Willamette Valley system, Lucky Peak Dam on the Boise River, and Mayfield Dam on the Cowlitz River (Figs. 1, 2, 3). There was also concern over the possibility of high concentrations in the reservoirs below Green Peter Dam and Lookout Point Dam (Fig. 2) which supply water for South Santiam Hatchery and Dexter Rearing Ponds, respectively (operated by Fish Commission of Oregon).

To determine whether discharges from the dams on the Willamette and Cowlitz River systems would create supersaturated concentrations of dissolved gas, extensive sampling and analysis for dissolved gases was done during 1970, 1971, and 1972. Samples were taken near dams over a wide range of river flow and spillway and regulating outlet discharges (regulating outlets are low level valved gates used to draw down reservoir water levels farther than possible by spilling) to obtain data on the relation between river flow and dam discharges and their effect on the total gas regime of the rivers.

Additional samples were taken at Lucky Peak Dam on the Boise River (Fig. 3) to determine the concentrations of dissolved gases below a flip bucket designed to dissipate energy in the spillrace and thereby eliminate supersaturated concentrations. The U.S. Army Corps of Engineers felt that such deflectors, if effective, could be a possible answer to the potential supersaturation problem at Lost Creek Dam.

This report presents data on gas concentrations and related water temperatures of water samples taken at forebays and tailraces of dams in the Willamette River drainage, Mayfield Dam on the Cowlitz River, and Lucky Peak Dam on the Boise River. All sampling and analysis were done by the National Marine Fisheries Service under contract with the U.S. Army Corps of Engineers.

PROCEDURE

Water samples were collected with a modified Van Dorn sampler and then put in standard biochemical-oxygen-demand sample bottles (300

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ml) by means of a tube running from the bottom of the sampler. The air interface and agitation of sample were minimized by placing the tube at the bottom of the sample bottle. The bottles were allowed to overflow up to 3 times their volume and were immediately placed in a chilled ice chest.

All of the samples were analyzed within 24 h of the time of collection. Dissolved nitrogen analyses were done with an Arthur H. Thomas modification of the Van Slyke-Neill manometric blood gas analyzer (Van Slyke and Neill 1924) and with a Fisher-Hamilton gas partitioner model No. 29. The method used was that described by Swinnerton, Linnenbom, and Cheek (1962).

The gas partitioner was calibrated by analyzing at least three samples on the partitioner and the Van Slyke. A graph of partitioner units versus Van Slyke concentration values (milligrams per liter) was established, so that other samples could be run on the partitioner and resulting saturation values derived from the graph. An Alsterburg modified Winkler method was used for the determination of the dissolved oxygen levels, and similar calibration techniques were used to calibrate the partitioner (American Public Health Association 1971).

PRESENTATION OF DATA

Tables 1-12 correspond to the numbers in Figures 2 and 3, which indicate the dams where water was sampled. These tables give the locations of the various sample stations at each dam and the dates on which samples were taken. They also give dissolved oxygen concentrations (mg/l and % of saturation), dissolved nitrogen plus argon concentrations (ml/l N_2 + Ar and % of saturation), total gas pressure (mm Hg and % of saturation), and related water temperature (°C). Saturation values were calculated from tables by Weiss (1970) and then corrected for altitude. In cases where hourly spill flow and hourly total flow are equal, the samples were taken directly from spillway discharge, and there was no possibility of dilution by turbine discharge. When the total hourly flow is larger than the hourly spill, the sample was taken during both spilling and powerhouse operation, and there was a good possibility of the discharges mixing.

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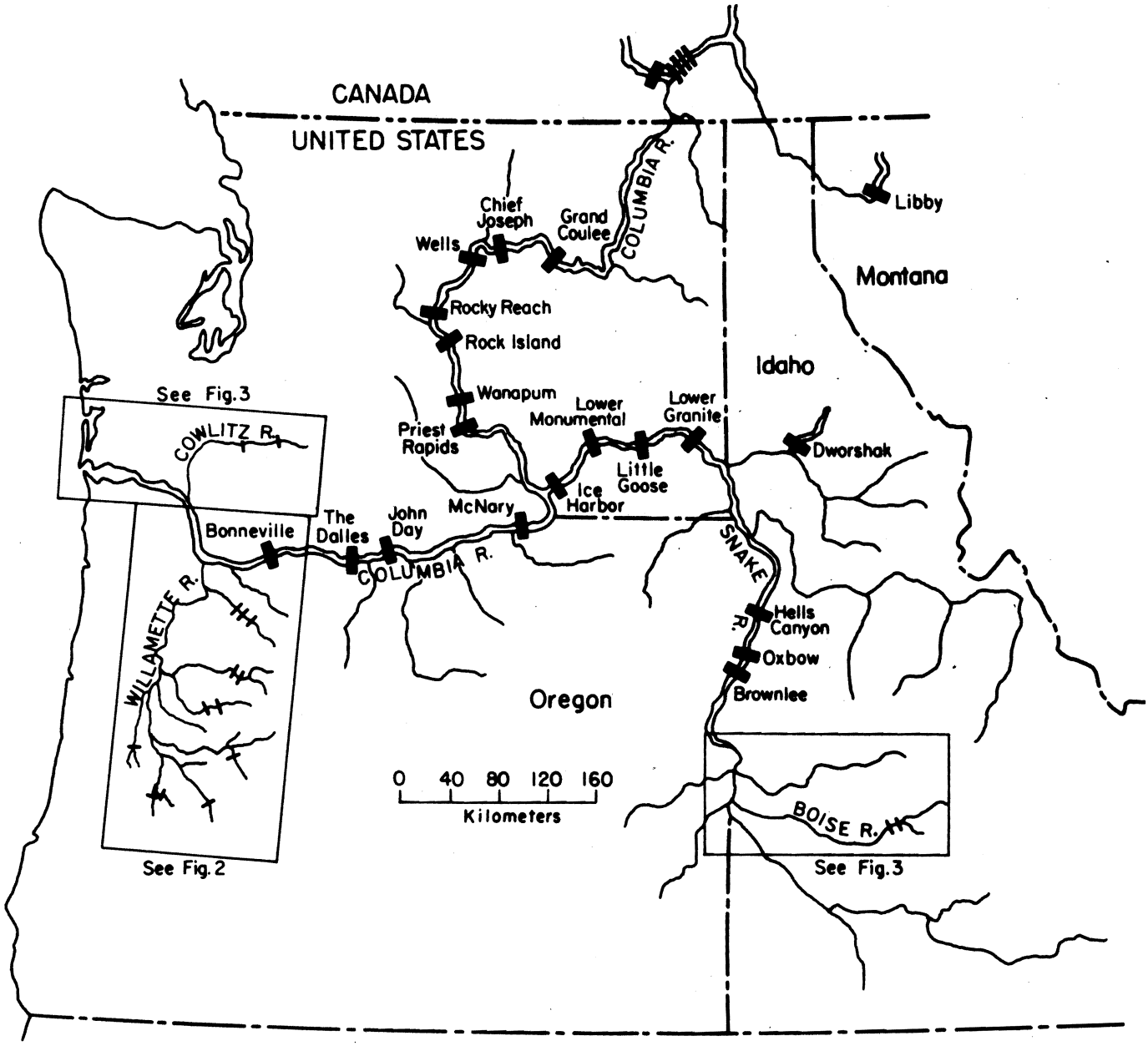

Figure 1.—Map of Columbia River drainage showing locations of tributaries sampled to determine concentrations of dissolved atmospheric gases.

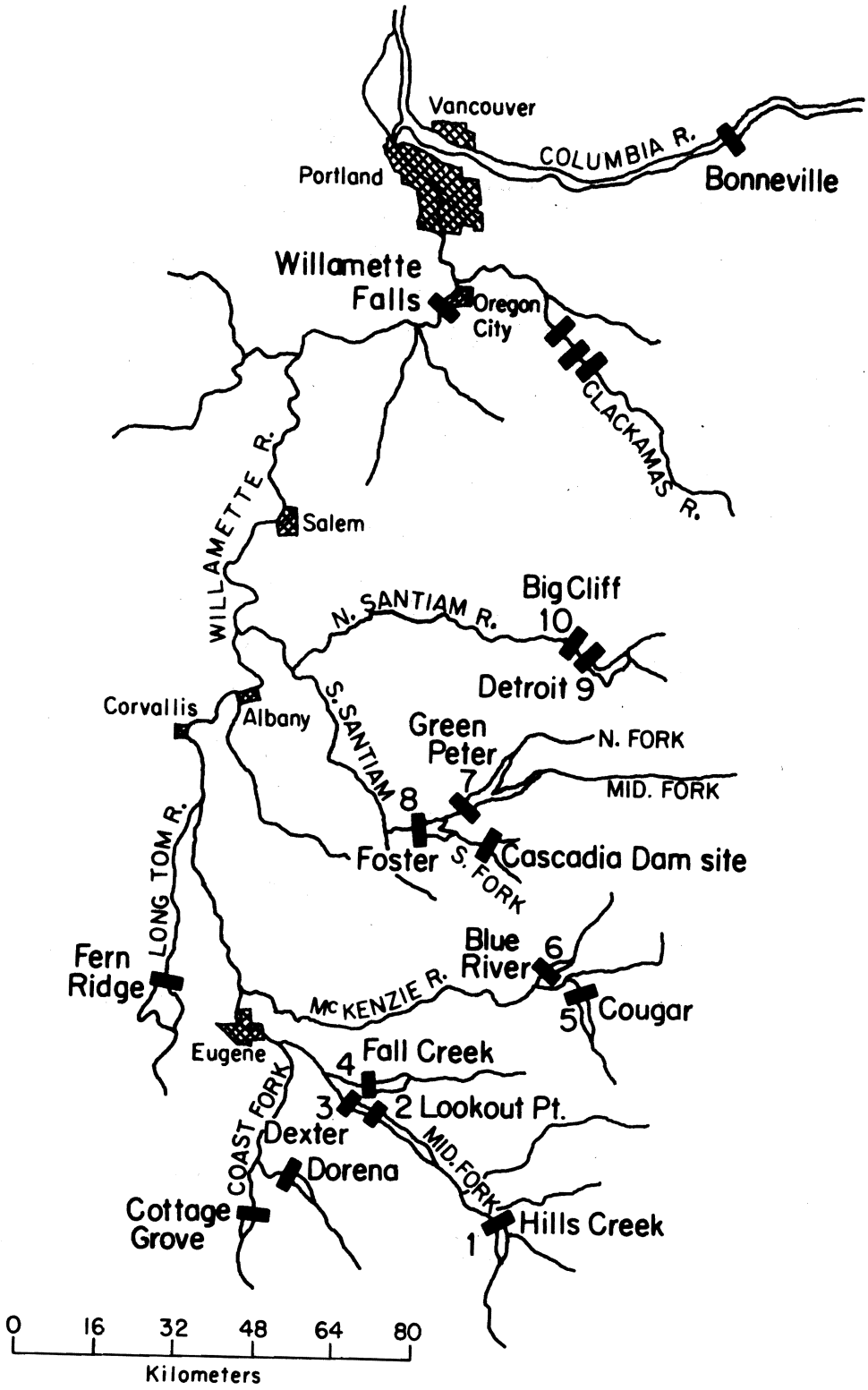

Figure 2.— Map of Willamette River drainage. Numbers indicate dams where water was sampled to determine concentration of dissolved atmospheric gases.

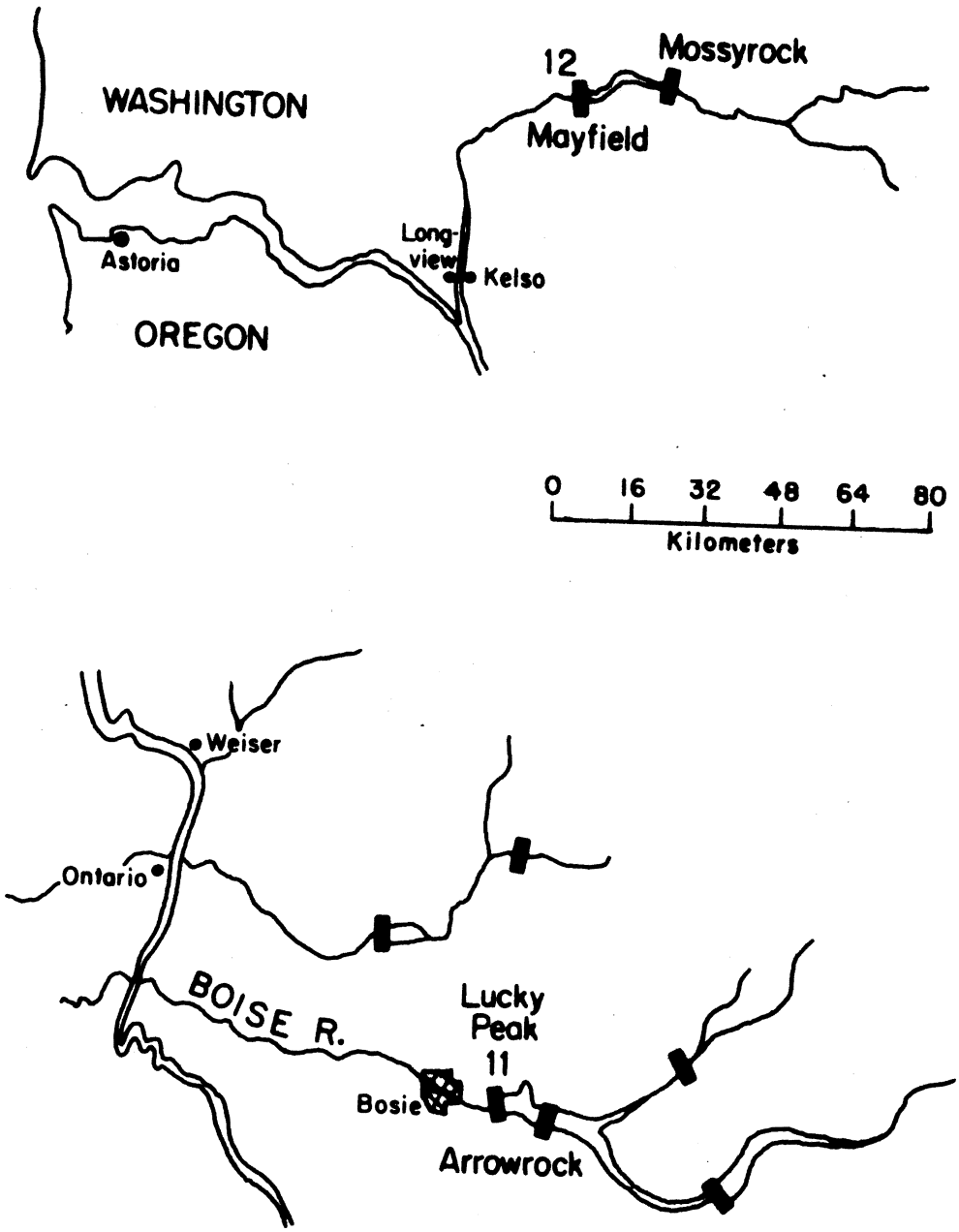

Figure 3.—Map of Cowlitz River (top) and Boise River (bottom). Numbers indicate dams where water was sampled to determine concentration of dissolved atmospheric gases.

Table 1.--Concentrations of dissolved atmospheric gases and related water temperatures at Hills Creek Dam.

Location		Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay	- spillway side (in front of intake for regulating outlets)	2	2	71	4	4.7	11.50	94.6	15.76	99.1	705.5	98.1	0	0.0	0.0
Tailrace	- regulating outlet (0.1 km downstream)	2	2	71	1	4.8	13.30	108.4	17.28	107.7	783.4	107.7	1	136	136
		2	2	71	1	4.8	13.10	106.8	17.28	107.7	780.9	107.4	1	181	181

Table 2.--Concentrations of dissolved atmospheric gases and related water temperatures at Lookout Point Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - powerhouse side (from upper deck of dam in front of turbine intakes)	7	27	71	37	12.8	9.30	91.0	13.76	101.3	729.1	99.2	0	0.0	0.0
	7	28	71	37	11.4	9.80	92.8	14.16	101.3	731.5	99.5	0	0.0	0.0
	7	29	71	37	11.4	10.00	94.7	13.52	96.7	708.1	96.3	0	0.0	0.0
Forebay - spillway side (from upper deck of dam, midway between spillways)	2	2	71	18	5.0	12.20	98.9	16.08	99.6	730.8	99.4	0	0.0	0.0
	7	27	71	16	15.0	9.10	93.4	13.44	103.5	745.3	101.4	0	0.0	0.0
	7	28	71	15	14.0	9.00	90.4	13.36	100.8	725.5	98.7	0	0.0	0.0
	7	28	71	15	12.6	9.20	89.6	13.28	97.4	704.4	95.8	0	0.0	0.0
	7	29	71	16	13.6	9.70	96.6	13.28	99.4	726.7	98.8	0	0.0	0.0
	8	3	71	64	8.8	8.75	78.0	14.48	97.9	689.3	97.3	0	0.0	0.0
	8	4	71	64	9.2	9.15	82.3	15.04	102.6	722.8	98.3	0	0.0	0.0
	8	4	71	64	9.2	9.50	85.5	14.24	97.1	696.3	94.7	0	0.0	0.0
	3	15	72	6	6.8	11.80	100.1	15.92	102.8	751.4	102.8	0	0.0	0.0
	3	15	72	6	6.8	11.80	100.1	15.92	102.8	751.4	102.8	0	0.0	0.0
	3	20	72	6	8.0	12.30	107.5	15.52	103.0	763.9	103.9	0	0.0	0.0
Tailrace - spillway (north bank, 0.5 km downstream)	2	5	70	1	6.7	13.60	114.1	17.92	114.5	847.1	114.2	1	71	71
	7	27	71	1	15.3	10.30	105.5	13.84	106.3	786.1	106.0	2	57	57
	7	28	71	1	16.9	10.50	111.3	14.24	112.8	832.4	112.3	5	113	113
	7	29	71	1	17.0	10.00	106.2	13.92	110.5	811.4	109.4	5	184	184
	7	29	71	1	18.1	10.40	113.0	14.56	118.0	864.7	116.6	1	57	57
	3	15	72	1	6.8	13.20	111.0	17.52	112.2	829.0	111.8	5	57	57
	3	20	72	1	8.1	13.30	115.5	17.44	115.1	852.4	114.9	5	85	85
	3	20	72	1	8.0	13.40	116.1	18.00	118.5	873.2	117.8	5	113	113
	3	20	72	1	8.0	13.60	117.8	18.00	118.5	875.8	118.1	5	170	170
Tailrace - regulating outlet (north bank, 0.5 km downstream)	2	2	71	1	5.3	15.10	122.3	20.32	125.7	924.4	124.7	1	113	113
	2	2	71	1	5.2	15.49	125.1	19.65	121.2	903.1	121.8	1	184	184
	8	3	71	1	10.3	12.70	116.3	16.64	115.2	854.5	115.2	3	113	113
	8	3	71	1	11.3	12.60	118.1	16.80	118.9	878.1	118.4	2	113	113
	8	4	71	1	12.8	11.30	109.6	14.96	109.2	809.3	109.1	3	57	57
	8	4	71	1	10.9	12.90	119.8	16.95	118.9	881.0	118.8	3	184	184
	8	4	71	1	11.0	13.10	121.9	17.20	120.9	896.0	120.8	2	113	113
Tailrace - powerhouse (from tailrace deck of powerhouse in turbine discharge)	7	27	71	1	9.9	10.10	91.6	14.16	97.2	712.3	96.1	0	0.0	67
	7	28	71	1	11.9	10.00	95.0	14.32	102.6	748.8	101.0	0	0.0	67
	7	29	71	1	13.1	9.80	95.7	14.00	102.9	751.2	101.3	0	0.0	67
	8	3	71	1	11.8	9.70	92.0	14.80	105.8	762.7	102.9	0	0.0	0.0

Table 3.--Concentrations of dissolved atmospheric gases and related water temperatures at Dexter Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - middle (from upper deck, between spillway and powerhouse)	2	5	70	1	6.3	12.40	103.0	16.64	105.4	776.8	104.8	0	0.0	0.0
	2	5	70	5	6.3	12.30	102.2	16.40	103.8	766.7	103.4	0	0.0	0.0
	7	28	71	13	12.6	9.90	95.6	13.60	98.9	728.2	98.2	0	0.0	0.0
	7	29	71	13	12.0	9.50	90.5	13.52	97.1	710.0	95.8	0	0.0	0.0
	3	15	72	8	6.6	12.10	101.3	16.48	105.1	772.5	104.2	0	0.0	0.0
	3	15	72	8	6.6	12.10	101.3	16.48	105.1	772.5	104.2	0	0.0	0.0
Forebay - spillway side (in front of water intake for Dexter Rearing Ponds)	8	3	71	13	12.6	9.10	87.9	13.59	98.8	715.9	96.6	0	0.0	0.0
	8	4	71	13	12.7	9.50	91.9	13.79	100.5	731.8	98.7	0	0.0	0.0
	3	15	72	11	6.5	12.60	105.2	16.40	104.3	774.2	104.4	0	0.0	0.0
	3	15	72	11	6.5	12.60	105.2	16.40	104.3	774.2	104.4	0	0.0	0.0
	3	20	72	11	7.4	11.70	99.9	16.48	107.0	781.7	105.4	0	0.0	0.0
Forebay - Dexter Rearing Pond (from first rearing pond, water supplies from forebay)	2	5	70	1	6.1	12.00	99.0	16.16	101.6	750.5	101.0	0	0.0	0.0
	2	2	71	1	5.4	11.63	94.2	16.5	102.1	745.8	100.4	0	0.0	0.0
	3	15	72	1	7.0	11.90	100.4	16.16	103.8	765.2	103.0	0	0.0	0.0
	3	15	72	1	7.1	11.00	93.0	16.16	104.0	755.2	101.7	0	0.0	0.0
	3	15	72	3	7.0	11.90	100.4	16.16	103.8	765.2	103.0	0	0.0	0.0
	3	15	72	3	7.1	11.00	93.0	16.16	104.0	755.2	101.7	0	0.0	0.0
	3	20	72	3	8.3	11.20	97.8	15.76	104.5	763.6	103.0	0	0.0	0.0
Tailrace - powerhouse (0.1 km downstream of powerhouse, in turbine discharge)	3	15	72	1	7.0	12.30	103.8	16.4	105.3	779.4	104.9	0	0.0	3.9
Tailrace - spillway (north bank 0.5 km downstream)	6	2	70	1	13.8	12.10	119.7	16.72	124.4	913.9	123.0	3	67	67
	6	2	70	4	13.5	12.20	119.9	16.72	123.6	909.9	125.5	3	67	67
	3	15	72	1	6.9	14.00	117.8	18.08	115.8	862.1	116.0	6	187	187
	3	20	72	1	7.0	13.90	117.3	18.32	117.7	871.9	117.3	4	215	215
Tailrace - spillway (north bank 3.7 km downstream)	3	15	72	1	7.5	13.40	114.5	17.28	112.3	836.1	112.5	6	187	297
Tailrace - spillway (north bank 7.4 km downstream)	3	15	72	1	7.8	12.70	109.3	16.32	109.4	811.3	109.2	6	187	297
	3	20	72	1	7.8	12.80	110.2	17.04	111.5	824.8	111.0	4	215	326

Table 4.--Concentrations of dissolved atmospheric gases and related water temperatures at Fall Creek Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - spillway side (in front of intake for regulating outlet)	8	6	70	1	22.3	8.50	101.0	11.92	104.8	766.6	103.9	0	0.0	0.0
	8	6	70	11	21.3	8.40	97.9	12.08	104.3	759.3	102.9	0	0.0	0.0
	8	6	70	22	16.1	3.80	39.8	13.68	107.3	688.1	93.3	0	0.0	0.0
	11	20	70	1	8.2	10.69	93.0	16.08	106.3	767.3	103.4	0	0.0	0.0
	12	16	70	11	6.1	11.88	98.7	15.98	101.2	742.4	100.6	0	0.0	0.0
	2	2	71	22	5.9	11.70	96.2	16.24	101.8	746.1	100.6	0	0.0	0.0
Tailrace - regulating outlets (from primary stilling basin)	8	6	70	1	17.3	9.20	98.3	14.00	111.7	806.6	108.7	1	14	14
	11	20	70	1	8.1	11.62	100.9	15.51	102.3	756.1	101.9	1	14	14
	12	16	70	8	6.1	13.22	109.2	17.68	111.3	821.6	110.7	1	42	42
	12	16	70	1	6.1	12.30	101.6	17.50	110.2	803.4	108.3	1	42	42
	12	16	70	3	6.1	13.17	108.8	17.92	112.9	829.8	111.8	1	42	42
	12	16	70	1	6.1	13.07	108.0	17.78	112.0	823.4	111.0	1	57	57
	12	16	70	2	6.1	13.31	109.9	17.92	112.9	831.6	112.1	1	57	57
	12	16	70	1	6.1	12.90	106.6	17.08	107.6	795.6	107.2	1	28	28
	12	16	70	3	6.1	12.75	105.3	17.20	108.3	798.1	107.6	1	28	28
	12	16	70	2	6.1	12.37	102.2	16.27	102.5	759.3	102.3	1	14	14
	12	16	70	1	6.1	12.01	99.2	16.04	101.0	746.3	100.6	1	14	14
	2	2	71	1	6.1	13.80	114.0	18.56	116.9	861.2	116.1	1	99	99
	2	2	71	1	6.1	14.10	116.5	18.64	117.4	867.9	117.0	1	127	127
Tailrace - regulating outlets (from secondary stilling basin)	8	6	70	1	17.2	9.10	97.0	13.92	110.8	799.8	107.8	4	14	14
	12	16	70	1	6.1	13.04	105.2	17.32	106.5	806.2	106.1	1	42	42
Tailrace - regulating outlets (from west bank, 0.1 km downstream)	11	20	70	1	8.2	11.92	103.7	17.13	113.2	824.0	111.0	1	14	14
	12	16	70	1	6.1	12.99	107.3	17.41	109.6	808.8	109.0	1	42	42
	12	16	70	1	6.1	13.16	108.7	17.38	109.5	809.9	109.2	1	57	57
	12	16	70	1	6.1	12.79	105.6	16.75	105.5	782.2	105.4	1	28	28
	12	16	70	1	6.1	12.41	102.5	16.13	101.6	754.7	101.7	1	14	14
Tailrace - regulating outlets (from bridge, 0.9 km downstream)	11	20	70	1	8.2	11.40	99.2	15.56	102.8	756.8	102.0	1	14	14
	12	16	70	1	6.1	12.97	107.1	17.20	108.3	800.9	107.9	1	42	42
Tailrace - regulating outlets (from bridge, 1.8 km downstream)	8	6	70	1	17.6	9.60	103.2	13.44	107.8	791.9	106.7	1	14	14
	11	20	70	1	8.2	11.39	99.1	16.03	105.9	774.7	104.4	1	14	14
	12	16	70	1	6.1	12.79	105.6	17.20	108.3	798.6	107.6	1	42	42

Table 5.--Concentrations of dissolved atmospheric gases and related water temperatures at Cougar Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - spillway side (in front of intake for regulating outlets)	9	10	70	1	18.8	9.30	106.4	12.64	107.7	767.2	107.3	0	0.0	0.0
	9	10	70	47	10.3	9.70	92.1	15.20	109.2	754.6	105.6	0	0.0	0.0
	11	19	70	21	9.2	10.17	93.7	14.28	99.7	707.0	98.5	0	0.0	0.0
Tailrace - powerhouse (.1 km downstream of powerhouse, in turbine discharge)	9	10	70	1	8.4	9.90	88.4	15.44	104.7	735.5	101.2	0	0.0	0.0
	11	19	70	1	9.0	10.31	93.4	14.40	98.9	710.5	97.8	0	0.0	62
	11	19	70	1	8.6	10.17	91.3	15.32	104.3	737.8	101.6	0	0.0	62
Tailrace - regulating outlets (from primary stilling basin)	9	10	70	1	10.1	11.90	110.7	16.48	116.0	833.2	114.7	1	8	8
	9	10	70	1	10.2	12.30	114.7	17.04	120.2	863.0	118.8	1	20	20
	9	10	70	1	10.3	13.10	122.4	17.68	125.0	901.8	124.1	1	33	33
	9	10	70	1	10.7	12.70	119.8	17.60	125.5	900.7	124.0	1	48	48
	11	19	70	1	9.6	12.75	117.2	16.95	118.0	854.4	117.6	1	31	31
	11	19	70	1	9.6	12.72	116.9	16.93	117.9	853.2	117.4	1	31	31
	11	19	70	1	9.5	12.89	118.2	17.12	118.9	861.2	118.5	1	71	71
	11	19	70	1	9.8	12.75	117.7	17.14	119.8	865.7	119.2	1	90	90
	2	3	71	1	4.7	14.50	118.0	19.52	121.4	875.5	120.5	1	99	99
	2	3	71	1	4.4	14.70	118.7	19.60	121.1	874.4	120.3	1	127	127
	2	3	71	1	4.4	14.40	116.3	18.80	116.1	842.6	116.0	1	170	170
Tailrace - regulating outlets (east bank, 0.9 km downstream)	11	19	70	1	9.0	10.48	94.9	14.66	100.7	723.0	99.5	1	33	33
	11	19	70	1	8.9	11.22	101.4	15.50	106.2	764.1	105.2	1	48	48
	11	19	70	1	9.4	12.40	113.4	16.76	116.2	838.4	115.4	1	71	71
	11	19	70	1	9.3	12.52	114.2	16.82	116.3	840.5	115.7	1	90	90
Tailrace - regulating outlets (from bridge, 4.4 km downstream)	9	10	70	1	11.4	11.70	112.2	15.76	114.0	824.4	113.5	1	48	48
	11	19	70	1	9.2	11.20	102.0	15.05	103.9	751.3	103.4	1	33	33
	11	19	70	1	9.5	11.57	106.1	15.46	107.4	777.6	107.0	1	90	90
	11	19	70	1	9.6	11.42	105.0	15.14	105.4	764.6	105.2	1	48	62
	11	19	70	1	9.6	11.45	105.2	15.75	109.6	789.1	108.6	1	71	71
	2	3	71	1	4.4	13.30	107.4	17.76	109.7	792.7	109.1	1	170	170

Table 6.--Concentrations of dissolved atmospheric gases and related water temperatures at Blue River Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - spillway side (in front of intake for regulating outlet)	3	7	72	15	5.0	11.90	98.0	16.48	103.7	741.3	102.4	0	0.0	0.0
	3	16	72	1	5.4	12.05	100.2	16.28	103.4	743.1	102.7	0	0.0	0.0
Tailrace - regulating outlets (east bank, 0.1 km downstream)	2	3	71	1	5.0	13.11	106.8	17.39	108.3	788.8	107.9	1	42	42
	3	7	72	1	5.0	14.40	117.4	19.44	121.1	877.8	120.0	1	105	105
Tailrace - regulating outlets (east bank, 0.25 km downstream)	3	7	72	1	5.0	14.40	117.4	10.52	121.5	880.7	120.4	1	105	105
	3	16	72	1	5.6	13.36	110.6	17.89	113.0	821.3	112.3	1	71	71
	3	16	72	1	6.0	13.00	109.4	17.51	111.6	811.8	111.0	1	71	71
Tailrace - regulating outlet (from bridge, 1.9 km downstream)	3	7	72	1	5.0	13.70	111.7	18.48	115.1	834.9	114.2	1	105	105
	3	16	72	1	6.0	13.16	110.0	16.88	107.6	789.8	108.0	1	71	71

Table 7.--Concentrations of dissolved atmospheric gases and related water temperatures at Green Peter Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - powerhouse side (from upper deck of dam in front of turbine intakes)	7	27	71	61	8.1	11.10	97.5	14.88	99.3	725.1	98.9	0	0.0	0.0
	7	29	71	37	7.5	10.50	90.0	15.52	102.2	731.6	99.8	0	0.0	0.0
	7	30	71	61	7.5	10.20	88.3	15.04	99.0	709.5	96.8	0	0.0	0.0
Forebay - spillway side (from upper deck of dam, midway between spillways)	1	22	71	1	4.7	11.70	94.4	16.16	99.6	722.2	98.5	0	0.0	0.0
	1	22	71	11	4.7	11.80	95.2	16.24	100.1	726.2	99.1	0	0.0	0.0
	1	25	71	1	5.0	11.80	95.9	16.24	100.9	731.5	99.8	0	0.0	0.0
	1	25	71	49	4.8	11.80	95.4	16.32	100.9	730.8	99.7	0	0.0	0.0
	7	27	71	12	12.4	10.30	100.1	14.04	102.8	749.4	102.2	0	0.0	0.0
	7	27	71	12	11.4	10.10	96.0	14.40	103.3	745.6	101.7	0	0.0	0.0
	7	28	71	12	10.8	10.10	94.6	14.32	101.4	732.9	100.0	0	0.0	0.0
	7	28	71	1	12.2	10.15	98.2	13.92	101.5	739.1	100.8	0	0.0	0.0
	7	29	71	12	11.2	10.00	94.6	14.32	102.3	737.8	100.6	0	0.0	0.0
	7	29	71	12	15.8	8.40	88.0	11.67	91.5	667.0	91.0	0	0.0	0.0
	8	2	71	80	7.5	9.50	82.2	15.41	101.5	714.3	97.4	0	0.0	0.0
	8	2	71	61	7.6	10.20	88.5	15.20	100.3	717.1	97.8	0	0.0	0.0
	8	2	71	80	7.6	9.80	85.1	15.04	99.2	705.8	96.3	0	0.0	0.0
	8	3	71	78	7.5	9.10	78.8	15.20	100.1	701.1	95.6	0	0.0	0.0
	8	3	71	78	8.0	9.10	79.8	15.12	100.7	706.1	96.3	0	0.0	0.0
	3	7	72	15	5.1	12.20	99.4	16.80	104.6	758.2	103.4	0	0.0	0.0
	3	14	72	8	6.2	12.90	108.1	17.12	109.4	799.0	109.0	0	0.0	0.0
	3	17	72	5	8.8	11.70	104.6	15.36	104.1	763.4	104.2	0	0.0	0.0
Tailrace - regulating outlets (from deck of fish evaluator, 2 km downstream)	2	3	70	3	6.8	14.70	123.7	19.92	127.6	937.6	126.5	2	190	190
	1	25	71	1	5.1	14.60	117.7	20.64	127.1	925.3	124.8	2	184	184
	7	30	71	1	7.0	12.90	109.1	16.43	105.7	788.3	106.3	2	57	57
	8	2	71	1	8.1	13.00	112.9	17.35	114.5	844.9	114.0	2	113	113
	8	3	71	1	8.0	14.20	123.1	17.52	115.4	865.5	116.7	2	184	184
Tailrace - spillway (from deck of fish evaluator, 0.2 km downstream)	2	3	70	3	6.9	14.20	119.8	19.28	123.8	909.4	122.7	2	190	190
	1	22	71	1	4.8	15.40	123.1	20.00	122.2	905.7	122.2	2	184	184
	1	22	71	1	4.9	15.30	122.7	20.56	126.0	926.6	125.0	2	184	184
	7	27	71	1	16.0	11.05	114.9	14.48	112.8	837.6	113.0	2	57	57
	7	28	71	1	16.0	11.14	115.9	15.44	120.2	882.1	119.0	2	113	113
	7	29	71	1	15.3	11.60	118.9	15.76	121.0	891.3	120.2	2	184	184
	3	7	72	1	5.6	14.80	120.8	19.76	123.1	907.0	122.3	2	312	312
	3	14	72	1	7.0	14.70	124.3	20.00	128.7	945.0	127.5	2	113	113
	3	14	72	1	6.5	15.10	126.1	19.60	124.7	924.4	124.7	2	184	184

Table 7.--Continued.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	$N_2 + Ar$ ml/l	$N_2 + Ar$ %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Tailrace - powerhouse (from deck of fish evaluator, 0.2 km downstream)	1	22	71	1	4.8	12.70	101.6	17.92	109.5	798.7	107.7	0	0.0	116
	1	25	71	1	4.9	12.80	102.6	17.76	108.8	796.1	107.4	0	0.0	184
	7	27	71	1	8.1	11.90	103.4	15.52	102.4	760.3	102.5	0	0.0	0.0
Tailrace - spillway (north bank of South Santiam River, just above mouth of Coal Creek)	1	22	71	1	4.9	14.30	114.6	19.04	116.6	860.2	116.0	2	184	184
	7	27	71	1	13.4	11.00	108.1	13.78	101.9	764.5	103.1	2	57	57
	7	28	71	1	15.9	10.59	109.9	14.00	108.8	807.2	108.9	2	113	113
	7	29	71	1	15.3	10.70	109.6	13.96	107.2	797.7	107.6	2	184	184
	3	7	72	1	5.7	14.10	115.4	18.72	116.9	862.7	116.4	2	312	312
	3	7	72	1	5.7	14.20	116.2	18.96	118.4	872.6	117.7	2	312	312
	3	14	72	1	6.7	13.90	116.7	18.16	116.1	859.8	116.0	2	113	113
	3	14	72	1	6.4	14.20	118.3.	18.56	117.8	872.4	117.7	2	184	184
Tailrace - regulating outlets (north bank of South Santiam River, just above mouth of Coal Creek)	1	25	71	1	5.1	14.10	113.6	19.20	118.2	867.6	117.0	2	184	184
	7	30	71	1	7.8	12.10	104.4	15.52	101.7	757.7	102.2	2	57	57
	8	2	71	1	9.8	12.50	113.1	16.32	111.8	829.7	111.9	2	113	113
	8	3	71	1	8.0	13.40	116.1	16.24	106.9	806.0	108.7	2	184	184

Table 8.--Concentrations of dissolved atmospheric gases and related water temperatures at Foster Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - spillway side (north bank of forebay, just above confluence with South Fork)	2	3	70	1	6.9	13.60	114.5	18.08	115.9	857.0	115.4	0	0.0	0.0
	2	3	70	5	6.9	13.30	112.0	18.16	116.4	856.1	115.2	0	0.0	0.0
	2	3	70	10	6.7	13.30	111.4	18.08	115.3	849.1	114.3	0	0.0	0.0
Forebay - spillway side (in front of water intake for South Santiam Hatchery)	2	3	70	16	6.9	13.10	110.3	18.08	115.9	850.5	114.5	0	0.0	0.0
	1	22	71	16	5.7	12.40	101.3	16.88	105.2	774.6	104.3	0	0.0	0.0
	7	21	71	20	9.4	10.04	89.8	14.92	101.1	733.6	98.7	0	0.0	0.0
	7	27	71	6	15.9	10.10	104.6	14.40	111.7	817.3	110.0	0	0.0	0.0
	7	28	71	2	18.8	8.90	97.9	12.64	103.6	760.5	102.4	0	0.0	0.0
	7	28	71	18	9.3	10.15	90.6	15.13	102.3	741.7	99.8	0	0.0	0.0
	7	29	71	2	18.6	9.10	99.7	12.47	101.8	753.0	101.4	0	0.0	0.0
	7	29	71	18	8.7	9.90	87.1	15.20	101.5	731.2	98.4	0	0.0	0.0
	8	2	71	2	23.0	8.10	96.8	11.52	101.8	748.6	100.8	0	0.0	0.0
	8	2	71	18	10.2	9.50	86.6	14.88	102.6	737.4	99.3	0	0.0	0.0
	8	3	71	2	22.8	7.20	85.7	10.47	92.2	676.9	91.1	0	0.0	0.0
	8	3	71	18	10.2	10.20	93.0	14.80	102.1	744.0	100.2	0	0.0	0.0
	3	7	72	10	5.8	14.20	116.3	18.64	116.4	863.1	116.2	0	0.0	0.0
Tailrace - spillway (north bank of South Santiam, 0.6 km downstream)	1	25	71	1	5.4	15.50	125.2	21.20	130.7	963.3	129.2	2	249	249
Tailrace - spillway (north bank of South Santiam, 1.9 km downstream)	3	7	72	1	5.8	14.20	115.9	18.64	116.0	863.1	115.8	2	334	411
Tailrace - spillway (north bank of South Santiam, 5.6 km downstream)	3	7	72	1	5.6	13.90	110.7	18.80	114.2	861.0	113.3	2	334	425

Table 8.--Continued.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Wiley Creek-from creek itself (0.1 km above confluence with South Santiam, not influenced by any dam)	3	7	72	1	5.1	12.50	100.2	16.88	103.4	764.8	102.6	0	0.0	0.0
South Santiam Hatchery - incubator tray	1	25	71	1	5.3	12.80	103.1	17.35	106.7	789.1	105.9	0	0.0	0.0
	3	7	72	1	5.9	13.20	107.9	17.28	107.7	803.0	107.6	0	0.0	0.0
South Santiam Hatchery - pond 8	2	3	70	1	6.9	12.50	104.9	18.08	115.5	842.7	113.1	0	0.0	0.0
	1	22	71	1	5.7	12.70	103.4	17.04	105.8	784.2	105.2	0	0.0	0.0
	1	23	71	1	6.7	13.20	110.2	17.76	112.9	836.0	112.2	0	0.0	0.0
	1	25	71	1	5.8	13.10	106.9	17.92	111.6	823.0	110.4	0	0.0	0.0
	3	7	72	1	5.5	13.10	106.0	17.92	110.7	817.3	109.6	0	0.0	0.0
South Santiam Hatchery - pond 2	1	22	71	1	5.7	10.90	88.7	16.56	102.9	744.1	99.8	0	0.0	0.0
	1	25	71	16	5.3	13.20	106.4	18.08	111.2	820.3	110.1	0	0.0	0.0
	1	25	71	1	5.9	11.00	90.0	16.95	105.8	763.1	102.4	0	0.0	0.0
South Santiam River - 2 km upstream from Cascadia dam site (not influenced by any dam)	3	7	72	1	5.5	12.60	100.1	17.12	103.8	782.1	102.9	0	0.0	0.0

Table 9.--Concentrations of dissolved atmospheric gases and related water temperatures at Detroit Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - spillway side (from upper deck of dam midway between spillways)	8	5	71	8	19.4	8.70	100.2	11.52	98.8	712.2	99.2	0	0.0	0.0
	8	5	71	8	17.2	8.50	93.6	12.47	102.6	723.6	100.8	0	0.0	0.0
	8	6	71	8	18.5	8.60	97.3	11.92	100.5	717.6	99.9	0	0.0	0.0
	8	6	71	8	18.6	9.10	103.2	12.16	102.7	738.5	102.8	0	0.0	0.0
	3	8	72	12	4.5	12.10	99.1	16.80	105.2	746.2	103.9	0	0.0	0.0
Forebay - powerhouse side (from upper deck of dam in front of turbine intakes)	8	5	71	50	8.3	10.00	90.1	14.56	99.6	701.4	97.7	0	0.0	0.0
Tailrace - spillway (from boat launch ramp, 1.2 km downstream)	3	8	72	1	4.8	14.50	118.1	19.04	118.5	860.6	118.2	6	201	201
Tailrace - powerhouse (from bridge, 0.3 km downstream)	8	5	71	1	9.0	10.10	91.3	14.16	97.1	698.3	95.9	0	0.0	55
Tailrace - spillway (from bridge, 0.33 km downstream)	8	5	71	1	17.1	10.20	110.6	13.84	112.1	812.4	111.6	6	57	57
	8	5	71	1	18.5	10.10	112.7	14.08	117.1	843.8	115.9	6	113	113
	8	5	71	1	17.6	10.50	115.0	14.40	117.8	850.9	116.9	6	184	184
	8	6	71	1	16.8	10.80	116.4	13.68	110.2	810.2	111.3	1	57	57
	8	6	71	1	17.7	10.30	113.1	13.92	114.0	827.1	113.6	1	113	113
	8	6	71	1	17.2	10.20	110.8	13.92	113.0	817.7	112.3	1	184	184
	3	8	72	1	4.6	14.50	117.5	19.20	118.9	862.1	118.4	6	201	201

Table 10.--Concentrations of dissolved atmospheric gases and related water temperatures at Big Cliff Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - spillway side (from upper deck of dam, midway between spillways)	8	5	71	8	9.1	10.10	91.6	16.00	110.0	771.7	106.0	0	0.0	0.0
	8	6	71	16	10.1	10.20	94.7	13.76	96.7	700.9	96.3	0	0.0	0.0
	3	8	72	10	4.5	14.10	114.0	18.88	116.7	843.9	115.9	0	0.0	0.0
Tailrace - spillway (from north bank, 3.2 km downstream)	3	8	72	1	5.1	14.50	118.6	19.35	120.9	877.9	120.2	2	241	326
Tailrace - spillway (from north bank, 0.3 km downstream)	3	8	72	1	5.2	15.80	129.6	20.64	129.3	942.4	129.0	2	241	326
Tailrace - spillway (from north bank, 0.06 km downstream)	3	8	72	1	4.7	14.50	117.4	19.12	118.3	861.3	117.9	2	241	241

Table 11.--Concentrations of dissolved atmospheric gases and related water temperatures at Lucky Peak Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - spillway side (intake for regulating outlet)	8	13	70	10	18.3	8.72	104.0	12.00	106.6	720.6	106.2	0	0.0	0.0
	8	13	70	1	19.3	9.00	109.5	11.92	107.9	735.0	108.3	0	0.0	0.0
	1	19	71	31	2.2	11.60	94.4	15.67	97.9	661.2	97.2	0	0.0	0.0
	1	19	71	31	2.1	11.58	93.9	15.61	97.3	657.3	96.6	0	0.0	0.0
	1	19	71	1	2.1	11.58	93.9	15.86	98.8	665.6	97.8	0	0.0	0.0
	1	19	71	40	2.1	11.60	94.1	15.88	99.0	666.5	98.0	0	0.0	0.0
	1	28	71	43	2.2	11.90	97.0	16.42	102.8	689.7	101.6	0	0.0	0.0
Tailrace - regulating outlet, bay 1 (from U.S.G.S. cable way, 0.8 km downstream)	8	13	70	1	15.0	9.57	105.5	13.09	108.2	737.2	107.6	1	122	122
	8	13	70	1	15.0	9.61	105.9	13.06	107.9	736.5	107.5	1	122	122
Tailrace - regulating outlet, bay 3 (from U.S.G.S. cable way, 0.8 km downstream)	1	19	71	1	2.3	13.11	106.2	17.52	109.0	742.2	108.4	1	85	85
	1	19	71	1	2.8	12.94	106.3	17.04	107.4	733.4	107.1	1	57	57
	1	19	71	1	3.2	13.09	108.6	17.26	109.8	750.0	109.5	1	113	113
Tailrace - regulating outlet, bay 5 (from U.S.G.S. cable way, 0.8 km downstream)	1	28	71	1	2.4	12.80	104.0	17.01	106.1	723.4	105.6	1	85	85
	1	28	71	1	2.8	13.05	107.1	17.26	108.7	742.1	108.3	1	113	113
Tailrace - regulating outlet, bay 3 (upstream of diversion dam, 3.2 km downstream)	1	19	71	1	2.4	12.98	105.4	17.12	106.8	729.2	106.5	1	85	85
	1	19	71	1	2.8	13.00	106.7	17.19	108.3	739.1	107.9	1	57	57
	1	19	71	1	3.2	12.93	107.3	17.07	108.6	741.6	108.3	1	113	113
Tailrace - regulating outlet, bay 5 (upstream of diversion dam, 3.2 km downstream)	1	28	71	1	2.5	13.00	105.9	17.26	107.9	736.0	107.4	1	85	85

Table 12.--Concentrations of dissolved atmospheric gases and related water temperatures at Mayfield Dam.

Location	Mo	Day	Yr	Depth (M)	Temp (°C)	O_2 mg/l	O_2 %sat	N_2 + Ar ml/l	N_2 + Ar %sat	TGP Hg(mm)	TGP %sat	No gates open	Hourly flow (cm) Spill	Hourly flow (cm) Total
Forebay - spillway side (from upper deck of dam midway between spillway)	3	11	71	10	4.3	11.85	92.6	16.44	98.3	726.8	97.1	0	0.0	0.0
	3	11	71	10	4.4	11.83	92.7	16.54	99.2	731.9	97.8	0	0.0	0.0
	8	26	71	1	16.7	10.55	110.3	13.80	107.9	810.1	108.2	0	0.0	0.0
	8	26	71	6	10.4	10.75	97.7	15.54	106.8	784.7	104.8	0	0.0	0.0
	8	26	71	12	10.0	10.24	92.2	15.54	105.9	770.9	103.0	0	0.0	0.0
Tailrace - spillway, bay 3 (north bank, 0.4 km downstream)	3	11	71	1	4.4	12.78	99.6	18.21	108.5	802.2	106.5	1	113	113
	3	11	71	1	4.4	13.20	102.8	18.62	110.9	821.7	109.1	1	198	198
Tailrace - spillway, bay 3 upstream from powerhouse on retaining wall)	3	11	71	1	4.4	13.00	101.3	17.86	106.4	792.5	105.2	1	283	283