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OREGON
ENVIRONMENTAL QUALITY
COMMISSION MEETING
MATERIALS 05/09/1994

DEQ

State of Oregon
Department of
Environmental
Quality

PUBLIC NOTICE

Special Emergency Telephone Conference Call Meeting

ENVIRONMENTAL QUALITY COMMISSION

Monday, May 9, 1994
3:00 p.m.

The Environmental Quality Commission (EQC) will hold an emergency meeting by telephone conference call for the purpose of considering adoption of an emergency rule to temporarily suspend the applicability of Oregon's water quality standard for Total Dissolved Gas on the Columbia River to allow spilling of water at dams to facilitate downstream migration of salmon smolts.

The public can attend the conference call at the following location:

Office of the Director
Department of Environmental Quality Offices
811 S. W. 6th Avenue
Portland, Oregon 97204

May 9 EQC Conference Call

- Bill Wessinger (here)
- Emery Castle (at home)
- Henry Lorenzen (at his office)
- Carol Whipple (at Lane County Extension Office)
- Linda McMahan (at home)

- Michael Huston (at office)

- Russ George (Corps of Engineers, Portland)
- Donna Darm (National Marine Fisheries Service, Seattle)

On call re: nitrogen questions:

Ron Boyce (Oregon Fish and Wildlife)
229-5410, extension 351

Major General Ernest Harrell
326-3700

State of Oregon
Dept of Environmental Quality
811 SW 6th Avenue
Portland, OR 97204-1390

FAX - (503) 229-6124

To: State of Oregon D.E.Q.	Date:5-9-94
From: PUBLIC AFFAIRS FAX USER	Page 001 of 002

SUBJECT: Emmergency EQC Meeting

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FROM: PUBLIC AFFAIRS FAX USER

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DEQ Headquarters (HQ7th)
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Steve Corson

DATE: 05-09-94
TIME: 13:17

CC:
SUBJECT: Emmergency EQC Meeting
PRIORITY:
ATTACHMENTS:

Public Notice

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Portland, Oregon 97204

Contact: Carolyn Young 503-229-6271

TEMPORARY RULE
Total Dissolved Gas - Columbia River

The following new rule was adopted by the Environmental Quality Commission as a temporary rule on May 9, 1994, and filed with the Secretary of State on May 10, 1994.

340-41-155 Effective on filing and for 7 consecutive days thereafter ending at midnight on the 7th day. This rule supersedes paragraphs 340-41-205(2)(n), 340-41-445(2)(n), 340-41-485(2)(n), 340-41-525(2)(n), 340-41-565(2)(n), 340-41-605(2)(n) and 340-41-645(2)(n) as these paragraphs apply to the Columbia River. In the Columbia River, the Total Dissolved Gas (TDG) concentration relative to atmospheric pressure at the point of sample collection shall not exceed 130 percent saturation as determined by the Department. The purpose of this temporary rule is to provide for emergency assistance to outmigrating salmon smolts in the mainstem of the Columbia River via increased spill over the mainstem dams. The responsible agency or agencies shall develop a monitoring program acceptable to the Department. The responsible agency or agencies shall conduct monitoring for TDG concentrations and for the incidence of gas bubble disease (GBD) sufficient to determine whether the resultant TDG concentrations cause a significant increase in GBD-related mortality in salmon populations. If such a significant increase in mortality is documented, as determined by the Director, the Director shall make such alteration in the maximum allowable TDG level, until a satisfactory level is achieved.

Statutory Authority: ORS 468.020 and 468B.048

Notice

Special Meeting

ENVIRONMENTAL QUALITY COMMISSION

Monday, May 16, 1994
9:00 a.m.

Conference Room 3a
Department of Environmental Quality Offices
811 S. W. 6th Avenue
Portland, Oregon 97204

On Monday, May 9, 1994, the Environmental Quality Commission held an emergency meeting by telephone conference call to consider a request to temporarily modify Oregon's water quality standard for Total Dissolved Gas on the Columbia River so as to allow additional water to be released over dam spillways to assist in the outmigration of juvenile salmon. After considerable discussion, the Commission adopted the attached Temporary Rule which raises the 110 percent of saturation to a maximum of 130 percent for a period of seven days. The Temporary rule requires monitoring of releases to determine the impact on beneficial uses.

On Monday, May 16, 1994, beginning at 9:00 a.m., the Commission will again meet to consider the matter. The Commission has expressed the desire to hear from fishery and water management experts and other parties that may be affected. Following receipt of testimony the Commission will deliberate further on the matter and may elect to extend the duration of the temporary rule, adopt a modified temporary rule, or take no action and thus allow the 110 percent of saturation standard to be reinstituted.

ENVIRONMENTAL QUALITY COMMISSION MEETING
Room 3A, DEQ Headquarters
811 SW Sixth Avenue, Portland
May 16, 1994

Agenda

9:00 a.m.*	Call to order
9:10 a.m.	Explanation of Request for Spill at Columbia River Dams (**Earl Dawley**, NMFS)
9:20 a.m.	Present Status of Spill and Total Dissolved Gas Concentrations at Columbia River Dams (**Jim Athearn**, Corps of Engineers)
9:30 a.m.	Interagency Panel on the Biological Effects of Total Dissolved Gas Supersaturation
	① **Mr. Ron Boyce** (ODFW) Mr. ~~Dr.~~ **Earl Dawley** (NMFS) **Dr. Allan Nebecker** (EPA) Mr. ~~Dr.~~ **Jim Athearn** (ACoE) **Dr. Margaret Filardo** (Fish Passage Center)
10:30 a.m.	Industry Panel
	② **Dr. Wes Ebel** **Dr. Gerald Bouck**
11:00 a.m.	Commercial Fishing Industry Panel
	③ Mr ~~Dr.~~ **Robert Heinith** (CRITFC) **Mr. Thane Tienson** (Save Our Wild Salmon)
11:30 a.m.	Environmental Advocacy Panel
	④ **Mr. Bill Bakke** (Oregon Trout) **Mr. Dan Rohlf** (NEDC)
12:00 noon	Lunch
1:00 p.m.	⑤ NMFS Monitoring Program Results (**Earl Dawley**)
2:00 p.m.	Public Testimony
	Commission Deliberation

* - times shown are approximations only, and panel presentations may begin earlier than times shown.

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Total Dissolved Gas - Columbia River

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340-41-155 Effective on filing and for 7 consecutive days thereafter ending at midnight on the 7th day. This rule supersedes paragraphs 340-41-205(2)(n), 340-41-445(2)(n), 340-41-485(2)(n), 340-41-525(2)(n), 340-41-565(2)(n), 340-41-605(2)(n) and 340-41-645(2)(n) as these paragraphs apply to the Columbia River. In the Columbia River, the Total Dissolved Gas (TDG) concentration relative to atmospheric pressure at the point of sample collection shall not exceed 130 percent saturation as determined by the Department. The purpose of this temporary rule is to provide for emergency assistance to outmigrating salmon smolts in the mainstem of the Columbia River via increased spill over the mainstem dams. The responsible agency or agencies shall develop a monitoring program acceptable to the Department. The responsible agency or agencies shall conduct monitoring for TDG concentrations and for the incidence of gas bubble disease (GBD) sufficient to determine whether the resultant TDG concentrations cause a significant increase in GBD-related mortality in salmon populations. If such a significant increase in mortality is documented, as determined by the Director, the Director shall make such alteration in the maximum allowable TDG level, until a satisfactory level is achieved.

Statutory Authority: ORS 468.020 and 468B.048

EPA - Qual. Criteria for H_2O

GASES, TOTAL DISSOLVED

CRITERION:

To protect freshwater and marine aquatic life, the total dissolved gas concentrations in water should not exceed 110 percent of the saturation value for gases at the existing atmospheric and hydrostatic pressures.

RATIONALE:

Fish in water containing excessive dissolved gas pressure or tension are killed when dissolved gases in their circulatory system come out of solution to form bubbles (emboli) which block the flow of blood through the capillary vessels. In aquatic organisms this is commonly referred to as "gas bubble disease". External bubbles (emphysema) also appear in the fins, on the opercula, in the skin and in other body tissues. Aquatic invertebrates are also affected by gas bubble disease, but usually at supersaturation levels higher than those lethal to fish.

The standard method of analyzing for gases in solutions has been the Van Slyke method (Van Slyke et al. 1934); now, gas chromatography also is used for determination of individual and total gases. For determination of total gas pressure, Weiss has developed the saturometer, a device based upon a thin-wall silicone rubber tube that is permeable to gases but impermeable to water. Gases pass from the water through the tube, thus raising the internal gas pressure which is measured by a manometer or pressure gauge connected to the tube (NAS, 1974). This method alone does not separate the total gas pressure into the separate components, but Winkler oxygen determinations can be run simultaneously, and gas concentrations can be calculated.

Total dissolved gas concentrations must be determined because analysis of individual gases may not determine with certainty that gas supersaturation exists. For example, water could be highly supersaturated with oxygen, but if nitrogen were at less than saturation, the saturation as measured by total gas pressure might not exceed 100 percent. Also, if the water was highly supersaturated with dissolved oxygen, the oxygen alone might be sufficient to create gas pressures or tensions greater than the criterion limits, but one would not know the total gas pressure or tension, or by how much the criterion was exceeded. The rare and inert gases such as argon, neon and helium are not usually involved in causing gas bubble disease as their contribution to total gas pressures is very low. Dissolved nitrogen (N_2), which comprises roughly 80 percent of the earth's atmosphere, is nearly inert biologically and is the most significant cause of gas bubble disease in aquatic animals. Dissolved oxygen, which is extremely bioactive, is consumed by the metabolic processes of the organism and is less important in causing serious gas bubble disease though it may be involved in initiating emboli formation in the blood (Nebeker et al. 1976a).

Percent saturation of water containing a given amount of gas varies with the absolute temperature and with the pressure. Because of the pressure changes, percent saturation with a given amount of gas changes with depth of the water. Gas supersaturation decreases by 10 percent per meter of increase in water depth because of hydrostatic pressure; a gas that is at 130 percent saturation at the surface would be at 100 percent saturation at 3 meters' depth. Compensation for altitude may be needed because a reduction in atmospheric pressure changes the water/gas equilibria, resulting in changes in solubility of dissolved gases.

There are several ways that total dissolved gas supersaturation can occur:

1. Excessive biological activity--dissolved oxygen concentrations often reach supersaturation because of excessive algal photosynthesis. Renfro (1963) reported gas bubble disease in fishes resulting, in part, from algal blooms. Algal blooms often accompany an increase in water temperature and this higher temperature further contributes to supersaturation.

2. Lindroff (1957) reported that water spillage at hydropower dams caused supersaturation. When excess water is spilled over the face of a dam it entrains air as it plunges to the stilling or plunge pool at the base of the dam. The momentum of the fall carries the water and entrained gases to great depths in the pool; and, under increased hydrostatic pressure, the entrained gases are driven into solution, causing supersaturation of dissolved gases.

3. Gas bubble disease may be induced by discharges from power-generating and other thermal sources (Marcello et al. 1975). Cool, gas-saturated water is heated as it passes through the condenser or heat exchanger. As the temperature of the water

rises, percent saturation increases because of the reduced solubility of gases at higher temperatures. Thus, the discharged water becomes supersaturated with gases and fish or other organisms living in the heated water may exhibit gas bubble disease (DeMont and Miller, 1972: Malouf et al. 1972; Keup, 1975).

In recent years, gas bubble disease has been identified as a major problem affecting valuable stocks of salmon and trout in the Columbia River system (Rulifson and Abel, 1971). The disease is caused by high concentrations of dissolved atmospheric gas which enter the river's water during heavy spilling at hydroelectric dams. A report by Ebel et al. (1975) presents results from field and laboratory studies on the lethal, sublethal and physiological effects of gas on fish, depth distribution of fish in the river (fish can compensate for some high concentrations of gas by moving deeper into the water column), detection and avoidance of gas concentrations by fish, intermittent exposure of fish to gas concentrations, and bioassays of many species of fish exposed to different concentrations of gas. Several conclusions resulting from these studies are:

1. When either juvenile or adult salmonids are confined to shallow water (1 m), substantial mortality occurs at and above 115 percent total dissolved gas saturation.

2. When either juvenile or adult salmonids are free to sound and obtain hydrostatic compensation either in the laboratory or in the field, substantial mortality still occurs when saturation

levels (of total dissolved gases) exceed 120 percent saturation.

3. On the basis of survival estimates made in the Snake River from 1966 to 1975, it is concluded that juvenile fish losses ranging from 40 to 95 percent do occur and a major portion of this mortality can be attributed to fish exposure to supersaturation by atmospheric gases during years of high flow.

4. Juvenile salmonids subjected to sublethal periods of exposure to supersaturation can recover when returned to normally saturated water, but adults do not recover and generally die from direct and indirect effects of the exposure.

5. Some species of salmon and trout can detect and avoid supersaturated water; others may not.

6. Higher survival was observed during periods of intermittent exposure than during continuous exposure.

7. In general, in acute bioassays, salmon and trout were less tolerant than the nonsalmonids.

Dawley and Ebel (1975) found that exposure of juvenile spring chinook salmon, Oncorhynchus tshawytscha, and steelhead trout, Salmo gairdneri, to 120 percent saturation for 1.5 days resulted in over 50 percent mortality; 100 percent mortality occurred in less than 3 days. They also determined that the threshold level where significant mortalities begin occurring is at 115 percent nitrogen saturation (111 percent total gas saturation in this test).

Rucker (1974), using juvenile coho salmon, Oncorhynchus kisutch, determined the effect of individual ratios of oxygen and nitrogen and established that a decrease in lethal effect occurred when the nitrogen content fell below 109 percent saturation even though total gas saturation remained at 119 percent saturation, indicating the importance of determining the concentration of the individual components (O_2 and N_2) of the atmospheric supersaturation. Nebeker et al. (1976a), using juvenile sockeye salmon, Oncorhynchus nerka, also showed that there was a significant increase in fish mortality when the nitrogen concentration was increased while holding the total percent saturation constant. They also showed that there was no significant difference in fish mortality at different CO_2 concentrations.

Research collected by Bouck et al. (1975) showed that gas supersaturated water at and above 115 percent total gas saturation is acutely lethal to most species of salmonids, with 120 percent saturation and above rapidly lethal to all salmonids tested. Levels as low as 110 percent will produce emphysema in most species. Steelhead trout were most sensitive to gas-supersaturated water followed by sockeye salmon, Oncorhyncnus nerka. Chinook salmon, Oncorhynchus tshawytscha, were intermediate in sensitivity. Coho salmon, Oncorhyncnus kisutch, were significantly the more tolerant of the salmonids though still much more susceptible than non-salmonids like bass or carp.

Dapnnia magna exhibited a sensitivity to supersaturation similar to that of the salmonids (Nebeker et al. 1975), with 115 percent saturation lethal within a few days. Stoneflies exhibited an intermediate sensitivity similar to bass with mortality at 130 percent saturation. Crayfish were very tolerant, with levels near 140 percent total gas saturation resulting in mortality.

No differences are proposed in the criteria for freshwater and marine aquatic life as the data available indicate that there probably is little difference in overall tolerances between marine and freshwater species.

The development of gas bubble disease in menhaden, *Brevoortia* sp., and their tolerance to gas saturation in laboratory bioassays and in the field (Pilgrim Nuclear Power Station Discharge Canal) are discussed by Clay et al. (1975) and Marcello et al. (1975). At 100 percent and 105 percent nitrogen saturation, no gas bubbles developed externally or in any of the internal organs of menhaden. At 105 percent nitrogen saturation, however, certain behavioral changes became apparent. Fish sloughed off mucus, swam erratically, were more excitable, and became darker in color. Menhaden behavioral changes observed at 110 percent nitrogen saturation were similar to those noted at 105 percent. In addition, at 110 percent gas emboli were found in the intestines, the pyloric caeca, and occasionally the operculum. The behavioral changes described were also observed at 115 percent, and clearly defined subcutaneous emphysema was observed in the fins and occasionally in the eye. At 120 percent and 130 percent nitrogen saturation, menhaden developed within a few hours classic symptoms of gas bubble disease. Externally, emboli were evident in all fins, the operculum and within the oral cavity.

Exophthalmia also occurred and emboli developed in internal organs. The bulbous arteriosis and swim bladder were severely distended, and emboli were found along the length of the gill arterioles, resulting in hemostasis. At water temperatures of 30

°C, menhaden did not survive, regardless of gas saturation level. At water temperatures of 15 , 22 , and 25 °C 100 percent of the menhaden died within 24 hours at 120 percent and 130 percent gas saturation. Fifty percent died after 96 hours at 115 percent (22 °C) Menhaden survival after 96 hours at 110 percent nitrogen saturation ranged from 92 percent at 22° and 25° to 83 percent at 15 °C. Observations on the relationship between the mortality rate of menhaden and gas saturation levels at Pilgrim Station during the April 1975, incident suggest that the fish may tolerate somewhat higher gas saturation levels in nature.

It has been shown by Bouck et al. (1975) and Dawley et al. (1975) that survival of salmon and steelhead smolts in seawater is not affected by prior exposure to gas supersaturation while in fresh water. No significant mortality of juvenile coho and sockeye salmon occurred when they were exposed to sublethal concentrations of supersaturated water and then transferred to seawater (Nebeker et al. 1976b).

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

: CITED

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Influence of Dissolved Atmospheric Gas on Swimming Performance of Juvenile Chinook Salmon

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ABSTRACT

Juvenile chinook salmon, *Oncorhynchus tshawytscha*, were exposed to selected levels of dissolved atmospheric gas ranging from 100 (control) to 120% of saturation, and surviving fish were then tested for maximal swimming performance.

Decreased swimming capability resulted from exposure to concentrations ranging from 106 to 120% of saturation if the fish were tested immediately; other tests indicated that recovery of swimming capabilities occurred within 2 hr if the fish were returned to equilibrated water (100% of atmospheric saturation) before testing.

Supersaturation of atmospheric gas in water as a result of air being entrained as it cascades from spillways has been well documented as a cause of gas bubble disease in Pacific salmon, *Oncorhynchus* sp., and steelhead trout, *Salmo gairdneri*, on the Columbia and Snake Rivers (Ebel 1969, 1971; Bouck et al. 1970). As nitrogen gas is responsible for exerting the greatest partial pressure (78.1%) of the atmospheric gases, this entrained gas phenomenon has been referred to as nitrogen supersaturation. However, the other atmospheric gases, particularly oxygen, contribute to the total gas pressure and must be considered. Direct mortality from gas bubble disease is a result of an air embolism in the heart and gill filaments or destruction of vital organs accompanied by characteristic red blood cell hemolysis (Pauley and Nakatani 1967; Bouck et al. 1970; Rucker 1972). Mortalities indirectly attributable to sublethal levels or exposures have received less attention.

The lowest level of supersaturated atmospheric gas to which juvenile salmon can be continually exposed without measurable detrimental effect is not known. Some investigators, however, have noted secondary effects from sublethal exposures. For example, Coutant and Genoway (1968) found fungus invasion at the site of gas bubbles on the fins of surviving adult salmonids subjected to high (greater than 118% of saturation) nitrogen concentrations, but reduced performance of the fish has not been studied.

Maximal swimming performance (Groves 1970) was chosen as an index of sublethal effects that could increase vulnerability to predation (Bams 1967). Maximal or absolute swimming performance reflects a total effort by the fish; such effort is sometimes needed to escape from dangerous situations. Groves utilized this measurement of swimming performance to assess sublethal effects of temperature shifts within varying acclimation ranges. This report describes tests conducted to determine if a significant difference existed in the swimming performance of salmonids subjected to the stress of supersaturated atmospheric gases.

MATERIALS AND METHODS

Test fish were spring chinook salmon, *O. tshawytscha*, from Leavenworth National Fish Hatchery at Leavenworth, Washington. The mean fork length of the fish was 118 mm and their mean weight was 16.0 g. They were acclimated to a water temperature at 15 C ± 0.5 C following the procedures of Brett (1952) in acclimation tanks described by Ebel, Dawley, and Monk (1971). The fish were fed to the point of satiation on a diet of Oregon Moist Pellets 5 days a week up until, but not including, the date of the swimming performance test.

Water supersaturated with atmospheric gas was generated by passing water through a high pressure pump operated under a back pressure produced by constriction of the discharge flow. Compressed air was then metered into the intake side of the pump, producing highly supersaturated water. Individual tanks were then adjusted to selected saturation levels by either manipulating the number of equilibrating screens through which the water flowed or by passing the water through a counter-current of air bubbles before it entered the test tank.

Procedure for analysis of dissolved nitrogen and argon was from Van Slyke and Neill (1924) using a manometric blood gas apparatus; and dissolved oxygen was analyzed using modified winkler procedures (American Public Health Association 1965). Gas concentration at saturation (100%) was taken from Weiss (1970).

Groups of 30–60 fish were stressed by introducing them directly into tanks 25 cm deep at mean total gas pressures of 100 (control), 104, 106, 112, 117, and 120% of atmospheric saturation. These levels had corresponding nitrogen plus argon concentrations of 102, 106, 110, 115, 121, 125% of saturation. The oxygen concentrations for the same respective levels were 94, 98, 98, 102, 106, and 103% of saturation. The total gas pressure varied less than ±2% of saturation in any test tank.

A companion study by Dawley and Ebel presents a more comprehensive account of the stress phase of this experiment and includes a complete presentation of mortality data.[1]

Tests of swimming performance were conducted on surviving fish stressed at a total gas pressure of 120% of saturation after the LC10 (10% mortality, mean value 10.5 hr) and after the LC50 (mean value 13.4 hr) points were reached. Tests of the surviving fish that had been stressed at the 117% level were conducted after the LC10 (mean value 26.9 hr) point was reached. The other groups of fish (those stressed at 104, 106, and 112% of saturation) did not have significant mortality, and their testing was completed after 35 days of exposure. All performance tests were repeated except those at the 120%-LC50 level. Performance tests immediately followed the stress of exposure and were made in equilibrated water (100% of atmospheric saturation). Normally the duration of the test period did not exceed 1 hr.

A study was also made on the swimming performance of fish that had been stressed by high concentrations of dissolved atmospheric gas and then given time to recover before testing. One test group stressed to LC50 at the 120% level was held for 2 hr in equilibrated water before testing, and another test group stressed to LC10 at 120% was held in equilibrated water for 15 days before testing.

The apparatus used to measure the maximal swimming performance was a long (14 m), narrow (8 cm), U-shaped channel wherein the fish could swim against a fixed flow (1.28 m/sec). Water depth was maintained at 5.5 cm. Dechlorinated tap water was recirculated through the channel, and water temperature was maintained at 15.0 C (the acclimation temperature). The channel was marked off in decimeter units and uniform overhead lighting of 10 candle power was maintained with incandescent lights.

Each fish was quickly transferred from a darkened container to the swimming channel and placed in the lower end with its head upstream into the flow. The change from dark to light in conjunction with the current generally stimulated the chinook salmon to swim strongly into the flow and up the channel. The total distance the individual fish swam and the total time spent actively swimming were recorded and were used as the main performance criteria in calculating and comparing performance of the test and control groups.

Evaluation of the results is based on the statistic "P" expressed as the product of upstream travel (distance) multiplied by the active swimming time for each performance of an individual fish. Thus, the statistic "P" incorporates both movement and stationary swimming activities over time. For example, a fish in these tests would often move forward in the performance channel and then maintain its position for several seconds before either moving forward again or falling back. If we had applied a simple rate formula in this

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[1] Dawley, E., and W. J. Ebel. MS. Lethal and sublethal effects of various levels of nitrogen and argon supersaturation on juvenile chinook salmon and steelhead trout. Nat. Oceanic Atmos. Admin., Nat. Mar. Fish. Serv., Northwest Fish. Center, Seattle, Wash.

TABı

Stress conditions and duration	D perf test
120% LC50 control	F F
120% LC50[b] control	M M
120% LC10 control	F F
120% LC10 control	F F
120% LC10[c] control	F F
117% LC50 control	M M
117% LC50 control	M M
112% 35d control	M M
112% 35d control	M M
106% 35d control	A A
106% 35d control[d]	A A
104% 35d control	M M
104% 35d control	M M

[a] Nonrespondents not
[b] 2-hr holding period
[c] 15-day holding per
[d] Same control group

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of comparison of
Hence, a nonpara
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to determine wl
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the stressed or t
perform (see Tab
calculation of the

TABLE 1.—*Stress history and results of chinook swimming performance tests*

Stress conditions and duration	Date of performance test (1972)	Number of test fish	Percent of fish not responding	Total distance swam (decimeters)	Total active swimming time (sec)	Mean value of the statistic P[a]
120% LC50	Feb. 10	17	29.4	273	91	209.6666
control	Feb. 10	14	7.0	512	129	683.2500
120% LC50[b]	Mar. 1	17	17.7	739	166	799.5000
control	Mar. 1	26	3.9	1,025	345	833.1200
120% LC10	Feb. 10	15	26.7	313	85	277.0909
control	Feb. 10	12	41.7	467	85	944.1429
120% LC10	Feb. 15	26	38.5	471	96	255.0625
control	Feb. 15	29	10.3	1,033	263	539.2692
120% LC10[c]	Feb. 25	20	10.0	503	186	485.1111
control	Feb. 25	26	19.2	603	232	411.3809
117% LC50	Mar. 1	22	13.6	534	119	277.8421
control	Mar. 1	25	12.0	750	214	455.9545
117% LC50	Mar. 3	25	28.0	802	183	607.1111
control	Mar. 3	28	3.6	1,229	387	906.5555
112% 35d	Mar. 14	21	28.6	304	98	226.8667
control	Mar. 14	28	28.6	660	216	495.6500
112% 35d	Mar. 16	25	8.0	581	161	283.6956
control	Mar. 16	27	25.9	506	208	566.3500
106% 35d	Apr. 11	28	21.4	823	312	620.4091
control	Apr. 11	32	18.8	1,060	393	794.6538
106% 35d	Apr. 11	28	28.6	638	211	453.0500
control[d]	Apr. 11	32	18.8	1,060	393	794.6538
104% 35d	Mar. 14	19	15.8	648	202	561.6250
control	Mar. 14	25	20.0	648	219	483.1000
104% 35d	Mar. 15	23	17.4	598	185	347.6842
control	Mar. 15	27	18.5	749	275	547.0000

[a] Nonrespondents not included (see text).
[b] 2-hr holding period in equilibrated water before performance testing.
[c] 15-day holding period in equilibrated water before performance testing.
[d] Same control group used for comparison of both groups stressed at 106% of saturation.

instance, the stationary swimming activity would have been reflected as a negative rather than positive swimming action.

Frequency distributions of the statistic "P" showed diffused tails with frequent outlying points for which classical parametric methods of comparison of samples were unsatisfactory. Hence, a nonparametric, one-sided Kolmogorov-Smirnov test (Conover 1971) was used to determine whether controls performed significantly better than the experimentally stressed fish.

The data were also examined to determine the percentage difference, D, between swimming performance of test and control fish.

$$D = \frac{\overline{P}_t - \overline{P}_c}{\overline{P}_c} \times 100$$

where $\overline{P}_c$ is the "P" statistic of the nonstressed or control fish and $\overline{P}_t$ is the "P" statistic of the stressed or test fish. Fish that did not perform (see Table 1) were excluded in the calculation of these values because statistical tests ($\chi^2 = 2.95$, d.f. $= 1$, $P < 0.05$) indicated no significant difference existed between the total number of nonrespondents in all test and control groups.

RESULTS

Swimming Performance with No Recovery Period. In statistical comparisons, significantly ($P < 0.05$) better swimming performance by control fish as compared to test fish was found only at those levels where test fish had been stressed at a total gas pressure of 120% of saturation (both the LC50 and LC10 test levels). However, all exposures to supersaturated water except that at 104% of saturation had a negative effect on the group performance of stressed fish (Fig. 1).

At the higher total gas pressures tested (117 and 120% of saturation), there was a significantly ($\chi^2 = 5.95$, d.f. $= 1$, $P < 0.025$) higher percentage of nonrespondent fish in stressed groups when compared with control groups (Table 1). This would indicate that

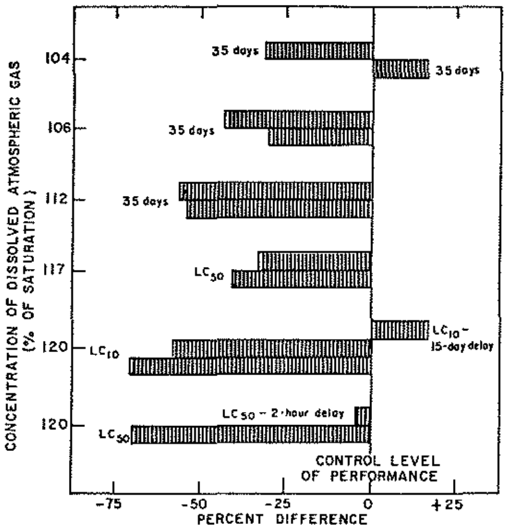

FIGURE 1.—Percent difference, D, in swimming performance between stressed and nonstressed fish. Values near bar graphs give duration of the pretest stress period or the LC level at which the test was terminated. Negative percentages indicate a lower level of performance by the stressed fish.

sublethal exposure to potentially lethal levels of gas supersaturation had the additional effect of rendering a greater percentage of fish nonresponsive than did chronic exposure to sublethal levels. Exclusion of the nonrespondents may have resulted in a conservative estimate of the effect of supersaturated atmospheric gas on swimming performance at the higher saturation levels.

Swimming Performance with a Recovery Period. Comparison of test and control group swimming performance after allowing a recovery period showed no difference in performance levels (Table 1). A recovery period of as little as 2 hr in equilibrated water after an exposure to a total gas pressure of 120% of saturation (LC50) was sufficient to allow recovery of test fish.

DISCUSSION

Decreased swimming performance resulting from sublethal exposures to supersaturated atmospheric gas could alter the ability of Pacific salmon to survive during their seaward migrations. For example, fish stressed by supersaturated gas—because of their reduced swimming capabilities—could become much more vulnerable to predators. This may be aggravated by the fact common salmonid predators may be less sensitive to supersaturated water conditions than salmon and trout. Bouck (G. R. Bouck, personal communication[2]) found that largemouth bass, *Micropterus salmoides*, can survive longer exposures to supersaturated atmospheric gas concentrations of 120% of saturation than can salmon and trout. Thus, the stressed chinook salmon, with its decreased ability to escape, could become easier prey.

Another important aspect of the seaward migration of the chinook salmon that could be affected by decreased swimming capabilities is passage through and over low head dams. Avoidance of dangerous areas in turbine penstocks or in stilling basins of spillways may require a high level of swimming performance. Observations by scuba divers (W. J. Ebel, personal communication[3]) observing fish behavior in turbine intake gatewells where these fish were diverted by traveling screens indicated that swimming performance was a vital factor in determining whether injuries would or would not occur. Fish that had the highest swimming capability did not become impinged on screens present in the gatewell. Thus, during periods of high atmospheric gas concentrations, migrating chinook populations traveling near the surface would be adversely affected not only by direct mortality from exposure to supersaturated atmospheric gas but also to mortality related to decreased swimming capabilities.

The final significant point these data reflect is the apparent rapid reduction of the detrimental effect of supersaturated atmospheric gas on swimming performance. A relatively limited recovery period of as little as 2 hr in equilibrated water reversed the debilitating effect the stress of supersaturated gas had on the swimming capabilities of chinook salmon tested after exposures at 120% of saturation. This rapid reversal phenomenon is also observed in the rapid disappearance of external gas bubble disease signs (see footnote 1).

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[2] Gerald R. Bouck, Environmental Protection Agency, Corvallis, Oregon.

[3] Wesley J. Ebel, National Marine Fisheries Service, Seattle, Washington.

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External gas bubbles that have formed over a short exposure to a high (greater than 120%) concentration of supersaturated water will disappear within a few hours of the fish's return to equilibrated water. This suggests that measures such as the spillway deflectors being considered for supersaturation control on Columbia and Snake River dams may well be useful if implemented on even a limited basis. Limited areas of reduced total gas pressure could provide short periods of relief where the migrating salmon could recover from the detrimental effect that supersaturated atmospheric gas has on swimming performance.

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Avoidance Responses of Salmon and Trout to Air-Supersaturated Water

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Abstract

Coho (*Oncorhynchus kisutch*), sockeye (*O. nerka*), and chinook (*O. tschawytscha*) salmon smolts, and rainbow trout (*Salmo gairdneri*) avoided air-supersaturated water when tested in a shallow round tank. Steelheads (*S. gairdneri*) did not consistently avoid the supersaturated water and died from gas bubble disease. The salmon and rainbow trout generally avoided 145 and 125% saturation but did not always avoid 115%. Territorial activity reduced avoidance by steelheads and rainbow trout.

The ability of certain species of fish to survive air-supersaturation of water may depend upon whether or not that fish can detect and avoid supersaturated water. Avoidance can be accomplished by either sounding or moving laterally away from the supersaturated water. Meekin and Turner (1974) reported that when given an alternative water source, chinook salmon (*Oncorhynchus tschawytscha*) showed a strong preference for equilibrated over supersaturated water. Blahm et al. (1976) tested juvenile chinook salmon and steelhead (*Salmo gairdneri*) in a divided trough having 130% N_2 on one side and 102% N_2 on the other side. Two groups of steelhead apparently did not avoid nitrogen supersaturation, as 50% died in 42.5 and 43 hours and all fish contracted gas bubble disease. However, no chinook salmon died during 192 hours exposure, and only 10% showed signs of gass bubble disease. No lateral avoidance was observed during these tests because of turbid water. Dawley et al. (1976) indicated that chinook salmon and steelheads may detect supersaturation and avoid it vertically by sounding in deep tanks. Gray and Haynes (1977) monitored adult chinook slamon in the Snake River with pressure-sensitive radio transmitters; fish migrating upstream in supersaturated water spent about 89% of their time below the critical supersaturation zone but swam at shallow depths during the following fall and spring migrations when the river was normally saturated.

The present studies conducted at the Western Fish Toxicology Station (WFTS) tested the lateral avoidance response of several fish species to various concentrations of supersaturated water.

Methods

All tests were done in unchlorinated well water aerated to near saturation under normal atmospheric pressure. The alkalinity and hardness were near 27 mg/liter (as $CaCO_3$) and the pH was 7.1 during the test period. Supersaturated water was produced and controlled by metered injection of compressed air into the water supply under pressure (Nebeker et al. 1976). Saturation levels were verified by five gas chromatograph determinations during the test period, and monitored by at least one Winkler dissolved oxygen determination during each individual test. Supersaturated water was delivered to a rectangular tank divided into four sections by glass partitions of decreasing height (Fig. 1). Excess gas was serially stripped from the water as it cascaded over the partitions. Water for the three test concentrations, 145%, 125%, and 115%, was taken from behind the partitions and the control water was supplied from a separate head tank.

The avoidance test tank (Fig. 1) was 183 cm in diameter and 92 cm deep. Water depth was maintained at 31 cm by a standpipe. The tank was divided into eight pie-shaped chambers by opaque Plexiglas panels 61 cm long and 36 cm high which left a central open area (61 cm in diameter) around the drain. The entrance into each chamber was 20 cm wide and the rear of the chamber consisted of a perforated Plexiglas panel which separated the chamber from the incoming water. This panel delivered an even

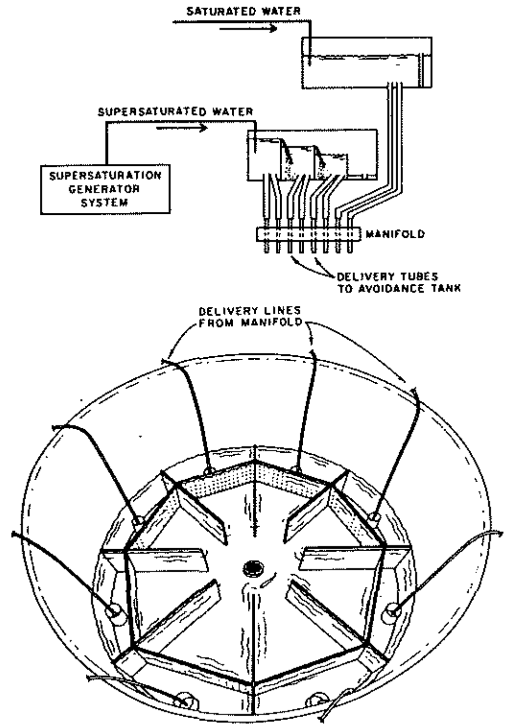

FIGURE 1.—*Diagrams of the delivery system for air-supersaturated water (upper panel) and of the test tank (lower panel) used in studies of salmonid avoidance of air-supersaturated water.*

flow of water into the test area. Water from a delivery manifold entered a standpipe at about 5 liters/minute and flowed through the perforated panel to the chamber. Dye tests indicated that the wedge-shaped plume of water leaving the chambers was maintained all the way to the center drain and was not significantly disrupted by fish activity.

The entire area above the tank was enclosed in black hardboard and plastic sheeting to prevent disturbance from room activity and lighting. Under the top of this tent were mounted a 16-mm motion picture camera and four fluorescent lights. The camera was activated by a motor-driven cam which exposed one frame every 2 minutes.

Fish used in the tests were reared from eggs provided by the Oregon Department of Fish and Wildlife. They included steelhead and coho salmon (*Oncorhynchus kisutch*) from the Alsea River, rainbow trout (*Salmo gairdneri*) and chinook salmon from the Willamette River, and sockeye salmon (*Oncorhynchus nerka*) from the Columbia River. All fish were parr-smolt size and their weight ranged from 30 to 45 g.

In each test 10 fish were placed in the tank for a minimum of 12 hours of acclimation in saturated water. The camera was started during the acclimation period and operated throughout the test period. Visual observations, without disturbing the fish, were also made to determine when avoidance behavior was established. When avoidance was observed, the various dissolved air concentrations were changed among chambers, generally by switching concentrations in opposite chambers. A continued avoidance response would be indicated by a decrease in the number of observations of fish in the higher concentrations (formerly lower concentrations) and a corresponding increase in observations of fish in the lower concentrations, an "observation" being the position of each fish in each film frame.

Water at each air concentration was piped into two adjacent chambers. The number of live fish recorded on the film in each pair of chambers was tabulated in hourly totals. Territorial activity was estimated by the number of frames that recorded sufficient disturbance of the water surface to distort the reflection of one of the fluorescent lamps. Fish that died were not counted or removed from the tank during the test period.

Differences between the hourly totals were subjected to analysis of variance to determine if there was a significant relationship between the changes in observations and the changes in concentration. The number of observations during the last hour before a concentration switch and those of the second hour after a change were used for the calculations. The differences between the number of observations 2 hours apart during the acclimation period provided the data for a zero-change in concentration. Data from the first hour of acclimation and the first hour after a change were not used, allowing the fish that time for adjustment.

Results and Discussion

The film record of the acclimation period indicated no preference of any species for any specific chamber or pair of chambers. Fish rarely were randomly distributed among chambers at the start of a test period, but this was a minor limitation for the experiments because it was

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TABLE 1.—*Distributio*
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Fish
Steelhead
Rainbow trout
Coho salmon
Sockeye salmon
Chinook salmon

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[a] Number in parenthes
[b] Concentrations of air
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TABLE 1.—*Distribution of salmonid fish in three concentrations of air-supersaturated water and a control. All species except steelhead showed significantly different distributions among gas concentrations in one or more tests (analysis of variance P < 0.05).*

				Mean number of observations per hour at each gas concentration[a]				
Fish	Test[b] number	Number of live fish	Test duration (hours)	High (145 ± 4)[c]	Inter-mediate (125 ± 3)[c]	Low (115 ± 2)[c]	Control (98 ± 2)[c]	Percent mortality during test
Steelhead	1	10	14	37 (22)	44 (25)	47 (27)	44 (26)	90
Rainbow trout	1	10	44	24 (15)	32 (21)	45 (29)	54 (35)	80
	2	2	5	9 (13)	12 (18)	30 (48)	13 (21)	0
Coho salmon	1	10	8	57 (18)	71 (22)	72 (22)	121 (38)	0
	2	10	16	32 (10)	39 (12)	95 (29)	158 (49)	0
	3	10	4	27 (8)	55 (17)	59 (18)	184 (57)	0
Sockeye salmon	1	10	7	53 (16)	63 (19)	93 (29)	115 (36)	0
	2	10	4	63 (20)	65 (20)	98 (31)	95 (29)	0
	3	10	2	46 (15)	17 (5)	78 (24)	180 (56)	0
	4	10	2	62 (19)	40 (13)	100 (31)	120 (37)	0
Chinook salmon	1	10	8	67 (21)	68 (21)	72 (23)	109 (35)	0
	2	10	16	45 (15)	61 (21)	93 (31)	99 (33)	20
	3	8	4	41 (16)	62 (24)	64 (25)	88 (35)	0

[a] Number in parentheses is percent of total observations.
[b] Concentrations of air were switched to opposite chambers between successive tests of a species.
[c] Total-gas percent saturation (mean ± SD).

the changes in distribution that were monitored.

The steelheads and rainbow trout suffered greater mortality than the salmon tested (Table 1). The steelheads died sooner than the rainbow trout and did not demonstrate any significant avoidance behavior. During the acclimation period and early parts of the test period we saw considerable amounts of territorial activity by one or more steelheads, which caused constant fish movement and turmoil in the test tank. The continued loss of steelheads suggests either they were more sensitive to supersaturation than the other species, or the absence of an effective avoidance response due to territorial activity of some fish.

Mortality among rainbow trout occurred more slowly and the survivors eventually showed a positive avoidance response that was significant at the 0.05 level. The two surviving rainbow trout preferred the low gas concentration over the control level.

Coho salmon generally preferred control water during the first test. Following the first and second concentration switch the fish avoided the high concentration and again showed an increased preference for control water. None of the fish died during the tests and the results were significant at the 0.005 level.

The avoidance response of sockeye salmon to supersaturated water occurred more rapidly than in other species. In successive tests, their response times shortened considerably; the fish actively avoided the high and intermediate gas concentrations within 2 hours. The shortened response time may have resulted from the schooling characteristics of sockeye salmon. The results were significant at the 0.005 level.

Chinook salmon did not show obvious avoidance of any concentration during the first test period. However, there was a general preference for control water. The next two tests indicated an avoidance of the high concentration. The results were significant at the 0.05 level.

Data to illustrate territorial activity were recorded from the last hour of acclimation and the first hour of the test period for each species. The percentage of frames showing considerable disturbance during these 2 hours for each species were steelheads 46%, rainbow trout 41%, coho salmon 14%, sockeye salmon 0%, and chinook salmon 6%.

These results indicate that juvenile rainbow trout and coho, sockeye, and chinook salmon can detect air-supersaturated water and that they will move laterally to avoid it. Our data support the findings of Meekin and Turner (1974) and Blahm et al. (1976) for chinook salmon. The lack of avoidance by steelheads is consistent with the research by Blahm et al. Our work does not address the possibility that steelheads and other species might sound vertically to avoid air-supersaturated water. It does show, however, that territorial activity by some fish may inhibit an escape from stressful conditions by others of their species.

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Transactions of the American Fisheries Society 109:755–759, 1980

Effects of Hydrostatic Pressure on Steelhead Survival in Air-Supersaturated Water

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Abstract

Juvenile steelheads (*Salmo gairdneri*) were placed in cages and suspended at various depths in water supersaturated with air at levels from 120 to 140% of normal atmospheric gas pressure. Survival times of fish held at 10, 50, and 100 cm depth increased with increasing depth at a given level of supersaturation. When the hydrostatic pressure (7.4 mm Hg per 10 cm of water depth) was subtracted from the excess gas pressure (relative to surface barometric pressure), mortality curves (times to 50% mortality versus excess gas pressure) for fish at all three depths essentially coincided. The significant measure of supersaturation appears to be the pressure of dissolved gases in excess of the sum of barometric and hydrostatic pressures. Steelheads held near the surface in supersaturated water for a near-lethal period and then lowered to a depth providing total hydrostatic compensation appeared to recover completely in about 2 hours. The longer fish remained at depth, the longer their survival time when they subsequently were reexposed to surface conditions.

When air is dissolved in water at pressures exceeding one atmosphere, more gas is driven into solution than is normal for most surface waters; such waters are said to be supersaturated. In the absence of vigorous surface turbulence, reequilibration to the normal saturation level occurs slowly even in shallow water. Conditions conducive to the production of supersaturation can occur in plunge basins below the spillways of dams, in power plants where saturated cooling waters are warmed and gas solubility is reduced, and in penstocks or other water pipes where air and water can be mixed at high pressures.

Dissolved gas levels between 100 and 140% of normal saturation have been reported in natural waters as a result of these conditions. When aquatic animals, especially fish, are exposed to water containing gas levels over 110%, they are often killed by air emboli collecting in vital organs. Stroud et al. (1975) have described the pathology associated with exposure of fish to supersaturated water. Several comprehensive reviews of the causes and effects of supersaturation have been published (Rucker 1972; Wolke et al. 1974; Fickeisen and Schneider 1976; Weitkamp and Katz 1980).

Although the lethality of air-supersaturated water to salmonids has been well documented, most of the work has been done in shallow tanks where water depth is not a major factor affecting the response of fish to supersaturation. Greater water depth adds the variable of hydrostatic pressure which inhibits the formation of air emboli in tissue fluids supersaturated with gases relative to ambient atmospheric pressure.

Previous supersaturation studies have shown qualitatively that deep-water exposure or intermittent deep- and shallow-water exposures produce lower mortality than shallow-water exposure (Dawley et al. 1976; Weitkamp 1976). However, these studies allowed considerable variability of depth so that exposure levels could have varied considerably, making quantitative analysis of effects difficult. Fickeisen and Montgomery (1978) conducted a study similar to ours, but they used only one level of supersaturation and did not fully quantitate the effects of hydrostatic compensation.

The first objective of this study was to determine if compensating hydrostatic pressure and excess gas pressure are simple additive factors determining fish survival. The second objective was to determine the extent to which total hydrostatic compensation can reverse the effect of a previous near-lethal exposure to supersaturation.

Methods

Juvenile steelheads (*Salmo gairdneri*) were reared at the Corvallis Environmental Research

TABLE 1.—*Temperature and nominal and measured total gas concentrations during supersaturation experiments with steelheads.*

Test	Temperature C	% total gas saturation			
		Nominal	Measured		
			N	Mean[a] ± SD	Range
1	10.8	140	27	139.8 ± 0.4	138.9–140.3
2	10.0	140	39	139.6 ± 0.9	135.5–141.0
3	11.0	135	41	136.4 ± 0.7	135.2–137.3
4	10.0	135	27	135.1 ± 0.2	134.8–135.7
5	11.5	130	36	130.0 ± 0.8	129.0–130.8
6	11.7	130	60	130.2 ± 0.6	128.1–130.9
7	11.0	130	55	130.4 ± 0.5	129.0–130.5
8	9.0	125	45	124.9 ± 0.4	124.0–125.7
9	9.5	125	25	125.0 ± 0.5	124.0–126.0
10	9.2	125	31	124.9 ± 0.6	124.0–125.2
11	10.2	120	26	120.1 ± 0.3	119.8–120.8
12	11.2	120	27	120.0 ± 0.4	119.4–120.8
13	9.5	120	41	120.2 ± 0.5	118.8–120.9
14[b]	14.0	120	45	119.7 ± 0.4	118.9–120.5
15[b]	12.0	120	54	119.8 ± 0.4	118.7–120.4
16[b]	13.6	125	25	126.6 ± 0.5	125.2–127.0
17[b]	14.0	125	42	126.5 ± 0.6	125.7–127.7
18[b]	12.5	130	15	130.5 ± 0.4	130.3–131.3

[a] Means of measurements in four tanks per test.

[b] Variable-depth exposure tests.

TABLE 2.—*Calculated percentage reduction (compensation) in air supersaturation based on pressure of the water column.*[a]

Water depth (cm)	Water column pressure (mm Hg)	Compensation (percentage of atmosphere)
10	7.4	1.0
20	14.8	1.9
30	22.2	2.9
40	29.6	3.9
50	37.0	4.9
60	44.4	5.8
70	51.8	6.8
80	59.2	7.8
90	66.6	8.8
100	74.0	9.7
110	81.4	10.7
120	89.8	11.7
130	96.2	12.7

[a] % compensation = [Water depth (cm) × 0.740 (mm Hg/cm water)]100/760 (mm Hg).

Laboratory from eggs obtained from the North Fork Alsea Hatchery, Alsea, Oregon. Fish culture and test facilities were supplied with soft well water (Samuelson 1976). The fish were reared on Oregon Moist Pellet diet but were not fed during the tests.

Tests were conducted by holding fish in cylindrical cages, 71 cm in diameter and 20 cm deep, suspended at various depths in four fiberglass tanks 3.1 m high and 79 cm in diameter. The water supply to the tanks was supersaturated to desired levels by regulating the flow of compressed air into a pressure chamber (Nebeker et al. 1976) which supplied water to each tank at a rate of 14 liters/minute. Nominal total gas saturations ranged from 120 to 140% (Table 1).

The air supersaturation of water was measured with a Weiss saturometer (dissolved gas tension meter), which registered the difference between the dissolved gas and atmospheric pressures (Nebeker et al. 1976). The tension meter was calibrated periodically with a Van Slyke gas analyzer. All saturation levels are expressed as percent of saturation with respect to ambient atmospheric pressure at the water surface and were uniform throughout the water column in each tank. Calculation of gas saturation levels followed the conventional procedure of dividing dissolved gas pressure (less water vapor pressure) by barometric pressure and multiplying the quotient by 100 (Fickeisen et al. 1975).

Tests were begun by placing 20 fish in each cage and then lowering the cage to the desired depth. Periodic in situ observations were made for deaths and for the saturation level of air in the water. A fifth group of 20 fish was placed in a cage and held in shallow ambient well water as a control. The median survival time (LT50) for fish in each cage was calculated on the assumption of a log-normal relationship between mortality and exposure time.

Constant Depth Exposure

The force driving the formation of gas emboli is the existence in body fluids of dissolved gas tensions in excess of the sum of atmospheric and hydrostatic pressures. In these experiments the excess gas tension was greatest in the cages just below the surface where the hydrostatic pressure at 10 cm was only about 7.4 mm Hg.[1] Because atmospheric pressure during the tests was always near 760 mm Hg, each percent supersaturation was equivalent to 7.6 mm Hg.

[1] H_2O pressure (mm Hg)

$$= \frac{\text{mm } H_2O \text{ depth} \times \text{density } H_2O}{\text{density Hg}}$$

$$= \frac{\text{depth} \times 1.000 \text{ g/cm}^3}{13.596 \text{ g/cm}^3}.$$

Therefore, each 10 cm of water depth should have created pressure nearly sufficient to counteract the gas tension created by one percentage unit of supersaturation (0.01 atmosphere) (Table 2). If the time to death due to gas emboli formation is solely a function of the excess gas pressure in the body fluids, then survival times at 10, 50, and 100 cm depth should be equal at identical excess gas pressures after adjustment for depth compensation. This was tested by the procedure outlined above.

Intermittent Depth Exposure

Another potential effect of increasing depth is the resolubilizing of emboli formed at lower hydrostatic pressures. Thus, fish in which potentially lethal emboli have formed may survive if they enter deeper water. The time required for gas resorption is unknown as is the influence of an earlier surface exposure and recovery at depth on survival during a second surface exposure. To test these effects, fish near the surface were exposed to lethal levels of supersaturation for several hours, lowered to a compensating depth (3 m) for 1, 2, or 3 hours, and then returned to the surface.

Total gas saturation levels in these tests were 130, 125, and 120%, and the times of initial exposure were 2.3, 3.3, and 5.9 hours, respectively. These periods were previously determined to be just short of the time to first death at these saturation levels.

Results and Discussion

When caged steelheads were exposed to a given level of gas supersaturation at one of three depths, 10, 50, or 100 cm (±10 cm volitional range), the fish died most quickly in the shallow cage and most slowly in the deep cage (Fig. 1A). Dose-response curves ($Y = aX^b$, where Y is median survival time, X is excess dissolved gas pressure, and a and b are constants) yielded r^2 values of 0.99, 0.96, and 0.83 for the 10, 50, and 100 cm depths, respectively.

When the median survival times were plotted against depth-corrected excess gas pressures, a single curve could be fitted to the data yielding an r^2 value of 0.95. Because the fish could have selected depths slightly above or below the mid-cage depths of 10, 50, and 100 cm used in the previous calculations, we attempted to fit better curves for other possible exposure depths. Best fits were obtained when fish in the shallow cage were assumed to have been near the bottom of their cage and those in the other two cages near the top. Figure 1B represents the response of fish at assumed depths of 17, 46, and 93 cm and has an r^2 value of 0.97. The results support the concept that depth provides protection against the lethal effects of supersaturation in

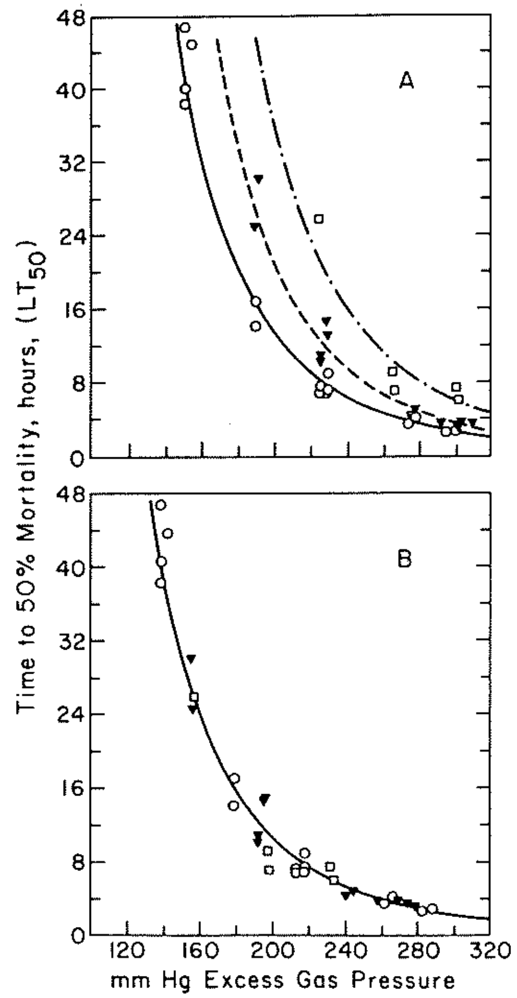

FIGURE 1.—*Relationship* ($Y = aX^b$) *between time to 50% mortality* (Y) *and mm Hg excess total gas pressure* (X) *for steelheads held at water depths of 10 cm (circles), 50 cm (triangles), and 100 cm (squares). Curves in A, calculated without allowance for hydrostatic pressure, have constants* (a, b) *of (1.243, −3.944), (4.468, −3.761), and (1.892, −3.187) for 10, 50, and 100 cm, respectively. The curve in B, calculated after allowance for hydrostatic pressure, has constants* (a, b) *of (4.830, −3.768).*

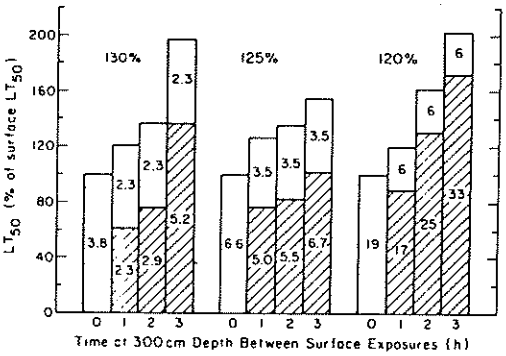

FIGURE 2.—*Time (at the water surface) to 50% mortality for steelheads allowed 0, 1, 2, or 3 hours at 3-m depth between shallow-water exposures to 120, 125, or 130% air saturation. White portions of histograms represent initial shallow exposures, crosshatched portions the second shallow exposures. Hours of exposure are indicated in the histograms; the single or lower number in each bar is time to 50% mortality for single or second surface exposures, respectively. Values for 120 and 125% saturation are means of two tests.*

direct proportion to the reduction in excess gas pressure provided by the hydrostatic pressure of the overlying column of water.

Hydrostatic pressure thus appears to provide a calculable protection against the apparent excess gas pressure measured at the water surface. The question remained as to the effectiveness of hydrostatic pressure in reversing or retarding the effects of a prior acute exposure to excess gas pressure. Consequently, we exposed fish to several levels of excess gas pressure near the surface for a period determined to be just short of the time required to produce death in the most susceptible fish. The fish were then lowered to a depth (3 m) calculated to produce total compensation. After 1, 2, or 3 hours, the fish were returned to the surface and their response observed; time to 50% mortality was the index of effect.

The simplest mechanism for enhanced survival of fish lowered to compensatory depths is resolubilization of already formed gas emboli. Among other effects, this would allow renewed blood flow to ischemic tissues, reoxygenation of tissue, and clearance of metabolic waste products.

Comparison of LT50's of fish kept near the surface with those of fish given shallow reexposure following depth compensation is complicated by several factors. These include gas equilibration time of body fluids (Beyer et al. 1976); unknown relationships among degree of equilbration, internal gas pressure, and onset and rate of emboli formation; and the relative rates of emboli formation in fish held at the surface and those brought into shallow water from a compensatory depth.

Our data suggest that for steelheads first exposed to excess surface gas tensions for nonlethal periods, the minimum time for full compensation at a 3-m depth is 2–3 hours at 125 and 130% saturation and 1–2 hours at 120% saturation (Fig. 2). However, at all three levels of air supersaturation, the longer fish remained at depth, the greater their subsequent tolerance of shallow conditions (as indicated by their higher LT50's).

Active fish are reported to be more susceptible to gas bubble disease than quiescent ones (Stroud and Nebeker 1976). Our handling of fish during the depth-compensation experiments could have induced varying activity levels and caused some of the differences noted in LT50 values. Still, our results suggest that physiological adaptation, as well as hydromechanical compensation, may occur in fish allowed a deep refuge in air-supersaturated water.

Acknowledgments

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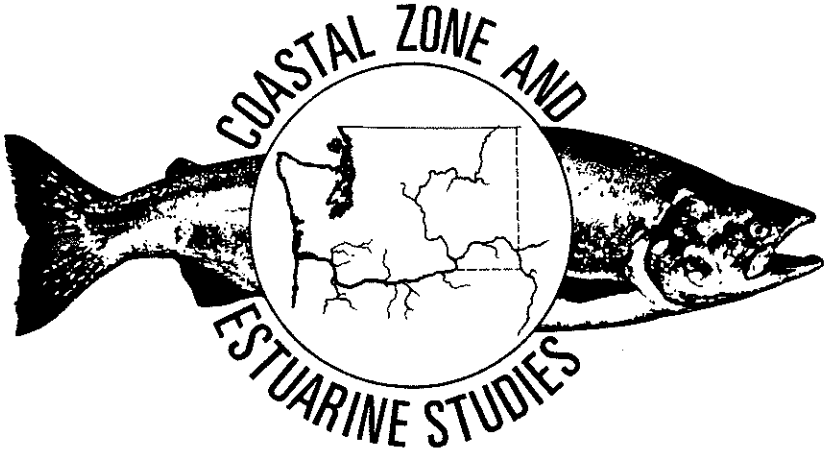
by

Earl M. Dawley

November 1986



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Coastal Zone and Estuarine Studies Division
Northwest and Alaska Fisheries Center
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CONTENTS

INTRODUCTION

Gas bubble disease (GBD) in freshwater fishes, resulting from supersaturation of dissolved atmospheric gases in water, has been studied by investigators since the early 1900s (Marsh and Gorham 1905; Rucker and Tuttle 1948; Harvey and Cooper 1962; Shirahata 1966). In the Columbia and Snake Rivers, GBD became evident in the 1960s and was attributed to supersaturation of dissolved gases caused by high volumes of water flowing over spillways at dams (Ebel 1969; Beiningen and Ebel 1970; Ebel 1971; Meekin and Allen 1974). Gas levels over 140% of saturation were not uncommon; from literature it was apparent that 110% was potentially lethal to fish. The problem was intensified for salmonids by an increased migration time, resulting from impoundments created by several new dams on the river.

From 1966 to 1975, estimates of mortality ranged from 40 to 95% for juvenile salmonids migrating from the Snake River; a major proportion of that mortality during high flow years was attributed to GBD (Ebel et al. 1975). During that period, research defined tolerance characteristics of juvenile and adult salmonids to supersaturation and documented dissolved gas concentrations throughout the river during high water flow and spill at dams (Parametrix, Inc. 1975; Ebel et al. 1975; Boyer 1974).

In the early 1970s, extensive efforts were made to reduce spill and to decrease the levels of supersaturation created by spill (Smith 1974). Several actions significantly decreased levels and duration of supersaturation: increased water storage in the upper reaches of the river basin, increased electrical generation at dams on the lower Snake and Columbia Rivers, and installation of flow deflectors on the spillways of several dams. Supersaturation greater than 130% became infrequent instead of common, and levels exceeding 120% [shown by Weitkamp (1976) to be the critical point in causing mortality from GBD in salmon held in situ at Rock Island Dam] were observed less often and in smaller sections of the river basin. As a result of these actions, little evidence of gas bubble disease in salmonids was observed in the late 1970s.

In the 1980s, a program of increased spill at dams was implemented to improve passage of juvenile salmonids. This created diurnal fluctuations of supersaturation within the river system. The U.S. Army Corps of Engineers (COE) and the National Marine Fisheries Service (NMFS) began to reevaluate the effects of current dissolved gas levels on salmon in the Columbia River system, including fluctuating supersaturation caused by designated spill for fish. In 1985, a field bioassay and monitoring program was established to evaluate the impacts of intermittent high supersaturation on both juvenile and adult salmonids. The reservoir of The Dalles Dam [River Kilometer (RKm) 308] was selected as the primary evaluation site because daily spill was expected at John Day Dam (RKm 347). In the 1970s, spill at John Day Dam created the highest dissolved gas levels in the river system, and in the 1980s, high dissolved gas levels resulting from intermittent spill were observed in the forebay of The Dalles Dam.

OBJECTIVES

The objectives of the bioassay and monitoring program were:

1. To obtain daily dissolved gas concentrations in the forebays of John Day and The Dalles Dams.

2. To observe and record signs of GBD in juvenile and adult salmonids sampled at various sites on the river.

3. To determine the migration rate of marked fish passing through The Dalles Dam reservoir.

4. To conduct holding studies with juvenile spring and fall chinook salmon, of hatchery and river-run stock, in The Dalles Dam forebay and examine depth distribution in relation to level of supersaturation.

5. To obtain depth distribution information for juvenile salmonids in the forebay of The Dalles and John Day Dams using hydroacoustics.

6. To assess the probable effects of dissolved gas supersaturation on salmonid migrants and compare the results with information obtained in the 1960s and 1970s.

METHODS

In 1985, the site of most field work was The Dalles Dam and its forebay to a few km upstream (Fig. 1). In 1986, biological data were collected at McNary, John Day, and Bonneville Dams.

Dissolved Gas Measurements

Dissolved gas concentrations were measured in the forebays of McNary, John Day, and The Dalles Dams and at Warrendale, Oregon, (downstream from Bonneville Dam) using continuous monitoring instruments operated by the North Pacific Division of the COE (U.S. Army Corps of Engineers 1985). Generally, measurements were recorded at 3-h intervals, which we believe were adequate for evaluating dissolved gas fluctuations in relation to river flow patterns.

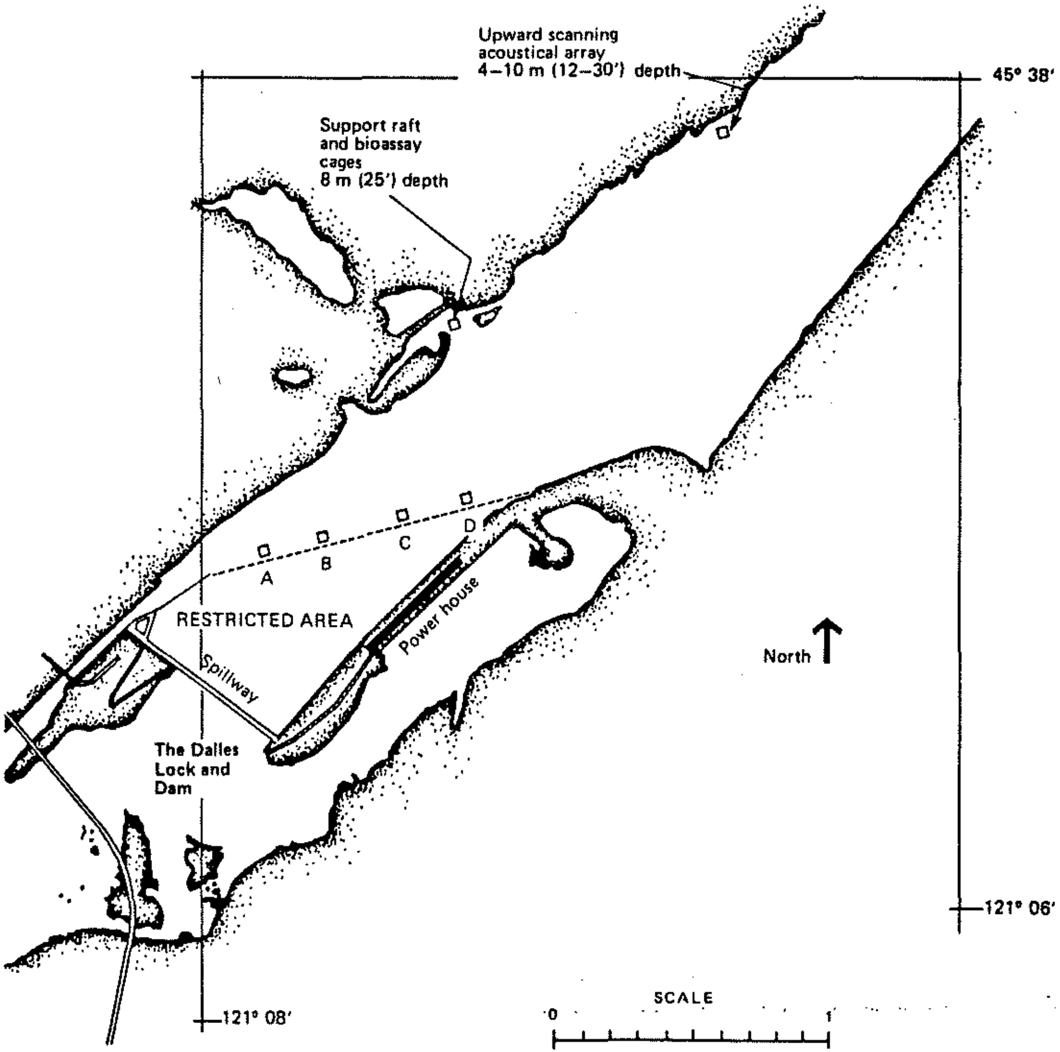

Figure 1.--Location of support raft for bioassay cages, upward scanning acoustical array, and restricted area of The Dalles Dam.

Gas Bubble Disease Observations

From April to June 1985, when gas levels might have caused GBD, NMFS personnel examined juvenile migrants for signs of GBD at John Day, The Dalles, and Bonneville Dams. Fish sampled several days per week for other research projects were also examined for macroscopic cutaneous and subcutaneous gas-filled blisters on the fins and body surfaces. Recoveries of marked fish were also recorded to provide estimates of exposure time to supersaturation during migration through the reservoirs of The Dalles and Bonneville Dams.

Plans for evaluation of GBD in 1986 were cancelled in April 1986 because of a below-average snowpack and little or no spill expected at John Day Dam or any dams other than Bonneville Dam. However, we took advantage of the unexpected high flow period in late May and early June to obtain data on GBD of yearling and subyearling migrants at lower Columbia River dams. Begining 1 June, daily examination for GBD was made by NMFS and Fish Passage Center personnel on 100 or more juvenile salmonids of each species at McNary, John Day, and Bonneville Dams. Adult migrants were examined at the trap in the north-shore fishway at McNary Dam.

Live Cage Studies

To observe the effects of ambient supersaturation on yearling and subyearling chinook salmon of both river-run and hatchery stocks, groups were held in cages 1.5 km upstream from The Dalles Dam. A floating platform was anchored in 8 m of water at the mouth of a slough on the north side of the river. Attached to the platform were six cages 0.6 x 0.6 x 1.0 m deep; two were placed at each of three depths: 0-1, 1-2, and 3-4 m. Two additional cages 0.6 x 0.6 x 6.1 m deep were used to allow unrestricted vertical movement of test fish (Fig. 2).

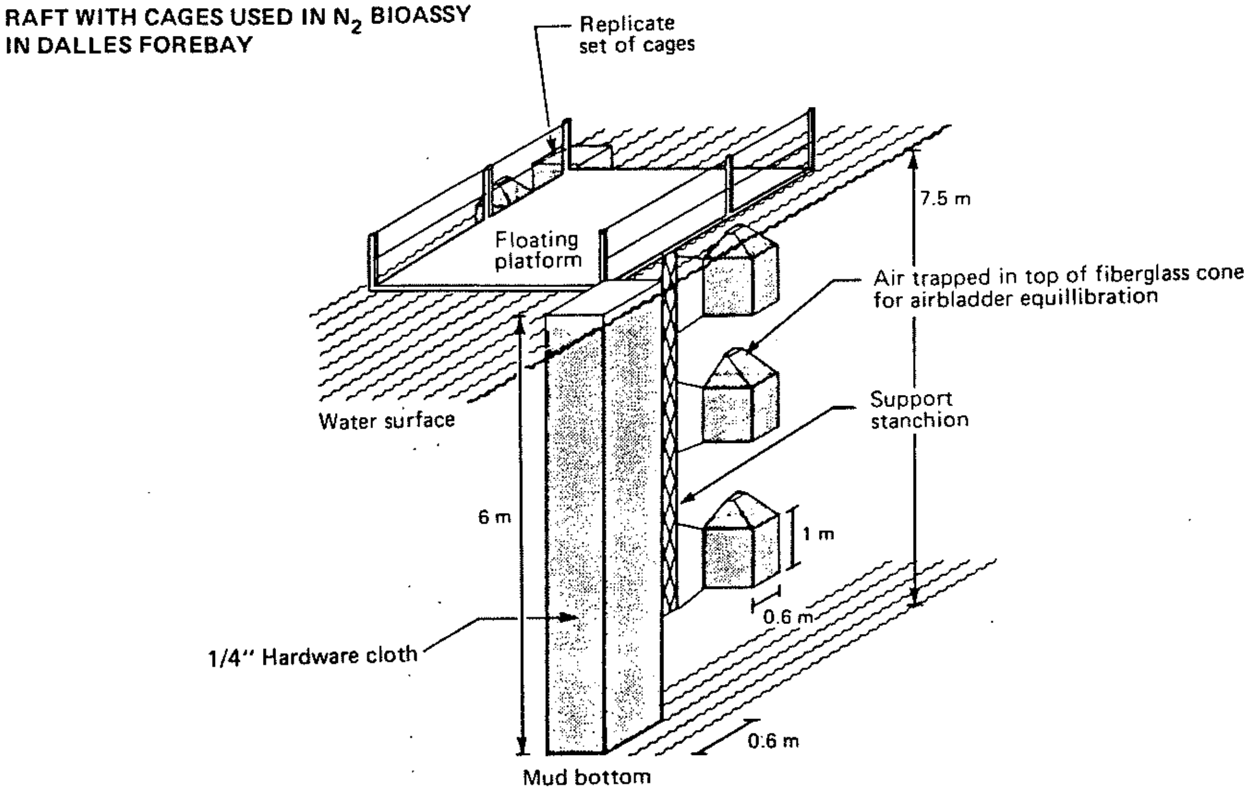

Figure 2.--Support raft with cages used for holding test in The Dalles Dam reservoir. Juvenile spring and fall chinook salmon were held at particular depths to evaluate the effects of spill at John Day Dam.

Holding tests were initiated when dissolved gas concentrations were expected to exceed 120% of saturation. Four- or five-day tests with yearling chinook salmon were begun on 13, 20, and 28 May, giving three replicate tests. Three- or four-day tests with subyearling chinook salmon were begun on 8 and 22 July and 12 August, also giving three replicate tests. Groups of 50 fish were placed in each cage. One set of four cages, positioned at 0-1, 1-2, 3-4, and 0-6.1 m, held river-run fish taken from gatewells at The Dalles Dam; the other set, positioned at the same depth intervals, held hatchery fish of the same age. Hatchery-reared yearling spring chinook salmon were obtained from Eagle Creek National Fish Hatchery (U.S. Fish and Wildlife Service), and subyearling fall chinook salmon were obtained from Washougal Salmon Hatchery (Washington Department of Fisheries). Fork lengths of both river-run and hatchery fish are listed in Table 1.

Fish in cages were observed daily by SCUBA divers at about 1300 h. Dead fish were collected and examined for signs of GBD. Underwater observations for signs of GBD in fish were attempted, but visibility was too poor. The vertical distributions of fish in the 6.1-m cages were recorded. To minimize fish following the divers during assessment of vertical distribution, divers simultaneously approached each cage from the bottom and top and ascended or descended with limited breathing. To enhance future holding tests, an underwater video monitoring system was fabricated which allows diel observations of vertical distribution in the volitional cages and eliminates the necessity for observations by SCUBA divers.

Table 1.-- Fork lengths of yearling and subyearling chinook salmon used in holding tests at The Dalles Dam forebay, 1985.

Test dates	Hatchery fish forklength (mm)		River-run fish forklength (mm)	
	Range	Mean	Range	Mean
	Yearling chinook salmon			
5/13-18	85-235	152	105-205	140
5/20-25	80-230	152	85-195	142
5/28-6/1	112-232	157	80-177	142
	Subyearling chinook salmon			
7/8-12	55-95	80	78-133	103
7/22-26	60-100	87	73-137	108
8/12-15	58-103	93	-[a]	-[a]

[a] No data

Hydroacoustic Depth Evaluation

Hydroacoustic assessments of the vertical distribution of fishes entering turbine intakes and passing over spillways at The Dalles Dam were made by BioSonics Inc.,[1] under contract to Bonneville Power Administration (Steig and Johnson 1986). A sophisticated network of transducers and data compilation devices were used to examine seven sites at the powerhouse and nine sites at the spillway. Counts were adjusted to screen out electronic interference and to correct for variation of beam width at the target range.

Monitoring of vertical distribution was also attempted by NMFS personnel at the buoy line of the restricted area in front of the dam and at a site 2 km upstream near the shoreline (Fig. 1). The echo sounder used in front of the dam was a Ross Fineline 200-A transmitting at 198 kHz through a sequencing series of four transducers (22°). The transducers were attached to 4-m outriggers on both sides of a boat (Fig. 3). Water depths ranged from 5 to 26 m. The echo sounder used at a fixed position near shore was a Benmar DR-680 transmitting at 400 kHz through a sequencing series of 20 transducers (20°). These transducers scanned upward from the bottom in water depths ranging from 4 to 10 m (Fig. 4) (Marshall 1976). Relative percentages of targets within particular depth ranges were adjusted for cone area at the distance of observation.

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

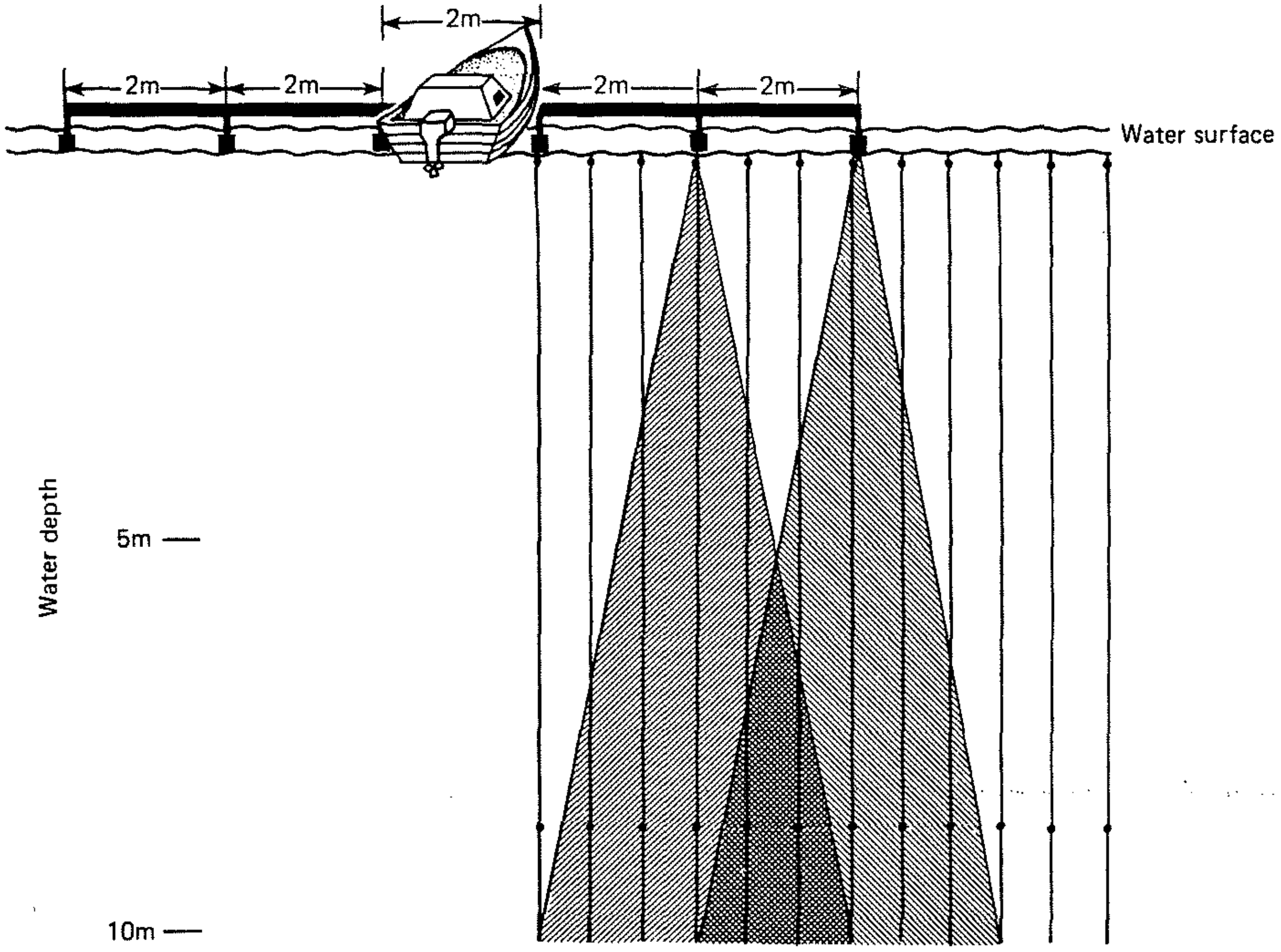

Figure 3.--The echo-sounding scheme 50-100 m in front of the powerhouse and spillway at The Dalles Dam, 1985; Ross fine-line 200-A (198 kHz) and four 22°-tranducers (sequenced).

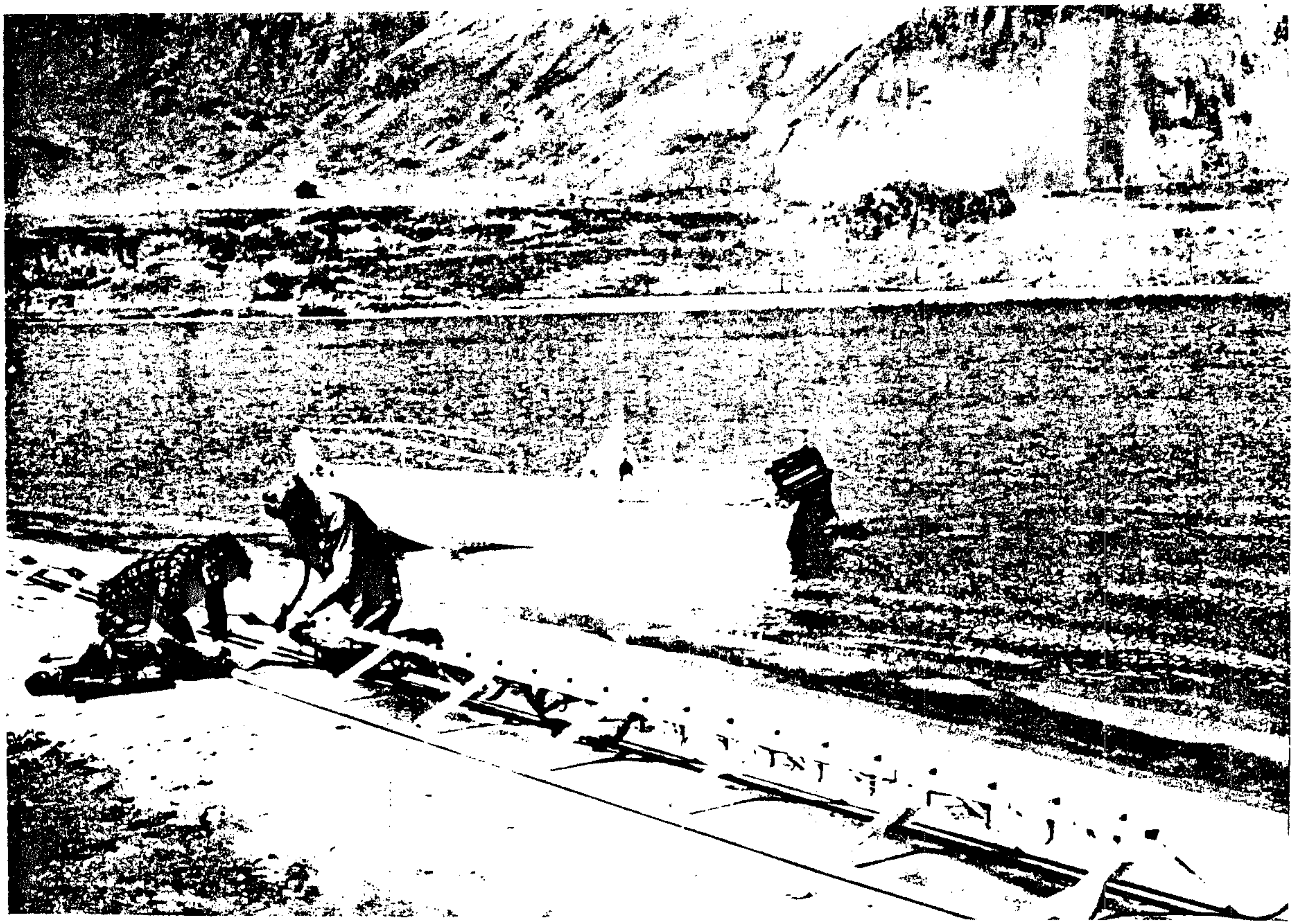

Figure 4.--Twenty-transducer sonic array used near shore 2 km upstream from The Dalles Dam, 1985; Benmar DR-680 with sequencing transducers (from Marshall 1976).

RESULTS AND DISCUSSION

1985

Dissolved Gas Levels

Predicted high flows did not occur in mid- to late-May, nor in other periods during the 1985 migration; as a consequence, dissolved gas concentrations in The Dalles reservoir seldom exceeded 120%. Because of the extensive setup efforts, we continued to evaluate the prevailing low supersaturation conditions. These data were collected for comparison with past laboratory and field data and with future field tests conducted at higher levels of supersaturation. Average daily flows during the evaluation were low for this time, ranging from 292 thousand cubic feet per second (kcfs)[2/] on 6 May to 64 kcfs on 28 July. Highest supersaturation values were observed in early May when daily spill lasted about 8 h and passed from 40 to 60% of the instantaneous flow through John Day Dam. In The Dalles reservoir, diurnal saturation levels near 120% were observed for about 8 h, levels below 110% of saturation for about 8 h, and intermediate levels during the interim (Fig. 5).

A comparison of spill rates at John Day Dam versus dissolved gas levels at The Dalles Dam (26 April to 17 May; river flows 170-292 kcfs) indicates that water passage time through The Dalles reservoir was 16 to 20 h (Fig. 5). Spilled water appeared to move through the reservoir as distinct masses. The durations that high and low supersaturated water passed through The Dalles Dam corresponded to the duration of high and low volumes of water spilled at John Day Dam hours earlier (Fig. 5).

[2/] The English units kcfs are used in this report in place of metric units because of common local usage (1 m^3 = 35.3 ft^3).

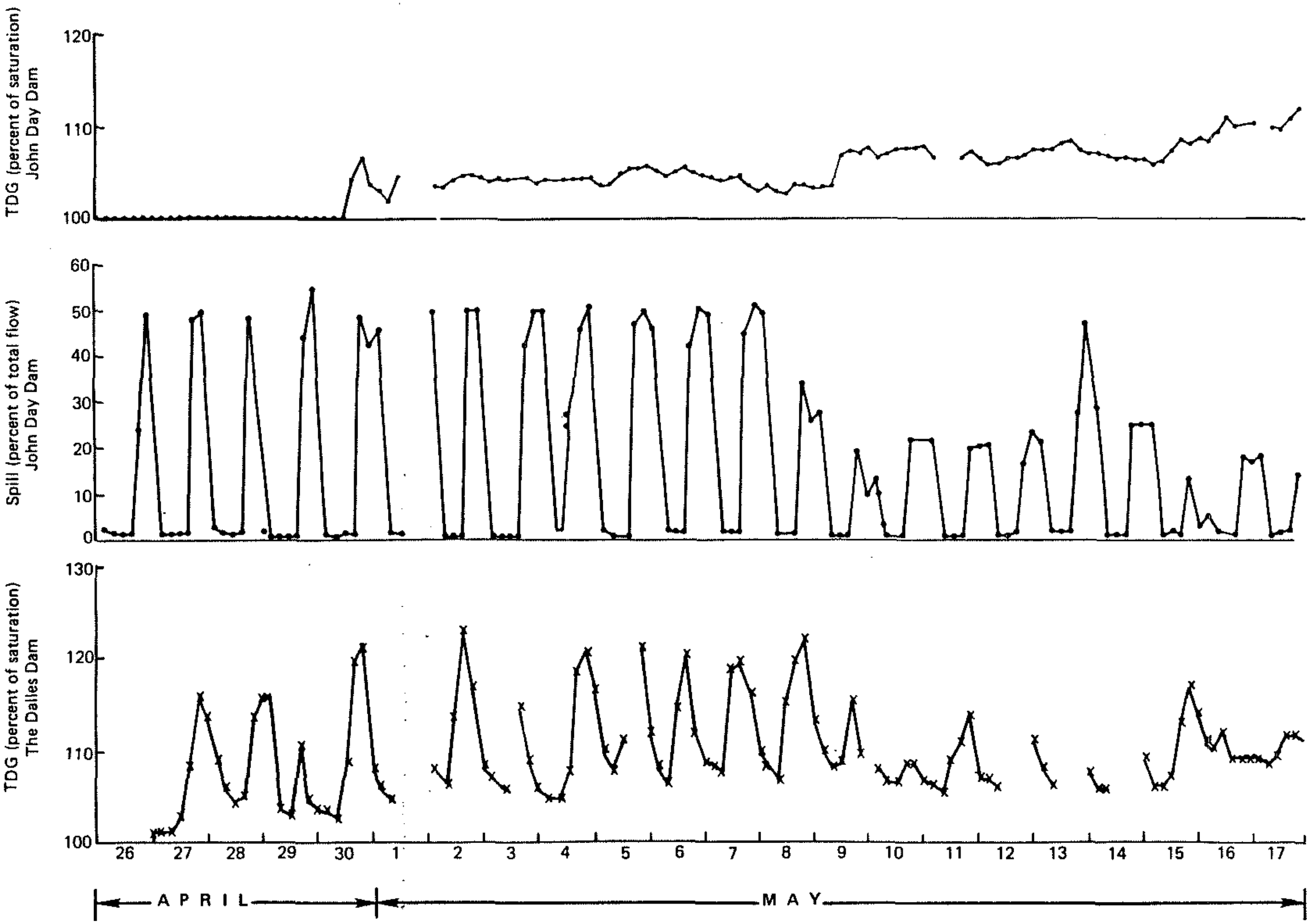

Figure 5.--Total dissolved gas (TDG) concentrations at John Day and The Dalles Dams, with spill flows in 3-h intervals, 26 April-17 May 1985.

Gas Bubble Disease in Migrants

During the period of highest supersaturation, the first week in May, signs of GBD were not observed in fish examined at The Dalles or Bonneville Dams. Dissolved gas levels were, however, only slightly greater than 120% of saturation for a few hours a day. Had the juvenile salmonids encountered 120% saturation for > 12 h diurnally, GBD signs would probably have been observed (Dawley and Ebel 1975). From mark recovery data we estimated that migration time through The Dalles reservoir was from 1 to 2 days for yearling chinook salmon. Migrants intermittently encountered supersaturation for several more days, because only slight equilibration of dissolved gas (change of gas concentration toward normal saturation — 100%) occurs in the river from The Dalles Dam to the estuary (from interpretation of dissolved gas data, 1966-1985). Some fish may have developed GBD downstream from Bonneville Dam, but the effects were probably not lethal even for fish swimming at the surface. Fish swimming at depth are provided compensation from supersaturation conditions by hydrostatic pressure. Each meter of depth provides about a 10% decrease in percent of saturation, therefore, fish swimming at 1 m encountered about only 110% of saturation.

Live Cage Studies

Gas Bubble Disease.--Consistent with observations of river-run juveniles at the dams, GBD signs were not observed in caged fish held for 5 days. Daily saturation levels during the first test of yearling chinook salmon were highest (111-118%) for about 8 h and substantially less for the other 16 h (Table 2). Signs of GBD on live fish in the cages could have been present for a day or two, however, visibility for SCUBA divers was too poor for that observation. Signs were not apparent at the end of the test when fish were

Table 2.-- Mortality, dissolved gas concentrations, and water temperatures observed during holding tests in The Dalles Dam forebay, 1985.

	Percent mortality in cages positioned at the indicated depth (m)[a]								Dissolved gas conc.[b] percent of saturation			Water temp. °C
	Hatchery fish				River-run fish							
Date	0-1	1-2	3-4	0-6.1	0-1	1-2	3-4	0-6.1	low	1300 h	high	
					Yearling chinook salmon							
5/13	Introduced 1500 h				Introduced 1700 h				106	-	111	11.4
5/14	0	0	-	0	10	0	-	0	105	105	118	11.4
5/15	0	0	-	0	5	2	-	0	106	107	116	11.4
5/16	0	0	-	0	0	0	-	0	109	109	113	11.5
5/17	0	0	-	0	0	0	-	2	108	110	111	12.5
5/18	0	1	-	0	2	0	-	0	110	110	111	12.9
Total	0[c]	1	-	0	17[c]	2	-	2	Weighted avg.		110.1	Avg. 11.9
5/20	Introduced 1500 h				Introduced 1700 h				108	-	108	13.5
5/21	0	0	0	0	0	0	0	4	107	107	109	13.7
5/22	0	0	0	0	0	12	15	0	109	109	109	14.3
5/23	0	0	0	0	2	0	0	0	109	110	110	14.3
5/24	0	0	0	0	2	0	0	0	109	109	112	14.8
5/25	0	0	0	0	0	0	5	0	106	106	110	14.8
Total	0	0	0	0	4	12	20	4	Weighted avg.		109.0	Avg. 13.9
5/28	Introduced 1500 h				Introduced 1600 h				109	-	109	14.9
5/29	0	2	0	2	5	0	5	5	106	106	109	15.0
5/30	0	0	2	2	0	-	0	0	106	106	109	15.1
5/31	0	0	0	0	0	-	0	0	106	106	109	15.3
6/01	0	0	0	0	0	-	0	0	106	106	109	15.0
6/02	0	0	2	0	0	-	5	5	104	104	108	14.9
Total	0	2	4	4	5	0	10	10	Weighted avg.		108.1	Avg. 15.0

Table 2.--continued.

Date	Percent mortality in cages positioned at the indicated depth (m)[a] Hatchery fish 0-1	1-2	3-4	0-6.1	River-run fish 0-1	1-2	3-4	0-6.1	Dissolved gas conc.[b] percent of saturation low	1300 h	high	Water temp. °C
							Subyearling chinook salmon[d]					
7/08	Introduced 1500 h								99	-	100	20.3
7/09	-	-	-	0	Introduced 1330 h				99	99	99	20.4
7/10	-	-	-	0	-	-	-	16	99	99	99	20.4
7/11	-	-	-	0	-	-	-	0	99	99	100	20.5
7/12	-	-	-	0	-	-	-	1	99	99	99	20.6
Total				0				17	Weighted avg. 99.1			Avg. 20.4
7/22	Introduced 1600 h				Introduced 1600 h				-	-	-	21.5
7/23	-	-	-	1	-	-	-	0	-	-	-	21.5
7/24	-	-	-	3	-	-	-	0	-	-	-	21.6
7/25	-	-	-	0	-	-	-	0	-	-	-	22.1
7/26	-	-	-	3	-	-	-	-	-	-	-	22.4
Total				7				0	Range 99-102[e]			Avg. 21.8
8/12	Introduced 0900 h				Introduced 0900 h				-	-	-	-
8/13	-	-	-	0	-	-	-	0	-	-	-	21.5
8/14	-	-	-	0	-	-	-	0	-	-	-	21.5
8/15	-	-	-	0	-	-	-	0	-	-	-	-
Total				0				0	Range 99-102[e]			Avg. 21.5

[a] Percent of the number of individuals at the start of testing (about 50).

[b] Dissolved gas concentrations within the 24-h period; lowest, highest, and at 1300 h (the aproximate time of the vertical distribution observation).

[c] Signs of gas bubble disease were not observed in any held fish. It is doubtful that signs could have been observed by SCUBA divers on fish swimming in the cages. If signs were present in fish on 14 and 15 May, it seems likely that none would have been observable by the end of that test when fish were examined individually at the surface.

[d] Fish were not held at 0-1 m, 1-2 m, and 3-4 m because dissolved gas concentrations were not expected to go above 105% of saturation.

[e] Extrapolated from measurements at John Day Dam.

Table 2.--continued.

	Percent mortality in cages positioned at the indicated depth (m)[a]								Dissolved gas conc.[b] percent of saturation			Water temp. °C
	Hatchery fish				River-run fish							
Date	0-1	1-2	3-4	0-6.1	0-1	1-2	3-4	0-6.1	low	1300 h	high	
					Subyearling chinook salmon[d]							
7/08	Introduced 1500 h								99	-	100	20.3
7/09	-	-	-	0	Introduced 1330 h				99	99	99	20.4
7/10	-	-	-	0	-	-	-	16	99	99	99	20.4
7/11	-	-	-	0	-	-	-	0	99	99	100	20.5
7/12	-	-	-	0	-	-	-	1	99	99	99	20.6
Total				0				17	Weighted avg. 99.1			Avg. 20.4
7/22	Introduced 1600 h				Introduced 1600 h				-	-	-	21.5
7/23	-	-	-	1	-	-	-	0	-	-	-	21.5
7/24	-	-	-	3	-	-	-	0	-	-	-	21.6
7/25	-	-	-	0	-	-	-	0	-	-	-	22.1
7/26	-	-	-	3	-	-	-	-	-	-	-	22.4
Total				7				0	Range 99-102[e]			Avg. 21.8
8/12	Introduced 0900 h				Introduced 0900 h				-	-	-	-
8/13	-	-	-	0	-	-	-	0	-	-	-	21.5
8/14	-	-	-	0	-	-	-	0	-	-	-	21.5
8/15	-	-	-	0	-	-	-	0	-	-	-	-
Total				0				0	Range 99-102[e]			Avg. 21.5

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[a] Percent of the number of individuals at the start of testing (about 50).

[b] Dissolved gas concentrations within the 24-h period; lowest, highest, and at 1300 h (the aproximate time of the vertical distribution observation).

[c] Signs of gas bubble disease were not observed in any held fish. It is doubtful that signs could have been observed by SCUBA divers on fish swimming in the cages. If signs were present in fish on 14 May and 15 May, it seems likely that none would have been observable by the end of that test when fish were examined individually at the surface.

[d] Fish were not held at 0-1 m, 1-2 m, and 3-4 m because dissolved gas concentrations were not expected to go above 105% of saturation.

[e] Extrapolated from measurements at John Day Dam.

examined out of water. Gas bubbles disappear relatively quickly at low dissolved gas levels (Dawley et al. 1976). Supersaturation during other tests (maximum of 112%) was not high enough to cause GBD in 8-h periods, even in the 0- to 1-m cage.

Mortality levels for fish held in the upper meter of the water column were not statistically greater (t=0.04, P>0.05, df=20) than for other groups held at greater depths, which allowed for greater hydrostatic pressure compensation (Table 2). On the first day of testing, 10% mortality of river-run fish occurred in the 0- to 1-m cage, but this was before dissolved gas levels reached 118% of saturation; GBD signs were not observed in dead fish from that cage. We assume stress from collection in the gatewell, transport, placement in the cage, and jostling of the cages by wave action on the flotation raft caused the mortality.

Results of the 1985 holding study compare favorably with laboratory studies on effects of supersaturation, and these results complement previous in situ evaluations in the Columbia River. Laboratory studies conducted in water depths <0.6 m, which provided little hydrostatic pressure compensation, showed that migrant-sized juvenile salmonids developed no GBD signs when saturations were 110% or less; at 115%, signs developed and mortality began in a few days (Dawley et al. 1976; Dawley and Ebel 1975; and Nebeker 1973; Meekin and Turner 1974). Tests with greater water depth availability (2.5 m) decreased GBD incidence and associated mortality. Effects were similar to those in shallow water tests at 10% lower supersaturation (Dawley et al. 1976). Previous in situ holding tests, evaluating effects of supersaturation in reservoirs, showed that test fish which were allowed access to water depths sufficient to alleviate GBD through hydrostatic pressure compensation, exhibited substantially less mortality than fish confined to surface levels (Ebel 1971; Weitkamp 1976).

Previous intermittent exposure tests showed that diel periods at low dissolved gas levels provided substantial benefit from the effects of supersaturation (Weitkamp 1976; Blahm et al.1976); internal gas pressures of test fish apparently decreased during the low level periods. Both investigations showed that subyearling chinook salmon suffered little mortality when subjected to 8 h of high dissolved gas levels (124 and 130%) and 16 h of low levels ($\leq$100%). The larger yearling chinook salmon tested at The Dalles Dam in 1985 are probably less tolerant to supersaturation because of size (Dawley et al. 1976); however, the fluctuating supersaturation at these somewhat lower levels also caused no detrimental effects.

Dissolved gas concentrations (99 to 102%) during tests of subyearling fish were not high enough to cause GBD. Therefore, tests were conducted only in volitional cages to examine vertical distribution at ambient levels of dissolved gas saturation.

Adults were not examined because of the low supersaturation levels.

Vertical Distribution.--Detection and avoidance of supersaturation were observed in previous tests with juvenile chinook salmon (Dawley et al. 1975; Blahm et al. 1976). Mortality was substantially reduced but not eliminated by apparent lateral and vertical avoidance. Juvenile steelhead tested in similar conditions generally did not show an avoidance reaction.

During holding tests with yearling chinook salmon, signs of GBD were not observed, even in the 0- to 1-m cages. Thus, we hypothesized that stress to fish from supersaturation in the volitional cage (0-6.1 m) was low, and the effects on the depth distribution of test fish were minimal. Mean depths of fish for each 5-day test period ranged from 3.6 to 4.3 m (Table 3). About 2% of the fish were observed at 0 to 1.2 m and 9% at 1.2 to 2.4 m of depth. Statistical evaluation of differences in vertical distribution between hatchery and river-run fish, the three replicate test series, and daily observations showed no significant differences ($P < 0.05$); three way ANOVA ($f=0.05$ $df=1,18$; $f=0.29$ $df=2,18$; $f=0.92$ $df=2,18$).

Vertical distributions of subyearling chinook salmon were consistent through the three series of tests; mean depths in the volitional cages ranged from 3.1 to 4.0 m (Table 3). About 6% of the fish were observed at 0 to 1.2 m and 15% at 1.2 to 2.4 m of depth. There were no significant differences among mean depths of subyearlings ($t=0.27$, $P<0.05$, $df=11$). Ebel[3/] observed that subyearlings, in volitional cages at Priest Rapids Dam reservoir, congregated at 2.5 to 3.5 m of depth at both high supersaturation (143%, where mortality was 0%) and low supersaturation (118%, where mortality was 6%).

Future comparisons of vertical distribution during high supersaturation are necessary to evaluate whether fish will alter their depth distribution to counteract supersaturation stress. Vertical distributions of yearling and subyearling fish observed in 1985 can be used as a quasi-control.

Hydroacoustic Observations

Vertical distribution of salmonids in front of The Dalles Dam was assessed by BioSonics, Inc. using hydroacoustic techniques. Fifty percent of the yearling chinook salmon observed were within 4.6 m of the surface

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[3/] W. J. Ebel, Biologist, National Marine Fisheries Service, 2725 Montlake Blvd. E., Seattle, WA 98112, unpublished data.

Table 3.--Vertical distributions of yearling and subyearling chinook salmon held in cages in The Dalles Dam forebay, 1985; percent of fish at depth interval.

	Hatchery fish						River-run fish					
	Depth interval (m)					Mean depth (m)	Depth interval (m)					Mean depth (m)
Date	0-1.2	1.2-2.4	2.4-3.7	3.7-4.9	4.9-6.1		0-1.2	1.2-2.4	2.4-3.7	3.7-4.9	4.9-6.1	
						Yearling chinook salmon						
5/14	0	40	50	0	10	2.8	0	0	0	100	0	4.3
5/15	2	3	28	49	18	4.0	5	10	48	30	8	3.4
5/16	0	5	25	50	20	4.1	2	14	34	45	5	3.5
5/17	0	0	4	45	51	4.9	0	5	14	47	34	4.4
Avg.	1	12	27	36	25	4.1	2	7	24	55	12	3.9
5/21	0	4	38	57	2	3.8	0	25	25	50	0	3.4
5/22	6	0	27	55	12	3.9	0	0	6	45	49	4.8
5/23	8	17	0	42	33	4.0	0	0	17	42	42	4.6
5/24	0	6	31	31	31	4.1	0	5	14	38	43	4.5
Avg.	4	7	24	46	20	3.9	0	7	15	44	33	4.3
5/29	0	20	40	40	0	3.3	0	40	60	0	0	2.5
5/30	0	0	0	100	0	4.3	4	0	0	75	21	4.4
5/31	4	0	8	58	38	4.5	0	8	31	62	0	3.7
6/01	3	0	13	37	47	4.6	0	17	19	28	36	4.1
Avg.	2	5	15	59	29	4.1	1	16	27	41	14	3.6

Table 3.--continued.

	Hatchery fish						River-run fish					
	Depth interval (m)					Mean depth (m)	Depth interval (m)					Mean depth (m)
Date	0-1.2	1.2-2.4	2.4-3.7	3.7-4.9	4.9-6.1		0-1.2	1.2-2.4	2.4-3.7	3.7-4.9	4.9-6.1	
						Subyearling chinook salmon						
7/09	6	21	29	34	10	3.3	-	-	-	-	-	-
7/10	10	11	26	37	15	3.5	0	5	36	36	23	4.0
7/11	0	3	16	40	40	4.5	7	19	19	28	28	3.7
7/12	2	6	31	31	31	4.1	2	0	20	39	39	4.4
Avg.	5	10	26	36	24	3.9	3	8	25	34	30	4.0
7/23	0	25	25	25	25	3.7	0	0	43	29	29	4.1
7/24	11	22	22	22	22	3.3	4	14	27	27	27	3.7
7/25	14	21	21	21	21	3.8	2	21	35	28	14	3.4
7/26	6	19	25	25	25	3.6	-	-	-	-	-	-
Avg.	8	22	23	23	23	3.4	2	12	35	28	23	3.7
8/13	11	7	25	25	32	3.8	-	-	-	-	-	-
8/14	12	12	23	27	27	3.6	14	50	29	3	4	2.2
8/15	0	4	27	32	37	4.3	0	0	41	35	24	4.1
Avg.	13	13	25	28	30	3.9	7	25	35	19	14	3.1

(Steig and Johnson 1986). Subyearlings were deeper; 50% were within 9.1 m of the surface at the powerhouse and within 5.8 m of the surface at the spillway. We estimate that the danger zone for salmonids, during high supersaturation, is 0-3 m depth; hydrostatic pressure below 3 m reduces the ambient supersaturation to tolerable levels for salmonids for most conditions encountered in the Columbia River. The percentages of migrants above 3 m at the powerhouse and spillway were: 22 and 8%, respectively, for yearling fish, and 10 and 15%, respectively, for subyearling fish. Both age classes had deeper vertical distributions during the night. Relative differences of vertical distribution associated with time of day and age class were consistent with observations at other Columbia River dams (Raemhild et al. 1984a, 1984b).

Hydroacoustic observations of migrant depth at dams do not necessarily represent distributions of fish migrating through the reservoir, nor of fish hesitating in front of the dam. Many targets observed by the echo sounders are fish in the process of passing into the turbines or under spill gates (T. Steig[4/]).

Daytime observations made by NMFS from a small boat traversing the reservoir 50 to 300 m upstream from The Dalles Dam were not very successful. Only 43 targets were observed--all yearling fish in May. Combined data from the surveys indicated that 48% of fish were in the upper meter, 32% from 1 to 2 m, 7% from 2 to 3 m, and 13% below 3 m in depth. The expansion factors used to adjust for area of the echo sounding cone at the

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[4/] T. Steig, BioSonics, Inc., 4520 Union Bay Place, Seattle, WA 98112, pers. commun. 1986.

first and second meter depth were very large and the targets very few, resulting in questionable data.

In round-the-clock hydroacoustic observations made near the shoreline upstream from the dam, 32% of the 108 targets were in the upper 3 m in daylight and 27% of the 64 targets in the upper 3 m at night. These observations, made in May and early June, presumably represent yearling salmonids; however, resident fishes may have influenced these observed depth distributions. The few subyearling fish observed do not warrant a report.

1986

Dissolved Gas Levels

Warm weather in late May caused a rapid snowmelt, leading to unexpected high flows in the Snake and mid- and lower-Columbia Rivers. From 30 May to 8 June, about 34% of the flow at Lower Granite Dam on The Snake River and 41% of the flow at Priest Rapids Dam on the Columbia River were spilled (Fig. 6); total flows averaged 194 and 160 kcfs, respectively, at the two dams. Consequently, dissolved gas levels increased to $\geq$120% through hundreds of miles of river (Fig. 6). Large diurnal fluctuations in gas concentrations, as observed in 1985, did not occur because water was spilled 24 h per day.

Gas Bubble Disease in Migrants

In the 8-day period of evaluation, 1-9 June, signs of GBD, predominately cutaneous bubbles between the rays of one or two fins, were observed in migrating juvenile salmonids (Table 4). From past research, we believe these signs were caused by short-term exposure to high levels of supersaturation (hours at > 115%) or long-term exposure at low levels of supersaturation (days at < 115%). The majority of observed migrants must have been at depths sufficient to keep the effective gas pressure in their bodies below 115%

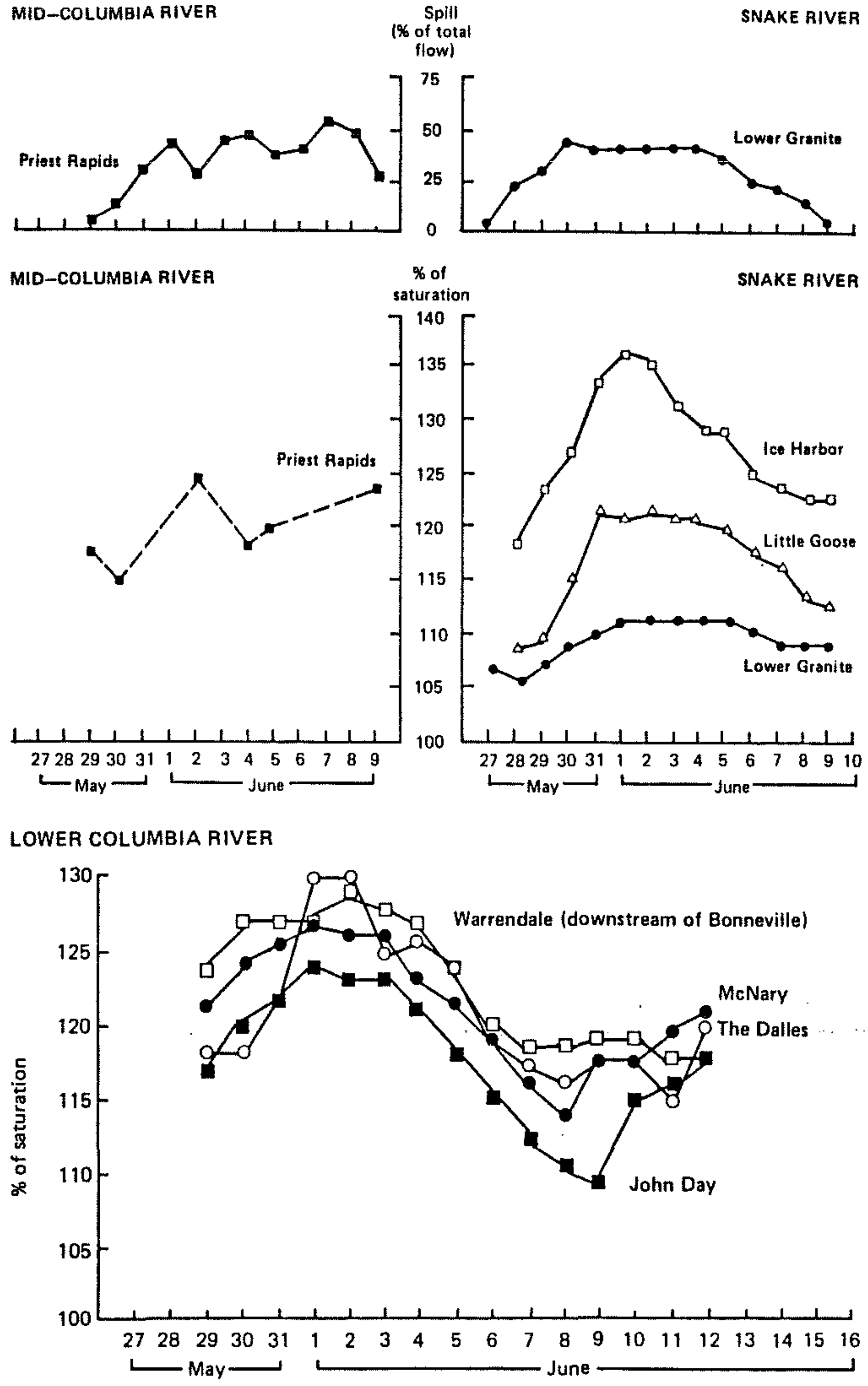

Figure 6.--Percentages of river flow spilled at Lower Granite Dam (Snake River) and Priest Rapids Dam (Columbia River) in May-June 1986. Dissolved gas levels at eight sites are also shown.

Table 4.--Incidence of gas bubble disease in juvenile salmonids sampled at McNary, John Day, and Bonneville Dams, 1986 (usually 100 or more individuals/sample).

Date	Percent with signs of gas bubble disease[a]														
	Steelhead			Subyearling chinook salmon			Yearling chinook salmon			Coho salmon			Sockeye salmon		
	McNary	John Day	Bonn.	McNary	John Day	Bonn.	McNary	John Day	Bonn.	McNary	John Day	Bonn.	McNary	John Day	Bonn.
1 June	4	–[b]	–	0	–	–	7	–	–	3	–	–	2	–	–
2	3	0	3	0	0	0	3	0	0	0	0	0	0	0	0
3	4	0	14(2)	0	0	0	1	0	0	5	0	0	0	0	0
4	2	0	16(2)	0	0	0	<1	0	0	1	0	0	0	0	0
5	2	0	13(1)	0	0	0	2	0	0	0	0	1	0	0	0
6	3	0	–	0	0	–	2	0	–	0	0	–	0	0	–
7	1	0	–	0	0	–	1	0	–	0	0	–	0	0	–
8	2	0	0	0	0	0	<1	0	0	0	0	0	0	0	–
9	1	0	0	0	0	0	<1	0	0	0	0	0	0	0	0

[a] Signs were primarily bubbles in fins--few in number. Profuse bubbles in fins, in mouth, or on head (indicating more severe stress) were observed only at Bonneville Dam; percent incidence denoted by the numbers in ( ).

[b] No observations are indicated by a dash (-).

(≥1 m; assuming an average 125% of saturation). Only juvenile steelhead at Bonneville Dam showed substantial signs of GBD (13-16% of individuals examined during a 3-day period); about 2% had severe signs (massive areas of bubbles in fins, on the operculum, or in the buccal cavity).

At McNary Dam, adult chinook salmon and steelhead were examined for GBD during the high flow period. Signs of GBD were not observed in any of the 28 fish examined.

CONCLUSIONS AND RECOMMENDATIONS

During 1985 and 1986, the impacts of supersaturation in the lower Columbia River (McNary Dam to the estuary) were minimal to juvenile and adult salmonids. Juvenile steelhead were affected most, but probably did not suffer substantial mortality because of their rapid movement to the ocean (Dawley et al. 1986).

Salmonid's tolerance to supersaturation and their ability to detect and avoid supersaturation seem dependent on life stage, species, stock, and environment (Dawley and Ebel 1975; Alderdice and Jensen 1985; and Lund and Heggberget 1985). Lethal conditions may prevail in certain areas at certain times, so knowledge of the tolerance limits for resident and migrant fishes impacted by supersaturation is essential to assess the necessity for counteractive measures.

Future studies at The Dalles Dam during a period of high supersaturation are necessary to satisfy the objectives of this study.

ACKNOWLEDGMENTS

I thank Dick Johnson and his staff at the Washougal Salmon Hatchery and James Holway and his staff at the Eagle Creek National Fish Hatchery for their substantial efforts in extending the rearing periods of the fish groups used in these holding tests. Each year they perform tasks beyond their job requirements, often after their workday and without remuneration or recognition to help various fisheries enhancement efforts.

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Effect of John Day Dam on Dissolved Nitrogen Concentrations and Salmon in the Columbia River, 1968

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ABSTRACT

Concentrations of dissolved nitrogen gas were measured in the lower 640 km of the Columbia River from April to September 1968 to determine the effect of newly-constructed John Day Dam on nitrogen saturation downstream. Observations were also made of symptoms of gas bubble disease and mortality in juvenile and adult salmon.

Heavy spillway discharge at the dam caused abnormally high (123–143%) supersaturation downstream, and mortalities of juvenile and adult salmon (*Oncorhynchus* spp.) and steelhead trout (*Salmo gairdneri*) were substantial. Delays in passage at John Day and The Dalles Dams coupled with supersaturation of nitrogen gas caused the mortalities.

The authors recommended that in future dam construction one or more turbines should be operable before the reservoir is filled. Increasing the flow through the turbines while decreasing flow over the spillways will reduce concentrations of nitrogen. In addition, every possible effort should be made to reduce the delay of salmon passing over dams.

INTRODUCTION

A study of the supersaturation of dissolved nitrogen in the Columbia River in 1965–67 (Ebel, 1969) showed that water falling over spillways into deep plunge basins of dams became supersaturated during heavy spillway discharges. This supersaturation appeared to be the direct cause of mortality of juvenile coho and chinook salmon (*Oncorhynchus kisutch* and *O. tshawytscha*) from gas bubble disease and to be linked also with unexplained mortalities of adult sockeye salmon (*Oncorhynchus nerka*) and steelhead trout (*Salmo gairdneri*). Until 1968, however, external symptoms of gas bubble disease had not been seen in adult chinook salmon and had been recognized in only a few adult sockeye salmon and steelhead trout.

Concentrations of dissolved nitrogen from Priest Rapids Dam, Washington, to the estuary were again observed in 1968, particularly to determine the effect of the newly constructed John Day Dam. Extremely high concentrations were expected, since the powerhouse was still under construction and all river flow was passed over the spillway. This report describes the changes brought about by John Day Dam on concentrations of dissolved gases and the effect these changes had on migrant salmon and steelhead trout near the dam.

METHODS

Ebel (1969) described the method for collection and analysis of gas samples. Observations were limited to the lower 640 km of the river in 1968. Twenty stations (Figure 1) were sampled monthly from April to September. The use of a float plane enabled us to collect and analyze all samples within a 24-hour period. Additional stations were sampled weekly at John Day and The Dalles Dams to document conditions related to fish passage problems. Water samples were stored in an ice chest to reduce changes in gas content that occur from temperature increases.

Dissolved nitrogen and oxygen concentrations were determined for each sample and expressed in percentage saturation—100% indicated equilibration of dissolved gases at one atmosphere (760 mm of mercury). No corrections were made for slight changes in elevation or barometric pressure. A Van Slyke-Neill blood gas analyzer, modified for water determinations, was used for the weekly series of samples. The Van Slyke-Neill apparatus was used in the calibration of a gas chromatograph which was used when large numbers of samples were analyzed. A detailed description of the chromatographic technique is given by Swinnerton, *et al.* (1962).

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[1] Present address: Fish Commission of Oregon, Research Laboratory, Route 2, Box 31A, Clackamas, Oregon 97015.

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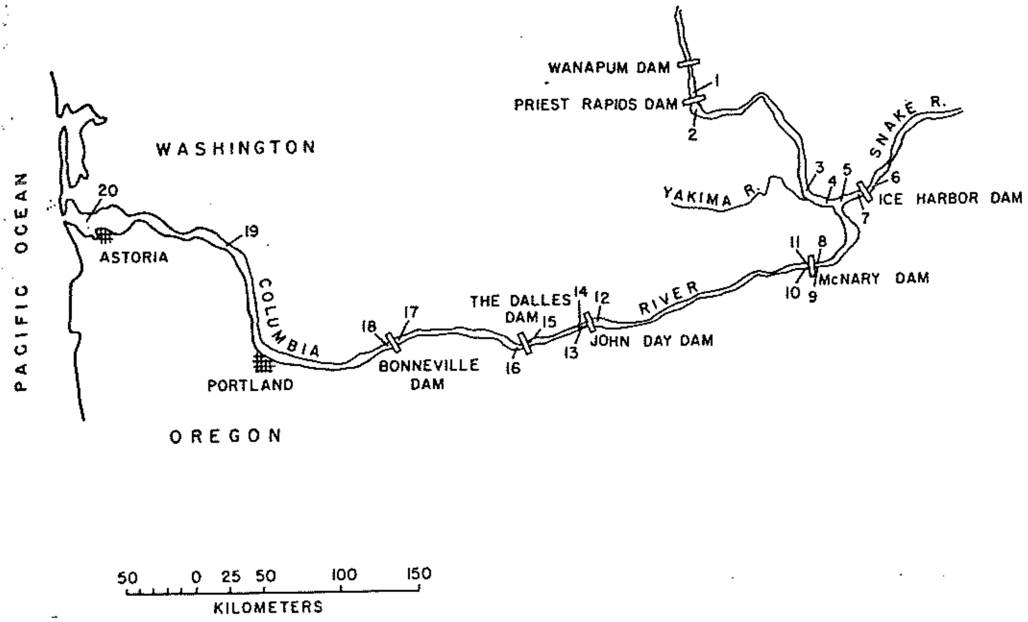

FIGURE 1.—Principal sampling stations (numbered from 1 through 20) on the Columbia and Snake Rivers, 1968.

CHANGES IN RIVER CONDITIONS CAUSED BY JOHN DAY DAM

Physical Alteration of the River

Construction of John Day Dam, 347 km upstream from the estuary (Figure 1), began in 1959. The U. S. Army Corps of Engineers, which supervised the project, closed the dam on April 14, 1968, and impounded the river before the powerhouse was opened, so that the fishways would be in operation before the spring salmon migrations. This procedure was carried out on the advice of Federal and State fisheries agencies responsible for sustaining fish populations in the Columbia River system. The reservoir was filled in 4 days, and fish ladders were in operation by April 20.

The John Day impoundment inundated the last free-flowing portion of the Columbia River between tidewater and the mouth of the Snake River, forming an uninterrupted series of impoundments over 300 km long.

Effect on Nitrogen Concentrations

In the preceding 3 years, saturation in the entire lower river downstream of Priest Rapids Dam was near equilibration with the atmosphere (100%) from late fall to May, when none of the 11 dams on the main stem of the river discharged water from the spillway regularly. Immediately after John Day Dam was closed on April 20, concentrations of nitrogen were high (over 125% of saturation) downstream from the dam, throughout The Dalles impoundment. These concentrations were considerably higher than those in 1966 and 1967 (Figure 2) and remained high during the entire salmon migration. In September they still exceeded 125%, long after concentrations at other dams had dropped to less than 105% of saturation.

Nitrogen concentration in the tailrace immediately downstream from John Day Dam were very high—123 to 145% of saturation—because of the heavy discharge over the spillway. In general, tailrace concentrations averaged 20% higher than forebay concentrations, which ranged from 96 to 123% of saturation (Figure 3).

Equilibration in Reservoirs

Comparison of nitrogen concentrations upstream and downstream in The Dalles impoundment confirmed the 1966–67 study,

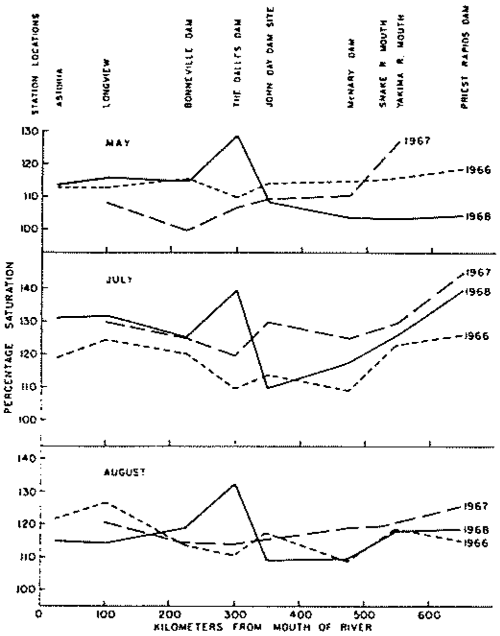

FIGURE 2.—Comparison of percentage saturation of dissolved nitrogen in forebays from Priest Rapids Dam to mouth of Columbia River, May, July, and August 1966 (short dashes), 1967 (long dashes), and 1968 (solid line).

which showed that the water supersaturated with dissolved nitrogen usually does not equilibrate completely during transit through a reservoir (Ebel, 1969). From May to August 1968, nitrogen concentrations decreased an average of only 4% between the tailrace of John Day and the forebay of The Dalles, 39 km downstream (Figure 3).

A second comparison—that between nitrogen concentrations in the farthest upstream and downstream sections of newly-formed John Day Reservoir, appeared to differ from findings in other reservoirs. During the warmer months (June and July) saturation at the head of the reservoir, which extends to the base of McNary Dam, was over 135%, whereas the average in the forebay of John Day Dam, 122 km downstream, was only 114% of saturation. The reduction indicated that equilibration occurred at a higher rate than observed in other reservoirs. Possibly supersaturated water equilibrated more rapidly in John Day Reservoir because its greater length offered a better opportunity for equilibration than in the shorter reservoirs.

Effect on River Temperatures

Because new dams have been built in the Columbia River, there have been many changes in the cooling and heating cycles of the river. High river temperatures have been increasingly common during times when such temperatures usually did not occur (Jaske, 1965; Moore, 1968). Before John Day Dam was completed, the Fish Passage Research Program of the Bureau of Commercial Fisheries predicted some of the physical, chemical, and biological changes that would be created by this new impoundment. Novotny and Clark (1967),[2] who computed a heat budget and forecast future water temperatures for the new reservoir, predicted a slight net increase in the water temperature over that entering the pool. Projected changes in temperature of water discharged at John Day Dam included increases ranging from 0.2 C in June to 1.5 C in October.

Water temperatures taken in conjunction with nitrogen studies reflected some change in the temperature regime of the Columbia River in 1968. Temperature curves (Figure 4) from data taken in John Day Reservoir during August, September, and October indicate a definite increase in the temperature gradient between McNary and John Day Dam. The temperatures we recorded appeared to substantiate the predictions of Novotny and Clark.

Temperature changes are difficult to identify because of irregular spills, release of flood storage, and abnormal precipitation and air temperatures, but a noticeable trend was evident in late summer. The temperature of the water mass moving through the new reservoir appeared to increase more rapidly than in the former river-run environment (Figure 4). Whereas the free-running river permitted some equilibration of water temperatures with air temperatures, especially when water temperatures dropped in the fall, the new im-

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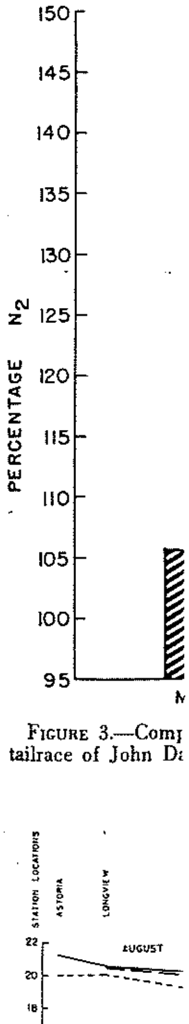
[2] Anthony J. Novotny and Shirley Miller Clark. 1967. Preliminary predictions of water temperatures in John Day Reservoir. U. S. Fish Wildl. Serv., Bur. Commer. Fish., Biol. Lab., Seattle, Wash., unpublished manuscript. 11 pp.



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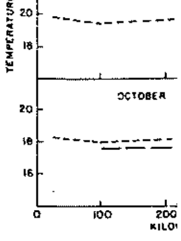

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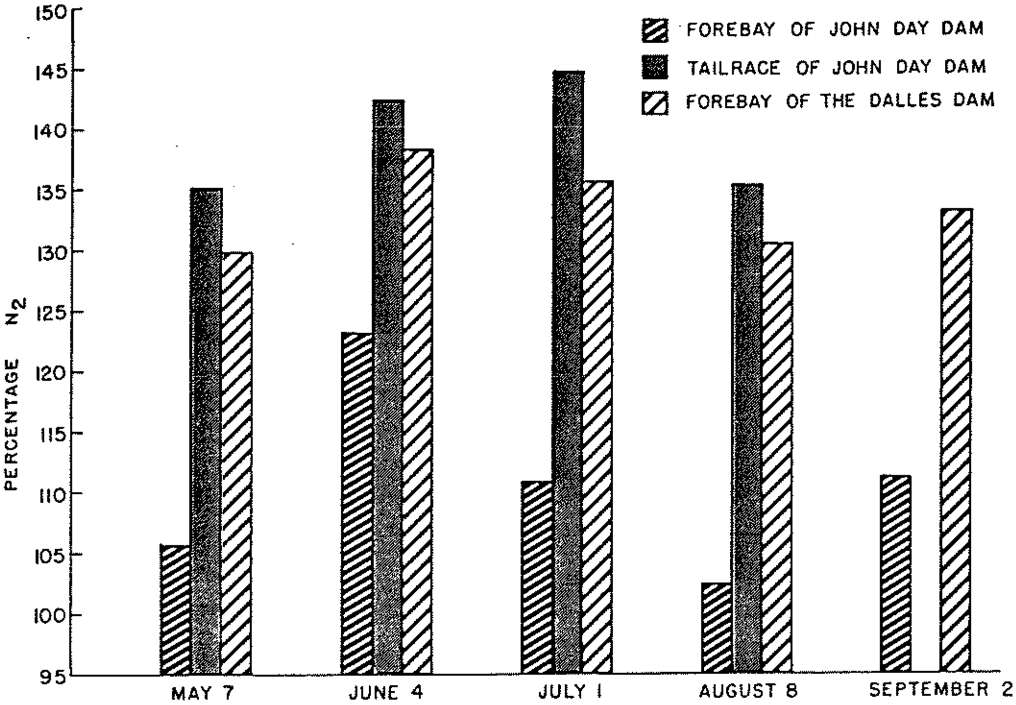

FIGURE 3.—Comparison of percentage saturation of dissolved nitrogen in forebay of John Day Dam with tailrace of John Day Dam and The Dalles Dam forebay, May–September 1968.

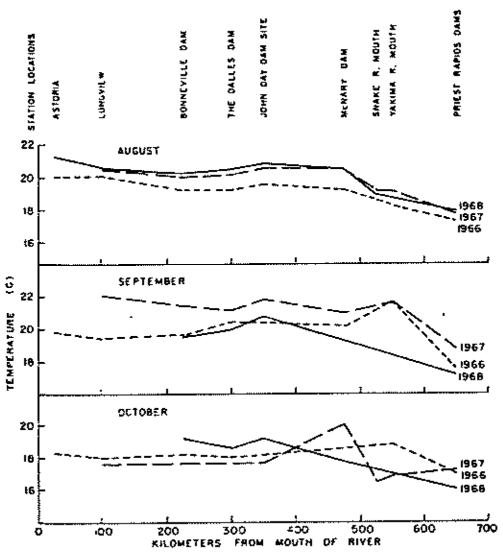

FIGURE 4.—Temperatures (C) at 10-m depth in the Columbia River from Priest Rapids Dam, Washington, to Astoria, Oregon, August–October 1966 (short dashes), 1967 (long dashes), and 1968 (solid line).

poundment retained the warmed water and delayed cooling until later in the year.

EFFECT OF HIGH CONCENTRATIONS OF NITROGEN GAS ON FISH DOWNSTREAM FROM JOHN DAY DAM

Effect on Juvenile Fish

Symptoms of gas bubble disease in juvenile Pacific salmon and steelhead trout downstream from John Day Dam in May 1968 were the same as in juveniles at Priest Rapids Dam in June, July, and August of previous years (Ebel, 1969). Bureau of Commercial Fisheries personnel, checking identifying marks on downstream juvenile migrants at The Dalles Dam, noticed unusually high mortalities among fish held for inspection (Howard L. Raymond, personal communication). Definite external symptoms of gas bubble disease were observed in juvenile coho salmon, chinook salmon, and steelhead trout (Figure 5). During one week in late May, 25% of the juvenile steelhead

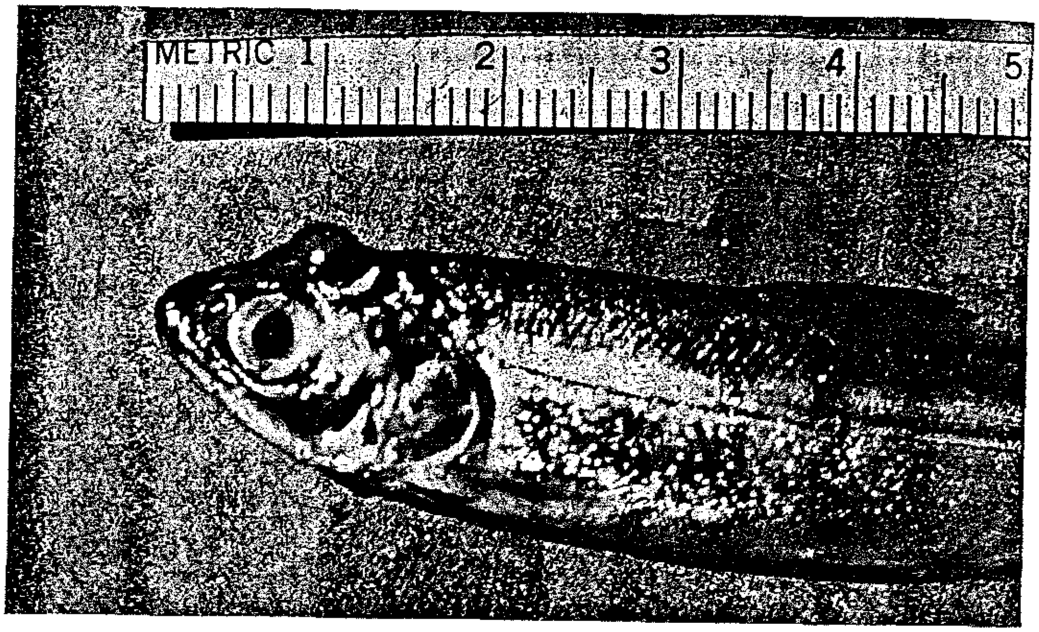

FIGURE 5.—Gas bubble on head of fingerling coho salmon, a symptom of gas bubble disease.

trout, 46% of the chinook salmon, and 68% of the coho salmon inspected had obvious external symptoms of gas bubble disease.

Despite the relatively low (11.4–15.2 C) water temperatures, compared with the 13.9–17.8 C range at Priest Rapids forebay in 1967 when mortalities occurred, symptoms of gas bubble disease and mortalities persisted during the remainder of the migration through mid-June. Nitrogen concentrations remained over 130% of saturation. These observations at The Dalles Dam parallel those in 1967 at Priest Rapids Dam where fish held in pens submerged at different depths had to remain below 2.5 m to avoid the effects of supersaturation (Ebel, 1969). Apparently salmon and steelhead trout fingerlings subjected to high saturation of nitrogen during their migration readily contract gas bubble disease and succumb to it.

Effect on Adult Fish

Three incidents of substantial mortality of adult salmon and steelhead trout were recorded downstream from John Day Dam by personnel of the Fish Commission of Oregon, Washington Department of Fisheries, Federal Water Quality Administration, Army Corps of Engineers, and the Bureau of Commercial Fisheries. All mortalities were observed during delays in migration.

The first incident occurred at John Day Dam shortly after the ladders were put into operation on April 20. Large numbers of spring chinook salmon failed to enter fish ladders below the dam because the flow in and near the ladders was insufficient to attract the fish.

A second delay occurred at The Dalles Dam, when a pump providing attraction flows to the south ladder failed on June 14. The pump

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FIGURE 6.—Vesicles in roof of mouth and distended eyes of adult sockeye salmon captured at entrance to south ladder at John Day Dam, 20 July 1968.

FIGURE 7.—Large gas bubble in eye tissue and numerous gas bubbles on operculum of adult sockeye salmon captured at entrance to south ladder at John Day Dam, 20 July 1968.

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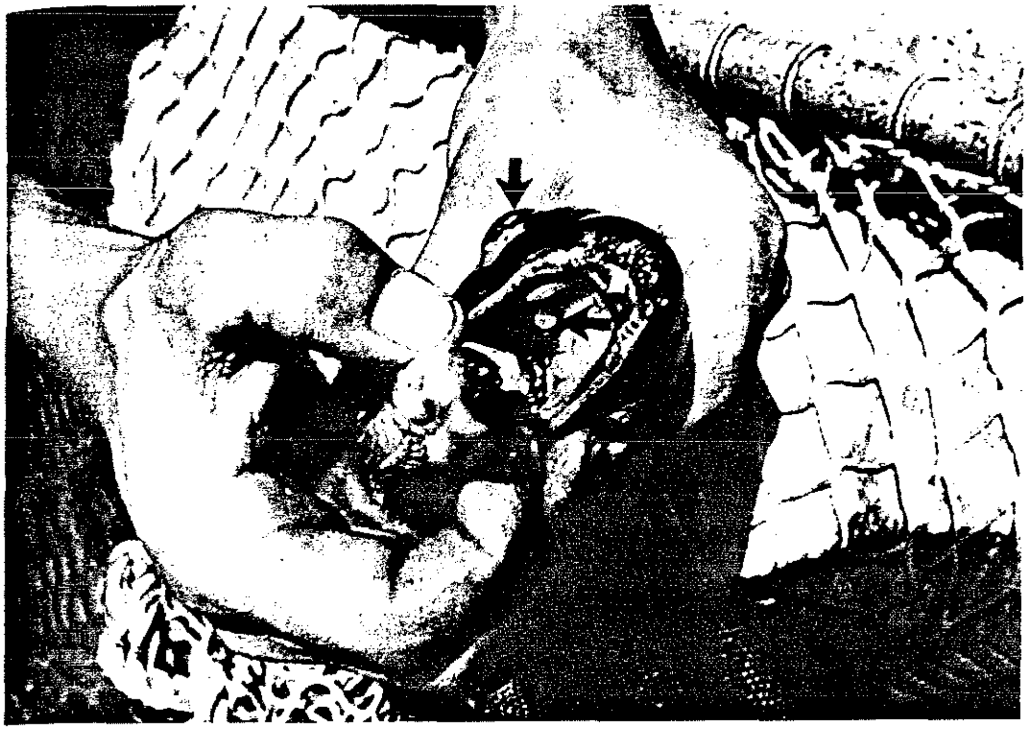

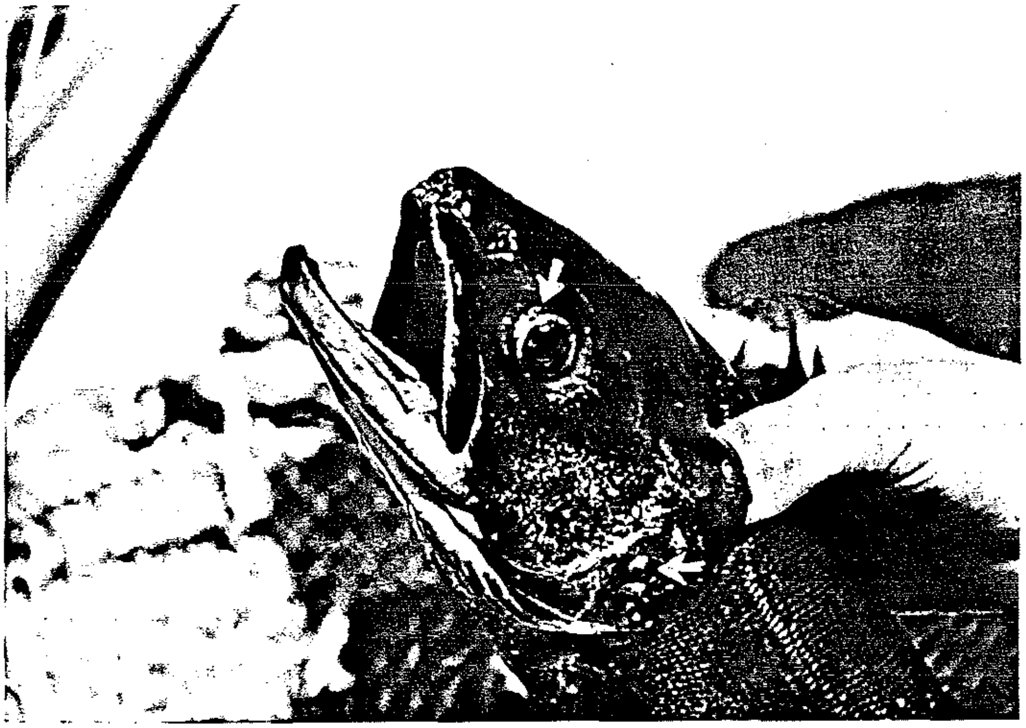

was restored to service a month later, but in the intervening period the passage of summer chinook salmon, sockeye salmon, and steelhead trout was substantially delayed.

Shortly after normal fish-passage conditions were restored at The Dalles Dam on July 13, a second major holdup occurred at John Day Dam. Large numbers of summer-run chinook and sockeye salmon and steelhead trout—as well as carp (*Cyprinus carpio*), sucker (*Catostomus* spp.), northern squawfish (*Ptychocheilus oregonensis*), and American shad (*Alosa sapidissima*)—were observed near the south ladder below the dam, but did not enter the ladder. Improperly adjusted attraction flows appeared to be the cause of this delay.

Counts of dead salmon floating downstream were made below John Day and The Dalles Dams after each delay; the largest number of dead fish—13 sockeye and 365 chinook salmon—was below John Day Dam on July 29. On the basis of the numbers of dead salmon and previous studies of recovery rates of dead salmon, the Fish Commission of Oregon later estimated that over 20,000 summer chinook salmon from the 1968 spawning population were missing between Bonneville and McNary Dams (Charles O. Junge, personal communication).

Gas bubble disease was in part responsible for these mortalities. Several sockeye salmon captured at the entrance to the ladder at John Day Dam exhibited obvious external symptoms: eyes distended (Figure 6) and hemorrhaged; bubbles in the subcutaneous layers surrounding the eyeball (Figure 7); and large vesicles between the epithelium and connective tissue in the roof of the mouth (Figure 6) and on the outside of the opercula (Figure 7). The eyes of one large chinook salmon hemorrhaged as the fish was removed from the entrance to the counting chamber.

We did not observe symptoms of gas bubble disease in salmon carcasses, but did not expect to see them because most of the fish had been dead for some time. Coutant and Genoway (1968) observed that external symptoms of gas bubble disease disappeared rapidly after death, nearly all evidence being lost within 24 hours.

Fish counters at the underwater viewing chamber in the south fishway at John Day Dam observed what appeared to be symptoms. The following are excerpts of their remarks (Daily Fishway Reports, John Day Dam, Portland District, U. S. Army Corps of Engineers, Portland, Oregon):

June 18: Two chinook with missing eyes
June 21: Many chinook with body blisters; some are nearly covered
June 26: Sockeye with spots (blisters) on body
June 29: Over 1,000 sockeye with spots (blisters) on body
July 1: Many sockeye with infected injuries
July 6: Many sockeye with red and protruding eyes
July 16: Most fish lying at entrance to ladder; not moving
July 17: Sockeye in poor shape; many with injuries
July 20: Sockeye with red eyes; they seem to swim blindly
July 23: Chinook and sockeye with missing eyes (or blind)
July 25: Steelhead, chinook, and sockeye with red eyes
July 26: Four sockeye with protruding eyes
July 28: Three chinook, 12 sockeye, and 1 steelhead with red eyes
July 30: Two chinook and 3 sockeye with red and protruding eyes

Daily reports from August 1 to 19 also noted salmon and steelhead trout, generally in poor condition, with red and protruding eyes.

Tissue specimens from salmon, steelhead trout, and several species of rough fish were collected and examined by Dr. Gerald R. Bouck, Federal Water Quality Administration, for histopathological studies. Preliminary findings (Bouck, personal communication) indicated definite tissue damage from gas bubble disease in spleen and gill lamellae of sockeye salmon and tentative indications of gas emboli in gill filaments of chinook salmon.

SUMMARY AND CONCLUSIONS

In 1968, death and injuries from gas bubble disease were observed near John Day Dam on the Columbia River among juvenile and adult salmon and steelhead trout. The completion of the dam just before the migration of spawning and smolting populations con-

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CONCLUSIONS

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tributed to a series of events that caused these mortalities.

Bureau of Commercial Fisheries studies have shown that high levels of dissolved nitrogen gas (over 125% of saturation) occur each year over a large portion of the Columbia River. Field experiments determined that these high levels are fatal to adult and juvenile salmon and steelhead trout when exposure is prolonged by delay.

Temperatures recorded in John Day Reservoir in August, September, and October 1968 indicate a change in the temperature regime of that section of the river when compared with 1966 and 1967. The increase in temperature from McNary Dam to John Day Dam appeared to be greater than in former years.

Discharge of most of the river flow over the spillway created abnormally high (123–143%) supersaturation of nitrogen downstream during the salmon migration. These levels produced symptoms of gas bubble disease and mortalities among juvenile salmon and steelhead trout migrating downstream during this period. Adult salmon were faced with a combination of factors which also produced distress and eventual death. On three occasions when salmon were exposed to warming water highly saturated with dissolved nitrogen during delays at fish ladders, we observed obvious external symptoms of gas bubble disease in sockeye salmon and counted substantial numbers of dead adult sockeye and chinook salmon.

It is our opinion that the prolonged delay of adult salmon downstream from John Day Dam, accompanied by abnormally high nitrogen supersaturation, caused a high percentage of the mortalities observed. We also believe that migrating juveniles will incur extensive mortalities in the future if they are subjected to temperature increases or are restricted from sounding (Ebel, 1969) while in water supersatured to the levels observed in 1968.

We recommend that in future construction of dams one or more turbines be operable before the reservoir is filled. By lessening the amount of flow over the spillway, the dissolved nitrogen concentrations in the tailrace will be correspondingly reduced; passage of water through turbines does not increase concentrations of dissolved nitrogen (Ebel, 1969). Moreover, every possible effort should be made to reduce the delay of salmon passing over dams.

ACKNOWLEDGMENTS

We thank Mr. Ivan Donaldson, Fishery Biologist, Portland District, U. S. Army Corps of Engineers, and Mr. Charles O. Junge, Fishery Biologist, Fish Commission of Oregon, for the advice and assistance given us during the preparation of this report.

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EFFECTS OF VARIOUS CONCENTRATIONS OF DISSOLVED ATMOSPHERIC GAS ON JUVENILE CHINOOK SALMON AND STEELHEAD TROUT

EARL M. DAWLEY AND WESLEY J. EBEL[1]

ABSTRACT

Bioassays in shallow tanks (25 cm deep) with dissolved nitrogen and argon gas concentrations ranging from 100 to 125% of saturation in water at 15°C were conducted to determine lethal and sublethal effects on juvenile chinook salmon, *Oncorhynchus tshawytscha*, and steelhead trout, *Salmo gairdneri*. Significant mortality of both species commenced at 115% saturation of nitrogen and argon (111% saturation of total dissolved atmospheric gas pressure). Over 50% mortality of both steelhead and chinook occurred in less than 1.5 days in water at 120 and 125% of saturation. Significant differences in swimming performance, growth, and blood chemistry were measured in groups of fish tested at sublethal exposures in various concentrations of dissolved gases. Sublethal stress for 35 days at 110% dissolved nitrogen (106% total atmospheric gas) decreased normal swimming ability of chinook. Growth of both steelhead and chinook was affected by sublethal exposures in water saturated with atmospheric nitrogen and argon at 105, 110, and 115%. Blood chemistry was affected at sublethal exposures in water at 115% saturation.

Supersaturation of atmospheric gas (mainly nitrogen) in waters of the Columbia and Snake rivers—caused by spillway discharges from dams—has been well documented as a serious problem to valuable stocks of Pacific salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdneri*. Gas bubble disease resulting from this supersaturation causes both direct and indirect mortalities. Direct mortality results from air emboli in the heart and gill filaments, destruction of vital organs, or characteristic red blood cell hemolysis (Marsh and Gorham 1905; Pauley and Nakatani 1967; Bouck et al. 1970[2]). Indirect mortality is a consequence of later invasion by disease organisms (Coutant and Genoway 1968[3]) or of increased predation due to reduced performance capabilities of the fish as the result of sublethal exposure to supersaturation.

The lowest level of nitrogen supersaturation at which juvenile salmon or steelhead trout can be exposed continually with no detrimental effects is not known. Several investigators have recorded the lowest level observed during various experiments where mortalities occurred from gas bubble disease; however, very little attention has been given to determining the effect of sublethal exposure on physiological and behavioral performance. Harvey and Cooper (1962) indicated 108-110% saturation produced gas bubble disease and subsequent mortalities in sockeye salmon alevins, *O. nerka*; Rucker and Tuttle (1948) indicated a level somewhere between 110 and 115% as being the critical range for trout. Shirahata (1966) conducted the most comprehensive study to date on the effects of various levels of nitrogen gas on rainbow trout (rainbow trout is the nonanadromous form of *S. gairdneri*, whereas the steelhead trout is the anadromous) from hatching to the swim-up stage, but such detail is lacking for other species of salmonids. In many experiments on gas bubble disease, either the water temperatures, nitrogen gas concentrations, or life stages of the test fish were omitted from record, thus making the results incomplete for critical applications.

Costs involved in alleviating the supersaturation problem in the Columbia and Snake rivers will be considerable. The extent of these costs will depend on the degree of protection required to afford a safe environment for the aquatic biota. It is imperative, therefore, that regulatory measures established to govern the level of saturation be

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[1] Northwest Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Boulevard East, Seattle, WA 98112.

[2] Bouck, G. R., G. A. Chapman, P. W. Schneider, Jr., and D. G. Stevens. 1970. Observations on gas bubble disease in adult Columbia River sockeye salmon (*Oncorhynchus nerka*). Pac. Northwest Water Lab. [Fed. Water Qual. Adm., Corvallis, Oreg.], June 30, 1970. Unpubl. manuscr., 19 p.

[3] Coutant, C. C., and R. G. Genoway. 1968. Final report on an exploratory study of interaction of increased temperature and nitrogen supersaturation on mortality of adult salmonids to U.S. Bur. of Commercial Fisheries, Seattle, Washington. Battelle Mem. Inst. Pac. Northwest Lab. Richland, Wash., November 28, 1968, 28 p.

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based upon a thorough understanding of the effects of dissolved gases on aquatic organisms.

This paper describes the results of dissolved gas bioassays with juvenile steelhead trout and spring chinook salmon, *O. tshawytscha*, conducted by the National Marine Fisheries Service during the spring of 1972. These experiments were designed to assess lethal and sublethal effects of supersaturation of atmospheric gases on test fish at levels found in the Columbia and Snake rivers during the spring freshet. Atmospheric nitrogen concentrations[1] were of major concern and test levels ranged from 100 to 125% of saturation. Special note is made of testing procedures and ramifications of the effects of these on the outcome of our tests.

METHODS

Bioassays were carried out in the laboratory in shallow tanks (25-cm water depth) to negate the effects of hydrostatic pressure compensation. These facilities were similar to those described by Ebel et al. (1971). Water flow into each test tank was maintained at 3 liters/min at a temperature of 15° ± 0.5°C. Test tanks were partitioned with perforated fiberglass plates to form four sections –in-flow area, test area A, test area B, and outflow section (Figure 1).

Supersaturated water was produced by metering 0.7 liter/min air into the suction side of a centrifugal pump which recirculated water through a 197-liter (52-gallon) closed receiver at a rate of about 190 liters/min (50 gal/min). Water pressure throughout the system was at 1.4 kg/cm^2 (20 psi) except in a short section of pipe on the discharge side of the pump where it was increased to 3.2 kg/cm^2 (45 psi) by use of a valve for additional back pressure necessary to achieve the required supersaturation. Water remained in the recirculatory system for about 10 min before passing to the test tanks. This arrangement supersaturated the water to about 145% of air saturation. Water was then piped to the test tanks where it passed over a series of perforated fiberglass plates into an inlet box with air bubbling through a bottom plate of porous polyethylene. The number of fiberglass plates and volume of air were adjusted to yield the various levels of saturation. An increase of air to water interface directly decreased the excess dissolved gas content.

Water samples for dissolved gas analyses were collected throughout the tests near the center of each test tank directly in front of the partition between A and B testing areas and in some tests at the center of each section of the tank. Frequency of analysis varied from once an hour to once a day depending on duration of test. Procedure for analysis of dissolved nitrogen was from Van Slyke and Neill (1924) using manometric blood gas apparatus; dissolved oxygen was analyzed using modified Winkler procedures

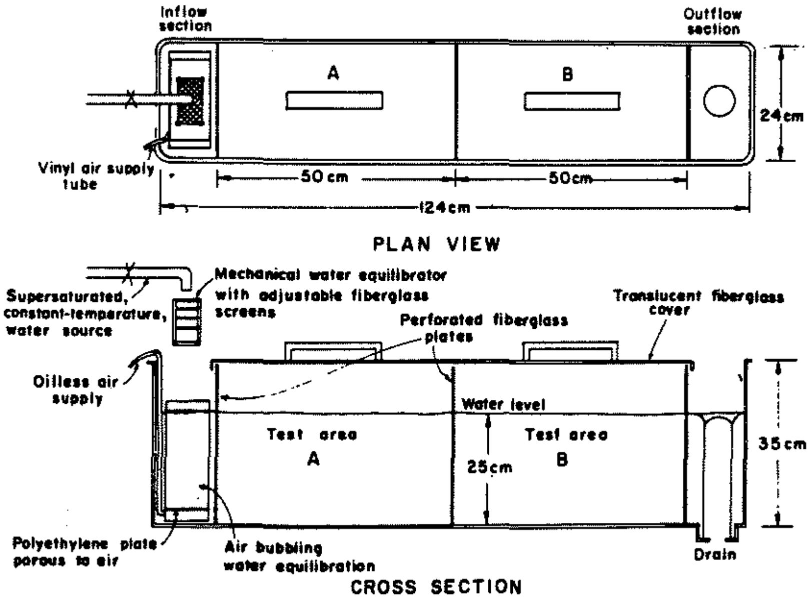

FIGURE 1.–Plan and cross-sectional views of test tank used for bioassay of dissolved gas.

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[1] Atmospheric nitrogen–nitrogen gas (98.8% by vol) plus argon gas (1.2% by vol) hereafter referred to as nitrogen or N_2 + Ar.

(American Public Health Association et al. 1971). Gas concentrations at saturation (100%) were taken from Weiss (1970).

To obtain the dissolved gas levels for the various tests, we adjusted the water equilibrators of each tank (screens plus air bubbling boxes) until the nitrogen concentration remained within ±2% of the desired value. The oxygen concentration was then measured and we found that the saturation value was 5 to 10% lower than that of N_2+Ar for each tank. This did not differ appreciably from prevailing oxygen saturations in the Columbia and Snake rivers which are usually 5 to 10% lower than dissolved nitrogen values (Beiningen and Ebel 1971; Ebel 1971). After introducing fish, however, we noted that the oxygen concentration dropped further (presumably because it was consumed), resulting in values from 8 to 28% of saturation below that of N_2 + Ar, particularly in test area B and the outlet area of the tank. Due to large numbers of fish required for experiments on the survivors of these bioassays, and the complexity of changing the dissolved gas ratios of the water source, we did not alter the O_2 concentrations in the tests but carefully documented the mid-tank gas concentrations. Data affected by this drop in oxygen partial pressure are discussed later in this report.

One-year-old spring chinook salmon from Leavenworth National Fish Hatchery, Leavenworth, Wash., and steelhead trout from the Washington Department of Game Hatchery at Aberdeen, Wash., were used in the tests. Test populations were acclimated to laboratory water at 15°C with normal dissolved gas concentrations for at least 2 wk before testing. Groups of 30 or 60 fish were placed simultaneously in control (100% atmospheric nitrogen saturation) and test tanks set at 105, 110, 115, 120, and 125% of N_2 + Ar saturation and one to four replicates of each test were made, depending on test level. When 60 fish were being tested, 30 were in each of the two test sections A and B. Fish were randomized before introduction into individual test tanks. Mean sizes of the fish at completion of the tests are indicated in Table 1. Measurement of size at the beginning of the tests was omitted to avoid placing additional stress on the test animals. Feeding of fish during the test period began 48 h after introduction to test tanks; thereafter they were fed to satiation once each weekday.

Lethal exposure times to 10 and 50% mortality (LE_{10} and LE_{50}) were averaged for lots of test fish held in tank sections A and B during the same time period, and the mid-tank gas concentrations were used for analysis with the exception of the steelhead groups stressed at 115% nitrogen; in these tests, exposure times and gas concentrations were measured separately for A and B sections of the tanks. In addition, lethal exposure times to 100% mortality (LE_{100}) for chinook and steelhead at all levels of supersaturation were taken only from groups held in the A section of the tanks.

Observations of behavior, progression of external signs of gas bubble disease, and mortality were recorded continuously for the first 6 h then every ½ h for 24 h and every 3, 6, or 12 h thereafter—depending on test concentration—until termination of the bioassay at 35 days. Observations of change in degree of external disease signs among test fish after a recovery period in normally saturated (100%) water also were made from selected groups.

Sublethal effects of supersaturation were as-

TABLE 1.—Comparison of mean weights and lengths of surviving test and control fish held in 15°C water with N_2 + Ar levels at 100 to 125% of saturation, February-April 1972.

Test level (% of saturation of N_2 + Ar)	Testing period[1] (mo/day)	Duration (individual tests)	Test fish		Control fish (100% N_2 + Ar)	
			Weight (g)	Length (mm)	Weight (g)	Length (mm)
		Spring chinook salmon				
105	2/8-3/14	35 days	13.6	115	15.5	119
110	3/7-4/11	35 days	17.5	125	17.9	126
115	2/8-3/14	35 days	13.6	115	15.5	119
120	2/8-3/3	≤55 h	16.2	120	16.0	122
125	2/8-3/1	≤38 h	16.8	117	16.6	118
		Steelhead trout				
105	4/3-5/8	35 days	18.8	130	22.6	135
110	4/10-5/15	35 days	20.0	130	22.0	132
115	4/13-5/13	≤35 days	19.8	130	20.9	132
120	4/3-4/18	≤53 h	20.6	124	—	—

[1] Replicates of tests at 115-125% levels were made at various time intervals throughout the indicated test period; others lasted the full indicated period.

sessed by using measurements of maximal swimming performance, blood chemistry, and photic response. Measurements were made on groups of survivors from lethal exposure tests immediately after the LE_{10} and LE_{50} points were reached or following a 2-wk recovery period in 100% saturated water. Swimming performance was measured by distance gained and time of swimming against a constant water current of 1.25 m/s within a U-shaped inclined trough (14 m long and 8 cm wide). Blood samples were analyzed on a Technicon Sequential Multiple Analyzer (SMA 12/60).[5] Pooled serum samples were analyzed for Ca, Na, PO_4, K, Cl, albumin, total protein, cholesterol, alkaline phosphatase, glucose, urea, uric acid, total bilirubin, lactic dehydrogenase and serum glutamic oxaloacetic-acid transaminase. Photic response was evaluated by electrophysiological monitoring of the optic tectum during retina stimulation with flickering light. A more detailed description of the methods used in the swimming performance and blood chemistry measurements appear in reports by Schiewe (1974) and by Newcomb (1974),[6] respectively.

RESULTS

Relationships Among Mortality, Exposure Time, and Gas Concentration

Mean exposure times at which 10, 50, and 100% mortality occurred at 120 and 125% N_2 + Ar saturation indicate no substantial difference between susceptibility of juvenile chinook and steelhead trout (Table 2). However, at 115% N_2 + Ar saturation, steelhead appeared to be more susceptible than chinook; i.e., steelhead reached the 50% mortality level within 35 days, whereas LE_{50} was never reached in test groups of chinook.

Mortalities of control fish for all tests (105-125%) ranged from 0 to 3.3% throughout the 35-day test periods. Because of the comparatively minor losses of controls, data from test groups are given as observed (not compensated for loss of controls). Mortalities observed in tests at 105 and 110% of nitrogen saturation were 5% or less for both species, and gas bubble disease was not the apparent cause of death.

The onset of mortality attributable to gas supersaturation occurred at about 115% dissolved nitrogen among both steelhead and chinook.

At about 120% nitrogen saturation the means of lethal exposure times to 50% mortality (LE_{50}) were 26.9 and 33.3 h for chinook and steelhead, respectively. LE_{50}'s for chinook and steelhead at 125% nitrogen saturation were 13.6 and 14.2 h, respectively, which are similar to those (11.3 and 14.0 h) observed in earlier tests by Ebel et al. (1971) at test concentrations of 125 to 130% N_2+Ar. Test fish stocks used previously were from different hatcheries and earlier brood years and were slightly larger (spring chinook—23 g and 135 mm, steelhead—54 g and 179 mm).

TABLE 2.—Mean values of lethal exposure time for juvenile steelhead and chinook acclimated to 15°C and then subjected to various levels of gas saturation[1] from 100 to 125% in shallow tanks (25-cm depth).

Percent saturation (N_2 + Ar)	Percent mortality	Exposure time (h)	
		Steelhead	Chinook
125	10	10.3	10.6
	50	14.2	13.6
	100	[2]23.0	[2]32.1
120	10	26.0	19.3
	50	[2]33.3	26.9
	100	[2]40.0	[2]55.0
115	10	[2]258.0	(7% mortality in 792 h)
	50	[2]486.0	Not reached
	100	Not reached	Not reached
110	Mortality of 5% or less recorded for either steelhead or chinook after 35 days at these concentrations. Gas bubble disease was not apparent cause of deaths.		
105			
100			

[1] Percentage saturation of nitrogen and argon was set as indicated in the table (± 2%). Oxygen concentrations ranged between 87 and 98% saturation in tanks set at 100-110% nitrogen plus argon saturation; in tanks set a 115-125% nitrogen saturation, O_2 levels ranged between 98 and 115%.

[2] Exposure times indicated for test replicates of section A only. Mortality in section B had not reached indicated level at termination of test.

Effect of Oxygen Concentrations on Time to Death Measurements

The role of atmospheric gases other than nitrogen (particularly oxygen) in causing gas bubble disease has been questioned by several investigators. Arguments for and against the assumption that dissolved atmospheric nitrogen is the exclusive cause of gas bubble disease are prevalent throughout the literature (Marsh and Gorham 1905; Doudoroff 1957; Egusa 1959, 1969; Shirahata

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[5] Trade names referred to in this publication do not imply endorsement of commercial products by the National Marine Fisheries Service, NOAA.

[6] Newcomb, T. W. 1974. Changes in juvenile steelhead (*Salmo gairdneri*) blood chemistry following sublethal exposure to various levels of nitrogen supersaturation. Northwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, Wash. Unpubl. manuscr.

1966; Bouck 1972[7]; Rucker 1972). Most of the comprehensive studies, however, have been analyzed in terms of nitrogen concentration, assuming it to be the controlling influence upon the effects of gas bubble disease (even greater than indicated by the 80/20 ratio of the partial pressures N_2/O_2). This assumption was based upon supposed biochemical decrease of the effective oxygen partial pressure within the fish.

In comparing data from this experiment with that from past research we should acknowledge that our primary criterion during planning and set-up stages was dissolved nitrogen + argon concentration. At the outset of these experiments, oxygen levels were monitored primarily for documentation of overall water quality rather than for use in analysis of their effect upon the test organisms. However, upon examination of initial results derived from each of the tests carried out to lethal exposures, we found that the times for LE_{10} and LE_{50} were consistently less in test section A than in Section B. Analyses of individual gas pressures in each of the two sections of the tanks were made to determine whether variations occurred among the component gases. We found that nitrogen concentrations were constant in both areas, but oxygen concentrations remained consistently lower (5-10%) in section B than in section A. The lower oxygen concentrations—thus lower (1-2%) total dissolved gas (TDG) saturations—appeared directly correlated with the lower mortality rates in section B of the test tanks. For example, when we examined mortality rates of individual groups of steelhead from A and B test sections at 115% N_2 + Ar, we found: N_2 + Ar saturation (in section B) of 116.0% and 88.2% of O_2 saturation (TDG at 110.0% of saturation) caused no mortality in 35 days for one replicate of 30 fish, whereas N_2 + Ar saturation (in section A) of 116.0% and 98.8% O_2 (TDG at 112.1%) caused 50% mortality in an average of 20 days for two replicates.

Effect of Supersaturation Stress on Growth

Exposure to sublethal concentrations (concentrations at which no substantial mortality occurred within 35 days) of N_2+Ar appeared to affect growth of both juvenile chinook and steelhead. Mean weights and lengths of test fishes after 35 days in dissolved nitrogen concentrations of 105, 110, and 115% of saturation (Figure 2) were in each instance less than those of controls.

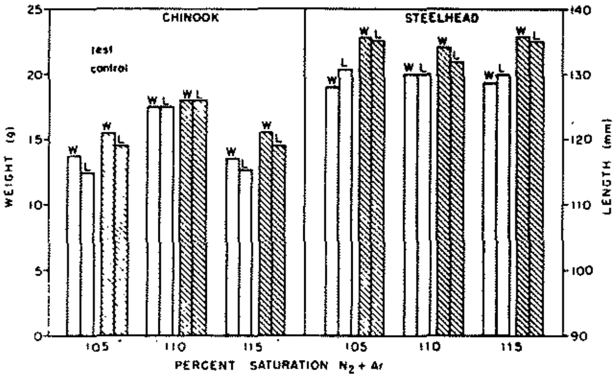

FIGURE 2.—Comparison of mean weights (W) and lengths (L) for test and control groups of juvenile chinook salmon and steelhead trout after 35 days at saturation levels of 100% (control), 105%, 110%, and 115%.

A statistical test of the hypothesis—that the slopes of the regression of mean weight of control fish groups and mean weight of test fish groups were equal—yielded a value of $t = 4.938$ ($P<0.02$ at 4 df). The same statistical test of mean lengths of control vs. test groups yielded $t = 1.36$ ($P<0.25$ at 4 df). The lower t value calculated from length data is attributable to the duration of the test not being long enough to significantly overcome the variation in lengths between individuals within groups. We attribute the difference between size of test and control lots to the effect of supersaturation on the normal growth of the test fish.

After 30 days of testing at the 115% level, feeding response of the chinook fingerlings became lethargic. Many of the test fish had spinal flexures, exophthalmia, and large buccal cavity gas blisters and were unable or unwilling to move and accept food when made available. By contrast, control fish exhibited aggressive feeding behavior throughout the tests. Gross gas bubble disease signs and behavioral changes were less evident at 110% N_2 + Ar and nonexistant at 105%.

Testing for changes in the condition factor of juvenile fall chinook and steelhead during long-term (2-4 mo) holding in water saturated 100 to 127% N_2+Ar is currently underway. Results of these tests may provide further information on effects of gas supersaturation on growth rate.

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[7] Bouck, G. R. 1972. Effects of gas supersaturation on salmon in the Columbia River. West. Fish. Toxicol. Stn., Environ. Prot. Agency, Corvallis, Oreg. Paper presented at Ecol. Soc. Am. Symp. Aug. 1972, 29 p.

FIGURE 3.—Gas bubbles (arrow) in lateral line of juvenile chinook salmon.

Progression of Gas Bubble Disease

Observations on the progression of external signs of gas bubble disease in spring chinook exposed to various levels of supersaturation revealed that the first developments such as bubble formation in the lateral line (Figure 3) appear within 2 h of exposure at 125%. Subcutaneous gas blisters between fin rays of at least one fin were present on each of the test animals before 11.5 h at 125%, and before 55 h at the 120% level. Several days' exposure were required before these signs occurred on fish tested at 115%. After 35 days, 56% of the fish at 110% had lateral line bubbles but only 4% had fin bubbles. Exophthalmia or "popeye," hyphema, cutaneous blisters of the head and buccal cavity, and spinal flexures were absent among fish tested at 120 and 125% but began appearing after 6 days on fish held at 115% and after 11 days on those held at 110% of nitrogen saturation. Apparently at the higher saturation levels, the fish died from cardiac occlusion or branchial artery occlusion (Figure 4) before development of these signs. By the end of 35 days, fish held at 115%

FIGURE 4.—Gas emboli occluding gill filaments and branchial artery of chinook salmon held in 125% nitrogen saturation for 20 h.

exhibited more than a 75% incidence of exophthalmia, 20% of the fish had spinal flexures, and 25% of the fish in section A became more or less immobile. After 35 days of exposure at 110% N_2 +Ar, only 12% of the test fish exhibited signs other than the lateral line bubbles. No apparent signs of gas bubble disease were observed in fish tested at 105% nitrogen.

Development of gas bubble disease signs in steelhead was similar to that of chinook—the signs occurred in the same sequence but the exposure time required to produce the signs was slightly less.

Recovery From Gas Bubble Disease

Observations on disappearance of gas bubble disease signs and delayed mortality following tests were made on groups of survivors of fish stressed to the LE_{50} level at 120, 125, and 130% of saturation. These survivors were placed in water at 100% gas saturation for up to 15 days. No delayed mortality could be attributed to prior exposure to supersaturation in either the chinook or the steelhead. The only significant mortality in any recovery group was a 10% loss of one replicate of steelhead subjected to 125% N_2+ Ar until LE_{50}, followed by a burst swimming performance test. Some mortality occurred after 102 h of recovery time, but the only observable disease sign was the presence of lateral line bubbles on one fish. Other mortalities during recovery were less than 3% of the fish held; no gas bubble disease signs were found. All external symptoms that were readily visible at the time the fish were removed from the recovery tanks had disappeared after 15 days in both species.

Steelhead that had undergone 16, 24, and 35 days' exposure at 115% nitrogen saturation still showed gas bubbles after being held 3 days in normally (100%) saturated water. After 1.5 days' recovery, 64% exhibited lateral line bubbles or fin ray gas blisters and one fish (7%) retained unilateral exophthalmia; after 2 days' recovery, 88% of another group retained signs of lateral line bubbles and fin gas blisters; at 3 days, 54% of the third group retained like signs of gas bubble disease. After 15 days' recovery, no gas bubble disease signs were observed on groups of test fish examined.

Effect of Supersaturation Stress on Survivors

Burst swimming performance and blood chemistry were examined as potential indices of stress from sublethal exposures to supersaturated water.

Swimming performance (Schiewe 1974) of chinook that survived from tests at 110-125% was significantly lower than that of control fish. Visual observations of behavior during swimming performance tests indicated genuine debilitation (inability to swim in some cases) which in turn resulted in lower swimming performance (i.e. less distance gained and less swimming time against a constant water current stimulus). No difference was apparent between performance of chinook salmon tested at 105% saturation and the control fish.

Swimming performance of steelhead trout that survived tests at 105-125% was not significantly different from the performance of control fish. Performance of test and control lots of steelhead trout was highly variable. Fish stressed by exposure to supersaturation often responded in an irritated or stimulated fashion, which often resulted in a high measure of performance. Further tests with steelhead are needed to determine whether swimming performance is a useful index of stress from supersaturation and, if so, whether test results in the laboratory apply to survival of fish in the river.

Blood serum from groups of chinook and steelhead surviving supersaturation tests to LE_{10} and LE_{50} were analyzed (Newcomb see footnote 6) using a SMA 12/60. A 5% decrease in serum calcium was noted in chinook exposed to 115% nitrogen plus argon when compared to those exposed to lower levels of supersaturation. Steelhead exposed to 115% nitrogen showed a 10 to 17% decrease in serum calcium and a decrease in serum albumin, total protein, serum chloride, cholesterol, and in alkaline phosphatase activity when compared to controls and those exposed to lower saturations. No significant changes in blood serum components were observed in samples taken from test groups exposed to levels of 105 and 110% of saturation when these were compared with controls.

Measurements of photic response of salmonids failed to provide any consistent evidence of stress-related phenomena due to supersaturation so these tests were discontinued.

DISCUSSION

Data from these tests indicate that the critical level of supersaturation of nitrogen where juvenile spring chinook and steelhead began to show mortality was about 115% N_2+Ar when O_2 saturations were about 95% (111% TDG). These data agree closely with the findings of Shirahata (1966), who indicated that the critical level for 2-mo-old rainbow trout was about 111.3%, N_2+Ar and 99.7% O_2 (109% TDG).

Although mortality from supersaturation did not occur until fish were exposed beyond 110% (± 2%) N_2 + Ar, swimming performance measurements with juvenile chinook showed some effect from stress caused by exposure to supersaturation at levels as low as 110% N_2 + Ar (106% TDG). We believe that one can infer from the results of these tests, that something less than normal survival will result when juvenile chinook and steelhead are exposed for 35 days or longer at or above 110% N_2+Ar (106% TDG).

Results of our testing program indicate that oxygen as well as nitrogen is responsible for causing gas bubble disease, even when O_2 concentrations are below saturation. The immediate conclusion drawn from this observation would be that total dissolved gas is the cause rather than any one or combination of component atmospheric gases. However, fish tolerance research by Egusa (1969) and by Rucker (1975) with various ratios of dissolved gas indicate that mortality from gas bubble disease is not necessarily in linear correlation with TDG. Egusa showed that oxygen saturation values of 400 to 500% were required to produce initial mortality of goldfish, *Carassius auratus*, and an eel *Anguilla japonica* when nitrogen concentrations were near 100% (TDG 160-180%). In earlier work with the same two species, however, Egusa (1959) recorded high mortality of goldfish with N_2+Ar at 132% and O_2 at 75% of saturation (TDG 123%), and of eel with N_2+Ar at 124%, O_2 at 66% (TDG 112). Rucker found that mortality rate of juvenile salmon declines considerably if the ratio of oxygen to nitrogen is increased even though the same TDG pressure is maintained.

It is apparent from our tests and those of Egusa and Rucker that the ratio of O_2 and N_2 must be considered as well as TDG when assessing possible effects from supersaturation.

Additional information is needed to quantify the effects of various gas ratios (nitrogen to oxygen) on tolerance limits of fish in general. It is probable that most fish could tolerate higher total gas pressure if the major portion of the excess gas were oxygen.

Dissolved gas measurements and resulting percentage saturations for the Columbia and Snake rivers (Ebel 1969, 1971; Beiningen and Ebel 1971) have been based on surface or atmospheric pressure plus vapor pressure. Corrections for the hydrostatic pressure (or depth) at which a sample was taken were not made. Thus, the calculations of percentage saturation were made as though the samples were collected at the surface. This is convenient when limnologists or oceanographers wish to compare values taken at various depths, but leads to confusion when attempting to assess how a given saturation measurement will affect a fish at depth.

The depth that populations of fish travel must be considered when one attempts to determine the effects of an exposure to supersaturated levels of dissolved gases. Bubble formation in the circulatory system or tissues of fish is directly dependent on the external hydrostatic pressure. For example, a fish traveling at a depth of only 1 m will be provided with enough hydrostatic pressure to compensate for a gas pressure in excess of 10% (110% saturation at surface pressures). A fish traveling at 3 m can compensate for 30%, or 130% saturation at surface pressures; a fish traveling at 10 m can compensate for an excess of 100% of saturation and so on. These tests were conducted in shallow tanks at essentially zero hydrostatic pressure with only a few centimeters depth compensation possible. The lethal exposure times we measured could only be applied directly to fish populations that could not compensate by sounding. Much more information is needed to determine how a given gas level in a river affects the population inhabiting the river. Information regarding the behavior of fish is obviously essential. We believe, however, that data from our tests support the 110% maximum allowable limit established by the Environmental Protection Agency primarily because significant mortalities did not occur until concentrations exceeded 110% TDG.

Gas bubble disease signs either singly or in combination with one another did not correlate well with mortality. Those generated from stress conditions of 120% saturation and higher seemed to be nearly the same at LE_{10} as at LE_{100} (gas blisters in the fins and lateral lines of most live and dead fishes). Signs that developed at lower levels (110-115%) were obviously different from those appearing at the higher saturations; i.e., gas blisters in and around the eye, exophthalmia, cutaneous gas blisters on the head and in the mouth, and spinal flexures. Neither set of signs (low-level or high-level types) correlate by percent of incidence or severity, with accumulative mortality. But they showed that one could determine with reasonable accuracy, whether fish observed in the river had been exposed to supersaturation for a long or short duration. Populations with signs of chronic exposure (exophthalmia, spinal flexures, etc.) could have been either 1.5 to 2.0 m deep in highly supersaturated water (130-135%) or near the water surface at near 115% saturation.

SUMMARY AND CONCLUSIONS

Bioassays in shallow tanks (25 cm) with dissolved nitrogen and argon gas concentrations ranging from 100 to 125% of saturation were conducted to determine lethal and sublethal effects on juvenile chinook salmon and steelhead trout.

Juvenile steelhead (130 mm fork length) reached the LE_{50} level within 35 days when exposed to 115% of nitrogen and argon saturation (112% TDG), whereas mortality of juvenile chinook (115 mm) did not exceed 7%. There appeared to be no substantial difference between susceptibility of chinook and steelhead at 120 or 125% saturation $N_2 + Ar$. No mortality related to supersaturation occurred in either juvenile chinook or steelhead trout exposed to 110 or 105% saturation $N_2 + Ar$. Signs of gas bubble disease (such as bubbles in lateral line and exophthalmia) were evident on both species, however, after 35 days exposure to 110%.

Time to death decreased in test tanks with higher oxygen concentrations (thus higher TDG) even though nitrogen and argon concentrations were identical, indicating that oxygen as well as nitrogen and argon concentrations must be considered when time to death values are compared.

The first notable sign of gas bubble disease was appearance of bubbles in the lateral line which appeared in some degree at all gas concentrations tested. Exophthalmia, dermal gas blisters of the buccal cavity and cephalic regions, and spinal flexures did not occur with short-term exposure (6 days) or at the higher levels (120 and 125%) but was prevalent after long exposure at both 115 and 110% saturation $N_2 + Ar$. External gas bubble disease signs disappeared within 15 days when fish were placed in normally saturated water (100%).

Fish stressed with supersaturation at sublethal levels for 35 days grew less than controls and the swimming performance of juvenile chinook exposed for sublethal periods to 110-125% nitrogen saturation was significantly lower than controls. Blood chemistry measurements indicated that significant differences occurred between blood samples taken from test and control chinook and steelhead after they were exposed to levels of 115% saturation. Serum calcium, for example, was 10-17% lower in samples taken from test groups of steelhead.

We concluded from these experiments that:

1. Significant mortality of both juvenile chinook and steelhead trout commences at about 115% saturation of nitrogen and argon (111% TDG).
2. Sublethal exposures to various concentrations of dissolved gas significantly affects swimming performance, growth and blood chemistry of chinook, and growth and blood chemistry of steelhead trout.
3. The first externally evident sign of gas bubble disease on juvenile chinook and steelhead trout exposed to supersaturation occurs as bubbles in pores of the lateral line.
4. Fish returned to normally (100%) saturated water appear to recover within 15 days from exposure to supersaturated water.

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QUALITY CRITERIA
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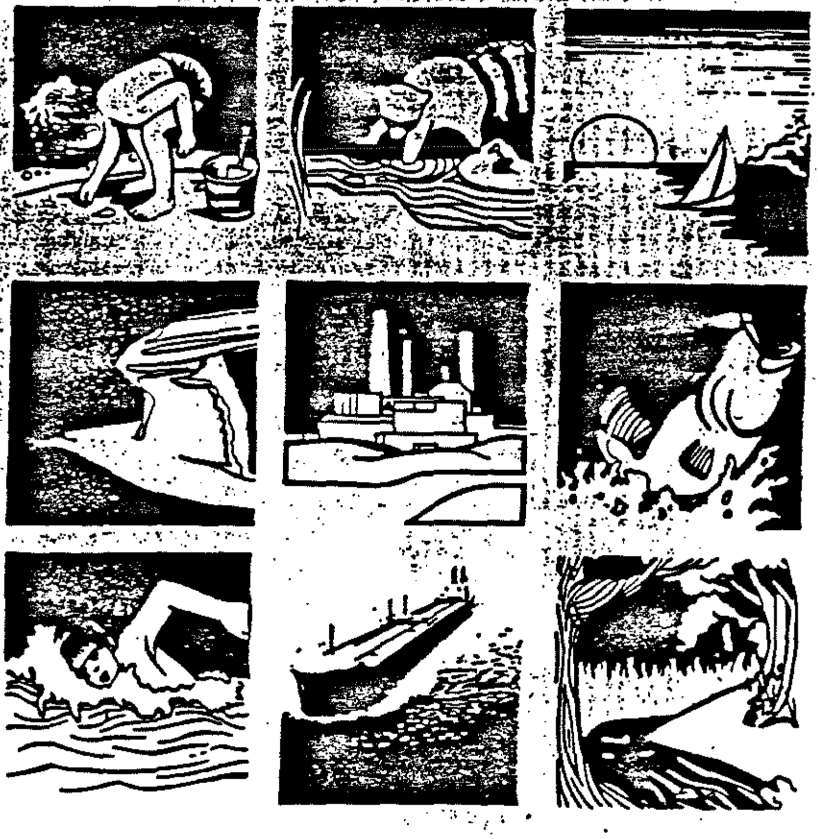

GASES, TOTAL DISSOLVED

CRITERION:

To protect freshwater and marine aquatic life, the total dissolved gas concentrations in water should not exceed 110 percent of the saturation value for gases at the existing atmospheric and hydrostatic pressures.

RATIONALE:

Fish in water containing excessive dissolved gas pressure or tension are killed when dissolved gases in their circulatory system come out of solution to form bubbles (emboli) which block the flow of blood through the capillary vessels. In aquatic organisms this is commonly referred to as "gas bubble disease". External bubbles (emphysema) also appear in the fins, on the opercula, in the skin and in other body tissues. Aquatic invertebrates are also affected by gas bubble disease, but usually at supersaturation levels higher than those lethal to fish.

The standard method of analyzing for gases in solutions has been the Van Slyke method (Van Slyke et al. 1934); now, gas chromatography also is used for determination of individual and total gases. For determination of total gas pressure, Weiss has developed the saturometer, a device based upon a thin-wall silicone rubber tube that is permeable to gases but impermeable to water. Gases pass from the water through the tube, thus raising the internal gas pressure which is measured by a manometer or pressure gauge connected to the tube (NAS, 1974). This method alone does not separate the total gas pressure into the separate components, but Winkler oxygen determinations can be run simultaneously, and gas concentrations can be calculated.

Total dissolved gas concentrations must be determined because analysis of individual gases may not determine with certainty that gas supersaturation exists. For example, water could be highly supersaturated with oxygen, but if nitrogen were at less than saturation, the saturation as measured by total gas pressure might not exceed 100 percent. Also, if the water was highly supersaturated with dissolved oxygen, the oxygen alone might be sufficient to create gas pressures or tensions greater than the criterion limits, but one would not know the total gas pressure or tension, or by how much the criterion was exceeded. The rare and inert gases such as argon, neon and helium are not usually involved in causing gas bubble disease as their contribution to total gas pressures is very low. Dissolved nitrogen (N_2), which comprises roughly 80 percent of the earth's atmosphere, is nearly inert biologically and is the most significant cause of gas bubble disease in aquatic animals. Dissolved oxygen, which is extremely bioactive, is consumed by the metabolic processes of the organism and is less important in causing serious gas bubble disease though it may be involved in initiating emboli formation in the blood (Nebeker et al. 1976a).

Percent saturation of water containing a given amount of gas varies with the absolute temperature and with the pressure. Because of the pressure changes, percent saturation with a given amount of gas changes with depth of the water. Gas supersaturation decreases by 10 percent per meter of increase in water depth because of hydrostatic pressure; a gas that is at 130 percent saturation at the surface would be at 100 percent saturation at 3 meters' depth. Compensation for altitude may be needed because a reduction in atmospheric pressure changes the water/gas equilibria, resulting in changes in solubility of dissolved gases.

There are several ways that total dissolved gas supersaturation can occur:

1. Excessive biological activity--dissolved oxygen concentrations often reach supersaturation because of excessive algal photosynthesis. Renfro (1963) reported gas bubble disease in fishes resulting, in part, from algal blooms. Algal blooms often accompany an increase in water temperature and this higher temperature further contributes to supersaturation.

2. Lindroff (1957) reported that water spillage at hydropower dams caused supersaturation. When excess water is spilled over the face of a dam it entrains air as it plunges to the stilling or plunge pool at the base of the dam. The momentum of the fall carries the water and entrained gases to great depths in the pool; and, under increased hydrostatic pressure, the entrained gases are driven into solution, causing supersaturation of dissolved gases.

3. Gas bubble disease may be induced by discharges from power-generating and other thermal sources (Marcello et al. 1975). Cool, gas-saturated water is heated as it passes through the condenser or heat exchanger. As the temperature of the water

rises, percent saturation increases because of the reduced solubility of gases at higher temperatures. Thus, the discharged water becomes supersaturated with gases and fish or other organisms living in the heated water may exhibit gas bubble disease (DeMont and Miller, 1972: Malouf et al. 1972; Keup, 1975).

In recent years, gas bubble disease has been identified as a major problem affecting valuable stocks of salmon and trout in the Columbia River system (Rulifson and Abel, 1971). The disease is caused by high concentrations of dissolved atmospheric gas which enter the river's water during heavy spilling at hydroelectric dams. A report by Ebel et al. (1975) presents results from field and laboratory studies on the lethal, sublethal and physiological effects of gas on fish, depth distribution of fish in the river (fish can compensate for some high concentrations of gas by moving deeper into the water column), detection and avoidance of gas concentrations by fish, intermittent exposure of fish to gas concentrations, and bioassays of many species of fish exposed to different concentrations of gas. Several conclusions resulting from these studies are:

1. When either juvenile or adult salmonids are confined to shallow water (1 m), substantial mortality occurs at and above 115 percent total dissolved gas saturation.

2. When either juvenile or adult salmonids are free to sound and obtain hydrostatic compensation either in the laboratory or in the field, substantial mortality still occurs when saturation

levels (of total dissolved gases) exceed 120 percent saturation.

3. On the basis of survival estimates made in the Snake River from 1966 to 1975, it is concluded that juvenile fish losses ranging from 40 to 95 percent do occur and a major portion of this mortality can be attributed to fish exposure to supersaturation by atmospheric gases during years of high flow.

4. Juvenile salmonids subjected to sublethal periods of exposure to supersaturation can recover when returned to normally saturated water, but adults do not recover and generally die from direct and indirect effects of the exposure.

5. Some species of salmon and trout can detect and avoid supersaturated water; others may not.

6. Higher survival was observed during periods of intermittent exposure than during continuous exposure.

7. In general, in acute bioassays, salmon and trout were less tolerant than the nonsalmonids.

Dawley and Ebel (1975) found that exposure of juvenile spring chinook salmon, Oncorhynchus tshawytscha, and steelhead trout, Salmo gairdneri, to 120 percent saturation for 1.5 days resulted in over 50 percent mortality; 100 percent mortality occurred in less than 3 days. They also determined that the threshold level where significant mortalities begin occurring is at 115 percent nitrogen saturation (111 percent total gas saturation in this test).

Rucker (1974), using juvenile coho salmon, Oncorhynchus kisutch, determined the effect of individual ratios of oxygen and nitrogen and established that a decrease in lethal effect occurred when the nitrogen content fell below 109 percent saturation even though total gas saturation remained at 119 percent saturation, indicating the importance of determining the concentration of the individual components (O_2 and N_2) of the atmospheric supersaturation. Nebeker et al. (1976a), using juvenile sockeye salmon, Oncorhynchus nerka, also showed that there was a significant increase in fish mortality when the nitrogen concentration was increased while holding the total percent saturation constant. They also showed that there was no significant difference in fish mortality at different CO_2 concentrations.

Research collected by Bouck et al. (1975) showed that gas supersaturated water at and above 115 percent total gas saturation is acutely lethal to most species of salmonids, with 120 percent saturation and above rapidly lethal to all salmonids tested. Levels as low as 110 percent will produce emphysema in most species. Steelhead trout were most sensitive to gas-supersaturated water followed by sockeye salmon, Oncorhyncnus nerka. Chinook salmon, Oncorhynchus tshawytscha, were intermediate in sensitivity. Coho salmon, Oncorhyncnus kisutch, were significantly the more tolerant of the salmonids though still much more susceptible than non-salmonids like bass or carp.

Dapnnia magna exhibited a sensitivity to supersaturation similar to that of the salmonids (Nebeker et al. 1975), with 115 percent saturation lethal within a few days. Stoneflies exhibited an intermediate sensitivity similar to bass with mortality at 130 percent saturation. Crayfish were very tolerant, with levels near 140 percent total gas saturation resulting in mortality.

No differences are proposed in the criteria for freshwater and marine aquatic life as the data available indicate that there probably is little difference in overall tolerances between marine and freshwater species.

The development of gas bubble disease in menhaden, Brevoortia sp., and their tolerance to gas saturation in laboratory bioassays and in the field (Pilgrim Nuclear Power Station Discharge Canal) are discussed by Clay et al. (1975) and Marcello et al. (1975). At 100 percent and 105 percent nitrogen saturation, no gas bubbles developed externally or in any of the internal organs of menhaden. At 105 percent nitrogen saturation, however, certain behavioral changes became apparent. Fish sloughed off mucus, swam erratically, were more excitable, and became darker in color. Menhaden behavioral changes observed at 110 percent nitrogen saturation were similar to those noted at 105 percent. In addition, at 110 percent gas emboli were found in the intestines, the pyloric caeca, and occasionally the operculum. The behavioral changes described were also observed at 115 percent, and clearly defined subcutaneous emphysema was observed in the fins and occasionally in the eye. At 120 percent and 130 percent nitrogen saturation, menhaden developed within a few hours classic symptoms of gas bubble disease. Externally, emboli were evident in all fins, the operculum and within the oral cavity.

Exophthalmia also occurred and emboli developed in internal organs. The bulbous arteriosis and swim bladder were severely distended, and emboli were found along the length of the gill arterioles, resulting in hemostasis. At water temperatures of 30

°C, menhaden did not survive, regardless of gas saturation level. At water temperatures of 15 , 22 , and 25 °C 100 percent of the menhaden died within 24 hours at 120 percent and 130 percent gas saturation. Fifty percent died after 96 hours at 115 percent (22 °C) Menhaden survival after 96 hours at 110 percent nitrogen saturation ranged from 92 percent at 22° and 25° to 83 percent at 15 °C. Observations on the relationship between the mortality rate of menhaden and gas saturation levels at Pilgrim Station during the April 1975, incident suggest that the fish may tolerate somewhat higher gas saturation levels in nature.

It has been shown by Bouck et al. (1975) and Dawley et al. (1975) that survival of salmon and steelhead smolts in seawater is not affected by prior exposure to gas supersaturation while in fresh water. No significant mortality of juvenile coho and sockeye salmon occurred when they were exposed to sublethal concentrations of supersaturated water and then transferred to seawater (Nebeker et al. 1976b).

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SEE APPENDIX C FOR METHODOLOGY

A Review of Dissolved Gas Supersaturation Literature

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Abstract

Dissolved gas supersaturation is a condition that results from natural and human-caused processes. Supersaturation can result in gas bubble disease which has been described in a wide variety of fishes and invertebrates. In recent years dissolved gas supersaturation resulting from dams and thermal discharges has produced mortalities of fish in several cases. This review discusses most of the available literature dealing with dissolved gas supersaturation and the recorded cases of gas bubble disease.

Gas bubble disease is a condition that affects aquatic animals residing in fresh or marine waters that are supersaturated with atmospheric gases. Supersaturation, and the gas bubble disease that may result in aquatic organisms, are not recent discoveries nor are they only caused by human activities. However, only in recent years has supersaturation become a problem of sufficient magnitude to draw widespread attention and concern.

The majority of research dealing with dissolved gas supersaturation has been stimulated by a problem of considerable magnitude that was observed in the Columbia River system beginning in the 1960's. More recently, interest has been further stimulated by the discovery of deleterious effects of supersaturation resulting from thermal effluents.

This review is an attempt to provide a greater dissemination of the available existing knowledge regarding dissolved gas supersaturation and the resulting gas bubble disease. The review discusses the causes of supersaturation, the organisms affected by supersaturation, factors affecting susceptibility of aquatic organisms to gas bubble disease, and various other related topics. The knowledge of this subject is considerable as evidenced by the length of this review. Many important questions remain to be answered. This is particularly true regarding the application of laboratory results to conditions faced by aquatic organisms under natural conditions. Much remains to be learned about the physiological aspects of gas bubble disease.

In order to understand gas bubble disease and its cause, it is necessary to be familiar with the physical laws governing dissolved gases and the factors that determine the level of supersaturation. Boyer (1974), Woelke et al. (1974), and Harvey (1975) discussed the solubilities of dissolved gases in water as they relate to gas bubble disease.

Harvey (1975) provided an excellent discussion of this subject for those not familiar with the physical laws describing the solubilities of gases in a liquid. The solubility of atmospheric gases in water is determined by the water's dissolved solids content, characteristics of the various gases, the total pressure, and the water temperature. Although total dissolved solids can affect solubility, this is not a significant variable in most fresh waters but must be considered as a significant variable in marine waters.

The atmospheric gases of importance are nitrogen, oxygen, and argon. These gases are present in air at partial pressures of approximately 78% nitrogen, 21% oxygen, and 1% argon. Nitrogen and argon are normally considered together because both are biologically inert gases while oxygen is a biologically active gas.

The solubility of each gas is determined b the mass of the individual gas and its partia pressure in the atmosphere. Oxygen (21%) ha only one-fourth the partial pressure of nitrogen (79%) in the atmosphere, but is twice as soluble as nitrogen. Therefore, in water, oxygen (35%) is one-half as plentiful as nitrogen (65%) (Harvey 1975).

The major environmental factors that affect solubility are pressure and temperature. According to Henry's Law, the mass of a gas dissolved in a liquid at a constant temperature is proportional to the pressure exerted on the solvent. Thus, as the pressure on a given volume of water increases, the capacity of that volume of water to hold dissolved gas also increases. Pressure is increased in water by hydrostatic head. Hydrostatic pressure increases rapidly with depth, greatly increasing the capacity of deeper water to hold dissolved gas as compared to shallow water.

The capacity of water to hold dissolved gas is inversely related to temperature. As the temperature of a volume of water increases, the volume of dissolved gas it will hold at equilibrium decreases. Thus, increasing water temperatures will produce supersaturation in water that is initially saturated.

This brief review of the factors affecting solubility only discusses a few of the major variables. Those interested in a more detailed review of the subject should refer to Harvey (1975) or to texts describing the gas laws in detail.

History of Gas Bubble Disease

Early Observations

There are several nineteenth century records of what appears to have been gas bubble disease. Hoppe-Seyler (1857), Bert (1873), and Regnard (1884) recorded external signs in fish that apparently represent gas bubble disease. The first complete description of gas bubble disease and its cause was provided in a series of papers resulting from an air supersaturation problem at the United States Bureau of Fisheries station at Woods Hole, Massachusetts (Gorham 1898, 1901; Marsh 1903, 1910; Marsh and Gorham 1905). This series of initial papers dealt with mortality, signs, and experiments to determine and correct the cause of the disease in aquarium fish.

The first description of the outward signs of gas bubble disease was given by Gorham (1901). Vesicles (gas bubbles or blisters) were found in the fins and other external surfaces of several marine fishes. Bubbles frequently occurred behind the cornea and in the loose connective tissues of the eye, producing a severe exophthalmia or "pop-eye" condition. Bubbles were found less frequently in the gills, lining of the mouth, or along the lateral line of exposed fish. These bubbles gradually increased in size as the length of exposure to supersaturation increased. Fish with these signs also showed loss of equilibrium. The time to death varied from several hours to several weeks following the appearance of detectable bubbles.

Marsh and Gorham (1905) further described internal signs and lesions of the disease. Free gas bubbles (or emboli) within blood vessels were observed. The amount varied from a few scattered bubbles to complete occlusion and distention of the vessels. The walls of the auricle and ventricle were often emphysematous. In some fish, the auricle was filled with gas even though it continued to beat. The main vessels of the gills contained gas bubbles. Gas in the gill filaments was described as the most constant and significant lesion of gas bubble disease. Death of the fish was attributed to stasis of the blood caused by emboli.

In addition to observations of fish, Gorham (1901) also reported signs of the disease in squid, bivalve mollusks, scallops, hydroids, squid egg-sacs, and green algae. No detailed discussion of the disease in these organisms was given by Gorham.

Gorham (1901) experimentally produced gas bubble disease in fish held in closed containers by reducing the pressure. He also was able to cause the signs to disappear by subjecting fish to a pressure comparable to that exerted by a water depth of 4.9 m. He concluded that gas bubble disease was caused by a reduction in the pressure to which fish normally were subjected. Marsh and Gorham (1905) later corrected this mistaken conclusion.

Gorham (1901) reported that whereas fish in shallow aquaria developed gas bubble disease, fish held in ponds 2–4 m deep with water from the same source remained free of it. This was the first indication of the major difference between artificially shallow water conditions and the more natural situations that permit hydrostatic compensation.

Later, Marsh and Gorham (1905) discussed the solubility of gases in water and the relationship of respiratory processes to gas bubble disease. They concluded that the disease was caused chiefly, if not solely, by excessive dissolved nitrogen gas. This conclusion was based on the analysis of bubbles from tissues and blood vessels of animals with gas bubble disease. These bubbles contained 92% to 97% nitrogen, the remainder being oxygen. Bubbles formed in the supersaturated water had nitrogen and oxygen in the same ratio as found in air. Marsh and Gorham concluded hemoglobin has the capacity to modify the effect of oxygen by removing it from the dissolved state.

Marsh and Gorham (1905) reported several instances of naturally occurring supersaturated fresh waters. Rainbow trout (*Salmo gairdneri*) in these waters showed the same signs of the disease as the marine fish from Woods Hole. Experimentally they determined that trout and some cyprinids have nearly equal susceptibility to gas bubble disease, whereas goldfish (*Carassius auratus*) are not affected by the same levels of supersaturation.

The prevention of the disease by removal of excess dissolved gases through aeration was discussed by Marsh and Gorham (1905). The supersaturation condition at Woods Hole was corrected by replacing an intake pipe that had allowed air to be sucked into the water supply. Marsh (1910) later removed excess gases by trickling water over stacks of perforated shallow pans.

In this series of papers, Marsh and Gorham established the basic knowledge of gas bubble disease. Most subsequent investigations have confirmed and expanded on their work. Anyone seriously interested in the problem would be well advised to read these early works, in particular, Marsh and Gorham (1905).

During the 40 years following the work by Marsh and Gorham a few scattered reports of gas bubble disease appeared in the literature. Shelford and Allee (1913) encountered it in experiments to test the reaction of fish to gradients of atmospheric gases. Supersaturation was produced by raising the temperature of water about 9 C. This study was designed to achieve other objectives and made no new contributions to the understanding of the disease.

Plehn (1924) reported the occurrence of gas bubble disease due to supersaturation brought about by photosynthetic activity. Dissolved nitrogen concentrations were not measured but those of dissolved oxygen were three times saturation. This situation occurred during winter conditions where photosynthetic activity occurred under clear ice, producing excess gas that could not escape to the atmosphere. Wiebe and McGavock (1932) experimentally exposed a variety of fishes to dissolved oxygen concentrations two to three times saturation for periods of 20 to 50 days. No signs of the disease were found in these fish even though evidence of it was sought.

Mrsic (1933) observed that fish reared in tap water suffered gas bubble disease when oxygen and nitrogen concentrations were below saturation but carbon dioxide was supersaturated. Mrsic reported 75% of fish in water with 138 mg/liter carbon dioxide suffered gas bubble disease whereas no fish in water having 135 mg/liter carbon dioxide showed signs of it. Although Mrsic attributed the disease to carbon dioxide it appears unlikely that a rise of only 3 mg/liter at those high concentrations would produce such a high incidence of the disease.

Embody (1934) reported gas bubble disease in trout fry at the Cornell University hatchery. The fry were hatched in water that had been heated to raise the temperature 5 C. Unhatched eggs were apparently unaffected whereas the yolk sacs of newly hatched fry were distended by gas bubbles. The disease was attributed to excess dissolved nitrogen and was prevented through aeration, which was accomplished by passing the water over a series of baffles.

Woodbury (1941) described a sudden mortality of fish showing signs characteristic of gas bubble disease in a Wisconsin lake. Bubbles were observed in the gills of these dying fish as well as between fin rays and under scales. The disease was attributed to dissolved oxygen levels in excess of 300% saturation. This mortality followed an extensive algal bloom during a period of sunny weather.

Rucker and Tuttle (1948) noted a hatchery water supply at Leavenworth, Washington, was supersaturated with nitrogen. Fish subjected to this water were reported to suffer gas bubble disease although few details are given.

In the late 1940's, the disease was encountered in larval marine fish at a Swedish hatchery (Dannevig and Dannevig 1950). Larval herring (*Clupea harengus*) and flatfish developed bubbles in the intestine. The flatfish larvae were able to pass the bubbles through the anus while the herring were unable to do so and suffered extensive mortalities. The cause of the supersaturation was air leaks in the water supply system. Henly (1952) described differences between physoclistous and physostomous fish larvae with the disease at this hatchery. She also noted that oyster larvae suffer great mortality when subjected to supersaturated water. Supersaturation in the Swedish hatchery water supply was corrected by passing the water through two sand filters.

Several cases of gas bubble disease were reported in the 1950's. Rucker and Hodgeboom (1953) described the disease in salmonid yolk sac fry reared in a spring water supply which had oxygen at 70% of saturation and nitrogen at 120% of saturation. Supersaturation was reduced by passing the water through an 18-m-long agitation weir.

Matsue et al. (1953) reported the disease in fishes held in supersaturated water supplies in Japan. Fish mortalities occurred in waters having nitrogen levels from 117% to 158% of saturation. Fish reportedly could not live in water with nitrogen levels above 130% of saturation. Satomi (1955) indicated there was no fear of gas bubble disease in adult trout reared in spring water that had dissolved nitrogen levels under 120% of saturation.

Renfro (1963) attributed the death of numerous marine fishes in Galveston Bay, Texas, to this disease. The mortality occurred following a period of calm sunny weather and intense photosynthesis. On the day following the mortality, dissolved oxygen concentrations were 250% of saturation.

These early instances of gas bubble disease were very minor in size and duration. In the Columbia River system, the disease has been recognized as a serious long-term problem affecting a large area and numerous fish.

Columbia River System

In the mid-1960's, it gradually became evident that a serious dissolved gas problem existed in the Columbia River system. Westgard (1964) observed adult chinook salmon (*Oncorhynchus tshawytscha*) suffering gas bubble disease at the McNary Spawning Channel in 1962. In this case, supersaturation was caused by the spawning channel intake. A dissolved nitrogen level of 119% of saturation was measured in an area of the channel where the fish spent considerable time.

(1967) described the occurrence of the disease during 1965 in juvenile chinook salmon held in aquaria at Rocky Reach Dam on the mid-Columbia River. These papers do not describe the source of the aquarium water which probably was supersaturated river water.

The first indication that a serious supersaturation problem existed throughout the Columbia River system was provided by Ebel (1969) and Meekin (1971). Monitoring of dissolved gas levels in the Columbia and Snake rivers during high-flow periods showed that levels of 120% to 130% saturation occurred in 1966 and 1967. Migrating juvenile chinook salmon which were examined at Priest Rapids Dam on the mid-Columbia River during 1966 showed signs of gas bubble disease. Considerable increases in the migration time of these fish resulted in long periods of exposure to supersaturation (Raymond 1968, 1969). The increased length of exposure coupled with the high levels of supersaturation apparently were responsible for the appearance of the disease in the migrating juveniles. Live-cage studies with juveniles at Priest Rapids Dam in 1967 also indicated the same problem. Adult salmonids were also observed for signs at several lower Columbia River dams in 1967; a small number of them showed indications of the disease.

In 1968, signs of gas bubble disease were again observed in juvenile salmonids in the lower Columbia River (Beiningen and Ebel 1970). High mortalities occurred among juveniles held for inspection at The Dalles Dam, where, at times, approximately half the fish showed signs of the disease. In addition, there were several mortalities of adult salmonids showing similar signs downstream from the recently completed John Day Dam. At John Day Dam in 1968, all water passing the dam traveled over the spillway before the turbines were installed. This situation produced dissolved nitrogen saturations of 123–143% downstream from the dam. Problems with fish-passage facilities further complicated the situation, causing delays of migrating adult salmonids in the highly supersaturated water. It was estimated that over 20,000 summer chinook salmon were lost in this area during this episode.

Ebel (1971) and Raymond (1970) reported mortalities and signs of gas bubble disease in both juvenile and adult salmonids in the Snake River during 1970. According to Ebel, dis-from 120% to 140% of saturation for well over a month. Juvenile chinook salmon held in live-cages at Ice Harbor Dam suffered severe mortalities during this period.

Meekin and Allen (1974c) estimated that 6% to 60% of adult salmonids in the middle region of the Columbia River died between 1965 and 1970. Carcasses of adult salmon were found in the river when N_2 supersaturation reached 120% or higher. Few carcasses were found when nitrogen saturations did not exceed 112%.

A general review of the supersaturation problem in the Columbia River system through 1970 was presented by the Environmental Protection Agency (USEPA 1971). That brief review was prepared prior to completion of the many reports available today.

Dissolved gas levels in the Columbia River system between 1965 and 1969 were given by Beiningen and Ebel (1971). In each of these years, dissolved gas levels in excess of 120% of saturation were measured. At times, dissolved nitrogen saturations exceeded 140%.

May (1973) described mortalities due to gas bubble disease in 1973 below the recently constructed Libby Dam in the upper reaches of the Columbia River system. All mountain whitefish (*Prosopium williamsoni*) and cutthroat trout (*Salmo clarki*) held in shallow live-cages were dead within 4 days at total dissolved gas saturations above 130%. When average total gas levels dropped below 120%, mortality rates dropped markedly. Most fish, in an area of the river exceeding 130% of saturation, showed signs of the disease, whereas fish collected from a downstream area with saturations of 105–118% showed no sign of it.

Raymond (1979) reviewed the history of salmon migrations in the Columbia and Snake rivers between 1964 and 1975. This review includes descriptions of dissolved gas supersaturation problems during these years and improving dissolved gas conditions by 1975. The supersaturation problem in the Columbia River system has since been essentially eliminated. Ebel (1979) stated that in the Columbia and Snake rivers "... fishery agencies believe the problem of supersaturation and corresponding losses of fish to gas bubble disease is solved."

Other Recent Observations

Wyatt and Beiningen (1971) encountered gas bubble disease in trout and salmon juveniles at a hatchery on the South Santiam River in Oregon. As in the Cultus Lake Hatchery episode (Harvey and Smith 1961), supersaturation was due to conditions that permitted air to be sucked into the water supply. Apparently most of these fish died within hours when subjected to supersaturation approaching 130%.

Although supersaturation at hydroelectric projects normally results from spilling water, MacDonald and Hyatt (1973) reported supersaturation was caused by air vented into turbines. Atlantic salmon (*Salmo salar*) and American eels (*Anguilla rostrata*) suffered gas bubble disease below the Mactaquac Dam on the St. John River, New Brunswick. An estimated 200 Atlantic salmon were killed in this incident. Nitrogen saturation of 118–125% was measured downstream of the dam.

Several recent disease incidents have occurred at steam-generating facilities. DeMont and Miller (1972) reported mortalities and signs of gas bubble disease in several species of fish at the Marshal Steam Station on Lake Norman, North Carolina, during 1970–1971. The disease occurred among fish in the discharge area during late winter and spring. No dissolved gas measurements were taken in this study, though Adair and Hains (1974) calculated that dissolved gas levels during this mortality period reached a high of 144% of saturation in March. The supersaturation resulted from temperature increase in cooling water at this steam station. Miller (1974) also reported signs of gas bubble disease in fishes at the Marshal Steam Station during 1971–1972, but the incidence was lower than in the previous year and maximum dissolved gas saturation levels of 131% were recorded.

Marcello and Strawn (1972) attempted to culture three fish species in the discharge canal of a steam-electric generating station at Galveston Bay, Texas. They attributed high mortalities of these fish to gas bubble disease.

Marcello and Fairbanks (1975) discussed a mass mortality of Atlantic menhaden (*Brevoortia tyrannus*) at the Pilgrim Nuclear Power Station, Boston, Massachusetts, in April 1973. An estimated 43,000 Atlantic menhaden died in this brief kill. Fish examined showed typical signs of gas bubble disease. Other fish observed near the thermal plume by scuba divers showed no indication of the disease. Total dissolved gas levels were not determined; however, oxygen levels were as high as 142% of saturation.

health of aquatic life than it really is. Several of these studies also show that high oxygen partial pressures can reduce the capacity of a given total gas pressure to produce the disease. This effect occurs only when the oxygen rises far above the partial pressures normally experienced in supersaturated waters (160–175%).

Critical Level of Supersaturation

The maximum or critical level of supersaturation has been defined or assumed to be the maximum level of supersaturation that can be permitted to ensure survival and propagation of aquatic biota. A few early studies indicated that 110% nitrogen saturation was a critical level for young salmonids held in shallow water. When supersaturation was first recognized as a problem in the Columbia River system, the critical level of 110% N_2 was adopted as a water quality standard by several northwestern states and the National Academy of Sciences (Water Quality Criteria 1972). The United States Environmental Protection Agency has since perpetuated this critical level as 110% TGP. More recent studies have shown that this value may be only the minimum level of supersaturation that can be safely tolerated by fish confined to shallow water. This does not, however, apply to most natural situations.

Bentley et al. (1976), Meekin and Turner (1974), Weitkamp (1976), and others have shown that a variety of fish, given the opportunity to sound, can survive for extended periods of time in deep water that is supersaturated at a level considerably higher than 110% TGP without a significant incidence of gas bubble disease or death. Fish in most waters that are likely to be supersaturated assume a depth distribution adequate to compensate for supersaturation well above 110% TGP. Johnson and Dawley (1974) and Weitkamp (1976) have shown that an apparent threshold level exists near 120–125% TGP for young salmon that are held in water of several meters depth. Relatively small increases in this range of supersaturation produce a marked increase in the incidence of gas bubble disease and death. Below this level, the incidence of the disease is low and few deaths occur. This is an indication that the present dissolved gas standards are far more restrictive than necessary to protect the fishery resource under natural conditions.

Ebel et al. (1975) have described how early mortality estimates for the Columbia River system were considerably higher than a more recent estimate based on additional information. Both Ebel (1973) and Bouck (1976) pointed out the difficulties in applying experimentally derived data to the natural situation. The differences between information derived from the laboratory and natural situations should be seriously considered in establishing or revising dissolved gas standards as well as in estimating mortality due to gas bubble disease.

Tolerance to Supersaturation

In order to prevent or eliminate gas bubble disease, it is desirable to know what levels of supersaturation can be tolerated by fish or other aquatic organisms. Frequently the causes of supersaturation are of sufficient economic, social, and political value to make their total removal unacceptable. Hydroelectric projects and steam power plants are far too valuable to be eliminated. It is, therefore, necessary to determine how much supersaturation aquatic organisms can tolerate under various conditions. With this information more effective management and engineering efforts can be made to reduce supersaturation to acceptable levels in those situations where it cannot be eliminated.

Factors that can affect an organism's tolerance to supersaturation include life stage, size, species, and depth distribution. The various major factors that have been studied are reviewed below.

Salmonids at Near-Surface Pressure

Many of the studies conducted to date, in particular most laboratory studies, have exposed fish to supersaturation in water depths of 0.5 m or less. Although these conditions are seldom encountered in natural waters they are pertinent to fish hatchery conditions and provide a practical means for studying many aspects of the problem.

Meekin and Turner (1974) exposed salmonid eggs and young salmonids to supersaturated water in water depths of 20 cm. At 112% TGP, chinook salmon eggs were not affected while eyed steelhead eggs suffered 50% mortality. No signs of gas bubble disease in the eggs were described by Meekin and Turner. Minimal mortalities of juvenile chinook salmon, coho salmon, and steelheads occurred at 103% and 106% TGP in periods of 30–60 days. Mortalities of 8–100% occurred among several groups of juvenile chinook salmon at 114% TGP in 6 days and 64–100% mortality occurred at 124% TGP in 5–7 days. Juvenile chinook salmon in river water of 124% TGP suffered 92–100% mortality in 5–7 days when held within 0.6 m of the surface.

Dawley and Ebel (1975) and Ebel (1973) exposed juvenile chinook salmon and steelheads to supersaturation in 25 cm of water. At 115% TGP, 7% of the chinook salmon and 50% of the steelheads died after 35 days' exposure. At supersaturations of 120% and 125% TGP, chinook salmon experienced a 50% mortality in 27 and 14 hours, respectively, while 50% of the steelheads died in 33 and 114 hours. No gas bubble disease mortalities occurred at levels of 105% and 110% TGP. Dawley et al. (1976) discussed the long-term effects of supersaturation in shallow water. These papers discuss further results of the experiments discussed above. Mortalities in fish held at 110% TGP increased at periods greater than 60 days. At 60 days the mortality in 110% TGP was 15%, but increased to 70% after 125 days' exposure. Disease not related to gas bubble disease was also involved in mortalities after the first 60 days.

Nebeker and Brett (1976) and Nebeker et al. (1979) exposed juvenile sockeye salmon, coho salmon, and steelheads to 110%, 115%, and 120% TGP in water 0.6 m deep. About 5% of the steelheads and none of the salmon suffered mortalities at 110% TGP during the 26–48-day tests. The steelheads suffered a 50% mortality in 21 days and in 2 days at 115% and 120% TGP, respectively. Sockeye salmon suffered a 50% mortality in similar times while coho salmon had only a 10% mortality in 26 days at 115% TGP. At 120%, coho salmon reached 50% mortality in 5½ days.

Weitkamp (1974) exposed wild chinook salmon smolts to Columbia River water of 100–110% TGP during a simulated migration down the lower Snake and lower Columbia rivers. No evidence of gas bubble disease was found in the fish held within 1 m of the surface at total gas pressures not exceeding 110%. The mortalities that occurred in this study were due to secondary fungal infections, following scale loss caused by screening and handling.

In a live-cage study in the Columbia River, Weitkamp (1976) held juvenile chinook salmon within 1 m of the surface for 10- and 20-day periods. A mortality of 50% was reached in 10 days at total dissolved gas saturations between 118% and 123%. In a third test, when the supersaturation rose to 125% TGP and higher, 50% of the test population died within 2 days. This study showed a dramatic increase in gas bubble disease mortality as total gas pressure increased.

Blahm (1974) and Blahm et al. (1976) described the exposure of juvenile salmonids and other fish to Columbia River water of ambient dissolved gas content in tanks 1 m deep. Total gas pressures varied from 110% to 126%. During 55 days of exposure, the mortalities of chinook salmon, steelheads, and cutthroat trout were 80%, 80%, and 42%, respectively. The chinook salmon and steelheads suffered about 40% mortalities within the first 10 days, with essentially no deaths occurring during the next 30 days' exposure. During the latter 30 days, the supersaturation remained near 118% TGP. Mortalities of all three species increased considerably during the last 5 days of the tests when supersaturation rose to about 123% TGP with a peak of about 127% TGP. This shallow-water bioassay also provides an indication of a marked increase in mortality as TGP rises about 120%.

Bouck et al. (1976) exposed juvenile and adult chinook, coho, and sockeye salmon, steelheads, and rainbow trout to various levels of supersaturation up to 130% mean TGP in water 0.65 m deep. All fish tested tolerated 110% TGP. At 115% TGP and above, the results were somewhat variable even within a given age-group of a single species. Coho salmon parr suffered 50% mortalities following exposures of 77 and 44 hours during two separate tests at a mean TGP of 125%. Above 115% TGP, such variation may be related to peaks of dissolved gas levels reached during the tests rather than the mean total dissolved gas pressures. In over half of the 10- and 14-day tests at 115% TGP, the test fish did not suffer 50% mortality. At 120% TGP there was 50% mortality in 2 to 10 days while at 125% TGP most test populations reached 50% mortality within 2 days in the shallow-water tests.

The above studies indicate that a dramatic change occurs in both the number of deaths and the time to death at approximately 120–125% TGP in shallow water (1 m or less). At gas pressures below this general level, a low incidence of gas bubble disease will be found in juvenile salmonids and deaths will occur at a low rate. Above 120–125% TGP, mortality due to gas bubble disease increases dramatically. This apparent critical level has not been clearly demonstrated but is indicated by these studies. For juvenile salmonids maintaining a deeper distribution, the critical level would be higher.

Hydrostatic Compensation

Marsh and Gorham (1905) recognized that hydrostatic pressure exerted on a fish provides compensation that limited the effects of supersaturation. The total gas pressure, in percentage of saturation, experienced by a fish may be quite different from the level measured and calculated for a fish subjected to near-surface pressure. Each meter of depth exerts additional pressure that increases the solubility of dissolved gases sufficiently to compensate for approximately 10% of saturation. In the range of depths and supersaturations normally of concern, the rule of 10% compensation per meter of water depth is a useful approximation. This means that a total gas pressure of 120% of saturation at the surface is actually only 110% at 1 m and 100% at 2 m, with no change in the volume of gas dissolved or in the partial pressures. Thus, depth is an important factor in determining the tolerance of fish to supersaturation in natural situations.

Several studies have been conducted in deep tanks to evaluate the effect of depth compensation for salmonids in supersaturated water. Ebel (1973) held juvenile chinook salmon in 2.4-m-deep tanks for 60 days. At 118% TGP, insignificant mortality occurred in the deep tanks compared to 100% mortality in 55 hours for fish held in 0.25 m of water. Dawley et al. (1976) reported further results of the same study. At 124% and 127% TGP, juvenile chinook salmon suffered 67% and 97% mortalities, respectively, in the 2.5-m-deep water. In water 0.25 m deep, mortalities in the same range occurred at lower supersaturation levels of 115% and 120% TGP. At 110% TGP in 0.25 m, 15% mortality occurred while only 5% mortality occurred in 2.4-m-deep tanks at 120% TGP.

Several studies have been conducted with flow-through deep tanks and supersaturated Columbia River water. Blahm et al. (1973) held juvenile chinook and coho salmon in tanks 2.5 m and 1 m deep. During the 72-day test period, the supersaturation ranged from 120% to 130%. In the 1.0-m-deep water, mortalities were 98% and 80%, for the two species, respectively. Mortalities of 50% were reached in 50 days for chinook salmon and in 67 days for coho salmon in the 2.5-m-deep water.

Blahm (1974) and Blahm et al. (1976) described further experiments under the same conditions. During 50–55-day tests, juvenile chinook salmon and steelheads suffered 11% and 6% mortalities, respectively, in 2.5-m-deep tanks compared to 80% mortalities for both species in 1-m-deep tanks (120% to 130% TGP). The majority of the deaths occurred near the end of the test when supersaturation rose to between 123% and 127% TGP. Juvenile cutthroat trout held under the same conditions showed far less depth compensation, with a 42% mortality in 1 m and a 27% mortality in 2.5 m.

A number of studies have attempted to simulate more natural conditions by placing live-cages in supersaturated river water. In live-cage studies at Priest Rapids Dam on the Columbia River in 1966, Ebel (1969) reported dissolved nitrogen saturations ranged from 118% to 143%. Juvenile coho salmon were held at depths of 0.5–1.5 m, 2.5–3.0 m, 2.5–3.5 m, and 0–6.0 m for periods of 8–12 days. Fish held below 2.5 m suffered less than 3% mortality in each test. In the 0–6-m cage, 6% and 16% of the fish died while in the surface cage, mortalities were 100% in the first two tests and 20% in the third test. During the third test (August) dissolved nitrogen concentrations were lower, reaching a low of 118%. Complete dissolved nitrogen data are not given by Ebel.

Ebel (1971) conducted similar tests at Ice Harbor Dam on the Snake River in 1970 where dissolved gas levels ranged from about 127% to 132% TGP during the 7-day tests. Juvenile chinook salmon held in a 0–4.5-m-deep cage suffered 45–68% mortality with most survivors showing signs of gas bubble disease. All fish held within 1 m of the surface died during the four tests. Fish held below 3 m suffered no deaths attributable to gas bubble disease.

Meekin and Turner (1974) tested juvenile chinook and coho salmon and steelheads in live-cages at Wells Dam, suspended at 0–0.6-m, 0.9–1.5-m, and 1.5–2.1-m depths in river water at 123% TGP. Nearly all fish held at 0–0.6 m died within 3 to 7 days during four tests. At 0.9–1.5 m. chinook salmon suffered 4–44%, and steelheads 24%. mortality. At the 1.5–2.1-m depth, chinook salmon had 4–16% mortalities while steelheads had 20% mortality in 14 days. Chinook salmon and steelhead juveniles and northern squawfish held between 2.4 and 3.1 m for 14 days in the 123% TGP river water suffered no mortalities and showed no signs of gas bubble disease. Coho salmon juveniles held at Rocky Reach Dam on the Columbia River in water of 125% TGP for 7 days suffered 100% mortality in the 0–0.6-m cage, 19% mortality at 0.9–1.5 m and no mortality at 1.5–2.1 m.

Meekin and Turner also held juveniles of chinook and coho salmon and steelhead in volition cages extending from the surface to 0.6-m, 2.1-m, and 3.1-m depths. Volition cages permit the fish to occupy the depth of their choosing within the confines of the cages. In this test at 126–127% TGP, all fish in the surface cage died in 3 days, while only 4% of the coho salmon and about 60% of the chinook salmon and steelheads died in the 0–2.1-m volition cage during the 30-day test. In 0–3.1-m cages, only 3% of the chinook salmon died, and none of the other two species died, during 21 days.

Weitkamp (1976) held juvenile chinook salmon in supersaturated river water for 10 and 20 days at various specific depths and in volition cages extending from the surface to 1-m, 2-m, 3-m, and 4-m depths. Supersaturation ranged between 118% and 126% TGP. None of these fish died during the 10-day test. During the 20-day test, however, mortalities of 17%, 21%, 1%, and 1%, occurred in populations held at 0–2 m, 0–3 m, 1–2 m, and 2–3 m, respectively. Most of these deaths occurred when the total gas pressure remained near 125%. During a 20-day live-cage bioassay, when total gas pressures remained near or above 125% for the first 11 days, mortality in all cages increased considerably. Chinook salmon held within 2 m of the surface (0–2-m cage) suffered 30% and 61% mortalities while fish permitted access to 1 m greater depth (0–3-m cage) had 1% and 7.5% mortalities. Juvenile chinook salmon held between the surface and 4 m experienced no mortality during these three tests. A few of the fish in the 0–4-m cage had a few bubbles in their fins at the end of the tests.

These reports indicate that the effect of hydrostatic compensation due to depth, in both the laboratory and in the field experiments, is as would be predicted by theory. The hydrostatic pressure compensates for about 10% of supersaturation for each 1 m of water depth. The live-cage studies also indicate that given the opportunity, at least under protected conditions, juvenile salmonids will remain deep enough to compensate for total gas pressures of approximately 120–125%. It is necessary to determine accurately the natural depth distribution of fish in supersaturated waters in order to predict their tolerance of supersaturation under natural conditions. This is an important factor in attempting to estimate or predict losses of fish in various situations. The results of laboratory and field bioassay experiments must be interpreted in terms of all discernible natural conditions if they are to provide accurate predictions of what will really happen.

Ebel (1973) made an attempt to estimate the actual gas bubble disease mortalities of juvenile salmonids in the Snake and Columbia rivers. His estimate was based on only a portion of the information now available, but Ebel's discussion points out the complexities involved in evaluating the deleterious effects of supersaturation on naturally migrating populations when the available information comes from limited laboratory tests. The application of experimentally derived information is also discussed by Bouck et al. (1976) who enumerated many of the factors that must be taken into consideration. Many of these factors have not been adequately considered in the formulation of existing dissolved gas standards.

Several recent studies have been conducted to provide information concerning the depth distribution of the migrating juvenile salmonids in the Columbia River system. The depth distribution is important to a determination of the hydrostatic compensation naturally afforded the fish. Smith (1974) found 58% of juvenile chinook salmon and 36% of juvenile steelheads, collected with a fixed gill net, were taken in the upper 4 m of the water column. In this study of a reservoir forebay, Smith also reported 46% of the chinook salmon and 28% of the steelheads were collected above 2 m; 19% of the chinook salmon and 8% of the steelheads were collected above 1 m.

In another study of depth distribution, Weitkamp (1974) collected small numbers of juvenile chinook and coho salmon and steelheads in the Columbia and Snake rivers in drifting and fixed gill nets extending to a depth of 5.5 m. Less than 5% of the chinook salmon were collected above 2 m in 1974. About 20% of the coho salmon were collected between the surface and 2 m, and about 10% of the steelheads were collected above 2 m. The depth distribution indicated that a major portion of the steelheads were below the bottom of the 5.5-m net. These fish were collected primarily in the shallower upstream portions of reservoirs.

Blahm (1974) and Blahm et al. (1976) used a depth sounder to determine the depth distribution of migrating juvenile salmonids. An array of 10 transducers described by Marshall (1976) was placed on the bottom of the Columbia River on a gently sloping beach. Approximately 72% of 776 fish detected with this apparatus were between 0.9 and 2.1 m deep. Two beach seine catches containing 37% juvenile chinook salmon in this area "approximately quantified" the species composition, but the depth distribution of the chinook salmon within the total group observed could not be determined.

The above studies do not provide all the information required to evaluate the effects of dissolved gas on the various species. Collection of fish at a specific depth does not indicate these individuals are at this depth for any significant period of time. They may be moving up and down in the water column or they may be remaining at fairly specific depths for long periods. The volition cage experiments reported by Meekin and Turner (1974) and Weitkamp (1976) indicated that all of the fish spent sufficient time at depth to avoid the effects of about 120–125% saturation. This indicates that fish under field conditions are actually experiencing an intermittent exposure to supersaturation through changes in depth. Fish collected near the surface in supersaturated water would show a high incidence of gas bubble disease and death if they remained continuously near the surface.

Table 1 is a summary of bioassay experiments on the tolerance of salmonids to supersaturation. The table includes test depths that are necessary if these results are to be extrapolated to natural river conditions, or when these studies are used to establish or justify dissolved gas standards.

Intermittent Exposure

Intermittent exposure may increase the level of supersaturation fish are able to tolerate because it increases the time over which a specific exposure accumulates. It also provides an opportunity for recovery to occur, particularly if it is accompanied by depth compensation. Intermittent exposure may occur through either changes in the concentrations of dissolved gases or through changes in depth of the fish.

Alternating exposure to spilled or heated waters with periods of little or no exposure to supersaturated water provides an opportunity for fish to reduce internal supersaturation. Although Beyer et al. (1976b) described evidence that critical tissues become saturated within 60–90 minutes, it is unlikely that the tissues would also equilibrate to a reduction of supersaturation in a similar time. Desaturation normally takes much longer than saturation, as evidenced by decompression tables for saturation diving by humans. No good evidence is available for determining the rate of equilibration to reduced supersaturation for fish.

Fish experiencing intermittent exposure by changing their depth will experience very rapid changes in internal saturation. The pressure change will be immediately transmitted to all tissues thus increasing or reducing internal supersaturation according to the changes in depth. Weitkamp (1976) found juvenile chinook salmon selected depths in 0–4-m volition cages sufficient to avoid death of supersaturations of approximately 125% TGP. This study was not designed to reveal any ability of fish to detect and avoid supersaturation, but other studies have indicated fish do not do so.

The effects of intermittent exposure have been examined in experiments with varying levels of supersaturation. Meekin and Turner (1974) alternately exposed juvenile chinook salmon and steelheads to supersaturated and equilibrated water. Using short exposures of 4–16 hours in 17-cm-deep water, they found juveniles can tolerate 122% TGP for periods of 16 hours if they are returned to saturated water (100% TGP) for 8-hour periods. Blahm et al. (1976) alternately exposed fish for 8 hours in supersaturated water of 110–130% N_2 (? TGP) and 16 hours in saturated Columbia River water per 24 hours, as well as by the reverse daily schedule. The time to death of 50% of the test population was closely related to the length

TABLE 1—*Summary of dissolved air supersaturation bioassays of salmonid fishes, compiled from literature sources. O_2: oxygen; N_2: nitrogen; TGP: total gas pressure; LE50: lethal exposure to 50% fish.*

Species	Supersaturation	Effect observed	Depth (m)	Reference
Rainbow trout fry	Not determined	"Slowly fatal"—day to weeks: gas blisters on head or mucous membranes; "emphysema of the skin"; death with free gas in heart; emboli in gill filaments	0–1.2	Marsh and Gorham 1905
Rainbow trout 12–15 cm	200–300% O_2	No deaths in 14 days	Aquaria	Wiebe and McGavock 1932
	520–380% O_2	No deaths, 24-h exposure		
Brook trout fry	112% TGP or greater	"Badly affected with gas bubble disease"	Hatchery troughs	Embody 1934
Rainbow trout fry, Cutthroat trout fry	115% N_2	"Excessive" mortality; bubbles in fins, under skin, in vascular system, in gills, and in kidneys	Hatchery troughs	Rucker and Hodgeboom 1953
Sockeye salmon				
alevins	108–120% TGP	Gas accumulated rapidly in yolk sac, 20% mortality	Hatchery troughs	Harvey and Cooper 1962
alevins	106–108% TGP	Some signs of gas bubble disease, 2% mortality		
fry	108–120% TGP	Petechial hemorrhages, necrotic areas on fins, exophthalmia		
Rainbow trout				
swimup fry	<130% N_2	No effect	Hatchery troughs, 12 cm	Shirahata 1966
	153–166% N_2	50% mortality		
2.4–2.6 cm	<120% N_2	No effect		
	148% N_2	50% mortality in 5 days		
2.6–2.9 cm	<110% N_2	No effect		
	121% N_2	50% mortality		
Chinook salmon				
adults	118% N_2	Nearly 50% mortality within 10 days	0.6	Coutant and Genoway 1968
Coho salmon				
juveniles		Test times 8–12 days		Ebel 1969
	~140% TGP	100% mortality	0.5–1.5	
		5–70% mortality	2.0–3.0	
		3% mortality	2.5–3.5	
		18% mortality	0.0–6.0	
	~120% TGP	10% mortality	0.5–1.5	
		5% mortality	2.0–3.0	
		0% mortality	2.5–3.5	
		6% mortality	0.0–6.0	
Chinook salmon juveniles	127–134% N_2	7-day tests		Ebel 1971
		100% mortality	0–0.75	
		100% mortality	0.75–1.0	
		34–86% mortality	1.5–2.0	
		2–38% mortality	3.0–4.0	
		45–68% mortality	0–4.5	
Coho and chinook salmon, steelhead juveniles	125–130% N_2	LE50 18 hours	0.2	Ebel et al. 1971

TABLE 1—*Continued.*

Species	Supersaturation	Effect observed	Depth (m)	Reference
Chinook salmon juveniles	154% N_2	5–10% mortality, 7.5 hours	0.6	Wyatt and Beiningen 1971
	152% N_2	100% mortality, 3 hours		
Cutthroat trout	119–136% N_2	60% mortality, 59 days	1.0	Blahm et al. 1973
		40% mortality, 11 days		
	112–130% N_2	40% mortality, 49 days	1.0	
		27% mortality, 49 days	2.5	
Steelhead	112–129% N_2	80% mortality, 55 days	1.0	
		6% mortality, 55 days	2.5	
Chinook salmon	112–129% N_2	80% mortality, 55 days	1.0	
		11% mortality, 55 days	2.5	
Cutthroat trout	130% N_2 for 16 hours/day; 100% N_2 for 8 hours/day	50% mortality, 72 hours		
Rainbow trout		50% mortality, 16–70 hours		
Chinook salmon		50% mortality, 120 hours		
Coho salmon		50% mortality not reached (192 hours)		
Cutthroat trout	130% N_2 for 8 hours/day; 100% N_2 for 16 hours/day	50% mortality, 103.5 hours		
Rainbow trout		50% mortality not reached (192 hours)		
Chinook salmon		50% mortality not reached (192 hours)		
Coho salmon (all fish juveniles)		50% mortality not reached (192 hours)		
Cutthroat trout	131–139% TGP	100% mortality, 3.8 days	0.6	May 1973
	125–131% TGP	100% mortality, 6 days		
		50% mortality, 2.2 days		
	110–127% TGP	50% mortality, 14 days		
	113–122% TGP	No mortality, 12 days		
	102–123% TGP	No mortality, 12 days		
		25% signs of gas bubble disease		
Mountain whitefish	131–139% TGP	100% mortality, 1.3 days		
	116–127% TGP	50% mortality, 12 days		
	113–122% TGP	40% mortality, 17 days		
	107–128% TGP	1 mortality, 17 days		
		75% signs of gas bubble disease		
Cutthroat trout	131–139% TGP	50% mortality, 17 days	3.0	
		55% mortality, 24 days		
Mountain whitefish		50% mortality, 18 days		
		67% mortality, 24 days		
Chinook salmon juveniles	122% TGP	32–100% mortality in 3–8 days	0.2	Meekin and Turner 1974
	114% TGP	8–100% mortality in 6 days		
	112% TGP	8–75% mortality in 18–67 days		
	106% TGP	0–8% mortality in 18–67 days		
Coho salmon juveniles	112% TGP	60–100% mortality in 6–35 days		
	106% TGP	0–4% mortality in 28–36 days		
		no signs of gas bubble disease		
Steelhead juveniles	122% TGP	100% mortality in 3 days		
	112% TGP	6–30% mortality in 6–30 days		
	106% TGP	No effect		

TABLE 1—*Continued.*

Species	Supersaturation	Effect observed	Depth (m)	Reference
Chinook salmon juveniles	123–125% TGP	92–100% mortality in 3–7 days	0–0.6	
		4–40% mortality in 14 days	0.9–1.5	
		4–16% mortality, 14 days	1.5–2.1	
		No effect	2.4–3.0	
Chinook salmon fry exposure from hatching to 50 days old	128% TGP	83% mortality	~0.2	Rucker and Kangas 1974
	124% TGP	73% mortality		
	120% TGP	68% mortality		
	116% TGP	16% mortality		
	112% TGP	12% mortality		
Chinook salmon juveniles	125% N_2	LE50 13.6 days	0.25	Dawley and Ebel 1975
	120% N_2	LE50 26.9 days		
	115% N_2	LE50 not reached		
	110% N_2	Same as controls		
Steelhead juveniles	125% N_2	LE50 14.2 days		
	120% N_2	LE50 33.3 days		
	115% N_2	LE50 486 days		
	110% N_2	Same as controls		
Chinook salmon, steelhead juveniles		28-day test	2.4	
	128% N_2	50% mortality		
	125% N_2	24% mortality		
	100–120% N_2	No significant mortality		
Cutthroat trout	112–136% N_2	32–50% mortality	1.0	Blahm et al. 1976
		37–50% mortality	2.5	
Steelhead	112–129% N_2	70% mortality	1.0	
		0% mortality	2.5	
Chinook salmon (all juvenile fish)	112–129% N_2	80% mortality	1.0	
		11% mortality (all corrected for control mortality)	2.5	
Chinook salmon adult	130% TGP	8.5–10 hours	<1.0	Bouck et al. 1976
Rainbow trout				
parr	125% TGP	27–35 hours		
yearling		31 hours		
Sockeye salmon parr		40 hours		
Coho salmon				
parr		12 hours		
adult		19–21 hours		
Chinook salmon parr		18 hours		
Rainbow trout				
parr	120% TGP	31 hours		
adult		79–92 hours		
Coho salmon adult		45–51 hours		
Chinook salmon adult		51 hours		
Chinook salmon 3–5 cm		Mortality in 60-day exposure		Dawley et al. 1976
	120% TGP	97%	0.25	
	115% TGP	80%		
	110% TGP	15%		
	105% TGP	<5%		
	127% TGP	80%	2.5	
	124% TGP	65%		
	120% TGP	<5%		
	115% TGP	<5%		
	110% TGP	<5%		

TABLE 1—*Continued.*

Species	Supersaturation	Effect observed	Depth (m)	Reference
Steelhead 16.5–19.5 cm		Mortality in 7-day exposure		
	120% TGP	100% (2 days)	0.25	
	115% TGP	37%		
	110% TGP	<5%		
	127% TGP	25%	2.5	
	120% TGP	5%		
	115% TGP	<5%		
Chinook salmon juvenile	119–123%	Mortality in 10-day exposure		Weitkamp 1976
		53%	0.1	
		0%	0–2, 3, 4	
		0%	1–2, 2–3	
	120–123% TGP	Mortality in 20-day exposure		
		88–100%	0–1	
		17–61%	0–2	
		5–7.5%	0–3	
		0	0–4	
		1–30%	1–2	
		1%	2–3	
		12–70%	16 hours at 0–1 8 hours at 3–4	
		4–39%	12 hours at 0–1 12 hours at 3–4	
		1–7%	8 hours at 0–1 16 hours at 3–4	

of the exposure to the supersaturated water. Less than 50% of chinook and coho salmon, steelheads, rainbow trout, mountain whitefish, and largemouth bass were killed by an 8-hour exposure per day to supersaturated water (130% N_2). Most of these fish, however, suffered 50% mortality in less than 24 hours during continuous exposure to supersaturation (130% N_2).

Controlled changes of depth also have been used to study the effects of intermittent exposure. Weitkamp (1976) intermittently exposed juvenile chinook salmon to Columbia River water by changing the depth of 1-m-deep live-cages on 8-16-, 12-12-, and 16-8-hour schedules. The live-cages were alternated between depths of 1–2 m and 3–4 m for one 10-day test and between 0–1 m and 3–4 m for two 20-day tests in an attempt to represent possible diel changes in migrating fish. No deaths or signs of gas bubble disease occurred in the 10-day test with saturations between 118% and 123% TGP. At 120–126% TGP, mortalities reached 1%, 4%, and 12% in 20 days of 8-, 12-, and 16-hour surface exposures, respectively. During the second 20-day test, supersaturation rose to near or above 125% TGP for an 11-day period. During this time, 50% mortality was reached in 5 days with the 16-hour surface exposure. In less than 48 hours during the same period, 50% mortality occurred for fish given continuous exposure at 0–1 m. At this higher level of supersaturation (125% TGP), mortalities in the 12- and 8-hour exposure cages were 39% and 7%, respectively. Dissolved gas levels below 125% during the last 9 days apparently enabled the surviving fish to lose all signs of gas bubble disease.

These studies indicate that intermittent exposure either by changes in the supersaturation of the ambient water or by changes in hydrostatic pressure will allow fish to tolerate supersaturation for a longer period. This increase in the exposure time that is tolerated is greater than the sum of the intermittent exposures, which indicates some recovery occurs during short periods of reduced supersaturation.

Detection and Avoidance

The ability of fish to compensate for supersaturation may be increased if the fish are able to detect and avoid supersaturation. Fish can avoid supersaturation by either refusing to enter supersaturated water when a choice exists or by sounding to compensate for supersaturation at surface pressures.

It has been generally accepted that fish are not able to detect supersaturation and avoid it. Several recent reports indicate that this theory may not be valid for all conditions. This question is of considerable importance as it can greatly affect the extrapolation of experimental data to the conditions faced by fish in natural waters. Fish in natural waters frequently have the opportunity to seek hydrostatic compensation or to avoid entering supersaturated waters if they are able to detect supersaturation.

Ebel (1971) found that juvenile chinook salmon held in 0–4.5-m volition cages suffered much higher mortality from gas bubble disease than fish forced to remain in deeper water (3–4 m). This suggests that these fish were unable to detect, or were unwilling to avoid, supersaturation.

The ability of juvenile chinook and coho salmon to detect and to avoid supersaturation when permitted an alternative in shallow water was studied by Meekin and Turner (1974). A divided trough with supersaturated water at 110–117% TGP on one side and equilibrated water at 101% TGP on the other side was used to test the fishes' response. The fish were introduced to the trough in the lower mixing zone of 110–113% TGP. Juvenile chinook salmon showed a strong preference for the equilibrated water and avoided the supersaturated water when the water supply was switched from one side of the trough to the other. Coho salmon showed no preference for either equilibrated or supersaturated water. These results are not definitive due to temperature differences between the two water sources used during part of the tests. The report does not indicate which fish were tested with water sources having different temperatures. Differences in the chemical composition of the water also may have influenced the results of these tests, as the two levels of supersaturation were drawn from different supplies.

Blahm et al. (1976) reported tests of juvenile chinook salmon and steelheads in a divided trough having 130% N_2 (? TGP) on one side and 102% N_2 on the other side. Steelheads did not avoid the supersaturation, for they reached 50% mortality in about 43 hours. Chinook salmon apparently avoided the supersaturation for they suffered no deaths during either of the 8-day tests. The results agree with Meekin and Turner's (1974) report of avoidance of supersaturation by juvenile chinook salmon.

Dawley et al. (1976) reported the apparent detection and avoidance of supersaturation in deep (2.4 m) tanks. The vertical distribution of juvenile chinook salmon and steelheads was apparently altered after 3 days' exposure to various levels of supersaturation. For the first days of exposure the depth distributions of various test groups were not significantly different. After 3 days, the mean depth of the groups in the supersaturated water was greater than that of fish in saturated water, and mean depths increased with increasing levels of supersaturation.

Bentley et al. (1976) described the apparent avoidance of supersaturation by northern squawfish below Little Goose Dam on the Snake River. Catches of northern squawfish below the dam were much lower during the period of higher supersaturation than they were before and after this period. The fish apparently either avoided the area of supersaturation or assumed a deeper vertical distribution during the high supersaturation period. Large numbers of northern squawfish were captured in a side arm of the reservoir below Little Goose Dam during this time. These fish may have been avoiding higher dissolved gas concentrations in the main river, although gas pressures in the side arm were not measured.

Stickney (1968) reported Atlantic herring (*Clupea harengus harengus*) showed a definite tendency to avoid supersaturation. This avoidance occurred only when the supersaturation was high enough to produce gas bubble disease: 120% N_2 and 130% O_2 (122% TGP).

These studies indicate some fish may be able to detect and avoid supersaturation and others may be unable to detect or do not avoid supersaturation. Reported mortalities caused by supersaturation in thermal discharges at electric generating stations indicate that some species are either not able to detect supersaturation or that their attraction to heated water overcomes their aversion to supersaturation. It is obvious that insufficient information is available to draw any useful conclusions on this issue.

Life Stage

The tolerance of fish species to dissolved gas supersaturation is not the same at all life stages. As discussed above, eggs show no signs of gas bubble disease when held in supersaturated water. They appear to be tolerant of levels of supersaturation that affect fish. Marsh and Gorham (1905) and other more recent reports indicate eggs do not develop the disease. Meekin and Turner (1974) provide the single known report of gas bubble disease in eggs. Steelhead eggs developed high mortalities but chinook salmon eggs did not when both were hatched in water having 112% TGP. It is possible that something other than supersaturation was responsible for the steelhead egg mortalities. No discussion of the egg pathology is provided. The majority of evidence indicates fish eggs are extremely tolerant of supersaturation.

In general, the tolerance of different life stages appears to follow two consecutive trends. In very early life stages, the tolerance to supersaturation decreases from very great tolerance in the egg to very low tolerance in older juveniles. Life stages following the juvenile stage appear to increase in tolerance to supersaturation, with adults being generally the most tolerant free-swimming life stage.

Marsh and Gorham, however, reported Atlantic cod (*Gadus morhua*) fry to be tolerant of levels of supersaturation that produced gas bubble disease signs in adult fish; however, they only held the fry in this supersaturated water for 2 days. Egusa (1959) found killifish (*Oryzias latipes*) fry to be resistant to supersaturation immediately after hatching, apparently due to "elasticity and tenacity of tissues of the body wall." Shirahata (1966) reported rainbow trout fry became increasingly less tolerant of supersaturation with increasing age for the first 2 months after hatching.

Meekin and Turner (1974) also reported decreasing tolerance with increasing age in juvenile chinook salmon. Mortalities of 100-mm chinook salmon were three to four times greater than those of fish under 40 mm. Larger individuals of coho salmon and steelhead also showed a reduced tolerance to supersaturation. Rucker (1975) compared small (38 mm and 46 mm) coho salmon to larger (100 mm) juveniles in 0.2-m-deep water at 112% TGP. The time to 50% mortality was 2.6 and 4.2 days for two groups of the larger fish, 2.7 days for the 46-mm fish and more than 30 days for the 38-mm fish. Dawley et al. (1976) tested several sizes of juvenile chinook salmon in 0.25-m-deep water at 112% TGP. They found fish 40 mm long to be significantly more tolerant of supersaturation than fish 53 mm and 67 mm long. The smaller fish suffered less than 10% mortality in 45 days while the larger fish reached over 50% mortality in less than 15 days. These studies indicate a general decrease in tolerance of juvenile salmonids with increasing age and size.

On the other hand, some workers have indicated that older fish are more tolerant of supersaturation than young fish. Harvey and Cooper (1962) reported sockeye salmon alevins (sac fry) appear to be particularly susceptible to supersaturation. Wood (1968) described the levels of nitrogen supersaturation detrimental to various life stages of salmonids as 103–104% for fry, 105–112% for young juveniles, and 118% for adults. No indication is given by Wood as to how this information was derived. Bouck et al. (1976) reported the results of a number of bioassays in 1-m-deep water using several life stages of salmonids and other fishes. Although there was considerable variation between individual tests, they found younger fish were generally less tolerant of supersaturation than older fish. At 115% TGP, the mean times to 20% mortality for salmonids were 125 hours for juveniles, 154 hours for smolts, and 309 hours for adults.

Individual fish at any particular life stage have shown considerable differences in their tolerance to supersaturation, as indicated by most of the bioassays discussed above. Becker (1973) discussed a more direct method of measuring individual tolerances than differences in the time to death. The formation of emboli in circulating blood was recorded by a telemetering flowmeter surgically implanted on the conus arteriosus of rainbow trout. The results in-

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Heritability

We have found only one study that addressed the heritability of tolerance to gas bubble disease. Cramer and McIntyre (1975) studied the tolerance to supersaturation of several stocks of chinook salmon from Oregon coastal streams and from the lower and upper Columbia River. Stocks with the longest history of exposure to supersaturation were the most tolerant of supersaturation. A comparison of 80 tank families produced from twenty males and four females indicated the tolerance is inherited.

Cramer and McIntyre (1975) made estimates of increases in survival that could be expected with each generation experiencing a given mortality due to gas bubble disease. For mortalities of 30%, 50%, and 70% in the salmon population, increases in survival of 0.4%, 0.7%, and 1.0% should occur with each succeeding generation. These increases are not great but do indicate an advantage to using tolerant stocks in waters that may be supersaturated. This study suggests that experiments on fish from rarely supersaturated waters may indicate more serious problems than are actually encountered by populations in frequently supersaturated waters.

Temperature

As water temperature affects many activities of fish, it is important to determine its relationship to gas bubble disease. The consideration of temperature effects is particularly important in the Columbia and Snake rivers where average water temperatures have been raised by many hydroelectric projects (Beiningen and Ebel 1970). The effect of temperature on tolerance to supersaturation is also important in discharges of heated water that may have become supersaturated within thermal power plants.

A number of studies have been conducted to determine if a synergistic or additive effect exists between high temperatures and supersaturation. Coutant and Genoway (1968) found that chinook salmon acclimated in or tested in supersaturated water (greater than 118% N_2 saturation) could not survive a temperature of 22 C. Fish acclimated and tested in water having a lower dissolved gas content (less than 110% N_2) also died, but at a slower rate. Using adult sockeye salmon, Bouck et al. (1970) found temperature increases in saturated water following exposure to supersaturation caused an increased rate of blindness; deaths at higher temperatures (20 and 22.5 C) were related to pathogenic bacteria.

The relationship between temperature and supersaturation for juvenile chinook salmon was studied by Coutant (1970), but the results were inconclusive. Ebel et al. (1971) reported that a stress of 115–120% N_2 for 12 hours did not greatly affect the temperature tolerance of juvenile chinook salmon. When tested in heated water supersaturated at 125–130% N_2, the prior stress significantly decreased the temperature tolerance of these fish. Fish tested at elevated temperatures in saturated water showed no effect that could be attributed to the prior stress of supersaturation.

The National Academy of Sciences/National Academy of Engineering (1972) concluded that supersaturation has no real effect on thermal tolerance. Becker (1973), however, reported that higher losses of juvenile salmonids occurred among those that had been subjected to the stress of supersaturation than among those that had not. He concluded that the exposure of salmonids to the Hanford thermal plume in the Columbia River was too brief to cause mortalities.

Fickeisen et al. (1976) studied the tolerance of black bullheads (*Ictalurus melas*) to supersaturation at temperatures of 8, 12, 16, and 20 C. Temperature effects were very slight within this range, and not of ecological significance. The TL50's were 126.7% TGP at 8 C and 124.4% TGP at 20 C.

Bouck et al. (1976) found adult sockeye salmon were considerably more tolerant to 120% and 125% supersaturation when they were acclimated slowly from 10 C up to 18 C than when they were permitted little or no acclimation. Young fish showed a variable response; increased temperatures increased tolerance in one test but decreased it in two others. The effect of temperature on tolerance to supersaturation appears to be so slight that it is often overshadowed by other factors. In the tests reported by Bouck et al. (1976), the acclimation temperature and period of acclimation appeared to significantly affect the test results.

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Temperature appears to have little direct influence on the tolerance of fish to supersaturation but it does produce an indirect effect by changing the solubilities of dissolved gases. As water temperatures increase the solubility of dissolved gases decreases, thus resulting in greater levels of supersaturation even though the dissolved gas concentration remains constant. This has long been recognized in research on gas bubble disease. Engelhorn (1943) used a rise in water temperature to bring about supersaturation and produce symptoms of gas bubble disease. Supersaturation as a result of warming hatchery water was reported by Rucker and Hodgeboom (1953). Westgard (1964) noted this mechanism was also responsible for a minor portion of the supersaturation problem at the McNary spawning channel. DeMont and Miller (1972), Adair and Hains (1974), Miller (1974), and Marcello and Fairbanks (1976) all discussed aspects of supersaturation associated with thermal effluents.

Malouf et al. (1972) described supersaturation produced by heating cold seawater in closed heat exchangers. The supersaturation was sufficient to cause gas bubble disease in three species of bivalve molluscs. Lightner et al. (1974) described the disease in shrimp resulting from supersaturation produced by heating seawater in a closed system. Zirges and Curtis (1975) encountered similar problems after heating a water supply for chinook salmon sac fry. The various aspects of these reports are discussed in greater detail in other sections of this review.

Isaacson (1977) questioned the role of gas bubble disease in heated effluents. This author pointed out that pop eye, a sign of this disease, can be caused by cold stress which could be confused with gas bubble disease in heated effluents. Although this may be true in some cases, it is unlikely that cold stress would cause emboli and other recorded signs that appear to be specific to the disease.

Saltwater Adaptation

In recent years there has been considerable concern about the ability of juvenile salmonids to adapt to salt water following exposure to supersaturation during their downstream migration. As gas bubble disease produces various tissue changes, described above, it has been theorized that it might also significantly reduce the ability of the juvenile salmonids to undergo the physiological changes required to make the transfer from fresh water to salt water.

Dawley et al. (1976) described an experiment with chinook salmon and steelheads that had survived supersaturation bioassays. Surviving fish exposed to 110%, 115%, and 120% TGP for 127 days were transferred to 25‰ seawater and held for 13 days. Most of the 50 chinook salmon died in this test; only eight of the larger fish survived the full test period. The majority of the fish may not have reached smolting size and thus did not have the ability to adapt to salt water. Survival was higher among the steelheads tested; most deaths were of smaller fish. The authors concluded that prior exposure to supersaturation seemed not to affect the ability of steelheads to adapt to salt water and that their data on chinook salmon were inconclusive with regard to saltwater adaptation.

Bouck et al. (1976) also tested the ability of various salmonids to adapt to salt water following exposure to supersaturation. Following exposure to 110%, 115%, and 120% TGP, steelhead and sockeye and chinook salmon juveniles were transferred to gas-equilibrated seawater. In all tests the transferred fish either survived for over 5 days, at which time the experiment was ended, or died from causes unrelated to supersaturation. Bouck et al. concluded that no latent or delayed mortalities occur due to gas bubble disease after salmonid smolts enter seawater.

Nonsalmonids

Although much of the recent research and publicity on gas bubble disease has concentrated on salmonids because of the Columbia River problem, there has been considerable research on other species. Gorham (1901) originally described the disease from scup, a marine species. Scup were killed by gas bubble disease when held in shallow aquaria containing water with 135–145% TGP (based on the solubilities used by Gorham). Marsh and Gorham (1905) reported the disease in a variety of other species, presumably at similar dissolved gas levels, but few quantitative details are provided.

Woodbury (1941) observed gas bubble disease in a variety of freshwater fish as the result of oxygen supersaturation caused by photosynthetic activity. Black crappies (*Pomoxis nigromaculatus*), bluegills (*Lepomis macrochirus*), northern pike (*Esox lucius*), and carp (*Cyprinus carpio*) all died at very high oxygen levels (30–32 ppm).

Dannevig and Dannevig (1950) and Henly (1952) discussed gas bubble disease in artificially hatched Atlantic cod, herring, and plaice (*Pleuronectes microcephalus*), but gave no details about dissolved gas concentrations. Stickney (1968) produced the disease in herring held in aquaria at 122% TGP.

Egusa (1959) compared the tolerance of five species to dissolved gas supersaturation by determining the "detrimental nitrogen limit" (signs of gas bubble disease in 50% of test fish within 2 weeks) and the "lethal nitrogen limit" (50% mortality within 2 weeks). The detrimental limits for the fish were 125% for adult goldfish and eel (*Anguilla japonica*); 130% for young goldfish, young carp, adult killifish, and adult bitterling (*Rhodeus acellatus*). The lethal limits were 120% for adult carp; 125% for adult goldfish; 130% for eel, young carp, bitterling, and young goldfish; over 140% for killifish. Supersaturation values given by Egusa are percent nitrogen saturation, and would be about 5% of saturation lower if reported as TGP.

Renfro (1963) reported gas bubble disease mortality for a number of marine fishes in Galveston Bay caused by oxygen saturations apparently over 250%: spotted seatrout (*Cynoscion nebulosus*); gulf menhaden (*Brevoortia patronus*); bay anchovies (*Anchoa mitchilli*); juvenile Atlantic croakers (*Micropogon undulatus*); speckled worm eels (*Myrophis punctatus*); longnose gar (*Lepisosteus osseus*).

Marcello and Fairbanks (1976) described a mortality of Atlantic menhaden due to gas bubble disease. Supersaturation resulted from temperature increases in the cooling water discharged from the Boston Edison Company's Pilgrim Nuclear Power Station. Dissolved oxygen levels measured during the mortality were frequently between 130% and 140% of saturation. Total dissolved gas levels were likely in the same range or higher. Several other species of fish and invertebrates were observed in the supersaturated area with no evidence of gas bubble disease. Clay et al. (1976) found Atlantic menhaden held in shallow tanks showed signs of the disease at 107% TGP within 96 hours.

DeMont and Miller (1972) and Miller (1974) described the occurrence of the disease in a number of species from Lake Norman, North Carolina. Signs occurred primarily in white bass, redbreast sunfish (*Lepomis auritus*), bluegills, and threadfin shad (*Dorosoma petenense*). Signs were also reported in a few individuals of ten other species. These fish experienced supersaturation as high as 130% TGP that was produced by the heating of lake water at the Marshal Steam Generating Station.

Fickeisen et al. (1976) studied the tolerance of black bullheads to supersaturation at several temperatures. The dissolved gas level required to produce a 50% mortality of the test population during 96-hour tests (TL50) was about 125% with slight differences depending on the water temperature.

Supersaturation bioassays were conducted by Blahm et al. (1976) on a variety of species, including largemouth bass and mountain whitefish, which were also tested in comparable intermittent-exposure tests. The largemouth bass were more tolerant of supersaturation than the salmonid species while the tolerance of mountain whitefish was about equal to that of coho salmon and steelheads. This conclusion was based on the time to mortality of 50% of the test population (LE50) at 130% N_2 for 24-, 16-, and 8-hour/day exposures. Bioassays of smelt, crappies, and northern squawfish were also conducted by Blahm et al. in river water at ambient supersaturation ranging from about 113% to 123% TGP. Although the tests measured different end points, they did indicate that the tolerance of smelt was similar to that of steelheads but less than that of most salmonids. The crappies and northern squawfish were more tolerant than the salmonids and suffered no deaths in 20 days and 35 days, respectively.

Bouck et al. (1976) reported less than 10% mortality of largemouth bass exposed for 20 days to about 125% TGP in 0.65 m of water. The largemouth bass were able to capture and eat juvenile salmon during this test. Apparently, supersaturation in the ranges normally experienced would have little effect on predation by this species. Bouck et al. (1976) reported shiners (*Notropis* sp.) and crappies (*Pomoxis* sp.) have a tolerance comparable to that of salmonids. Bluegills, northern squawfish, and warmouth (*Lepomis gulosus*) were more tolerant to supersaturation than shiners and crappies but were less tolerant than largemouth bass, bullheads (*Ictalurus* sp.), and carp.

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A number of studies have examined the tolerance of the northern squawfish, a major predator of juvenile salmonids during their downstream migration. Meekin and Turner (1974) found adult northern squawfish to be more tolerant to 111% TGP than steelhead and chinook salmon juveniles, but the adult squawfish were of equal or lower tolerance to 122% TGP when tested in shallow water (20 cm). Juvenile chinook salmon and steelheads placed in a trough with northern squawfish were vulnerable to predation at 100% TGP but were more active than the predators, and were ignored by them, at 111% TGP. This indicates that sublethal supersaturation may produce greater effects on a principal predator of salmonids than on the prey.

Bioassays of northern squawfish in constantly supersaturated water were conducted in shallow tanks (0.25 m) by Bentley et al. (1976). Twelve-day mortalities were 100% at 126% TGP; 60% at 120% TGP; 32% at 117% TGP; and 0% at 110, 107, and 100% TGP. At 126% TGP, all fish died in less than 1 day. All survivors of the 120% and 117% TGP tests, and most of the fish exposed to 110% TGP, showed signs of gas bubble disease at the end of the 12 days.

Bentley et al. (1976) also found that northern squawfish collected from the Snake River during periods of moderate to high supersaturation showed less evidence of feeding than the fish collected during times when little or no supersaturation was present in the area. Feeding was decreased by about 50% at 115% TGP. In the bioassays, northern squawfish tended to remain on the bottom of the test tanks during exposure to supersaturation. This behavior may be responsible for the reduced feeding observed in nature, and may contribute to better survival through depth compensation.

Parametrix (1974) sampled resident species downstream from Grand Coulee Dam in Lake Rufus Woods, where levels of supersaturation have been as high as 145% TGP in previous years. During the time of this particular survey, supersaturation reached 110% TGP for a brief period. The presence of a variety of adult fish of several age-classes in Lake Rufus Woods was taken as an indication that the populations were surviving the previous years' high levels of supersaturation. Although recruitment of fish from downstream reservoirs or from tributaries is not possible in this area it is probable that recruitment of at least some adult fish occurred from Lake Roosevelt, which is behind Grand Coulee Dam. Lake Roosevelt had also been supersaturated (140% TGP) in the previous year (Seattle Marine Laboratories 1972b).

The studies discussed above indicate that the tolerance of different species to supersaturation can vary considerably. Salmonids are among the least tolerant fish but others, such as Atlantic menhaden, may be even less tolerant. In natural situations the tolerance of a species will be affected by behavioral patterns such as depth distribution or attraction to heated waters.

Causes of Supersaturation

Water may become supersaturated with atmospheric gases through any one of several different processes, either caused by humans or nature. These processes either cause an increase in the amount of air dissolved or they reduce the amount of air water will hold.

Lindroth (1957) discussed four ways by which water may become supersaturated: (1) water contains dissolved gas coming from a gas mixture containing a higher percentage of that gas than is normally found in air; (2) water contains gas that was dissolved under a higher-than-atmospheric pressure; (3) water contains gas dissolved at a lower-than-ambient temperature; (4) two bodies of saturated water at different temperatures are mixed.

The first mechanism is probably of little importance as it is likely to be encountered only in experimental situations. The second mechanism has been involved in many of the documented supersaturation problems, indicated in the following discussions of air injection and hydroelectric projects. The second mechanism is also involved in the supersaturation of natural springs. The third mechanism has caused supersaturation in the heating of water supplies for fish culture, the cooling waters of power generating facilities, and in geothermal heating of natural waters. The fourth mechanism may cause supersaturation but is unlikely to produce levels high enough to cause gas bubble disease under most circumstances. An additional mechanism not mentioned by Lindroth (1957) is photosynthesis. Photosynthetic activity has been responsible for several reported cases of the disease.

Air Injection

Any situation that allows air to be mixed with water under pressure much greater than one atmosphere can produce supersaturation if adequate volumes of air are available. The initial description of gas bubble disease and its cause by Marsh and Gorham (1905) resulted from this mechanism. A leak on the suction side of the saltwater supply system for the Woods Hole aquarium system permitted air to be drawn in with the water.

The supersaturation problem at Flodevigen marine fish hatchery was reported by Dannevig and Dannevig (1950). In this instance, air was sucked into the system at the shaft bearings of the pump. Harvey and Smith (1961) described a Canadian hatchery intake system that permitted air to be sucked into the intake under various conditions causing supersaturation. Wyatt and Beiningen (1969, 1971) found a similar situation at an Oregon hatchery intake. In both cases partial occlusion of the intake permitted sufficient air to be drawn into the systems to produce supersaturation and gas bubble disease in exposed fish. Hughes (1968) encountered a supersaturation problem resulting from air leaks in a lobster hatchery water supply.

Such air leaks on the low pressure side of a water supply system can easily cause supersaturation in a fish culture facility. This should be one of the first sources investigated when supersaturation problems are encountered in a pumped water source.

Johnson (1976) reported a somewhat different source of supersaturation. Seawater was pumped into an unused line that was filled with air. The pressure in the line caused the air to supersaturate the water sufficiently to produce gas bubble disease in the blue crabs and several fish. This appears to be an unusual cause of supersaturation but one that could easily be encountered in any piped water supply.

Fast et al. (1975) and Fast (1979) reported dissolved nitrogen supersaturation in New York and California lakes. In both cases, artificial aeration caused dissolved nitrogen concentrations to reach 140–150% of saturation.

Hydroelectric Projects

Spillways of hydroelectric projects cause air and water to be mixed and carried to substantial depths in a plunge basin. At the depths normally encountered in plunge basins, the hydrostatic pressure is sufficient to greatly increase the solubilities of atmospheric gases. The air thus passes into solution in sufficient amounts to produce supersaturation with respect to surface or atmospheric pressure. These sources of supersaturation frequently have the capacity to supersaturate large volumes of water and thus cause a major problem.

Jarnefelt (1948) recognized supersaturation associated with a hydroelectric project and measured oxygen supersaturation as high as 127% at a Swedish project. Total dissolved gas pressures were likely at least as high. Lindroth (1957) also measured supersaturation below a dam on the Indalsalven River, Sweden.

High levels of supersaturation in the Columbia and Snake rivers were first reported by Ebel (1969). During the 1966 spill period (July and August), nitrogen levels above 120% saturation were measured in the Columbia River. Dissolved gas levels remained near saturation during the remainder of 1966. In 1967, Columbia River saturation levels were comparable to those of 1966. Diurnal variations in nitrogen saturations were measured at The Dalles Dam during 1966; dissolved nitrogen concentrations were found to vary only 0.6 mg/liter during a 24-hour period of constant spill.

The effect of John Day Dam on the dissolved nitrogen levels in the Columbia River during 1968 was described by Beiningen and Ebel (1970). The dam was closed in April 1968, before the generators were operational, so that the reservoir could be filled and the fishways put into operation to accommodate the spring salmon migrations. This required total spill of all water passing John Day Dam and produced dissolved gas levels from 120% to 145% of saturation. Levels in excess of 125% of saturation were recorded below John Day Dam through September 1968. Water temperatures also increased due to the warming of water in the newly created John Day Reservoir.

Dissolved gas levels and associated variables for numerous locations on the Columbia and Snake rivers are presented by Beiningen and Ebel (1970) for the years 1965–1969. Ebel (1971) presented additional data for the year 1970. Dissolved gas levels were generally lower in 1970 than in previous years for the Columbia River but were high in the Snake River due to the spill at Little Goose Dam.

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Roesner and Norton (1971) developed a mathematical model to evaluate air entrainment in water passing over spillways. The model was developed from monitoring data collected at three lower Columbia River dams (John Day, The Dalles, and Bonneville).

Meekin and Allen (1974a) reported dissolved gas levels associated with controlled-flow studies at Chief Joseph Dam on the Columbia River. Widely varying dissolved gas levels were measured in the upstream reservoir, as well as downstream, between individual controlled-flow tests. The reported variations within short time periods (2 hours or less) have not been found in other dissolved-gas monitoring studies. Although the report indicates the variations in supersaturation are probably due to different blocks of water, this conclusion does not appear to be supported by the data presented in the report.

Meekin and Allen (1974b) presented the results of dissolved gas monitoring in the mid-Columbia River from 1965 and 1971. Supersaturation occurred throughout this region of the Columbia River during high-flow periods. Grand Coulee Dam produced high levels of supersaturation, and the dams below Grand Coulee in this region increased the levels of supersaturation only slightly over those in water arriving at each dam. Priest Rapids and Rocky Reach dams actually reduced supersaturation when the water arriving in their forebays was highly supersaturated.

Meekin and Allen (1974b) also monitored the river upstream of Grand Coulee Dam in 1965, 1970, and 1971. During these years, this water was supersaturated to some degree. It exceeded 120% TGP in 1970 and approached this level in 1971. Seattle Marine Laboratories (1972b, 1974) monitored dissolved gas levels above and below Grand Coulee Dam in 1972 and 1973. Lake Roosevelt, the reservoir behind Grand Coulee, contained water supersaturated to over 120% TGP. This supersaturation was present in Columbia River water entering the United States from Canada. Downstream from Grand Coulee Dam, the Columbia River water exceeded 140% TGP in 1972.

Blahm (1974) and Blahm et al. (1975) described dissolved gas monitoring below Bonneville Dam on the lower Columbia River in 1974. Dissolved gas levels averaged near or above 120% TGP in this lower reach of the river during May and June. The reports also described changes in dissolved gas concentrations as the river water traveled 110 km downstream from Bonneville Dam. The United States Army Corps of Engineers (1975, 1977) provided complete reports for dissolved-gas monitoring data for the Columbia and lower Snake rivers in 1974, 1975, and 1976. Boyer (1974) presented a detailed analysis of the dams and the various physical factors involved in the supersaturation problem in the Columbia River system, a valuable resource to anyone dealing with supersaturation resulting from dams.

Seattle Marine Laboratories (1972a) presented results of dissolved-gas monitoring studies on the middle and upper reaches of the Snake River in Idaho. This major tributary to the Columbia River contains numerous dams. Dissolved gas levels in the upper reaches of the river remained below 110% TGP. Water below a series of three dams in Hells Canyon along the middle reach of the river exceeded 120% TGP at times. Downstream from the last dam in Hells Canyon, dissolved gas levels gradually decreased to below 110% TGP at the confluence of the Snake and Salmon rivers. Parametrix (1974) again measured high dissolved nitrogen concentrations below the Hells Canyon dams; however, total dissolved gas levels did not exceed 110% due to low oxygen concentrations.

Dissolved gas concentrations in the Canadian portion of the Columbia River, its tributaries, and several other rivers were reported by Clark and Regan (1973), Clark (1974, 1976), and Abelson (1975). These rivers frequently exceeded 110% TGP and the Columbia River exceeded 120% TGP at times.

Thermal Increases

In recent years, electrical generating facilities have been constructed that significantly raise the temperature of large volumes of water. These temperature increases frequently have been sufficient to cause supersaturation of the water. Supersaturation occurs because the solubility of a dissolved gas decreases as the temperature rises while the actual volume of gas dissolved remains the same.

Harvey (1967) reported that water in a Canadian lake became naturally supersaturated during the late spring and summer of 1961. Solar radiation increased the temperature of the lake sufficiently to produce supersaturation of 110–120% TGP at the level of the lake's thermocline.

DeMont and Miller (1972), Adair and Hains (1974), Jensen (1974), and Miller (1974) discussed various aspects of supersaturation of cooling waters from three steam generating stations in North Carolina. Supersaturation in the heated effluent of the Marshal Steam Station exceeded 120% TGP and apparently reached 130% TGP at times. Two associated steam stations, Allen and Riverbend, also caused supersaturation of cooling waters but a low incidence of gas bubble disease. The Marshal Steam Station caused greater temperature increases and produced supersaturation at high levels over a longer period of time than the other two stations. The level of supersaturation was related to the depth of discharge outlets and volumes of flow.

Marcello and Fairbanks (1976) described a similar problem at the Pilgrim Nuclear Power Station on Cape Cod. Although only dissolved oxygen was measured, these measurements do indicate that total dissolved gas levels exceed 140% at times and were frequently above 120% TGP. Experience has shown that oxygen levels normally are equal to or lower than total dissolved gas levels unless supersaturation is caused primarily by photosynthetic activity. The high levels of supersaturation at the Pilgrim Station were caused by temperature increases of 13–25 C over ambient temperatures. Only slight decreases occurred in the volumes of dissolved gases as indicated by oxygen concentrations presented in the report.

Supersaturation has been caused in other situations where water has been heated for culture purposes. Shelford and Allee (1913) heated water in a closed system, which caused supersaturation. The temperature increases of 8–17 C, without loss of dissolved gases, produced supersaturation sufficient to cause gas bubble disease. These temperature increases would have produced supersaturations of 115–130% TGP if the water had been saturated prior to heating and no gas was allowed to escape.

Embody (1934) heated water in a closed system to hatch trout eggs. Temperature increases over 5 C caused gas bubble disease in hatching [illegible]. A temperature increase in this range probably caused supersaturation of 112% TGP as the water supply was apparently near saturation prior to being heated.

Erdman (1961) reported the disease in Atlantic salmon fry in stream water heated more than 2.8 C. The cold stream water was near saturation prior to the temperature rise. No dissolved gas levels were reported for the gas bubble disease incident. Stickney (1968) reported that Gulf of Maine waters were supersaturated due to photosynthesis and heating. Nitrogen levels as high as 128% were apparently due to temperature increases. Total gas pressures as high as 120% apparently caused no problem in natural waters but did cause the disease in fish when the water was pumped into the laboratory.

Lightner et al. (1974) encountered supersaturation in a heated seawater supply that caused gas bubble disease in brown shrimp. This seawater was heated from 22 C to 28.8 C in a closed system. The 7 C increase would have produced a supersaturation of about 112% TGP if the water were saturated prior to being heated.

Zirges and Curtis (1975) raised the temperature 4.5 C for the water supply to a chinook salmon hatching facility. Supersaturation was high enough to cause gas bubble disease in sac fry. Dissolved gas levels were reported to be 106% for oxygen and 190% for nitrogen. The 190% nitrogen figure appears to have been a misprint as the nitrogen level would only have increased to 110% due to the temperature rise if the water had been saturated prior to heating.

The episodes of supersaturation reported above indicate that supersaturation should be considered any time aquatic organisms may be exposed to heated water. This includes cooling waters of large industrial facilities or waters heated for aquatic culture purposes.

Natural Causes

Supersaturation is not a new or necessarily a human-caused phenomenon. Spring and well waters are frequently supersaturated with dissolved nitrogen although oxygen levels are frequently low. Marsh and Gorham (1905) discussed such situations in the well water supplies at a Tennessee and a New Hampshire fish hatchery. The aspirating effect of water flowing downward into aquifers carries air with it. The air is thus mixed with water under considerable

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Marsh (1910) described a supersaturated well supply for a fish culture station along the Potomac River where dissolved nitrogen levels exceeded 140% of saturation. Rucker and Tuttle (1948) described a Washington State hatchery water supply having 110% TGP (120% nitrogen, 80% oxygen). Matsue et al. (1953) discussed a variety of artesian wells and springs in Japan that produced supersaturated water. Dissolved nitrogen saturations as high as 150–160% were reported.

Flowing surface waters may also be supersaturated by natural causes. Jarnefelt (1948) described how rapids can cause air entrainment and supersaturation just as dam spillways do. Ebeling (1954) and Höll (1955) both recorded oxygen supersaturation of streams, apparently due to falls and rapids. Mortimer (1956) described how bubbling and violent agitation, as in a turbulent stream flow, can produce supersaturation as well as reduce it. Lindroth (1957) observed that falls with deep plunge basins produce supersaturation while those with shallow basins at their base produce little or no supersaturation. Harvey and Cooper (1962) observed similar situations in a British Columbia coastal stream. Supersaturation occurred at high river flows with high falls having deep plunge basins.

Parametrix (1974) reported the Salmon River contained dissolved nitrogen levels as high as 121%; however, total dissolved gas levels seldom exceeded 110%. Even these levels of supersaturation are high when it is considered that river flows were extremely low in 1973, the year of monitoring. Supersaturation was the result of both temperature increases and slight increases in dissolved nitrogen concentrations as the water moved downstream. The increases in the amount of dissolved nitrogen were the primary factor producing supersaturation during the higher flow periods.

As discussed above under the topic of oxygen as a cause of gas bubble disease, photosynthesis can lead to high levels of dissolved oxygen in natural waters. Woodbury (1941), Alikunhi et al. (1951), Schmassmann (1951), Rukavina and Varenika (1956), Renfro (1963), and Supplee and Lightner (1976) all recorded cases of supersaturation caused by photosynthesis. It is likely temperature also played a role in these cases as the intense sunlight necessary for high levels of oxygen production through photosynthesis would also cause significant increases of the water temperature.

One case of natural supersaturation caused by geothermal heating has been reported (Bouck 1976). Total gas pressures of 107–110% were measured in streams heated by geothermal action in Oregon. Although 105% TGP was sufficient to cause hatchery trout fry to develop gas bubble disease, fish in the natural stream with 107–110% TGP showed no signs of the disease. This is a minor but obvious demonstration of the differences between natural and artificial situations and the difficulty that can be encountered in assuming the two are equally susceptible to any perturbation.

Solutions to Supersaturation

Supersaturation of water with dissolved gas results in an unstable condition that tends to return to a state of equilibrium. The rate at which this naturally occurs is usually too slow to prevent the problems discussed in this review. It is important to recognize that water is supersaturated only with respect to atmospheric or surface conditions. Hydrostatic pressure may greatly reduce or eliminate the tendency of the large volume of deeper water to equilibrate with respect to surface pressures. Deeper waters in reservoirs, rivers, oceans, et cetera, may actually have no tendency to lose dissolved gases as they are not truly supersaturated. The hydrostatic pressure that frequently causes the air to become dissolved at high concentrations will also maintain the high concentrations in subsurface water.

A variety of solutions to supersaturation in artificial water supplies have been used over the years. Marsh (1910) flowed water through shallow troughs with rough bottoms and over stacks of six perforated pans to reduce supersaturation. Both of these systems worked for small water flows. Embody (1934) was able to remove supersaturation by passing the water over a series of baffles placed at the head of a trough. Rucker and Tuttle (1948) succeeded in reducing dissolved nitrogen from 140% to near saturation by cascading water through a series of six troughs or shelves about 0.25 m apart. Harvey and Cooper (1962) used a splash tower with

12 sets of baffles to reduce nitrogen from near 120% to near saturation.

Dennison and Marchyshyn (1973) described a small inexpensive box designed to equilibrate water. The water flows in a thin layer over a perforated plate through which air is pumped to strip excess gases from the water. This device reduced oxygen saturations from 118% to 100%. Wold (1973) described the use of a large aerator facility for removal of excess dissolved gases at the Dworshak National Fish Hatchery in Idaho. These large agitators were able to reduce dissolved nitrogen levels from 130% to less than 105%.

Removal of excess dissolved gases in large bodies of water is considerably more difficult due to the stability of the supersaturated gases under many conditions. Harvey (1961) found that solar heating and mixing caused nitrogen supersaturation in lake water to a depth of 6–15 m. This supersaturated water mass remained fairly stable in volume and gas content from June through August. Rapidly flowing turbulent streams do not necessarily provide rapid equilibration of dissolved gases. As Mortimer (1956) pointed out, rapidly flowing streams may even produce supersaturation, and once supersaturated, water reaches equilibrium with the atmosphere slowly.

Ebel (1969) reported that no equilibration occurs in the five reservoirs between Chief Joseph and McNary dams (400 km) on the Columbia River during the high-flow period. Failure of the supersaturated water to equilibrate was blamed on lack of circulation and warming of surface water. When water is warmed, the decrease in the water's capacity to hold dissolved gas may compensate for any loss in the actual dissolved gas content and thus a high level of supersaturation will be maintained.

Beiningen and Ebel (1970) also discussed equilibration of supersaturated Columbia River water. They found that supersaturated water equilibrated to a greater degree in John Day Reservoir than in other previously studied reservoirs in 1968. This equilibration was thought to be due to the reservoir's great length and long retention time as compared to that of many of the other reservoirs.

Lake Roosevelt provided only slight equilibration of the supersaturated water that enters from Canada and travels 225 km to Grand Coulee Dam (Seattle Marine Laboratories 1972b, 1974). During summer months, the surface water of this reservoir tends to equilibrate in the downstream portion of the reservoir. The deeper waters apparently moving through the reservoir show little loss of dissolved gas.

The various mechanical solutions to the problem of supersaturation were discussed by Smith (1972). Perforated bulkheads to be placed in skeleton turbine bays have been built and tested. These reduced supersaturation but were detrimental to fish passing through the orifices. Long and Ossiander (1974), Long et al. (1975), and United States Army Corps of Engineers (1979) described tests to evaluate the effect of perforated bulkheads on juvenile salmon. Perforated bulkheads have also been proposed as a device for reducing the effective hydraulic head for operational turbines. Reducing the effective head would permit the passage of large volumes of water with minimum power generation. This procedure may be effective during the spring high-flow period when power requirements are about one-half of the maximum capacity of the major dams on the Columbia River.

Flip lips or spillway deflectors offer the potential of reducing the level of supersaturation produced by water passing over a spillway. These devices are structural modifications to the downstream face of a spillway that direct the spilled flow along the surface of the tailwater rather than allowing it to plunge to the bottom of the stilling basin. Tervooren (1972, 1973) reported the first results of tests performed on spillway deflectors installed at Bonneville Dam. These indicated that, under varying water conditions, deflectors would reduce the normal increase of excess dissolved gas in the spillway tailwater by 50%. These results were obtained when the forebay gas levels were between 100% and 120% saturation. This means that the installation of spillway deflectors for all bays at Bonneville Dam would result in downstream gas levels of 110% of saturation if forebay water did not exceed 100% of saturation.

Spillway deflectors are effective in reducing supersaturation without causing increased mortalities of juvenile salmonids. Johnson and Dawley (1974) reported that the Bonneville deflectors reduced supersaturation by 6–12% with no decrease in the survival of fish passing over them; Monan and Liscom (1975) actually found

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improved adult survival. Long et al. (1975) also reported an increased survival of steelhead smolts passing over deflectors at Lower Monumental Dam on the lower Snake River.

The recent status of spillway deflectors has been reviewed by United States Army Corps of Engineers (1979). Ebel et al. (1975) estimated that the installation of recommended deflectors and turbines by 1980 will eliminate the problem of supersaturation in the Columbia and Snake rivers for all practical purposes. Ebel (1979) concluded the supersaturation problem in the Columbia system has been solved.

A third proposed solution to the supersaturation in the Columbia River system is the collection and transportation of juvenile salmonids from upstream dams to the lower river (Ebel et al. 1973; Ebel et al. 1975). Although the supersaturation problem is apparently being solved by other means, this method is still being utilized to reduce the turbine mortalities that are considerably greater than supersaturation mortalities.

Supersaturation problems caused by cooling waters of power generating facilities have been less of a problem than hydroelectric projects and therefore have received far less attention. Kraback and Marcello (1976) discussed the feasibility of removing excess dissolved gases from the Pilgrim Nuclear Power Station cooling water. Heated seawater would be degassed by means of an air bubbler system. Tests in a flume installed in the discharge canal indicated that the system would work.

Lee and Martin (1975) computed the capacities of high- and low-velocity discharges of cooling to produce supersaturation problems. They concluded that high-velocity discharges are unlikely to cause supersaturation problems because of rapid dilution. Localized supersaturation problems may occur with low-velocity discharges.

Dissolved Gas Analysis

The measurement of dissolved gas levels is the one aspect of supersaturation that is least familiar to most people who must deal with the problem of gas bubble disease. Analysis of the levels of supersaturation is, however, essential for the evaluation and solution of the supersaturation problem. Although most people likely to encounter supersaturation are familiar with dissolved oxygen analysis, few have had any reason to become familiar with the techniques for dissolved nitrogen determination or of total dissolved gas analysis. This section of the review describes a few of the more recent reports that discuss useful information dealing with such analyses.

The solubility of the individual atmospheric gases in water has been described in numerous recent reports. Elmore and Hayes (1960), Klotts and Benson (1963), Green and Carritt (1967), Douglas (1964, 1965), Murray et al. (1969), and Tolk et al. (1969) all discussed the solubilities of oxygen, nitrogen, and argon. The solubilities most commonly used in recent supersaturation research are those provided by Weiss (1970).

There are several different techniques available for dissolved gas analysis. Swinnerton (1962) described the use of gas chromatography for this purpose. Beiningen (1973) provided a complete discussion of the use of the time-consuming Van Slyke apparatus (Oesting 1934) for determining the oxygen and nitrogen-plus-argon concentrations of water samples. Beiningen discussed in easy-to-follow detail the operation of this apparatus as well as the calculations required for the separate dissolved gas analyses. He included sections on the correct procedures for field sampling, procurement of the necessary apparatus, and the Winkler method of oxygen determination. This manual is extremely useful for anyone using the Van Slyke method to determine dissolved gas concentrations in water samples.

Post (1970) described a simplified volumetric method for determining dissolved gas concentrations. This method apparently has received little use and may provide significant errors of 5–7%.

By far the simplest method for determination of total dissolved gas levels is that provided by the Weiss saturometer. As far as can be determined, this apparatus has not been described in any journal or other widely distributed publication. Fickeisen et al. (1975) gave a brief description and picture of a Weiss saturometer. A similar device is produced commercially by ECO Enterprises, Seattle, Washington, and is now widely used to measure total dissolved gas pressure.

D'Aoust and Smith (1974) and D'Aoust et al. (1976) described a modification (tensionometer) of the Weiss saturometer. The tensionometer provides for sensing of the gas pressure by means of a solid state electronic pressure transducer rather than the Bourden tube gauge used in the saturometer. According to D'Aoust et al., the tensionometer has the advantages of much smaller size, and a response time of about 8 minutes. This compares with a response time of 20–30 minutes for the saturometer. The more rapid response time of the tensionometer is due to the much smaller dead space permitted with the pressure transducer. The tensionometer also offers the advantage of remote sensing which is required when dissolved gas measurements are made at depth. Agitation is still required to remove bubbles from the silastic tubing when the water is truly supersaturated, such as at surface pressures of about one atmosphere. This is not a problem at water depths over 3 m where the water is not actually supersaturated due to the increased pressure of the hydrostatic head. D'Aoust et al. (1976) provided a complete parts list and instructions for building the tensionometer.

The operation of the Weiss saturometer was evaluated by Fickeisen et al. (1975). The saturometer was mechanically agitated at rates of 108, 132, and 168 cycles per minute. At the two faster rates, equilibrium was reached in 15–25 minutes. It requires 10–15 minutes longer to reach equilibrium at the slower rate of agitation. Manual operation produced comparable results with an experienced operator but lower readings with a novice operator.

Jenkins (1976) attempted to develop a method for unattended monitoring "in situ" of dissolved gas concentrations. An incomplete system was designed to pump the water to be sampled and to strip the dissolved gases from this water by a modified spinning disc oxygenerator. Major problems remain to be solved in the detection of the gases once they are stripped from the sample water.

The various corrections that have been applied to dissolved nitrogen partial pressure data were discussed by Boyer (1974). He concluded that the sum total of these corrections is less than the inherent errors of the sampling and analysis techniques. Boyer also discussed the "true" value of the supersaturation level resulting from a dam spillway and described what is needed to develop an empirical formula that is unique for each spillway.

Cratin et al. (1971) studied the in situ fixation and analysis of dissolved oxygen samples at depth using an underwater habitat (Tektite II). In marine waters, they found a decrease of about 2–6% in the dissolved oxygen concentration of samples fixed at the surface as compared to those fixed at depth. This loss of oxygen was limited to samples whose oxygen concentrations were greater than the surface saturation value. The loss of dissolved oxygen should not be a problem with supersaturation monitoring as the few deep samples collected are normally fixed immediately after collection. There is no indication of how dissolved nitrogen concentrations vary prior to analysis by Van Slyke or gas chromatograph. The amount of dissolved gas these samples can hold is normally increased during storage by reducing the temperature of the samples to below 4 C. Thus, supersaturation in the samples is reduced or eliminated, preventing loss of dissolved nitrogen.

Regulation of Supersaturation

Since the identification of dissolved gas supersaturation as a problem in the Columbia River system in the late 1960's, there have been criteria and standards promulgated by a variety of regulatory entities. The National Academy of Sciences/National Academy of Engineering (1972), using available data, recommended that aquatic life will be protected when total dissolved gas pressure in water is no greater than 110%. Subsequently the states of Washington, Idaho, and Oregon promulgated dissolved gas standards, initially for dissolved nitrogen and later for total dissolved gas. The regulations specified human activities should not increase dissolved gas levels above 110% in Washington and Idaho and 105% in Oregon. Other states have since passed similar regulations.

The water quality standards were reviewed in 1975 by a group of four agency representatives from the United States Environmental Protection Agency, Idaho, Oregon, and Washington (Rulifson and Pine 1976). This group suggested a standard of 115% total gas saturation for the Columbia-Snake River system except during particularly high-flow years. Their recommendation was ignored by the Environmental Protection Agency criterion issued in 1976 (USEPA 1976), which again recommended a criterion of 110% TGP. Recently, Ebel et al. (1979) have reviewed the most recent Environmental Protection Agency criterion, and in-

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Effects of Hydroelectric Development and Fisheries Enhancement on Spring and Summer Chinook Salmon and Steelhead in the Columbia River Basin

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Abstract.—Trends in abundance of spring and summer chinook salmon *Oncorhynchus tshawytscha* and steelhead *Salmo gairdneri* returning to the Snake River and mid-Columbia River above Priest Rapids Dam were determined by analyzing the percentage of adults returning from the smolt out-migrations of 1962–1984. Runs declined as a result of hydroelectric development of the river; the main cause for the decline was the mortality of juveniles migrating downstream through as many as nine dams and impoundments en route to the ocean. Mid-Columbia River summer chinook salmon runs experienced the greatest decline because of higher mortalities incurred during their migration to sea as subyearlings in July and August. Mortality was lower for remaining races of fish that migrate to sea as yearlings in the spring during higher river flows, more spill at dams, and cooler water temperatures. Enhancement measures to offset dam-related mortality of smolts began in 1970 on the Snake River and in 1975 on the mid-Columbia River. These measures included increased numbers of smolts released from hatcheries, spillway deflectors to reduce dissolved gas saturation, fingerling bypasses at dams, transportation of smolts around dams, supplemental river flows to minimize delay for smolts passing through reservoirs, and supplemental spill at dams to minimize turbine mortality of smolts at dams without fingerling bypasses. These actions have reversed the decline of steelhead but not of salmon. Enhancement has improved the rate of return of wild spring chinook salmon, but wild fish contribution is minimal at this time because stocks were reduced by earlier hydroelectric development. Presently, runs are mostly of hatchery origin and have not responded well to enhancement. Mortality of hatchery fish may be due to activation of bacterial kidney disease by stresses encountered during downriver migrations, transportation, or subsequent transition into seawater.

The Columbia River once supported vast numbers of salmon *Oncorhynchus* spp. and steelhead *Salmo gairdneri*. Tributary dams, unscreened irrigation diversions, habitat degradation from logging, mining, and grazing, and a host of other factors eliminated or severely degraded many of the valuable spawning and rearing areas used by these fish. Poorly regulated commercial fishing in the lower 322 km of the Columbia River between 1860 and 1900 concentrated on and soon severely depleted large runs of spring and summer chinook salmon *O. tshawytscha*. Pacific salmon, though, are resilient creatures. Once adequate regulations of fisheries were imposed and efforts were made to restore the habitat, fish runs rebounded and again provided a viable fishery. In the early 1930s, the federal government began a program to produce hydroelectric power. By 1975, the Columbia

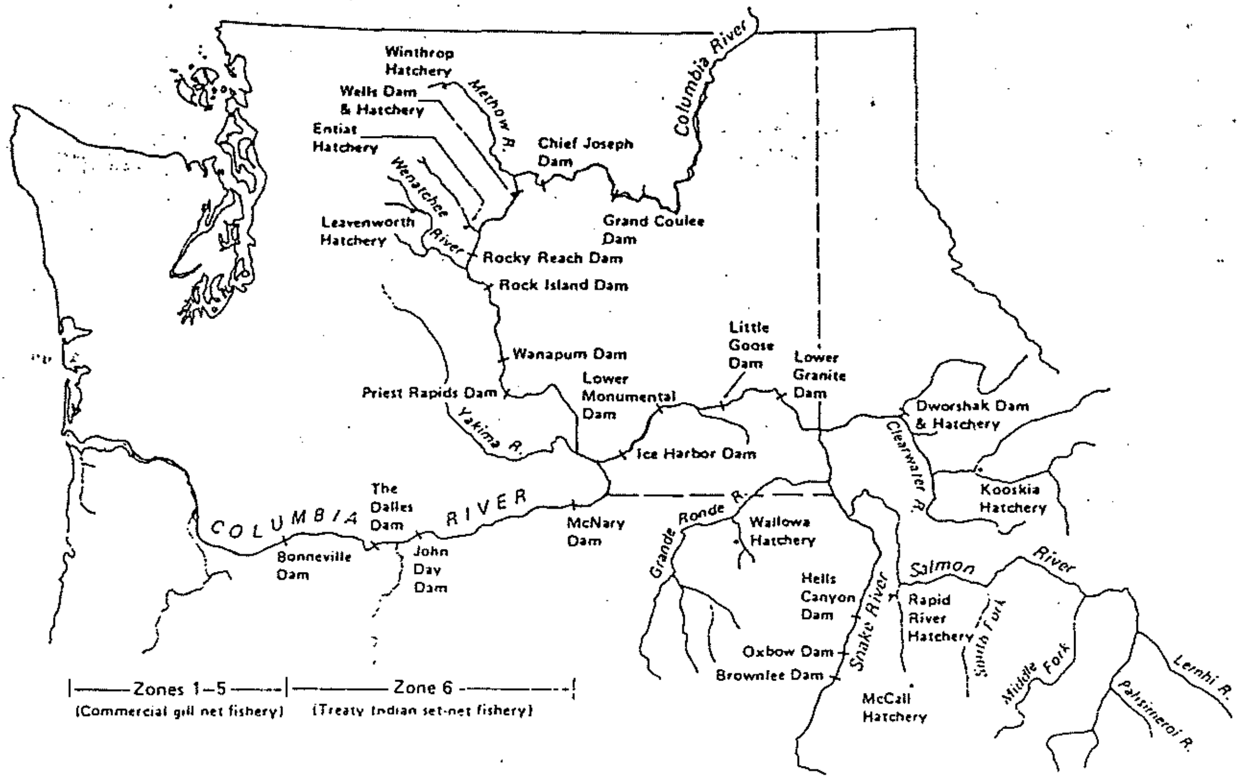

FIGURE 1.—Locations of dams and hatcheries in the Columbia River basin.

River Power System consisted of 28 dams (19 of which are shown in Figure 1) that produced more than 13,000 MW of low-cost electricity, provided vast amounts of water for irrigation, and regulated natural river flows to provide flood control and more efficient power generation. Unfortunately for those stocks of fish spawning above McNary Dam, the end result was a major decline in fish runs because of the elimination of over 50% of the spawning habitat, large mortalities of smolts migrating downriver through the eight or nine dams and impoundments en route to the sea (Raymond 1979), and losses of adults passing upriver through the dam complex to spawn (Junge and Carnegie 1976).

Largely because of the depressed status of upriver runs, the 1980 Pacific Northwest Electric Power Planning and Conservation Act mandated the development of a program to mitigate harmful effects of the hydroelectric development of the Columbia River and to protect and enhance affected fish and wildlife. Among the goals of the Northwest Power Planning Council, which oversees this program, is documentation of the effects of hydroelectric development on the many races of salmon and steelhead in the Columbia River basin. The council also desires to document the benefits of measures intended to reduce dam-related mortalities of salmon and steelhead smolts, e.g., transportation of smolts around dams, fingerling bypasses, spills, and augmented river flows. The aim of this paper is to provide documentation for spring and summer chinook salmon and steelhead returning to the Snake River and to the Columbia River above Priest Rapids Dam (hereafter termed mid-Columbia River).

Methods

Annual estimates of the percentages of downstream migrant salmon and steelhead that return as adults will form the basis for assessing the effects of hydroelectric development and enhancement measures taken to offset dam-related mortalities. This is a much better approach than simply using counts of returning adults because adult counts are related to the numbers of smolts produced as well as to survival of smolts through the dam complex. For example, beginning in 1970 on the Snake River and in 1975 on the mid-Columbia River, releases from new hatcheries more than doubled the number of smolts that started migrations to sea. Many adult runs thereafter did not show a decline because losses of smolts at dams were offset by the increased smolt production. When adult returns are expressed as percentages of emigrating smolts, such bias is eliminated.

I assessed smolt migrations from the Snake River at dams each year between 1966 and 1975. From the positive relation found between rates of return of adults and survival rates of smolts, it was apparent that mortality of smolts migrating downriver through the dam complex was the main cause of the decline in Snake River salmon and steelhead runs (Raymond 1979). There was no comparable assessment of smolt migrations in the mid-Columbia River and, therefore, there is no measure of survival for that reach of the river. Because we showed a relation between smolt survival and adult returns in the Snake River, however, it follows that the rate of adult return would also provide a measure of fish passage conditions encountered by smolts from the mid-Columbia River each year.

Spring and summer chinook salmon and steelhead were selected for analysis because there are smolt indices and data available on adult runs to obtain estimates of adult return percentages. There are only small ocean harvests of these fish to bias estimates of adult returns, except for summer chinook salmon destined for the Columbia River above Priest Rapids Dam (Duke 1985; Johnson 1985). I assumed a constant annual rate of harvest of mid-Columbia summer chinook salmon in Alaska and British Columbia, an assumption based on data supplied by the Pacific Fishery Management Council (1985); from this, I also assumed there was no significant bias caused by the ocean fishery. Fall chinook salmon and sockeye salmon *O. nerka* were not included in my analyses because needed data, especially smolt indices, were unavailable.

Natural variations in ocean mortality due to El Niño events, fluctuations in coastal upwelling, changes in abundances of predators and prey, and varying quality of hatchery fish released each year have certainly affected adult returns, but the relative importance of each of these factors cannot be accurately determined. However, variations in ocean survival of Snake River runs migrating to sea through 1975 must have been modest or there would not have been the positive correlation between survival rates of smolts and rates of return of adults (Raymond 1979).

The estimation of percentage returns of adults from yearly indices of smolt abundance requires counts of adults at dams, harvest data for the river, and a method for obtaining relative annual indices of numbers of smolts starting seaward migrations. Such data were available and were used to obtain these estimates from the mid-Columbia River starting in 1962 and from the Snake River beginning in 1964. Prior to that time, there were no dam counts with which to distinguish the Snake River and mid-Columbia River portions of the upriver adult runs and no means for obtaining needed indices of smolt abundance each year. Trends of abundance of upriver runs for those earlier years, therefore, had to be derived from estimated numbers of adults that entered the Columbia River each year and migrated above Bonneville Dam (Oregon Department of Fish and Wildlife and Washington Department of Fisheries 1966). Because all of the summer chinook salmon and over 60% of the spring chinook salmon and steelhead passing Bonneville Dam are destined for the Snake or mid-Columbia rivers, I assumed that trends in abundance of the overall runs provided a reasonable indication of the status of these fish runs between 1938 and 1961.

Snake River (1964–1984)

The percentages of adults returning to the Snake River from the smolt out-migrations of 1964–1982 were derived from estimated numbers of smolts passing the first dam encountered by smolts each year (hereafter termed first dam) and numbers of adults returning from each year's smolt migration after spending 1–3 years at sea. Smolt numbers were obtained from population estimates of chinook salmon and steelhead made each year at the first dam on the Snake River—Ice Harbor Dam 1964–1969, Little Goose Dam 1970–1974, and Lower Granite Dam 1975–1984 (Raymond 1979; DeLarm et al. 1984).

I estimated the number of hatchery-produced and naturally produced (hereafter termed wild) chinook salmon and steelhead smolts at the first dam between 1966 and 1975 (Raymond 1979). The number of hatchery smolts each year was derived from the total numbers released from hatcheries and their relative survival to the first dam; this number, when subtracted from the total population estimate calculated at the first dam, provided an estimate of wild fish each year. Using the same methods, I have since calculated comparable estimates for 1976–1984. In most years, sufficient numbers of marked fish were recovered for calculations of relative survival. For the few years in which there was no marking at hatcheries or recoveries were insufficient for analysis, I used the average survival rate for the years bracketing the missing data to estimate survival.

Numbers of wild chinook salmon were allocated to spring and summer components based on redd counts made by Idaho Fish and Game staff at index streams between 1962 and 1982. For each out-migration year, I multiplied the ratio of spring to summer chinook salmon redds in the year smolts were produced by the number of smolts.

To calculate numbers of adults returning from each year's smolt migration, I first added the counts of spring and summer chinook salmon and steelhead at Ice Harbor Dam (the lowest dam on the Snake River) to the estimated catch of Snake River fish in the river fishery for each year. I then calculated the number of fish in each return year that had spent 1, 2, and 3 years at sea. Returns were then related to the year of out-migration.

Ages of wild chinook salmon were determined from body measurements made during spawning-ground surveys in Idaho. Ages of hatchery spring chinook salmon that returned were determined from measurements made at Rapid River Hatchery from 1968 to 1987. Ages of returning steelhead were determined from length measurements taken at hatcheries, counting windows, and adult traps at dams.

The estimated catches of Snake River fish in zones 1–5 of the commercial fishery and the sport fishery below Bonneville Dam and the zone-6 commercial fishery above Bonneville Dam (Figure 1) were calculated differently depending on species. Upriver spring chinook salmon originate from tributaries of the Bonneville pool, the Deschutes and John Day rivers in Oregon, the Yakima River in Washington, and tributaries of the Snake and mid-Columbia rivers. I assumed equal fishery exploitation rates for all of these fish runs, and the estimated catch of Snake River spring chinook salmon then was directly proportional to their overall share of the upriver harvest in zones 1–5 and to their share of the escapement beyond zone 6. Total commercial catch in zones 1–6 and the sport catch below Bonneville Dam each year were obtained from Oregon Department of Fish and Wildlife and Washington Department of Fisheries (1966, 1987).

All summer-run chinook salmon are destined for either the Snake or mid-Columbia rivers. Again, I assumed equal rates of harvest of each of these runs, and estimated the catch of Snake River fish from the relative numbers of summer chinook salmon passing through Ice Harbor and Priest Rapids dams. To assign the catch to the proper smolt migration year, I assumed that the ages of spring and summer chinook salmon taken in the fishery were the same as indicated from escapement data.

Most steelhead harvested prior to 1975 were taken in the lower river sport and commercial fisheries. I assumed that proportions of fish that had spent 1 or 2 years at sea (1-ocean and 2-ocean, respectively) were the same as for escapement data. This assumption appears reasonable because sport gear is not size selective and the mesh used in the commercial gill-net fishery was small enough to capture 1-ocean fish. Since 1975, most of the harvest has occurred in zone 6. There has been no commercial fishery for steelhead in zones 1–5 and few steelhead have been caught by anglers below Bonneville Dam since 1975. Because 20-cm-mesh gill nets were used in the late-August–September zone-6 fishery, the majority of the steelhead harvested in recent years were the larger 2-ocean fish, such as those from the Clearwater River in Idaho, that pass Bonneville Dam after August 25. The majority of the fish from the Salmon River or mid-Columbia River that migrated upriver in July and early August were smaller 1-ocean fish. Those that delayed their upriver migrations and were exposed to the fall fishery usually escaped the nets because of their smaller size.

The estimated proportions of wild and hatchery spring chinook salmon in the escapement and fishery each year was determined from the percentages of hatchery and wild fish counted at Ice Harbor Dam. The percentage of hatchery fish was the actual returns to Rapid River and Kooskia hatcheries plus Salmon River harvest divided by the total count at Ice Harbor Dam. The difference was the percentage of wild fish. I assumed that these proportions were the same in the Columbia River fishery.

Proportions of wild and hatchery steelhead were calculated in a similar manner. Estimated sport catches of hatchery fish in Idaho and returns to Dworshak Hatchery and Pahsimeroi River (Niagara Springs Hatchery) each year were obtained from Idaho Department of Fish and Game (1967–1986), Pettit (1985), and K. Ball (Idaho Fish and Game, personal communication).

Summer chinook salmon were considered to be wild fish. Hatcheries released none of this race until 1980, and few through 1984.

Mid-Columbia River (1962–1984)

Similar methodology was used to estimate the percentage of adults returning from each year's out-migration of smolts from the mid-Columbia River between 1962 and 1984. Smolt indices were not as readily available as they were for the Snake River because there was no ongoing indexing of smolts at dams except at Priest Rapids Dam between 1965 and 1967. To compare mid-Columbia and Snake river smolt estimates, methods were developed for estimating the number of hatchery and wild smolts emigrating each year to the first dam (either Rock Island, Rocky Reach, or Wells, depending on tributary and hatchery).

Smolts.—The estimated number of hatchery smolts arriving at the first dam each year was based on numbers released and estimates of their survival from the hatchery to the dam. For steelhead, I assumed 90% survival because of the short distance between point of release and the dam and because steelhead smolts normally have a higher survival rate than chinook salmon smolts (Raymond 1979). For chinook salmon, I assumed 80% survival for yearling spring stocks and 50% for subyearling summer stocks. The 80% survival rate is similar to that measured for marked spring chinook salmon from Leavenworth Hatchery (Wenatchee River) that were released below Priest Rapids Dam and recovered at McNary Dam in 1982 and 1983 (McKenzie et al. 1983, 1984). The 50% survival rate for subyearlings assumes their mortality to be more than twice that of yearling releases. The assumption is reasonable because the much smaller subyearlings released at Wells Hatchery have to travel the entire 75 km of the reservoir before arriving at the first dam (Rocky Reach). Even though releases are in May and early June, data from marked fish indicate many delay up to a month before actively migrating downriver. During that time, substantial losses could result from predation and disease (Park 1969). In contrast, yearling releases are made just upstream from the first dam in April and arrival is usually within a few days after release.

The estimated number of wild chinook salmon passing the first dam each year was based on annual redd counts in index streams since 1960 and a multiplier derived from the average number of smolts per redd between 1965 and 1967. Park (1969) estimated the number of smolts passing Priest Rapids Dam each year from 1965 to 1967. These estimates were divided by 0.85 to account for dam-related mortalities for each dam between the first dam encountered and Priest Rapids Dam. For fish migrating from the upper tributaries (the Okanogan, Methow, and Entiat rivers), the first dam would have been Rocky Reach (1962–1966) or Wells (since 1967), and the migrants would have passed three or four dams on their way to Priest Rapids Dam. Those migrating from the Wenatchee River would pass two dams (Rock Island and Wanapum) before they reached Priest Rapids Dam (Figure 1). Differences in counts of adults between Rocky Reach and Rock Island dams indicated that 30% of the 1965–1967 smolts were from the Wenatchee River. The estimated number of smolts passing the first dam (N) in each of these years was derived from the equation

$$N = 0.30M/(0.85)^2 + 0.70M/(0.85)^3;$$

M = estimated number of smolts passing Priest Rapids Dam; $0.30M/(0.85)^2$ represents the contribution from the Wenatchee River; $0.70M/(0.85)^3$ represents the contribution from upper tributaries. This estimate was obtained for each year 1965–1967, divided by the redd count for the year producing the smolts, and averaged (e.g., the estimated number of yearling spring chinook salmon in 1965 was divided by the number of redds in index streams in 1963). This yielded multipliers of 500 for spring and 1,000 for summer chinook salmon. Thus, redd counts that were lagged 2 years for yearling spring chinook salmon and 1 year for subyearling summer chinook salmon were multiplied by the appropriate number to estimate the total number of wild chinook salmon passing the first dam during each year of this study.

Estimates of numbers of wild steelhead smolts between 1965 and 1967 were obtained by subtracting 90% of the estimated numbers of hatchery fish from the estimated totals passing the first dam. To obtain numbers in other years, I developed a method to relate differences in spawning escapement each year to numbers of wild smolts produced. This was obtained by multiplying adult counts at Priest Rapids Dam (lagged 2 years to represent spawners producing each year's smolt emigration) by 16.7 (the average number of wild smolts produced by an adult during 1965–1967). I assumed that annual fluctuations in counts of adults in the spawning population would translate into numbers of smolts produced 2 years later. An argument against this assumption is the unknown mix of hatchery and wild fish in adult returns from year to year. Much of this argument is negated by the management practices of the Washington Department of Game. During this period, the department released most hatchery-reared fish in distant streams, and adults did not return to the hatchery. Eggs were obtained from adults trapped in fish ladders at dams. Because the rate of trapping was fairly constant, I assumed the number of naturally produced smolts from the remaining mix of hatchery and wild spawners each year was proportional to differences in escapement.

In summary, then, my overall indices of smolt abundance for the mid-Columbia River each year are as follows: (1) steelhead, 0.9 × numbers released from hatcheries plus 16.7 × counts of adults that produced that year's emigrating wild smolts; (2) spring chinook salmon, 0.8 × numbers released from hatcheries plus 500 × numbers of redds producing that year's emigrating wild smolts; (3) summer chinook salmon, 0.6 × numbers released from the hatchery plus 1,000 × numbers of redds producing that year's emigrating wild smolts.

Adults.—The number of adults returning from each year's smolt migration was determined from counts of fish passing Priest Rapids Dam each year plus the estimated contribution of mid-Columbia River fish to the commercial and sport fisheries. The same methods used for Snake River stocks were employed to estimate the catch in the fisheries, except counts at Priest Rapids Dam, instead of at Ice Harbor Dam, were used to obtain needed proportions and, as mentioned previously, the smaller size and different timing of mid-Columbia River steelhead were taken into consideration.

Returns each year were then split into proportions that spent 1, 2, and 3 years at sea to relate returns to year of out-migration. Ages of hatchery spring chinook salmon and steelhead were obtained from length measurements of adult returns to hatcheries. Ages of wild spring chinook salmon were obtained from carcass measurements made on spawning-ground surveys by Washington Department of Fisheries staff.

Similar data were not available for summer chinook salmon because spawning-ground surveys were conducted from the air, and no age determinations were made at Wells Hatchery. Generally, most summer chinook salmon spend 3 years at sea before returning to spawn. John Easterbrook, Washington Department of Fisheries, and J. McGee, Douglas County Public Utility District (personal communications), agreed that there were some variations in age of adults spawning and at the hatchery, but that 3-ocean fish usually predominated. I therefore used that figure for relating adult returns to each cohort of emigrating smolts.

Estimates of proportions of hatchery and wild fish in the adult runs of summer chinook salmon and steelhead could not be made because returns to hatcheries were highly variable or nonexistent. Many summer chinook salmon and steelhead needed for brood stock, including wild fish, are trapped at dams. In addition, the limited marking done at hatcheries between 1962 and 1984 was insufficient to determine the contribution of hatchery production to adult runs each year.

The limited marking and variable returns of spring chinook salmon to hatcheries also made it difficult to separate the wild and hatchery contribution to the total adult run of spring chinook salmon each year. Efficiency of collection at Entiat and Winthrop hatcheries has varied greatly from year to year, and there were problems with collection and holding at Leavenworth Hatchery until new facilities were completed in 1979 (Mullan 1982). To obtain an estimate of the hatchery contribution, I devised an approach that did not require hatchery returns. I used counts at Priest Rapids Dam and redd counts to estimate total numbers of wild fish in each year's return of spring chinook salmon. This estimate was obtained by determining the average number of adults per redd between 1962 and 1973 when runs of these fish were all wild. Redd counts on streams, such as Icicle Creek, that might have been used later for spawning by returns of hatchery fish were excluded. The result was 6.4 adults per redd. This is a relative index number only, not the number of adults using each redd. The redd count is derived from sampling of index streams only, and does not represent total spawning. Redd counts multiplied by 6.4 each year between 1974 and 1987 provided the estimate of numbers of wild spring chinook salmon passing Priest Rapids Dam in each of these years. The hatchery proportion, then, was the count at Priest Rapids Dam minus estimated wild fish each year. These proportions were then used to estimate numbers of hatchery and wild fish taken in the fishery.

I emphasize that data such as smolt indices are less precise for the mid-Columbia reach than for the Snake River, and the estimated percentages of adult returns generated may not be as accurate. Nevertheless, similar methodology was used throughout the analysis period and should be sufficient for showing trends in abundance of fish runs with respect to hydroelectric development and actions taken to offset dam-related mortalities of smolts.

Run Trends, Hydroelectric Development, and Enhancement of Fish Populations

An examination of the upriver runs of spring and summer chinook salmon and steelhead returning to the Columbia River each year from 1938 to 1987 provides a general overview of trends in their abundance over the last 50 years (Figure

2). The difference between run size and escapement represent the catch in the river fishery each year. There are considerable differences in trends among these groups of fish. In general, spring chinook salmon runs were initially low, nearly doubled in size by 1952, remained relatively high through 1973, declined sharply until 1984, then increased. Summer chinook salmon runs after 1940 remained low until 1950, increased each year through 1957, declined steadily between 1958 and 1981, and remained low thereafter. Steelhead runs increased from 1938 through 1940, declined sharply between 1940 and 1948, rose sharply through 1953, and declined steadily between 1953 and 1975. In contrast to salmon runs, though, steelhead runs remained at a higher level; since 1981, they have been much higher than predam levels.

In the discussion to follow, I intend to show how hydroelectric development, the river fishery, and enhancement measures (hatcheries, spills and fingerling bypasses at dams, augmented river flows for fish, transportation of smolts around dams, e[illegible]er the years have affected each of these fish r[illegible]or this, I have divided the analysis into the early (1938–1957), middle (1958–1968), and late (1969–1984) periods of hydroelectric development.

Early Period (1938–1957)

Spring chinook salmon runs declined to 56,000 fish in 1944, but then increased to a peak of 281,000 fish in 1955 (Figure 2). Runs of summer chinook salmon likewise declined during the early 1940s, but they remained below 100,000 fish through 1950. By 1957, the run was back up to 207,000 fish, larger than the size of the run in 1938. Steelhead runs showed no apparent trends.

Causes of declines.—Dam construction and rate of harvest in the fishery had varying effects on fish runs between 1938 and 1957. Because of its size, no facilities were provided for passage of adult fish at Grand Coulee Dam on the Columbia River. As a result, 1,830 lineal kilometers of spawning grounds were lost indefinitely to an estimated 100,000 chinook and sockeye salmon and steelhead in 1939 (Fish and Hanovan 1948). I also presume that smolts migrating to sea in 1939 and 1[illegible]hich provided the adult runs between 1941 and 1943, would have had difficulty in passing the partially completed dam. In addition, there were probably some adverse effects on both juvenile and adult migrations from the completion of Bonneville Dam in 1938. Initial effects on juvenile salmon migrations from McNary Dam, completed in 1953, appeared minimal. The 1955, 1956, and 1957 runs of spring and summer chinook salmon that returned from smolt migrations between 1953 and 1955 were at or near record high levels. However, this may have been a result of excellent egg-to-smolt and ocean survival that might have more than offset dam-related mortalities of smolts.

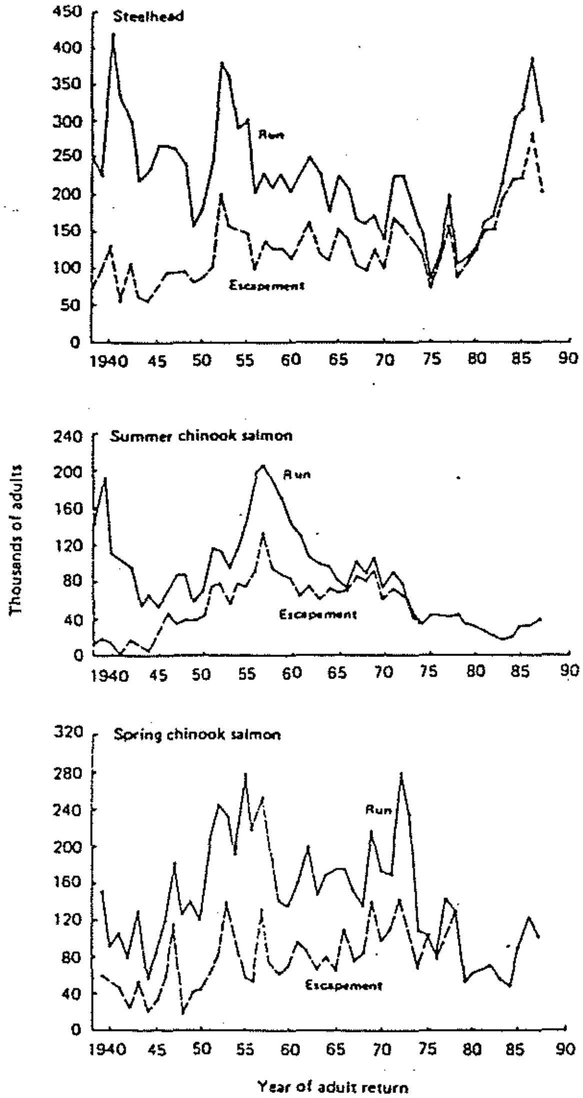

FIGURE 2.—Estimated total runs of stocks of spring and summer chinook salmon and steelhead that originated above Bonneville Dam on the Columbia River, 1938–1987. Escapement represents total run minus the number harvested.

The run of 152,000 spring chinook salmon in 1939 consisted largely of returns from the 1936 and 1937 smolt out-migrations that went to sea prior to the completion of Bonneville and Grand Coulee dams. The sharp decline down to a run of 56,000 fish by 1944 was at least partially the result of construction of these dams. Harvests by the river fishery averaged 60% of the total runs between 1938 and 1955, and escapement in most years appeared adequate (Figure 2). Therefore, I assume a minimal effect from the fishery during this period.

Though summer chinook salmon runs were also affected by these dams, overharvest in the river fishery (averaging 88% of the total run) between 1938 and 1944 (Figure 2) probably caused a greater effect. Escapement during this period averaged 11,500 fish—far too few for adequate seeding of the spawning grounds. The net result was low smolt production from each of these runs and subsequently poor returns of adults between 1942 and 1949.

Reasons for recoveries.—Both the successful salvage operations to transfer Grand Coulee stocks of fish to downstream rivers and the Lower Columbia River Development Program were instrumental in the rebound of spring and summer chinook salmon and, to a lesser degree, steelhead.

The relocation of the anadromous fish runs cut off by Grand Coulee Dam began in 1939. It consisted of trapping adult salmon and steelhead at Rock Island Dam and transporting them to holding areas where they matured. The eggs were then taken to satellite hatcheries at Leavenworth, Entiat, and Winthrop, Washington. Fish were reared to smolting size at these sites and released into the drainages of the Wenatchee, Entiat, and Methow rivers; several years' evaluation of this program indicated conclusive success (Fish and Hanovan 1948; Fulton and Pearson 1981).

The Lower Columbia River Development Program that began in 1949 was designed to maintain the runs supporting the commercial and sport fisheries at the highest level of abundance. Major components of the program included screening of irrigation diversions, stream improvement, and increased production of smolts in hatcheries. The screening of irrigation diversions especially benefited spring chinook salmon that spawned mainly in tributary streams. Prior to this program, millions of young salmon each year passed down the extensive network of irrigation ditches and were stranded in cultivated fields. As an example, the Lemhi River in Idaho was reduced to only a meager run of salmon before 85 irrigation diversions were screened in the 1950s. By 1961, the run had increased to over 4,000 fish (Netboy 1980). The increase in overall spring chinook salmon runs to 200,000 fish or more each year between 1951 and 1957 reflected the ability of salmon runs to rebound, given favorable downriver and ocean survival in combination with effective enhancement programs like those just described.

The shortening of the commercial fishing season for summer chinook salmon to allow greater escapement was the major reason for the restoration of these runs. Between 1945 and 1949, average harvest rate dropped to 47%, and average escapement increased to 37,000 fish. Between 1950 and 1954, average harvest rate dropped even more to 35%, and averaged escapement increased to 67,000 fish. With annual increases in smolt production each year from greater spawning escapement and no additional dam development, the run increased from 58,000 fish in 1948 to 207,000 fish by 1957.

Middle Period (1958–1968)

Runs of spring chinook salmon averaged 232,000 fish between 1951 and 1957, but only 162,000 fish between 1958 and 1968 (Figure 2). Adult steelhead returns that averaged 269,000 fish between 1938 and 1957 declined to an average 209,000 fish between 1958 and 1968. Summer chinook salmon runs declined from 207,000 fish in 1957 to 75,000 fish by 1966. Because of depressed runs, the entire river was closed to harvesting of summer chinook salmon beginning in 1965.

Causes of declines.—Declines in fish runs resulted from the completion of The Dalles Dam in 1957, Priest Rapids Dam in 1959, Rocky Reach Dam in 1961, Wanapum Dam in 1963, Wells Dam in 1967, and John Day Dam in 1968 (Figure 1). These low-head dams provided passage for adults but the dams delayed migrations and caused mortality of migrating adults (Junge and Carnegie 1976), substantial mortality of juveniles passing through the turbines (Schoeneman et al. 1961), delay and mortality of juveniles passing through the reservoirs behind each dam (Raymond 1979), and mortality of both juveniles and adults from gas supersaturation resulting from spills at dams (Ebel and Raymond 1976). The fishery was not a major factor because harvest rates during this period were reduced sharply to 46% for spring chinook salmon, 20% for summer chinook salmon, and 35% for steelhead (Oregon Department of Fish and Wildlife and Washington Department of Fisheries 1966, 1984).

Actual effects of dams on fish runs could not be measured in the early part of this period. Data that provided the percentage return of adults to mid-Columbia and Snake rivers were not available until the returns from the 1962 and 1964 migrations, respectively. I assumed that the total effect prior to 1962 was less because there were fewer dams and many stretches of free-flowing river remained between dams. Gas supersaturation was not a problem because the water was able to equilibrate quickly in the free-flowing river below Priest Rapids and McNary dams (Ebel 1969). Effects from turbines and reservoirs on smolts were much less than in later years because of fewer dams, fewer turbines at each dam, higher spill, and higher river flows during the spring, there being fewer large reservoirs to store natural runoff from melting snows.

Percentage returns of salmon and steelhead originating from the mid-Columbia reach of river between 1964 and 1968 declined faster than those of Snake River fish (Figure 3). Percentage returns of summer chinook salmon to the mid-Columbia declined from 2.0% in 1964 to 0.8% by 1967 (average, 1.3%), and spring chinook salmon declined from 5% in 1964 to less than 1% in 1968 (average, 2.6%). In contrast, percentage returns of both spring and summer chinook salmon to the Snake River during this period averaged 4%. Steelhead returns to the mid-Columbia River declined from 3.8% in 1964 to 1.4% in 1968 (average, 2.8%) but averaged 5.0% for Snake River returns.

The lower rates of return of spring chinook salmon and steelhead to the mid-Columbia River between 1964 and 1968 must have been caused by increased smolt mortalities at dams, not differences in ocean survival. Smolts from the mid-Columbia River had to pass three dams in 1962, four dams between 1963 and 1966, and five dams thereafter. By comparison, there were no low-head dams on the Snake River until Ice Harbor Dam was built in 1962, and there was only that dam to pass between 1962 and 1968. Timing of seaward migrations of smolts from each reach of river, however, remained similar; therefore, differences in ocean survival should have been small.

The lower average rate of return of mid-Columbia River summer chinook salmon runs resulted from the timing of their seaward migration. I assumed, as did Park (1969), that because summer chinook salmon from the mid-Columbia River migrated to sea as subyearlings in July and August during low river flows, small spills, and warm water, their survival was lower than the survival of the other runs of fish that migrated to sea as yearlings in April and May when river flows and spills were generally higher and water temperatures lower. The basis for this conclusion was my finding that survival of Snake River smolts was much lower in years of low river flows and spills than in years of higher river flows and spills (Raymond 1979).

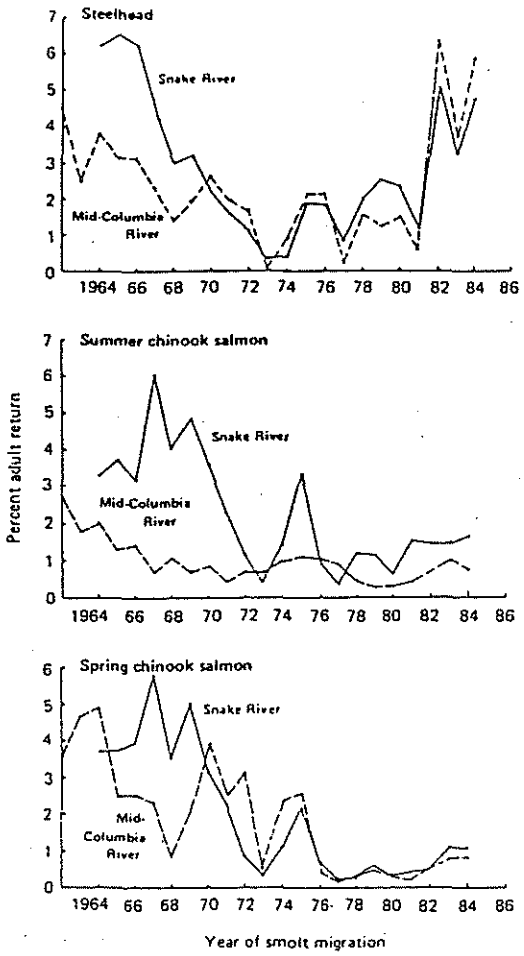

FIGURE 3.—Percent return of spring and summer chinook salmon and steelhead to the Snake and mid-Columbia rivers from smolt migrations of 1962–1984.

Enhancement activities.—There were no important hatchery releases of spring and summer chinook salmon or steelhead through 1966. Leavenworth Hatchery continued to rear sockeye salmon and coho salmon *O. kisutch*, whereas Entiat and Winthrop hatcheries changed their production from spring chinook salmon to coho salmon and rainbow trout (nonanadromous *Salmo gairdneri*). Rapid River and Niagara Springs hatcheries were constructed to compensate for fish runs lost through the construction of the Brownlee–Oxbow Dam complex on the Snake River. Rapid River Hatchery, on the Salmon River, made its first release of 588,000 spring chinook salmon in 1966. Niagara Springs Hatchery near Twin Falls, Idaho, began to rear steelhead in 1966. The first release of 1,250,000 steelhead was into the Pahsimeroi River near Salmon, Idaho, in 1967. Returns from

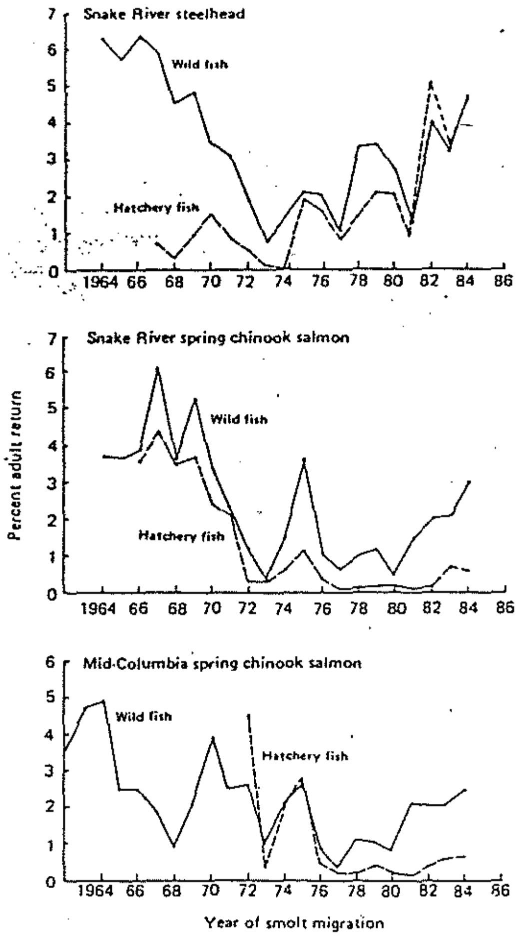

FIGURE 4.—Percent return of wild and hatchery spring chinook salmon and steelhead to the Snake and mid-Columbia rivers from smolt migrations of 1962–1984.

smolts released from Rapid River Hatchery between 1966 and 1968 ranged between 3.5 and 4.5%, only slightly lower than the returns of wild fish during this period. In contrast, steelhead returns from the first Niagara Springs Hatchery releases were poor. Rates of return from releases in 1967 and 1968 were less than 1%, compared to 4–6% for wild fish (Figure 4).

Late Period (1969–1984)

Smolt mortality caused by the new dams built on the Snake River after 1968 and the already completed dams on the lower Columbia River dropped the return rates of Snake River spring and summer chinook salmon and steelhead from above 4% of smolt emigrations through 1968 to averages of less than 1.5% between 1970 and 1974 gure 3). Record low river flows in 1973 and 1977 resulted in returns of less than 0.5% because 95% or more of the emigrating smolts died in those years (Sims et al. 1978; Raymond 1979); 1973 and 1977 also were bad years for mid-Columbia smolts, judged by the low adult return rates (Figure 3). Summer chinook salmon runs from the mid-Columbia were already down to about a 1% return rate by 1969 and have remained there since. Substantial increases in numbers of smolts being released from hatcheries and actions taken since 1975 to minimize mortalities of smolts migrating downriver have helped some fish runs to recover.

Causes of declines.—The declines in fish runs were caused by major increases in smolt mortalities due to turbines, delays in passage through reservoirs, and supersaturation of atmospheric gases caused by accelerated development of the Columbia and Snake rivers' hydroelectric system between 1969 and 1982. In 1968, smolts from the Snake River, for example, had to pass only five dams with a combined total of 47 turbine units. By 1975, they had to pass three additional dams on the Snake River—Lower Monumental (completed in 1969), Little Goose (1970), and Lower Granite (1975)—which brought the total to 77 turbine units. By 1982, the number was up to 94 units, over double that of 1965 (Table 1). The added turbines have markedly reduced smolt survival. As a case in point, the number of turbines at Snake River dams increased from three to six per dam between 1975 and 1980. The capacity of a single turbine is about 570 m^3/s of river flow. At a typical river flow of 3,400 m^3/s during the smolt migration, all of the water and fish must pass through turbines; when there were three turbines, 50% of the water and fish passed by the safer route through the spillway (Schoeneman et al. 1961). Storage reservoirs were also being built in the upper Columbia River to regulate the river for more efficient power production. By 1973, the combined storage of Mica, Duncan, Arrow, Albeni Falls, Libby, Hungry Horse, and Grand Coulee dams was over 43 × 10^9 m^3 of runoff each year. This has reduced Columbia River flows by about 50% during May and June in most years, the time when yearling fish migrate to the sea (Figure 5).

The combination of nearly total impoundment of the Columbia and Snake rivers, regulation of flows, and increased generating capacity has been deadly for smolts migrating through the dam complex. During average or below-average runoff years, the regulated runoff rarely exceeds powerhouse capacity, and there is little or no spillage at dams. Direct mortality of smolts passing through turbines has been estimated at about 11% (Schoeneman et al. 1961). Indirect mortality, such as in-

TABLE 1.—Number of turbine units at hydroelectric dams on the Snake River and Columbia River affecting anadromous fish runs, 1935–1985.

Dam	Cumulative number of turbine units in place by year										
	1935	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985
Mid-Columbia River											
Wells								10	10	10	10
Rocky Reach							8	11	11	11	11
Rock Island	10	10	10	10	10	10	10	10	10	18	18
Wanapum							10	10	10	10	10
Priest Rapids						10	10	10	10	10	10
Subtotal	10	10	10	10	10	20	38	51	51	59	59
Snake River											
Lower Granite									3	6	6
Little Goose								3	3	6	6
Lower Monumental								3	3	6	6
Ice Harbor							3	3	6	6	6
Subtotal							3	9	15	24	24
Lower Columbia River											
McNary					14	14	14	14	14	14	14
John Day								16	16	16	16
The Dalles						16	16	16	22	22	22
Bonneville		10	10	10	10	10	10	10	10	10	18
Subtotal		10	10	10	24	40	40	56	62	62	70
Grand total	10	20	20	20	34	60	81	116	128	145	153

creased predation on stunned fish, can also be substantial. Long and Ossiander (1974) showed that the direct plus indirect mortality can be as high as 30% at a single dam. Prior to 1970, in contrast, there was usually substantial spillage at dams and much of the migration could pass through the spillways, where mortality was 3% or less (Schoeneman et al. 1961).

The reductions in flows due to storage reservoirs have further delayed smolt migrations already slowed by passage through the essentially impounded Snake and Columbia rivers (Raymond 1968, 1969; Bentley and Raymond 1976). Ebel and Raymond (1976) calculated that, during low-flow years, juvenile chinook salmon and steelhead emigrating from the Salmon River would take 65 d to reach The Dalles Dam, arriving there about 35 d later than they did before dams were constructed. Actual travel time during the record low runoff in 1977 was close to this prediction; smolts took 57 d to travel from the Salmon River to The Dalles Dam, arriving there in mid-June instead of early May (Sims et al. 1978). The total effect of this drastic change in the timing of anadromous fish movements, which are precisely tuned to specific environmental patterns such as correct time of entry into seawater, is not yet completely known. One immediate effect, though, is increased mortality from the additional travel time required to pass through eight or nine reservoirs and prolonged exposure to predation and disease. For example, near-record low flows in 1973 and the record low runoff in 1977 resulted in 95 and 98% mortality of smolts, respectively (Sims et al. 1978; Raymond 1979). These losses were incurred during passage through five and six projects (dam and reservoir combinations). This equates to a mortality of 45% per project. By contrast, in 1978, a year of high runoff and about a 35% spill at Snake River dams, mortality per project was only 15% (Sims and Ossiander 1981). The 30% additional

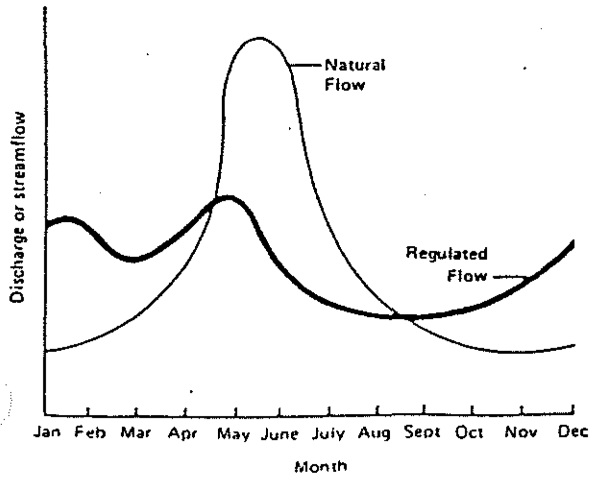

FIGURE 5.—Typical effects of regulated flows on runoff in the Columbia River.

mortality per project resulted from added delay in passage through the reservoir and higher direct and indirect turbine mortality because nearly all of the fish passed through turbines. Sims and Ossiander (1981) computed a positive correlation between river flow and survival of smolts ($r = 0.87$ and 0.95 for chinook salmon and steelhead, respectively). I found (Raymond 1979) that survival of chinook salmon and steelhead from the forebay to the tailrace of Little Goose Dam during high runoff in 1974 was significantly higher than that measured during the low runoff in 1973.

During high runoff and spill, the water can become supersaturated with atmospheric gases to levels that are lethal to fish. Ebel (1969) showed that water plunging over spillways is the main cause of supersaturation. When there were only a few dams on the river, effects were low because gases equilibrated with the atmosphere in the free-flowing sections of river. Once most of the Columbia and Snake rivers were impounded after 1968 and 1970, respectively, the problem worsened because little equilibration of supersaturated gases occurs in reservoirs associated with dams. Ebel and Raymond (1976) and Raymond (1979) documented significant mortalities from gas supersaturation during the juvenile and adult migrations of 1970, 1971, and 1974. To reduce dissolved gas supersaturation, slotted bulkheads were installed in 1972 in empty turbine bays of Little Goose Dam to increase the amount of river flow through turbines and reduce the amount of spill. Gas supersaturation was reduced, but the slotted bulkheads caused a 61% mortality of juvenile chinook salmon in the Snake River that year (Ebel and Raymond 1976; Raymond 1979).

The similar rates of returns of spring chinook salmon and steelhead to the mid-Columbia and Snake rivers in most years since 1970 (Figure 3) suggest that smolts from each river encountered similar passage conditions. The decreasing rates of return between 1970 and 1974 to both reaches of river reflected declining smolt survival due to hydroelectric development. Actions taken since 1974 to reduce or compensate for mortalities of smolts from the dam complex did increase the return rates of some fish runs.

Enhancement activities.—Supersaturation of dissolved atmospheric gases (mostly nitrogen) was reduced by spillway deflectors, which are concrete sills placed near the base of the spillway to direct flow horizontally into the stilling basin. Johnsen and Dawley (1974), Long and Ossiander (1974), and Monan and Liscom (1974, 1985) showed that the deflectors substantially reduce gas supersaturation without adverse effects on fish. The U.S. Army Corps of Engineers installed deflectors at Lower Granite, Little Goose, and Lower Monumental dams on the Snake River and at McNary and Bonneville dams on the Columbia River. These installations, coupled with increased turbine capacity and regulated river runoff, have substantially reduced dissolved gas supersaturation in the Snake and lower Columbia rivers.

There was no simple way to minimize or offset losses of smolts migrating through reservoirs and turbines at dams. Research was conducted into these problems, but most fishery agencies in the late 1960s and early 1970s opted for increased production at hatcheries to mitigate losses at dams. This enhancement more than doubled the numbers of smolts arriving at the first dam beginning in 1970 on the Snake River and in 1976 on the mid-Columbia River. Releases of juvenile spring chinook salmon from Rapid River and Kooskia hatcheries and of steelhead from Dworshak and Niagara Springs hatcheries increased Snake River emigrations from about 3.0 million wild smolts between 1964 and 1967 to a mix of over 8.0 million wild and hatchery smolts by 1970 (Tables 2, 3). There was no hatchery enhancement of summer chinook salmon populations until 1980 and then the contribution each year from McCall Hatchery at Lower Granite Dam was only between 80,000 and 150,000 smolts (Table 4). For the mid-Columbia reach, spring chinook salmon emigrations changed from 0.2 to 1.1 million wild smolts annually through 1971 to a mix of between 2.0 and 3.7 million hatchery and wild smolts after the Leavenworth Hatchery complex began releasing smolts in 1976 (Table 5); summer chinook salmon emigrations changed from 1.0–2.2 million wild smolts through 1968 to a mix of over 3.0 million Wells Hatchery and wild fish by 1978 (Table 6); and steelhead changed from 0.3–0.6 million hatchery and wild smolts through 1974 to 0.5–0.9 million smolts each year since then (Table 7).

These hatchery releases, and relatively high survival of smolts, enhanced fish runs through 1975 whenever there was average or above-average runoff. Rates of return of both wild and hatchery spring chinook salmon to the Snake River, for example, were over 3%, and the adult returns from the smolt emigrations of 1966–1971 were generally above 70,000 fish annually. Hatchery plantings, though, were not sufficient to offset the 95% mortality of smolts emigrating through the dam complex during low river flows in 1973. Only

TABLE 2.—Numbers of adult spring chinook salmon returning to the Snake River, and their percentages of the estimated numbers of smolts passing the first dam they encountered on the Snake River, 1964–1984.

Year of smolt migration	Millions of smolts passing first dam[a]			Thousands of adults returning after 1–3 years at sea[b]			Percent return		
	Hatchery	Wild	Total	Hatchery	Wild	Total	Hatchery	Wild	Combined
1964		2.0	2.0		74	74		3.7	3.7
1965		1.4	1.4		52	52		3.7	3.7
1966	0.22	1.8	2.0	8	70	78	3.6	3.9	3.9
1967	0.18	1.3	1.5	8	79	87	4.4	6.1	5.8
1968	0.4	1.4	1.8	14	50	64	3.5	3.6	3.5
1969	0.3	1.4	1.7	11	74	85	3.7	5.3	5.0
1970	1.8	2.2	4.0	44	84	128	2.4	3.4	3.2
1971	1.7	1.7	3.4	36	41	77	2.1	2.4	2.3
1972	1.6	2.3	3.9	5	27	32	0.3	1.2	0.8
1973	2.1	1.9	4.0	7	7	14	0.3	0.4	0.3
1974	1.5	1.5	3.0	9	24	33	0.6	1.6	1.1
1975	2.2	1.7	3.9	24	63	87	1.1	3.7	2.2
1976	2.4	1.9	4.3	11	19	30	0.4	1.0	0.7
1977	1.2	0.6	1.8	1	2	3	0.1	0.3	0.2
1978	2.0	0.7	2.7	2	7	9	0.1	1.0	0.3
1979	2.3	1.3	3.6	5	16	21	0.2	1.2	0.6
1980	2.4	2.2	4.6	5	10	15	0.2	0.5	0.3
1981	2.3	0.6	2.9	2	9	11	0.1	1.5	0.4
1982	1.4	0.2	1.7	4	4	8	0.3	2.0	0.5
1983	2.6	0.8	3.4	19	17	36	0.7	2.1	1.1
1984	4.2	0.7	4.9	26	21	47	0.6	3.0	1.0

[a] First dam—Ice Harbor 1964–1968, Lower Monumental 1969, Little Goose 1970–1974, Lower Granite 1975–1984.

[b] Count at Ice Harbor Dam plus the estimated catch of Snake River fish in zones 1–6 of the Columbia River fishery.

TABLE 3.—Numbers of adult steelhead returning to the Snake River, and their percentages of the estimated numbers of smolts passing the first dam they encountered on the Snake River, 1964–1984.

Year of smolt migration	Millions of smolts passing first dam[a]			Thousands of adults returning after 1–3 years at sea[b]			Percent return		
	Hatchery	Wild	Total	Hatchery	Wild	Total	Hatchery	Wild	Combined
1964		1.6	1.6		100	100		6.3	6.3
1965		1.5	1.5		85	85		5.7	5.7
1966		1.6	1.6		102	102		6.4	6.4
1967	0.8	1.8	2.6	6	107	113	0.7	5.9	4.3
1968	1.0	1.8	2.8	3	81	84	0.3	4.5	3.0
1969	0.8	1.3	2.1	6	62	68	0.9	4.8	3.2
1970	2.6	1.6	4.2	38	54	92	1.5	3.4	2.2
1971	3.2	1.8	5.0	26	56	82	0.8	3.1	1.6
1972	1.4	1.1	2.5	7	21	28	0.5	1.9	1.1
1973	2.5	1.3	3.8	3	9	12	0.1	0.7	0.3
1974	3.6	1.4	5.0	5	18	23	0.1	1.4	0.5
1975	2.4	0.8	3.2	45	17	62	1.9	2.1	1.9
1976	1.8	1.4	3.2	28	28	56	1.6	2.0	1.8
1977	0.9	0.5	1.4	7	5	12	0.8	1.0	0.9
1978	1.2	0.9	2.1	17	30	47	1.4	3.3	2.2
1979	1.5	1.1	2.6	31	37	68	2.1	3.4	2.6
1980	2.6	1.0	3.6	55	27	82	2.1	2.7	2.3
1981	2.4	1.3	3.7	29	15	44	1.2	1.2	1.2
1982	3.3	1.0	4.3	167	40	207	5.1	4.0	4.8
1983	2.1	0.8	2.9	67	27	94	3.2	3.4	3.2
1984	3.2	1.0	4.2	151	46	197	4.7	4.6	4.7

[a] First dam—Ice Harbor 1964–1968, Lower Monumental 1969, Little Goose 1970–1974, Lower Granite 1975–1984.

[b] Count at Ice Harbor Dam plus the estimated catch of Snake River fish in zones 1–6 of the Columbia River fishery.

TABLE 4.—Numbers of adult summer chinook salmon returning to the Snake River, and their percentages of the estimated numbers of smolts passing the first dam they encountered on the Snake River, 1964–1984.

Year of smolt migration	Millions of smolts passing first dam[a]	Thousands of adults returning after 1–3 years at sea[b]	Percent return
1964	0.9	30.0	3.3
1965	0.8	30.0	3.8
1966	1.0	33.0	3.2
1967	0.7	42.0	6.0
1968	0.7	29.0	4.1
1969	0.7	34.0	4.8
1970	1.0	32.0	3.2
1971	0.6	14.0	2.3
1972	0.9	8.8	1.0
1973	1.0	4.0	0.4
1974	0.6	7.5	1.3
1975	0.5	17.0	3.4
1976	0.6	5.6	0.9
1977	0.2	1.0	0.5
1978	0.3	3.6	1.1
1979	0.5	5.5	1.1
1980	0.6[c]	4.7	0.8
1981	0.4[c]	5.3	1.5
1982	0.4[c]	5.8	1.4
1983	0.4[c]	6.4	1.4
1984	0.5[c]	8.4	1.7

[a] First dam—Ice Harbor 1964–1968, Lower Monumental 1969, Little Goose 1970–1974, Lower Granite 1975–1984.

[b] Count at Ice Harbor Dam plus the estimated catch of Snake River fish in zones 1–6 of the Columbia River fishery.

[c] Includes the estimated contribution from McCall Hatchery.

14,000 adult spring chinook salmon returned to the Snake River from that year's smolt migration (Table 2). After 1975, regardless of runoff, returns of hatchery spring chinook salmon were very small. Possible reasons for this are discussed in the subsequent section on responses of spring chinook salmon to protection and enhancement.

When it became apparent in early 1975 that Snake River salmon and steelhead runs were in jeopardy, fishery and water management agencies met to develop the following recommendations for maintaining valuable upriver runs of fish: (1) expand research to perfect fingerling bypasses and transportation of smolts around dams; (2) accelerate installation of fingerling bypasses at dams; (3) begin mass transportation of smolts collected at Lower Granite and Little Goose dams on the Snake River to waters below Bonneville Dam; (4) improve passage of adults at dams; and (5) form a Committee on Fishery Operations (COFO). The COFO's assignment was to oversee management of timely releases of water from reservoirs to supplement river flows, thereby reducing migration delays for smolts and providing spill at dams without fingerling bypasses to minimize turbine mortality.

These recommendations established the groundwork for the protection of runs not only in the Snake River but in the mid-Columbia River as well. Much of the information obtained from the research programs and COFO was used to develop the Fish and Wildlife Program of the Pacific Northwest Electric Power Planning and Conservation Act, signed in 1980. I present a summary of these enhancement activities.

Fingerling bypasses.—Fingerling bypass systems often include submersible traveling screens to divert fingerlings out of turbine intakes into gatewells and orifices to pass fish out of gatewells into a bypass (Figure 6). Another type of bypass is that used at The Dalles Dam, where the ice and trash sluice is used to skim fish out of the forebay of the dam (Nichols and Ransom 1981). Bypasses and traveling screens have now been installed by the Corps of Engineers at Bonneville, John Day, McNary, Little Goose, and Lower Granite dams. Plans are in progress to provide similar bypasses at mid-Columbia River dams and Lower Monumental, Ice Harbor, and The Dalles dams. Research has shown that traveling screens that work at one dam may be far less efficient at another dam. Therefore, evaluations are being conducted at each dam to ensure that the fish guiding efficiency of the submersible traveling screen is adequate and that bypasses are functioning correctly. Another recent discovery is that fish guidance can vary among years as well as within years and between species at a given dam. Tests at Lower Granite Dam in 1984 and 1985, for example, showed that the guiding efficiency for chinook salmon early in their migration was only 30–40% but later improved to 70%. In contrast, the guiding efficiency for steelhead remained above 75% throughout emigrations in all 3 years. Measures of vertical distribution indicated that low guiding efficiency resulted whenever a high percentage of fish were below the intercept level of the submersible traveling screen in the turbine intake. One explanation is that earlier-migrating yearling chinook salmon (mostly hatchery releases) may not be far along in the parr-to-smolt transformation during some years, and migrate deeper in the water column (Pinder and Eales 1969).

Tests at McNary Dam in 1984 showed that guiding efficiency for subyearling chinook salmon, emigrating in July and August, was 50% or less. In 1985, the efficiency was less than 25% for sub-

TABLE 5.—Numbers of adult spring chinook salmon returning to the mid-Columbia River, and their percentages of the estimated numbers of smolts passing the first dams they encountered on the mid-Columbia River, 1962–1984.

Year of smolt migration	Thousands of smolts passing first dam[a]			Thousands of adults returning after 1–3 years at sea[b]			Percent return		
	Hatchery[c]	Wild[d]	Total	Hatchery	Wild	Total	Hatchery	Wild	Combined
1962		833	833		30.3	30.3		3.6	3.6
1963		200	200		9.5	9.5		4.7	4.7
1964		550	550		27.0	27.0		4.9	4.9
1965		395	395		9.7	9.7		2.5	2.5
1966		769	769		19.2	19.2		2.5	2.5
1967		525	525		9.3	9.3		2.5	2.5
1968		1,117	1,117		7.8	7.8		0.7	0.7
1969		642	642		12.7	12.7		2.0	2.0
1970		690	690		27.4	27.4		4.0	4.0
1971		430	430		10.8	10.8		2.5	2.5
1972	200	425	625	9.1	10.9	20.0	4.5	2.6	3.2
1973	467	349	816	2.0	3.5	5.5	0.4	1.0	0.5
1974	384	395	779	7.9	8.5	16.4	2.1	2.1	2.1
1975	574	833	1,407	16.4	22.0	38.4	2.8	2.6	2.7
1976	1,637	450	2,087	6.9	3.7	10.6	0.4	0.8	0.5
1977	2,308	618	2,926	5.4	1.7	7.1	0.2	0.3	0.2
1978	2,323	320	2,643	5.4	3.7	9.1	0.2	1.1	0.3
1979	2,038	486	2,524	7.4	4.9	12.3	0.4	1.0	0.5
1980	3,031	699	3,730	6.5	4.9	11.4	0.2	0.7	0.3
1981	3,175	164	3,339	4.2	3.5	7.7	0.1	2.1	0.2
1982	3,056	245	3,301	11.2	5.4	16.6	0.4	2.2	0.5
1983	3,054	219	3,273	18.2	6.4	24.6	0.6	2.9	0.8
1984	2,868	245	3,113	19.3	5.8	25.1	0.7	2.4	0.8

[a] First dam—either Rock Island, Rocky Reach, or Wells, depending on tributary and hatchery.

[b] Count at Priest Rapids Dam plus the estimated catch of mid-Columbia fish in zones 1–6 of the Columbia River fishery.

[c] Numbers released from hatcheries × 80% survival to first dam.

[d] Redd count 2 years previously × 500.

yearlings in July at John Day Dam. Measures of vertical distribution again revealed that many subyearlings passed below the traveling screen in the turbine intake. Tests at Bonneville Dam indicated that guiding efficiency is 75% at the first powerhouse but only 20–50% at the newer second powerhouse. Recent prototype modifications improved the efficiency for yearling fish but not for the deeper-migrating subyearlings. The Corps of Engineers is presently examining the feasibility of a longer traveling screen or an added screen on the trashrack to intercept deeper-running fish. Details on recent research on fingerling bypasses may be found in Krcma et al. (1980, 1982, 1985), Gessel et al. (1985), and Swan et al. (1985).

Transportation of smolts.—The concept of smolt transportation is to collect smolts diverted out of turbine intakes at upriver dams, such as Lower Granite Dam, and to transport them by truck or barge to safe release areas below Bonneville Dam, thus bypassing the rigors of intervening dam–reservoir systems. Benefits from transportation of both steelhead and chinook salmon smolts were realized in early experiments at Ice Harbor Dam in 1968–1970 (Ebel et al. 1973) and Little Goose Dam in 1971–1973 (Ebel 1980). As a result of these findings, the Corps of Engineers began mass transportation of smolts from the Snake River in 1975. Approximately 15% of the populations of both chinook salmon and steelhead were transported in 1975 and 1976, and over 65% in 1977. About 50% of the chinook salmon and 75% of the steelhead were hauled from the Snake River each year between 1978 and 1981. In 1979, transportation of smolts from the mid-Columbia and Snake rivers began at McNary Dam. About 10% of the spring chinook salmon and steelhead were hauled in 1979, 10% in 1980, and 25% in 1981. Large numbers of subyearling summer chinook salmon from the mid-Columbia River and fall chinook salmon from natural spawning and hatcheries below Priest Rapids Dam were also hauled each year. By 1982, it was apparent that transportation was providing greater benefits to steelhead and subyearling chinook salmon runs than to spring chinook salmon runs. Starting in 1982, fishery agencies reduced the numbers of spring chinook salmon being transported and opted to protect smolts of

TABLE 6.—Numbers of adult summer chinook salmon returning to the mid-Columbia River, and their percentages of the numbers of smolts passing the first dam they encountered on the mid-Columbia River, 1962–1984.

Year of smolt migration	Millions of smolts passing first dam[a]			Thousands of adults returning after 1–4 years at sea[b]	Percent return
	Hatchery[c]	Wild[d]	Total		
1962		1.0	1.0	27.5	2.7
1963		1.7	1.7	30.1	1.8
1964		1.5	1.5	30.3	2.0
1965		2.1	2.1	28.0	1.3
1966		1.5	1.5	21.5	1.4
1967		3.1	3.1	22.5	0.7
1968		2.2	2.2	26.1	1.1
1969	0.3	2.6	2.9	22.0	0.7
1970	0.3	1.7	2.0	16.9	0.8
1971	0.3	3.0	3.3	14.3	0.4
1972	0.4	2.5	2.9	21.0	0.7
1973	0.5	2.0	2.5	18.0	0.7
1974	0.2	1.8	2.0	19.6	1.0
1975	0.3	1.6	1.9	21.3	1.1
1976	0.3	1.8	2.1	23.6	1.1
1977	0.5	1.3	1.8	18.0	0.9
1978	1.3	1.8	3.1	14.0	0.4
1979	1.1	2.2	3.3	11.5	0.3
1980	1.1	1.7	2.8	9.2	0.3
1981	1.4	1.8	3.2	15.0	0.4
1982	0.7	1.3	2.0	17.0	0.8
1983	0.8	0.8	1.6	17.0	1.0
1984	0.2	1.6	1.8	13.0	0.7

[a] First dam—either Rock Island, Rocky Reach, or Wells, depending on tributary and hatchery.

[b] Count at Priest Rapids Dam plus the estimated number of mid-Columbia fish in zones 1–6 of the Columbia River fishery.

[c] Numbers of artificially reared fish released from Wells Hatchery × 50% survival to first dam.

[d] Redd count 1 year previously × 1,000.

TABLE 7.—Numbers of adult steelhead returning to the mid-Columbia River, and their percentages of the estimated numbers of smolts passing the first dam they encountered on the mid-Columbia River, 1962–1984.

Year of smolt migration	Thousands of smolts passing first dam[a]			Thousands of adults returning after 1–2 years at sea[b]	Percent return
	Hatchery[c]	Wild[d]	Total		
1962	130	120	250	10.9	4.4
1963	180	140	320	8.0	2.5
1964	330	140	470	18.0	3.8
1965	300	130	430	13.6	3.2
1966	250	110	360	11.7	3.2
1967	260	140	400	9.3	2.3
1968	280	200	480	6.6	1.4
1969	360	110	470	8.8	1.9
1970	400	150	550	14.1	2.6
1971	280	100	380	7.3	1.9
1972	380	90	470	8.0	1.7
1973	390	180	570	0.8	0.1
1974	350	90	440	4.0	0.9
1975	470	110	580	12.5	2.2
1976	470	50	520	11.7	2.2
1977	390	40	430	0.9	0.2
1978	470	150	620	10.1	1.6
1979	630	160	790	10.0	1.3
1980	540	70	610	9.1	1.5
1981	630	140	770	5.6	0.7
1982	700	140	840	54.1	6.4
1983	760	150	910	34.0	3.7
1984	680	110	790	45.0	5.7

[a] First dam—either Rock Island, Rocky Reach, or Wells, depending on tributary and hatchery.

[b] Count at Priest Rapids Dam plus the estimated catch of mid-Columbia fish in zones 1–6 of the Columbia River fishery.

[c] Numbers released from hatcheries × 90% survival to first dam.

[d] Numbers derived from sampling at Priest Rapids Dam in 1965–1967 and 16.7 × adult count at Priest Rapids Dam 2 years previously for other years.

this race by means of spillage and fingerling bypasses. The idea was to "spread the risk" and use both means of enhancing survival until it can be determined which is the best method.

Adult passage.—Losses of up to 15% per dam, fallback rates up to 35% over the spillway at Bonneville Dam, and substantial delays in passage at dams have resulted in high overall losses of adults migrating upstream through the dam complex to spawn (Junge and Carnegie 1976; Monan and Liscom 1985). In high-flow years, adult loss rates may have been similar to those for smolts. Since 1975, passages of adults past dams has been markedly enhanced by better-formed spills, better attraction facilities at ladder and powerhouse collection entrances, and reduced powerhouse generation next to ladder entrances. In addition, studies by Damkaer and Dey (1986) revealed that fluorides discharged from an aluminum plant were

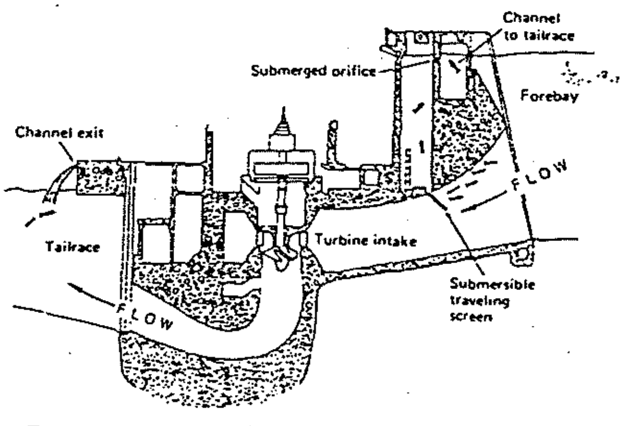

FIGURE 6.—Schematic diagram of the system to bypass juvenile migrants around turbines.

delaying passage of adults at John Day Dam. When fluoride concentrations were reduced, passage time significantly improved. Finally, the added power generation at dams reduced the spill levels and, in turn, the adult fallback problem and losses associated with dissolved gas supersaturation. As a result, present losses of adults are much lower than in earlier years.

Committee on Fishery Operations (COFO).— Augmented river flows and spill were provided, starting in 1975, to protect smolts migrating down the river each year. Minimum flow standards developed by the fishery agencies to minimize delay in passing through reservoirs were used as guidelines for providing flows when needed for fish migrations. The common goal of both the fishery agencies and water management agencies was to provide a balance between the flows and spill required for smolt migrations and the water required for electricity and irrigation. This was especially critical during the record drought of 1977, when spills at dams and releases of water from storage reservoirs were provided for fish. The levels, while not up to minimum standards, at least provided some protection for smolts yet had little effect on the water management agencies (Columbia River Water Management Group 1977). The COFO, consisting of representatives from fishery agencies, the Corps of Engineers, the Bonneville Power Administration, public utility districts, investor-owned utilities, and the U.S. Bureau of Reclamation, oversaw river operations until 1983, when the Water Budget Center was formed as part of the Northwest Power Planning Council's Fish and Wildlife Program. Between 1977 and 1982, mass transportation was the primary means for enhancing survival of Snake River runs; spill, bypass, and supplemental river flows were used to protect mid-Columbia River runs.

Responses to Protection and Enhancement

Spring Chinook Salmon

Spring chinook salmon (combined hatchery and wild fish) returned to the mid-Columbia and Snake rivers at generally similar rates from the smolt migrations of 1970–1984 (except from that of 1972, when slotted bulkheads were in place; Figure 3). Higher rates of return from smolt migrations in 1970 and 1975 to both reaches of river reflected years of more favorable downriver survival. Low rates of return from migrations in 1973 and 1977 were caused primarily by poor downstream survival during record low river flows. The low rates of return to both reaches of river that followed smolt emigrations every year since 1975 (except 1977) probably reflect low survival of hatchery fish shortly after entry into the ocean more than mortality at dams.

The health of smolts and their subsequent ocean survival may be more important (especially during favorable-flow years) to the viability of spring chinook salmon runs than their downriver survival through the dam complex. Survival of smolts from the Snake River to The Dalles Dam in 1970 and 1975, for example, was about 20%—considerably less than the 34% measured in 1974 (Raymond 1979) or the 30–40% measured between 1978 and 1982 (Sims et al. 1983). Yet, rates of return of adults (2–3%) from 1970 and 1975 emigrants were much higher than the 0.5% return from later emigrants with better downriver survival. The improved downriver survival of spring chinook salmon smolts but low return of adults implies that problems other than mortality at dams are affecting spring chinook salmon runs. As shown in Figure 3, the rates of return to the mid-Columbia and Snake rivers have been consistently poor—0.5% or less between 1975 and 1982—in spite of mass transportation, augmented river flows and spill, fingerling bypasses, and reduction of gas supersaturation.

When rates of return of wild and hatchery spring chinook salmon to each reach of river were distinguished (Figure 4; Tables 2, 5), it became obvious that the problem was with hatchery fish. Their rates of return from the 1976–1982 emigrations were 0.4% or less to both reaches of river, indicating little or no response to enhancement measures employed to improve downriver survival. In contrast, wild stocks have responded to enhancement, as indicated by their improved rate of return to both reaches of river each year since the 1977 emigration, except those from the 1980 smolt migration. The 1984 emigrants had about a 3% return to the Snake River, considerably higher than the 0.5% return from the 1977 emigration when downstream survival was poor. The similar increases in rate of return of wild stocks to each reach of river indicate that both the transportation and spill–bypass–supplemental flow methods provided similar protection of smolts between 1978 and 1984. The recent increases in rate of return of wild fish suggest that passage conditions in the river and conditions in the ocean were favorable for survival. Therefore, the consistently low rate of return of hatchery fish must have resulted because of their inability to survive in the ocean rather than because ocean conditions themselves were adverse.

The return of hatchery spring chinook salmon has not always been poor. Rates of return of hatchery fish from smolt migrations between 1966 and 1971 and in 1973 were only slightly below those of wild fish to the Snake River (Table 2). In contrast, returns of hatchery fish were only one-third to one-half the wild fish rates from smolt migrations in 1972, 1974, 1975, 1976, and 1977. Between 1978 and 1982, returns were a consistently dismal 0.1–0.3% compared to 0.5–2.0% for wild fish. Returns of fish released from Leavenworth Hatchery and other hatcheries on the mid-Columbia River also compared favorably with rates for wild fish through 1977; indeed, the return rate from the first release in 1972 was almost twice that of wild fish (Figure 4). For the emigrants of 1978–1982, though, the return of hatchery fish remained below 0.5%, while the rate of return of wild fish increased to 2.2% (Table 5).

Why the poor returns of hatchery fish when downriver survival from the Snake River has improved in recent years? I suspect the major problem is mortality of hatchery fish from bacterial kidney disease (BKD) either during migrations through the dam complex or, more likely, shortly after entry into the ocean. In recent years, BKD has been prevalent in hatcheries at least at subclinical levels (Congleton et al. 1985). Even though the disease may not have manifested itself in the hatchery, it can be activated by stresses encountered in downriver migration, transportation, and subsequent seawater transition. Once activated, it usually takes 1–3 months to kill fish (Bullock et al. 1975). Because travel time from Lower Granite Dam to John Day Dam during the last 10 years has averaged 11–14 d (Sims et al. 1983), there is not enough time during passage through the dam complex for mortalities from BKD to occur, and they would not show up in measures of downriver survival. However, below John Day or The Dalles dams or after entry in the ocean, once sufficient time has elapsed, substantial mortalities could occur. In contrast, if there is an outbreak of BKD in the hatcheries, depending on timing of the outbreak, mortalities can begin occurring during the migration through the dam complex. In 1981 there was a major outbreak of BKD at mid-Columbia River hatcheries (Gib Taylor, U.S. Fish and Wildlife Service, personal communication) in combination with low river flows. With the migration delayed by low runoff, many of these hatchery fish died between Priest Rapids and McNary dams. In 1982, a similar outbreak occurred but, with higher river flows, most of the mortality occurred between McNary and John Day dams (Columbia River Water Management Group 1982, 1983).

The results of recent studies strongly indicate that BKD severely limits the ocean survival of spring chinook salmon. Banner et al. (1983) found that spring chinook salmon smolts from three Oregon hatcheries suffered losses attributed to BKD ranging from 45 to 81% during 200 d that they were held in seawater. Similarly, Congelton et al. (1985) presented data indicating that spring chinook salmon smolts from several Idaho hatcheries suffered mortalities attributed to BKD ranging from 33 to 85% during 130 d in seawater. In both of these studies, test fish were exposed to stresses associated with capture and loading at the hatcheries and subsequent transfer to the seawater holding facilities. The National Marine Fisheries Service also conducted tests to determine the effects of stresses on the survival of Snake River spring chinook salmon held in seawater. Results indicated that survival was adversely affected by the stresses of passage through the collector system at Lower Granite Dam and of subsequent transportation. Most deaths did not occur until after 42 d and ranged between 60 and 75% after 146 d. Nearly all of the mortalities were associated with BKD (Matthews et al. 1985; Park et al. 1986).

If upriver spring chinook salmon runs are to survive, the quality of smolts being released from hatcheries needs to be improved and numbers of wild fish need to be increased. If this can be accomplished, the runs probably will rebuild, because high-quality hatchery fish should respond as positively as wild fish to protection measures employed at dams. There are hopeful signs. Numbers and rates of return of hatchery fish from 1983 and 1984 releases to both reaches of river increased dramatically from previous years. For the Snake River, fish numbers were 19,000 and 26,000, respectively, and rates of return averaged 0.65%. By comparison, returns averaged only 3,000 fish and 0.18% for releases between 1978 and 1982 (Table 2). For the mid-Columbia River, fish numbers were 18,000 in 1983 and 19,000 in 1984 and the rate of return also averaged 0.65%. By comparison, returns averaged only 5,000 fish and 0.25% from releases between 1976 and 1981 (Table 5). The increase to 17,000 and 21,000 wild fish returning to the Snake River from 1983 and 1984 smolt migrations is most encouraging. The 3% return from 1984 is even approaching predam return rates (Table 2). Rates of return of wild fish to the mid-

Columbia River were similar (Table 5), but there was no significant increase in numbers of wild fish based on index redd counts between 1985 and 1987. The reasons for the recent high returns are unknown but could include better quality hatchery fish migrating downriver in 1983 and 1984, more wild smolts in the Snake River population, stocking of fingerlings in unpopulated streams, reduced stress due to improvements of collection facilities at dams (particularly debris removal operations), spill in combination with transportation from dams, and better survival in the ocean.

Summer Chinook Salmon

Summer chinook salmon migrations from the Snake River, in contrast to those of spring chinook salmon, are mostly of wild origin. Both races migrate to sea as yearlings at the same time each spring. From the emigrations of 1969–1982, summer chinook salmon and wild spring chinook salmon had similar return rates (Figures 3, 4; Tables 2, 4). Declining return rates of summer chinook salmon from most emigrations between 1969 through 1977 reflected lower survival of smolts migrating to sea through the dam complex (Sims et al. 1978; Raymond 1979). The higher return of 3.4% from smolt migrations in 1975 and the lower one of 0.9% from 1976 probably reflect differences in survival after entry in the ocean, because downriver survival rates in those 2 years were generally similar (Sims and Ossiander 1981). The improvement in return rate, to about 1.5%, from smolt migrations in most years since 1977 is a positive sign that these fish runs are responding to enhancement programs during smolt migrations between 1978 and 1982.

Numbers of wild Snake River summer chinook salmon, both of smolts and of returning adults, declined during the 1970s. The 1.0 million smolts that emigrated in 1970 led to 32,000 returning adults, but only 200,000 smolts left in 1977 and only 1,000 of them came back as adults (Table 4). Numbers have increased some since then; 450,000 smolts emigrated in 1984, of which 8,400 returned as adults. McCall Hatchery, built to enhance numnbers of smolts, made its first releases in 1980; numbers produced, however, have ranged only between 100,000 and 250,000 each year through 1983—insufficient to offset the population lost to dams during this decade. The increase to 1.0 million smolts being released from McCall Hatchery starting in 1986 should result in increases in adult returns of summer chinook salmon by 1988.

Rates of return of summer chinook salmon to the mid-Columbia River from smolt migrations between 1969 and 1982 have remained a low 0.3–1.1% (Figure 2; Table 6). This is considerably lower than returns to the Snake River in every year except returns from the 1973 and 1977 smolt migrations that incurred a 95% or higher mortality during their migrations to sea. This consistently lower rate of return provides further evidence that fingerlings from the mid-Columbia River, which migrate to sea as subyearlings in July and August, usually incur substantially higher mortalities than yearlings from the Snake River, which migrate to sea in April and May. This higher mortality is probably the primary reason why this run has not improved despite enhancement measures. Returns declined from 26,000 fish from smolt migrations in 1968 to only 14,000 fish from migrations in 1971, even though 500,000 or more smolts have been released from Wells Hatchery each year since 1969 (Table 6). There was some increase in returns from smolt migrations between 1972 and 1977, averaging 20,000 fish and about a 1% rate of return. However, the run has since declined to an average of 13,000 adults and a 0.3% return rate. This 35% decline in numbers of adults is particularly alarming because it occurred in spite of a 35% increase in numbers of smolts starting seaward migrations each year beginning in 1978. It does not appear that the ocean fishery can be blamed for the decline in fish runs because there has been no major increase in overall fishing effort or in numbers of chinook salmon taken in that fishery since 1977 (Pacific Fisheries Management Council 1985). Therefore, the problem must be related to high downriver mortality that has negated much of the compensation from Wells Hatchery in most years, and even affected runs of wild fish. Redd counts, which remained consistently between 1,500 and 2,000 each year between 1973 and 1980, dropped to about 800 in 1982 and 700 in 1983. This indicated that wild fish runs returning from the 1979 and 1980 smolt migrations were about 50% less numerous. Redd counts were back up to 1,600 in 1984 and to over 2,000 by 1987, indicating better survival of wild fish migrating to sea since 1980.

Actions taken since 1975 to provide flows, spills, and transportation to enhance survival of smolts have generally concentrated on spring-migrating fish. Little or no spill has been provided in summer months through the mid-Columbia reach. Some spill for fish has been provided at John Day Dam in the summer but none specifically for fish at The Dalles or Bonneville dams. Since 1980, many subyearlings have been transported from McNary Dam in July and August. This has provided some protection for fish reaching that dam but does nothing to reduce mortalities of those migrating past mid-Columbia River dams. Supplemental flows to minimize delays in migration are probably not needed. Miller and Sims (1984) found no correlation between amount of river flow and travel time of subyearlings migrating in July and August, and concluded this was because the parr were not ready to migrate. Migration occurs when the subyearlings grow to smolt size; until then, they stay in the reservoir regardless of the amount of river flow.

In summary, summer chinook salmon runs in the Snake River appear to be responding to smolt protection activities, but the run size has not improved because insufficient numbers of smolts are being produced. In contrast, the rate of return of mid-Columbia runs has remained less than 0.4% mostly because of inadequate protection of smolts at dams and poor survival of hatchery releases. Better enhancement is required to offset smolt mortalities if we wish to improve mid-Columbia runs. Enhancement should include (1) spills, fingerling bypasses, or some form of transportation of smolts at mid-Columbia River dams, (2) increased transportation of smolts from McNary Dam and spills or fingerling bypasses at The Dalles and Bonneville dams, and (3) greater contributions from hatcheries, which possibly should alter the size of fish released or the time of release to conform more closely to the timing of yearling migrations. Data presently indicate only minimum benefit from the large numbers of smolts currently being released. Improved quality of smolts being reared and a different time of, or size at, release may improve survival.

Steelhead

The rates of return of steelhead to both the mid-Columbia and Snake rivers from smolt migrations between 1969 and 1984 dramatically portray the effects on these runs both of dams and of enhancement measures since 1974 (Figure 3; Tables 3, 7). The similar declines in return rate to both reaches of river from smolt migrations between 1970 and 1974 and in 1977 reflect low survival of smolts because of poor passage conditions during their seaward migrations in these years. The improved rates of return to both reaches of river since 1974 (except 1977) reflects the improved survival of steelhead smolts passing through the dams and reservoirs brought on by enhancement actions taken since 1975 to reduce mortality of smolts.

The response to mass transportation of smolts from the Snake River has been excellent. Since 1977, between 64 and 79% of the steelhead from the Snake River each year have been transported by truck or barge around the dams to release sites below Bonneville Dam. Data indicate that most returns to the Snake River, especially in low-flow years, were from transported fish (Park 1985). Sims et al. (1983) found that survival of nontransported fish between 1977 and 1980 was low, especially in 1977, and Park (1985) showed positive enhancement of steelhead due to transportation. During this period, few mid-Columbia steelhead were transported from McNary Dam; the remainder probably were subjected to passage conditions like those encountered by nontransported Snake River fish and, consequently, had a lower rate of return than transported fish. The difference in rates of return from 1977 smolt migrations best portrays the benefits of transportation. Rate of return of fish from the Snake River, most of which were transported, was about 1%—over three times the rate for nontransported fish from the mid-Columbia River (Figure 3). During higher-flow years, such as 1978–1981, benefits of transportation were not as great because nontransported fish survived better. Even so, average return rates were 2.1% to the Snake River and 1.3% to the mid-Columbia River.

Returns to both reaches of the river in 1981 declined. I believe this resulted from decreased survival in the ocean. Returns to streams without dams around Puget Sound, Washington, and the lower Columbia River also showed significant declines in returns from the 1981 out-migrations (Gary Fenton, Washington Department of Game, personal communication).

Returns from the 1982 smolt migrations were about 5% to the Snake River and 6% to the mid-Columbia River, figures closely approximating 1962–1966 return rates (Figure 3; Tables 3, 7). The high returns were probably due to a combination of 48% downriver survival of nontransported smolts, the highest since 1968 (Sims et al. 1983), and apparently excellent survival after entry into seawater, as evidenced by much higher returns from 1982 than 1981 smolt migrations in Puget Sound streams. Survival was good because there were high river flows and spills, and measures were in place to control nitrogen supersaturation. Survival in the mid-Columbia River, although not measured, was probably similarly enhanced because spill levels and river flows were much higher than in the previous 4 years (5,380 m^3/s average river flow and 3,420 m^3/s average spill in May 1982, compared to the 1978–1982 May average of 3,960 m^3/s flow and only 510 m^3/s spill).

The hatchery program is another reason for the success of steelhead. Prior to 1975, rates of return of hatchery fish to the Snake River were much lower than those of wild fish (Figure 4). Returns from the early years of smolt releases from Dworshak and Niagara Springs hatcheries were disappointing. Since then, rates of return of hatchery steelhead to the Snake River have been nearly as high as returns of wild fish and, in 1982, exceeded those of wild fish (Figure 4). Similar successes are now being realized with releases of smolts in the Methow and Wenatchee rivers from Wells and Chelan hatcheries.

Because of large increases in numbers released from hatcheries and better survival of all steelhead since 1977, runs from the Snake River increased from record low returns of 12,000 fish from the 1973 and 1977 smolt migrations to record high returns of 207,000 fish from the 1982 migration (Table 3). Runs to the mid-Columbia River increased from less than 1,000 fish from the 1973 and 1977 emigrations to a record 54,000 from the 1982 smolt migration (Table 7). Returns to both rivers from the 1983 and 1984 smolt migrations were also near record-high levels. The turnabout reflects a positive response of steelhead to both supplementation from hatcheries and enhancement of survival through the dam complex.

Summary

Hydroelectric development changed the Columbia and Snake rivers from mostly free-flowing rivers in 1938 to a series of dams and impoundments by 1975. Storage reservoirs built in Canada to regulate the river for flood control and for more efficient power production reduced river flows in most years by about 50% during much of the migration of chinook salmon and steelhead smolts in April and May. These developments and added turbines at dams have substantially increased mortality of smolts because of added delays in passage through impoundments and because more smolts pass through turbines rather than over spillways. Dams also caused delays and losses of adults, particularly during high river flows and spill. Actions taken to offset dam-related mortalities have enhanced some but not all runs of fish. Data obtained from rates of return of spring and summer chinook salmon and steelhead to the Snake and mid-Columbia rivers demonstrated how hydroelectric development and activities to offset smolt mortalities have affected runs of salmon and steelhead from these rivers. Major findings were as follows.

(1) Dams built between 1938 and 1955 probably affected fish runs but overharvest, especially of summer chinook salmon, was more detrimental. Once escapement was allowed to increase and enhancement activities began, runs began to rebound. By 1955, most fish runs were as large as or larger than they were in 1938.

(2) The rate of return of mid-Columbia fish runs declined from 2–5% in 1964 to 0.8–2% (depending on species) by 1968. In contrast, the rate of return of Snake River fish remained a consistent 4–5% during this period. Mid-Columbia River smolts suffered greater mortalities because they had to pass 2–4 more dams than did Snake River fish.

(3) The rate of return of summer chinook salmon from the mid-Columbia River was lower than for other fish runs between 1962 and 1968. I suggest the reason was greater mortality of smolts migrating to sea as subyearlings in July and August, when river flows and dam spills were lower and water temperatures were higher, than was suffered by other smolt races emigrating as yearlings in April and May.

(4) Smolt mortalities from new dams built on the Snake River after 1968, plus the already completed dams on the lower Columbia River, caused the rate of return of Snake River salmon and steelhead to drop from about 4% through the 1968 smolt emigration to less than 1.5% between the 1970 and 1974 emigrations.

(5) The 95% or greater mortality of smolts during low river flows in 1973 and 1977 equates to a mortality of 45% at each project (dam plus reservoir) as compared to 15% mortality per project during the higher runoff and spill in 1978. The 30% additional mortality per project was caused by increased passage through turbines and added delays in passage through reservoirs.

(6) Enhancement measures designed to offset dam-related smolt mortalities began in 1975. These measures included spillway deflectors to reduce dissolved gas supersaturation, fingerling bypasses at dams, transportation of smolts around dams, supplemental river flows to minimize delay in passing through reservoirs, and supplemental spills at dams to minimize turbine mortality at dams without fingerling bypasses.

(7) Adult losses and delays have been significantly reduced in recent years by providing better attraction at ladder entrances, reducing or shaping

spill at dams to minimize fallback, and adding spillway deflectors to reduce dissolved gas supersaturation.

(8) Enhancement practices improved downriver survival of spring chinook salmon smolts, but the rate of return of adults has remained 0.7% or less since the 1977 smolt emigration because of the low survival of hatchery fish in the ocean.

(9) The rate of return of hatchery spring chinook salmon has not always been poor. Through the 1973 class of emigrants, their rates of return were similar to those of wild fish. Hatchery fish return rates dropped to 50% of wild fish rates through 1977 and to 10–25% since then. I suspect the major problem in recent years has been mortality of smolts shortly after entry into the ocean. The activation of bacterial kidney disease by stresses encountered during downriver migrations, transportation, or transition into seawater is the most likely cause.

(10) Wild spring chinook salmon from mid-Columbia and Snake rivers have responded to enhancement activities, as indicated by an increase in rate of return from 0.2 to 3% between the 1977 and 1984 emigrations. The similar increases for both rivers suggest little difference between the transportation and spill–supplemental flow methods for enhancement of smolt survival. The latter increases in return rate also suggest that conditions in the ocean were favorable for survival in those years.

(11) Most summer chinook salmon from the Snake River are wild, and return rates are generally similar to those of wild spring chinook salmon.

(12) Rates of return of summer chinook salmon from the mid-Columbia River have remained a low 0.3–1.1% since the 1969 smolt emigration, considerably lower than returns of summer chinook salmon to the Snake River, especially in recent years. This lower rate reflects inadequate protection at mid-Columbia River dams (no spill in summer when the fish migrate to sea) and poor survival of hatchery fish.

(13) The rates of return of steelhead to both the mid-Columbia and Snake rivers from smolt migrations between 1969 and 1984 dramatically portrayed the effect of dams on these runs and positive responses to enhancement measures since 1974.

(14) The response of steelhead to mass transportation of smolts from the Snake River since 1977 has been significant. Between the 1977 and 1981 emigrations, the rates of return to the Snake River, from which most of the fish were transported, were about double those of nontransported mid-Columbia smolts. The benefits have been highest in low-runoff years.

(15) Because of enhancement, runs of steelhead from the Snake River went from a record-low return of 12,000 fish from the 1977 smolt migration to a record-high return of 207,000 fish from the 1982 migrations. For those same years, runs from the mid-Columbia River increased from less than 1,000 fish to over 54,000 fish.

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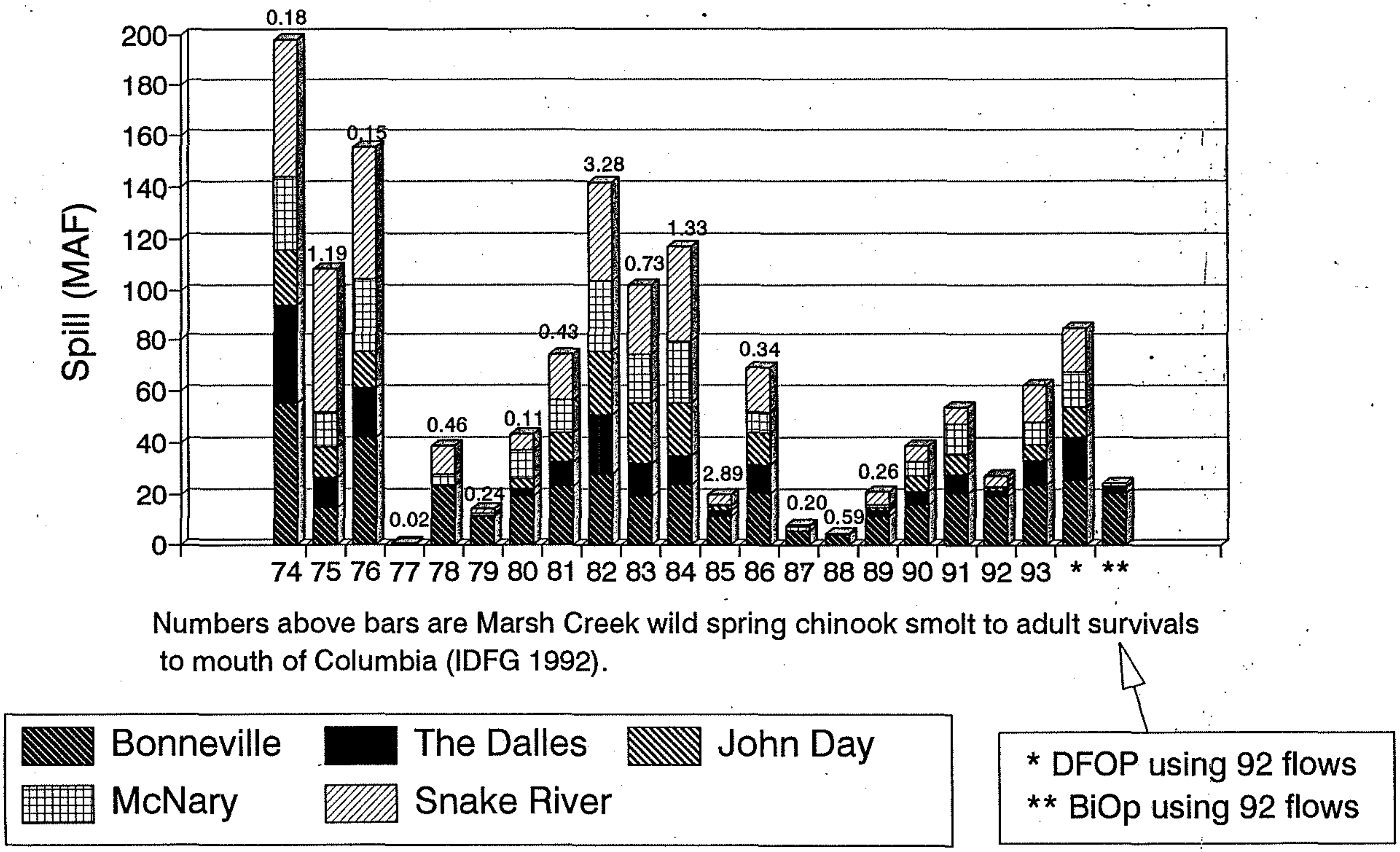
Total Spill in Snake and Lower Columbia

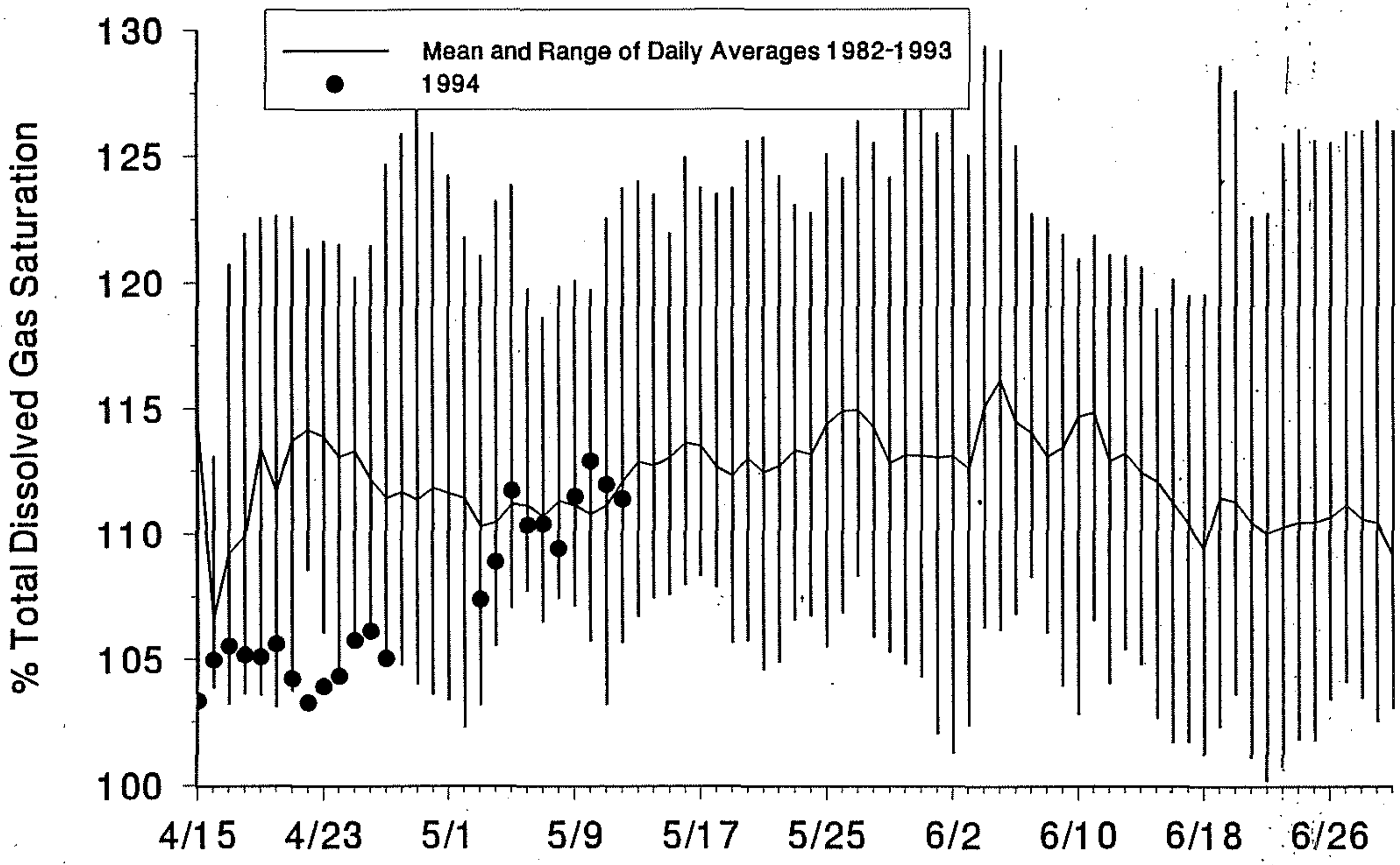
April 1 through August 31



Numbers above bars are Marsh Creek wild spring chinook smolt to adult survivals to mouth of Columbia (IDFG 1992).

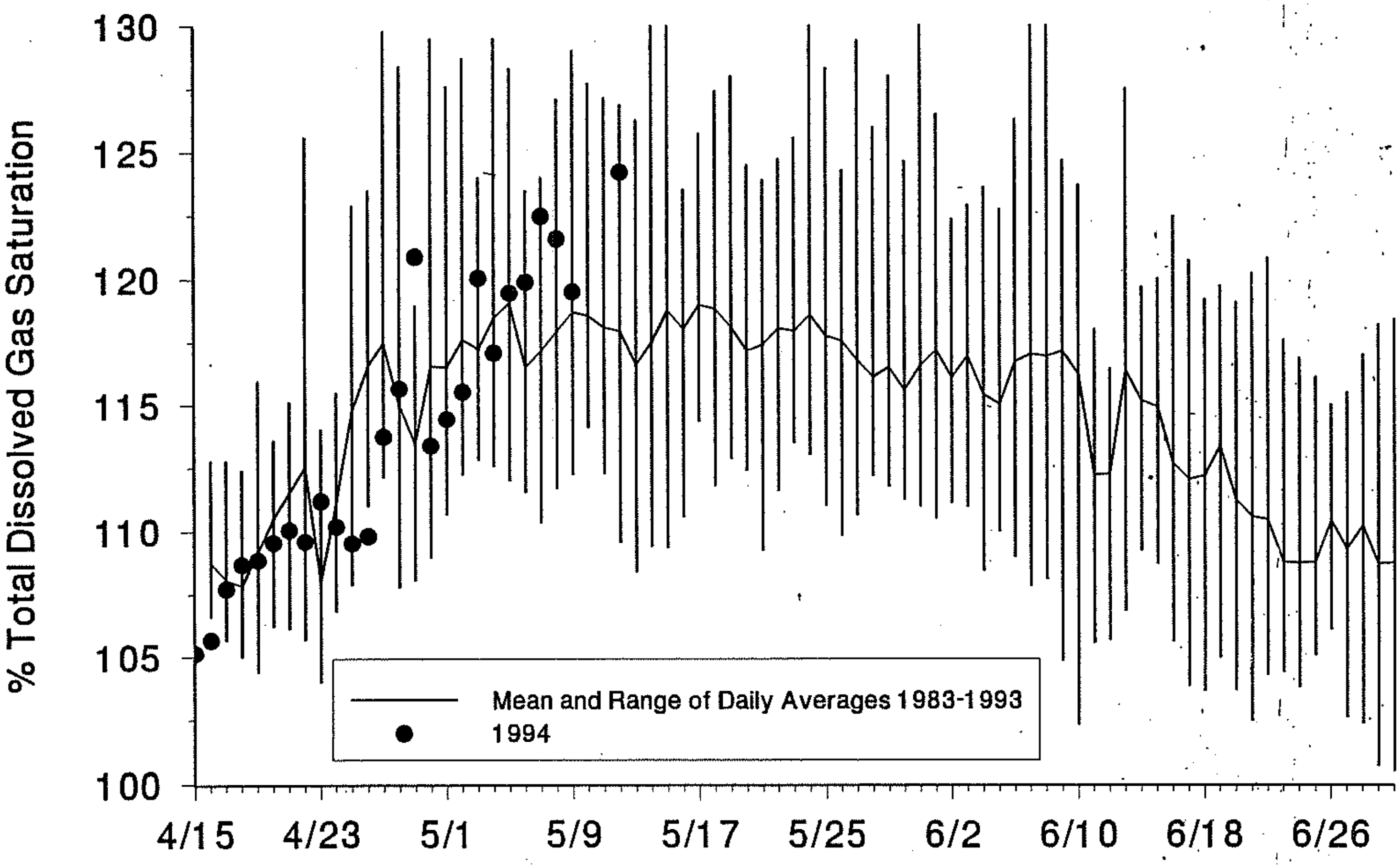
* DFOP using 92 flows
** BiOp using 92 flows

Ice Harbor Dam Forebay



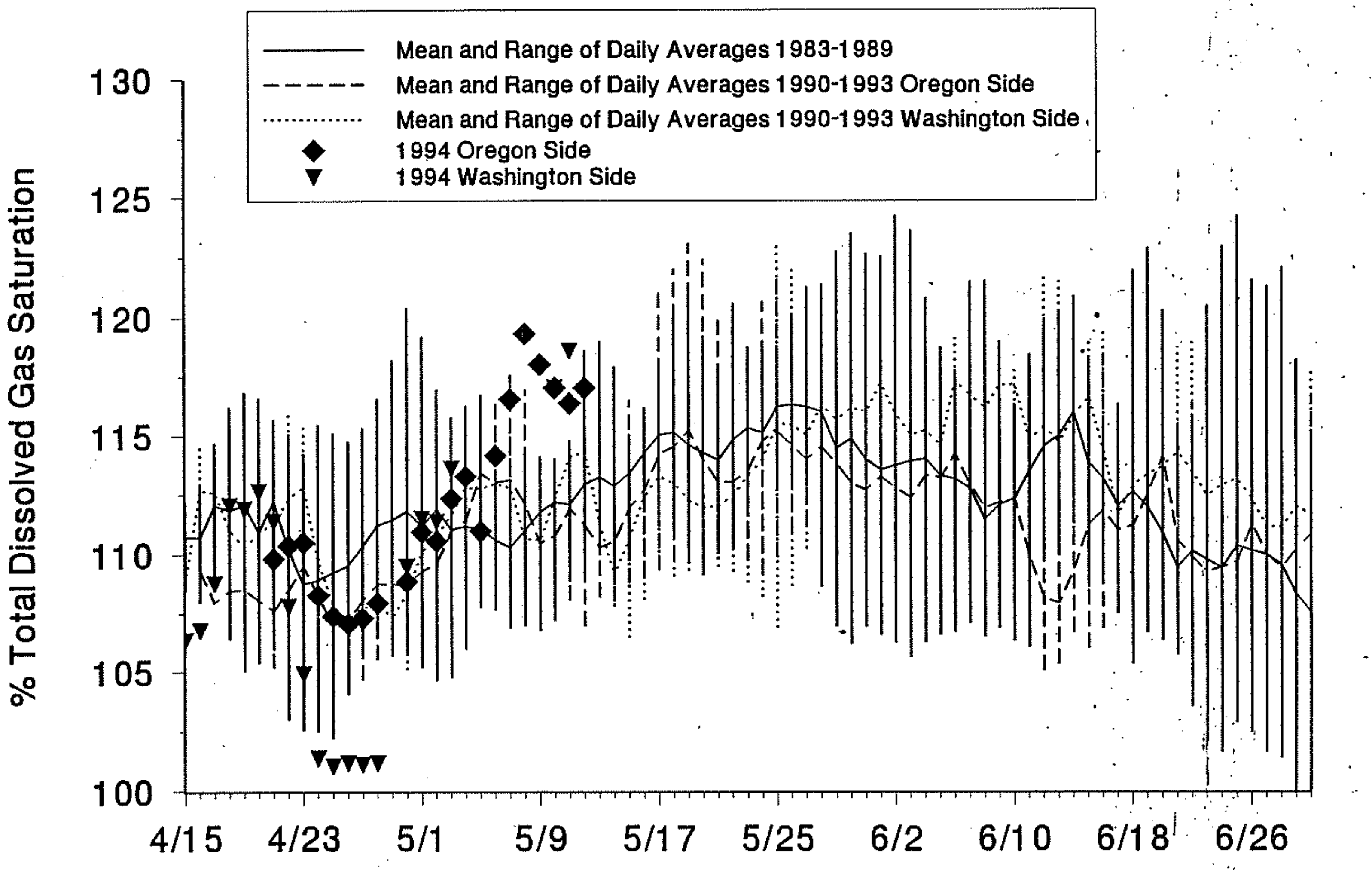
TPC

Priest Rapids Dam Forebay

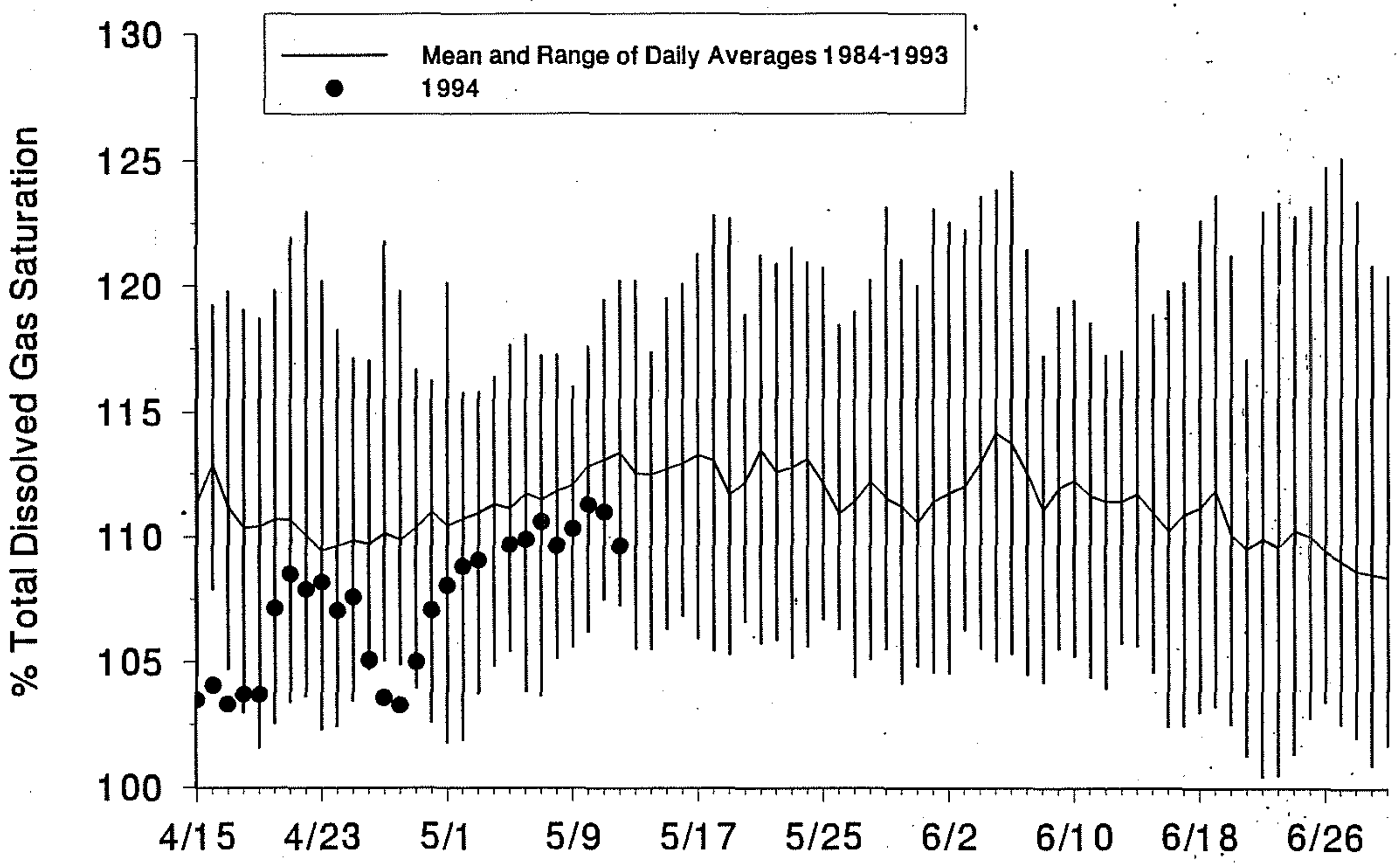


FPC

McNary Dam Forebay



Warrendale


Mean and Range of Daily Averages 1984-1993
● 1994
% Total Dissolved Gas Saturation
130
125
120
115
110
105
100
4/15
4/23
5/1
5/9
5/17
5/25
6/2
6/10
6/18
6/26

1994 SNAKE RIVER SMP GAS BUBBLE SYMPTOMS

		LGR			LGS			LMN		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	HCH1	0	95	0.0%	0	100	0.0%	0	94	0.0%
	WCH1	0	5	0.0%	0	17	0.0%	0	38	0.0%
	CHO	---	0	---	---	0	---	0	1	0.0%
	HST	0	100	0.0%	0	100	0.0%	0	100	0.0%
	WST	0	100	0.0%	0	14	0.0%	0	11	0.0%
	WSO	0	9	0.0%	0	6	0.0%	0	1	0.0%
05/12	HCH1	0	96	0.0%	0	113	0.0%	0	100	0.0%
	WCH1	0	3	0.0%	0	34	0.0%	0	60	0.0%
	CHO	---	0	---	---	0	---	---	0	0.0%
	HST	0	100	0.0%	0	101	0.0%	0	100	0.0%
	WST	0	76	0.0%	0	16	0.0%	0	50	0.0%
	WSO	0	21	0.0%	0	3	0.0%	0	13	0.0%
05/13	HCH1	0	76	0.0%	0	100	0.0%		60	0.0%
	WCH1	---	0	---	0	69	0.0%		53	0.0%
	CHO	---	0	---	---	0	---		3	0.0%
	HST	0	100	0.0%	0	100	0.0%		77	0.0%
	WST	0	80	0.0%	0	100	0.0%		51	0.0%
	WSO	0	19	0.0%	0	27	0.0%		14	0.0%
05/14	HCH1	0	28	0.0%	0	100	0.0%	4	5822	0.1%
	WCH1	0	1	0.0%	0	18	0.0%	0	590	0.0%
	CHO	---	0	---	---	0	---	0	6	0.0%
	HST	0	80	0.0%	0	100	0.0%	0	1832	0.0%
	WST	0	58	0.0%	0	12	0.0%	0	361	0.0%
	WSO	0	13	0.0%	0	2	0.0%	0	30	0.0%
05/15	HCH1	0	99	0.0%			---	39	3664	1.1%
	WCH1	0	1	0.0%			---	0	261	0.0%
	CHO	---	0	---			---	0	6	0.0%
	HST	0	100	0.0%			---	2	1247	0.2%
	WST	0	81	0.0%			---	1	358	0.3%
	WSO	0	13	0.0%			---	1	14	7.1%

1994 SNAKE RIVER SMP GAS BUBBLE SYMPTOMS

		LGR			LGS			LMN		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	HCH1	0	95	0.0%	0	100	0.0%	0	94	0.0%
	WCH1	0	5	0.0%	0	17	0.0%	0	38	0.0%
	CHO	---	0	---	---	0	---	0	1	0.0%
	HST	0	100	0.0%	0	100	0.0%	0	100	0.0%
	WST	0	100	0.0%	0	14	0.0%	0	11	0.0%
	WSO	0	9	0.0%	0	6	0.0%	0	1	0.0%
05/12	HCH1	0	96	0.0%	0	113	0.0%	0	100	0.0%
	WCH1	0	3	0.0%	0	34	0.0%	0	60	0.0%
	CHO	---	0	---	---	0	---	---	0	0.0%
	HST	0	100	0.0%	0	101	0.0%	0	100	0.0%
	WST	0	76	0.0%	0	16	0.0%	0	50	0.0%
	WSO	0	21	0.0%	0	3	0.0%	0	13	0.0%
05/13	HCH1	0	76	0.0%	0	100	0.0%		60	0.0%
	WCH1	---	0	---	0	69	0.0%		53	0.0%
	CHO	---	0	---	---	0	---		3	0.0%
	HST	0	100	0.0%	0	100	0.0%		77	0.0%
	WST	0	80	0.0%	0	100	0.0%		51	0.0%
	WSO	0	19	0.0%	0	27	0.0%		14	0.0%
05/14	HCH1	0	28	0.0%	0	100	0.0%	4	5822	0.1%
	WCH1	0	1	0.0%	0	18	0.0%	0	590	0.0%
	CHO	---	0	---	---	0	---	0	6	0.0%
	HST	0	80	0.0%	0	100	0.0%	0	1832	0.0%
	WST	0	58	0.0%	0	12	0.0%	0	361	0.0%
	WSO	0	13	0.0%	0	2	0.0%	0	30	0.0%
05/15	HCH1	0	99	0.0%			---	39	3664	1.1%
	WCH1	0	1	0.0%			---	0	261	0.0%
	CHO	---	0	---			---	0	6	0.0%
	HST	0	100	0.0%			---	2	1247	0.2%
	WST	0	81	0.0%			---	1	358	0.3%
	WSO	0	13	0.0%			---	1	14	7.1%

1994 SNAKE RIVER SMP GAS BUBBLE SYMPTOMS

		LGR			LGS			LMN		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	HCH1	0	95	0.0%	0	100	0.0%	0	94	0.0%
	WCH1	0	5	0.0%	0	17	0.0%	0	38	0.0%
	CHO	---	0	---	---	0	---	0	1	0.0%
	HST	0	100	0.0%	0	100	0.0%	0	100	0.0%
	WST	0	100	0.0%	0	14	0.0%	0	11	0.0%
	WSO	0	9	0.0%	0	6	0.0%	0	1	0.0%
05/12	HCH1	0	96	0.0%	0	113	0.0%	0	100	0.0%
	WCH1	0	3	0.0%	0	34	0.0%	0	60	0.0%
	CHO	---	0	---	---	0	---	---	0	0.0%
	HST	0	100	0.0%	0	101	0.0%	0	100	0.0%
	WST	0	76	0.0%	0	16	0.0%	0	50	0.0%
	WSO	0	21	0.0%	0	3	0.0%	0	13	0.0%
05/13	HCH1	0	76	0.0%	0	100	0.0%		60	0.0%
	WCH1	---	0	---	0	69	0.0%		53	0.0%
	CHO	---	0	---	---	0	---		3	0.0%
	HST	0	100	0.0%	0	100	0.0%		77	0.0%
	WST	0	80	0.0%	0	100	0.0%		51	0.0%
	WSO	0	19	0.0%	0	27	0.0%		14	0.0%
05/14	HCH1	0	28	0.0%	0	100	0.0%	4	5822	0.1%
	WCH1	0	1	0.0%	0	18	0.0%	0	590	0.0%
	CHO	---	0	---	---	0	---	0	6	0.0%
	HST	0	80	0.0%	0	100	0.0%	0	1832	0.0%
	WST	0	58	0.0%	0	12	0.0%	0	361	0.0%
	WSO	0	13	0.0%	0	2	0.0%	0	30	0.0%
05/15	HCH1	0	99	0.0%			---	39	3664	1.1%
	WCH1	0	1	0.0%			---	0	261	0.0%
	CHO	---	0	---			---	0	6	0.0%
	HST	0	100	0.0%			---	2	1247	0.2%
	WST	0	81	0.0%			---	1	358	0.3%
	WSO	0	13	0.0%			---	1	14	7.1%

1994 SNAKE RIVER SMP GAS BUBBLE SYMPTOMS

		LGR			LGS			LMN		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	HCH1	0	95	0.0%	0	100	0.0%	0	94	0.0%
	WCH1	0	5	0.0%	0	17	0.0%	0	38	0.0%
	CHO	---	0	---	---	0	---	0	1	0.0%
	HST	0	100	0.0%	0	100	0.0%	0	100	0.0%
	WST	0	100	0.0%	0	14	0.0%	0	11	0.0%
	WSO	0	9	0.0%	0	6	0.0%	0	1	0.0%
05/12	HCH1	0	96	0.0%	0	113	0.0%	0	100	0.0%
	WCH1	0	3	0.0%	0	34	0.0%	0	60	0.0%
	CHO	---	0	---	---	0	---	---	0	0.0%
	HST	0	100	0.0%	0	101	0.0%	0	100	0.0%
	WST	0	76	0.0%	0	16	0.0%	0	50	0.0%
	WSO	0	21	0.0%	0	3	0.0%	0	13	0.0%
05/13	HCH1	0	76	0.0%	0	100	0.0%		60	0.0%
	WCH1	---	0	---	0	69	0.0%		53	0.0%
	CHO	---	0	---	---	0	---		3	0.0%
	HST	0	100	0.0%	0	100	0.0%		77	0.0%
	WST	0	80	0.0%	0	100	0.0%		51	0.0%
	WSO	0	19	0.0%	0	27	0.0%		14	0.0%
05/14	HCH1	0	28	0.0%	0	100	0.0%	4	5822	0.1%
	WCH1	0	1	0.0%	0	18	0.0%	0	590	0.0%
	CHO	---	0	---	---	0	---	0	6	0.0%
	HST	0	80	0.0%	0	100	0.0%	0	1832	0.0%
	WST	0	58	0.0%	0	12	0.0%	0	361	0.0%
	WSO	0	13	0.0%	0	2	0.0%	0	30	0.0%
05/15	HCH1	0	99	0.0%			---	39	3664	1.1%
	WCH1	0	1	0.0%			---	0	261	0.0%
	CHO	---	0	---			---	0	6	0.0%
	HST	0	100	0.0%			---	2	1247	0.2%
	WST	0	81	0.0%			---	1	358	0.3%
	WSO	0	13	0.0%			---	1	14	7.1%

1994 SNAKE RIVER SMP GAS BUBBLE SYMPTOMS

		LGR			LGS			LMN		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	HCH1	0	95	0.0%	0	100	0.0%	0	94	0.0%
	WCH1	0	5	0.0%	0	17	0.0%	0	38	0.0%
	CHO	---	0	---	---	0	---	0	1	0.0%
	HST	0	100	0.0%	0	100	0.0%	0	100	0.0%
	WST	0	100	0.0%	0	14	0.0%	0	11	0.0%
	WSO	0	9	0.0%	0	6	0.0%	0	1	0.0%
05/12	HCH1	0	96	0.0%	0	113	0.0%	0	100	0.0%
	WCH1	0	3	0.0%	0	34	0.0%	0	60	0.0%
	CHO	---	0	---	---	0	---	---	0	0.0%
	HST	0	100	0.0%	0	101	0.0%	0	100	0.0%
	WST	0	76	0.0%	0	16	0.0%	0	50	0.0%
	WSO	0	21	0.0%	0	3	0.0%	0	13	0.0%
05/13	HCH1	0	76	0.0%	0	100	0.0%		60	0.0%
	WCH1	---	0	---	0	69	0.0%		53	0.0%
	CHO	---	0	---	---	0	---		3	0.0%
	HST	0	100	0.0%	0	100	0.0%		77	0.0%
	WST	0	80	0.0%	0	100	0.0%		51	0.0%
	WSO	0	19	0.0%	0	27	0.0%		14	0.0%
05/14	HCH1	0	28	0.0%	0	100	0.0%	4	5822	0.1%
	WCH1	0	1	0.0%	0	18	0.0%	0	590	0.0%
	CHO	---	0	---	---	0	---	0	6	0.0%
	HST	0	80	0.0%	0	100	0.0%	0	1832	0.0%
	WST	0	58	0.0%	0	12	0.0%	0	361	0.0%
	WSO	0	13	0.0%	0	2	0.0%	0	30	0.0%
05/15	HCH1	0	99	0.0%			---	39	3664	1.1%
	WCH1	0	1	0.0%			---	0	261	0.0%
	CHO	---	0	---			---	0	6	0.0%
	HST	0	100	0.0%			---	2	1247	0.2%
	WST	0	81	0.0%			---	1	358	0.3%
	WSO	0	13	0.0%			---	1	14	7.1%

1994 LOWER COLUMBIA SMP GAS BUBBLE SYMPTOMS

		MCN			JDA			BON		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	CH1	0	1246	0.0%	0	113	0.0%	0	101	0.0%
	CHO	0	5	0.0%	---	0	---	0	103	0.0%
	HST	0	346	0.0%	0	139	0.0%	0	103	0.0%
	WST	0	68	0.0%	0	103	0.0%	0	100	0.0%
	CO	0	958	0.0%	0	118	0.0%	0	102	0.0%
	HSO	0	17	0.0%	0	22	0.0%	0	60	0.0%
	WSO	0	286	0.0%	0	132	0.0%	---	0	---
05/12	CH1	0	1336	0.0%	0	775	0.0%	0	100	0.0%
	CHO	0	15	0.0%	0	1	0.0%	0	100	0.0%
	HST	0	261	0.0%	0	347	0.0%	0	113	0.0%
	WST	0	57	0.0%	0	185	0.0%	0	107	0.0%
	CO	0	886	0.0%	0	341	0.0%	0	100	0.0%
	HSO	0	5	0.0%	0	6	0.0%	0	100	0.0%
	WSO	0	182	0.0%	0	147	0.0%	---	0	---
05/13	CH1	0	1033	0.0%	0	121	0.0%	0	104	0.0%
	CHO	---	0	---	---	0	---	0	104	0.0%
	HST	0	204	0.0%	0	110	0.0%	0	100	0.0%
	WST	0	50	0.0%	0	105	0.0%	1	108	100.0%
	CO	0	657	0.0%	0	104	0.0%	0	100	0.0%
	HSO	---	0	---	0	11	0.0%	0	13	0.0%
	WSO	0	121	0.0%	0	114	0.0%	0	105	0.0%
05/14	CH1	0	899	0.0%	0	222	0.0%	0	163	0.0%
	CHO	---	0	---	---	0	---	0	134	0.0%
	HST	0	146	0.0%	0	120	0.0%	0	113	0.0%
	WST	0	48	0.0%	0	97	0.0%	0	106	0.0%
	CO	0	396	0.0%	0	146	0.0%	0	353	0.0%
	HSO	---	0	---	0	5	0.0%	0	5	0.0%
	WSO	0	94	0.0%	0	105	0.0%	0	147	0.0%
05/15	CH1	0	1188	0.0%	0	103	0.0%	0	175	0.0%
	CHO	0	16	0.0%	0	1	0.0%	0	122	0.0%
	HST	0	170	0.0%	0	109	0.0%	0	98	0.0%
	WST	0	44	0.0%	0	100	0.0%	1	94	1.1%
	CO	0	323	0.0%	0	134	0.0%	0	426	0.0%
	HSO	0	3	0.0%	0	15	0.0%	0	12	0.0%
	WSO	0	62	0.0%	0	127	0.0%	0	142	0.0%

1994 LOWER COLUMBIA SMP GAS BUBBLE SYMPTOMS

		MCN			JDA			BON		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	CH1	0	1246	0.0%	0	113	0.0%	0	101	0.0%
	CHO	0	5	0.0%	---	0	---	0	103	0.0%
	HST	0	346	0.0%	0	139	0.0%	0	103	0.0%
	WST	0	68	0.0%	0	103	0.0%	0	100	0.0%
	CO	0	958	0.0%	0	118	0.0%	0	102	0.0%
	HSO	0	17	0.0%	0	22	0.0%	0	60	0.0%
	WSO	0	286	0.0%	0	132	0.0%	---	0	---
05/12	CH1	0	1336	0.0%	0	775	0.0%	0	100	0.0%
	CHO	0	15	0.0%	0	1	0.0%	0	100	0.0%
	HST	0	261	0.0%	0	347	0.0%	0	113	0.0%
	WST	0	57	0.0%	0	185	0.0%	0	107	0.0%
	CO	0	886	0.0%	0	341	0.0%	0	100	0.0%
	HSO	0	5	0.0%	0	6	0.0%	0	100	0.0%
	WSO	0	182	0.0%	0	147	0.0%	---	0	---
05/13	CH1	0	1033	0.0%	0	121	0.0%	0	104	0.0%
	CHO	---	0	---	---	0	---	0	104	0.0%
	HST	0	204	0.0%	0	110	0.0%	0	100	0.0%
	WST	0	50	0.0%	0	105	0.0%	1	108	100.0%
	CO	0	657	0.0%	0	104	0.0%	0	100	0.0%
	HSO	---	0	---	0	11	0.0%	0	13	0.0%
	WSO	0	121	0.0%	0	114	0.0%	0	105	0.0%
05/14	CH1	0	899	0.0%	0	222	0.0%	0	163	0.0%
	CHO	---	0	---	---	0	---	0	134	0.0%
	HST	0	146	0.0%	0	120	0.0%	0	113	0.0%
	WST	0	48	0.0%	0	97	0.0%	0	106	0.0%
	CO	0	396	0.0%	0	146	0.0%	0	353	0.0%
	HSO	---	0	---	0	5	0.0%	0	5	0.0%
	WSO	0	94	0.0%	0	105	0.0%	0	147	0.0%
05/15	CH1	0	1188	0.0%	0	103	0.0%	0	175	0.0%
	CHO	0	16	0.0%	0	1	0.0%	0	122	0.0%
	HST	0	170	0.0%	0	109	0.0%	0	98	0.0%
	WST	0	44	0.0%	0	100	0.0%	1	94	1.1%
	CO	0	323	0.0%	0	134	0.0%	0	426	0.0%
	HSO	0	3	0.0%	0	15	0.0%	0	12	0.0%
	WSO	0	62	0.0%	0	127	0.0%	0	142	0.0%

1994 LOWER COLUMBIA SMP GAS BUBBLE SYMPTOMS

		MCN			JDA			BON		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	CH1	0	1246	0.0%	0	113	0.0%	0	101	0.0%
	CHO	0	5	0.0%	---	0	---	0	103	0.0%
	HST	0	346	0.0%	0	139	0.0%	0	103	0.0%
	WST	0	68	0.0%	0	103	0.0%	0	100	0.0%
	CO	0	958	0.0%	0	118	0.0%	0	102	0.0%
	HSO	0	17	0.0%	0	22	0.0%	0	60	0.0%
	WSO	0	286	0.0%	0	132	0.0%	---	0	---
05/12	CH1	0	1336	0.0%	0	775	0.0%	0	100	0.0%
	CHO	0	15	0.0%	0	1	0.0%	0	100	0.0%
	HST	0	261	0.0%	0	347	0.0%	0	113	0.0%
	WST	0	57	0.0%	0	185	0.0%	0	107	0.0%
	CO	0	886	0.0%	0	341	0.0%	0	100	0.0%
	HSO	0	5	0.0%	0	6	0.0%	0	100	0.0%
	WSO	0	182	0.0%	0	147	0.0%	---	0	---
05/13	CH1	0	1033	0.0%	0	121	0.0%	0	104	0.0%
	CHO	---	0	---	---	0	---	0	104	0.0%
	HST	0	204	0.0%	0	110	0.0%	0	100	0.0%
	WST	0	50	0.0%	0	105	0.0%	1	108	100.0%
	CO	0	657	0.0%	0	104	0.0%	0	100	0.0%
	HSO	---	0	---	0	11	0.0%	0	13	0.0%
	WSO	0	121	0.0%	0	114	0.0%	0	105	0.0%
05/14	CH1	0	899	0.0%	0	222	0.0%	0	163	0.0%
	CHO	---	0	---	---	0	---	0	134	0.0%
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	HSO	---	0	---	0	5	0.0%	0	5	0.0%
	WSO	0	94	0.0%	0	105	0.0%	0	147	0.0%
05/15	CH1	0	1188	0.0%	0	103	0.0%	0	175	0.0%
	CHO	0	16	0.0%	0	1	0.0%	0	122	0.0%
	HST	0	170	0.0%	0	109	0.0%	0	98	0.0%
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	CO	0	323	0.0%	0	134	0.0%	0	426	0.0%
	HSO	0	3	0.0%	0	15	0.0%	0	12	0.0%
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1994 LOWER COLUMBIA SMP GAS BUBBLE SYMPTOMS

		MCN			JDA			BON		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	CH1	0	1246	0.0%	0	113	0.0%	0	101	0.0%
	CHO	0	5	0.0%	---	0	---	0	103	0.0%
	HST	0	346	0.0%	0	139	0.0%	0	103	0.0%
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	CO	0	958	0.0%	0	118	0.0%	0	102	0.0%
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	WSO	0	286	0.0%	0	132	0.0%	---	0	---
05/12	CH1	0	1336	0.0%	0	775	0.0%	0	100	0.0%
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05/13	CH1	0	1033	0.0%	0	121	0.0%	0	104	0.0%
	CHO	---	0	---	---	0	---	0	104	0.0%
	HST	0	204	0.0%	0	110	0.0%	0	100	0.0%
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	HSO	---	0	---	0	11	0.0%	0	13	0.0%
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	CHO	---	0	---	---	0	---	0	134	0.0%
	HST	0	146	0.0%	0	120	0.0%	0	113	0.0%
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	CO	0	396	0.0%	0	146	0.0%	0	353	0.0%
	HSO	---	0	---	0	5	0.0%	0	5	0.0%
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05/15	CH1	0	1188	0.0%	0	103	0.0%	0	175	0.0%
	CHO	0	16	0.0%	0	1	0.0%	0	122	0.0%
	HST	0	170	0.0%	0	109	0.0%	0	98	0.0%
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	HSO	0	3	0.0%	0	15	0.0%	0	12	0.0%
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1994 LOWER COLUMBIA SMP GAS BUBBLE SYMPTOMS

		MCN			JDA			BON		
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	HST	0	346	0.0%	0	139	0.0%	0	103	0.0%
	WST	0	68	0.0%	0	103	0.0%	0	100	0.0%
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05/12	CH1	0	1336	0.0%	0	775	0.0%	0	100	0.0%
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	WSO	0	182	0.0%	0	147	0.0%	---	0	---
05/13	CH1	0	1033	0.0%	0	121	0.0%	0	104	0.0%
	CHO	---	0	---	---	0	---	0	104	0.0%
	HST	0	204	0.0%	0	110	0.0%	0	100	0.0%
	WST	0	50	0.0%	0	105	0.0%	1	108	100.0%
	CO	0	657	0.0%	0	104	0.0%	0	100	0.0%
	HSO	---	0	---	0	11	0.0%	0	13	0.0%
	WSO	0	121	0.0%	0	114	0.0%	0	105	0.0%
05/14	CH1	0	899	0.0%	0	222	0.0%	0	163	0.0%
	CHO	---	0	---	---	0	---	0	134	0.0%
	HST	0	146	0.0%	0	120	0.0%	0	113	0.0%
	WST	0	48	0.0%	0	97	0.0%	0	106	0.0%
	CO	0	396	0.0%	0	146	0.0%	0	353	0.0%
	HSO	---	0	---	0	5	0.0%	0	5	0.0%
	WSO	0	94	0.0%	0	105	0.0%	0	147	0.0%
05/15	CH1	0	1188	0.0%	0	103	0.0%	0	175	0.0%
	CHO	0	16	0.0%	0	1	0.0%	0	122	0.0%
	HST	0	170	0.0%	0	109	0.0%	0	98	0.0%
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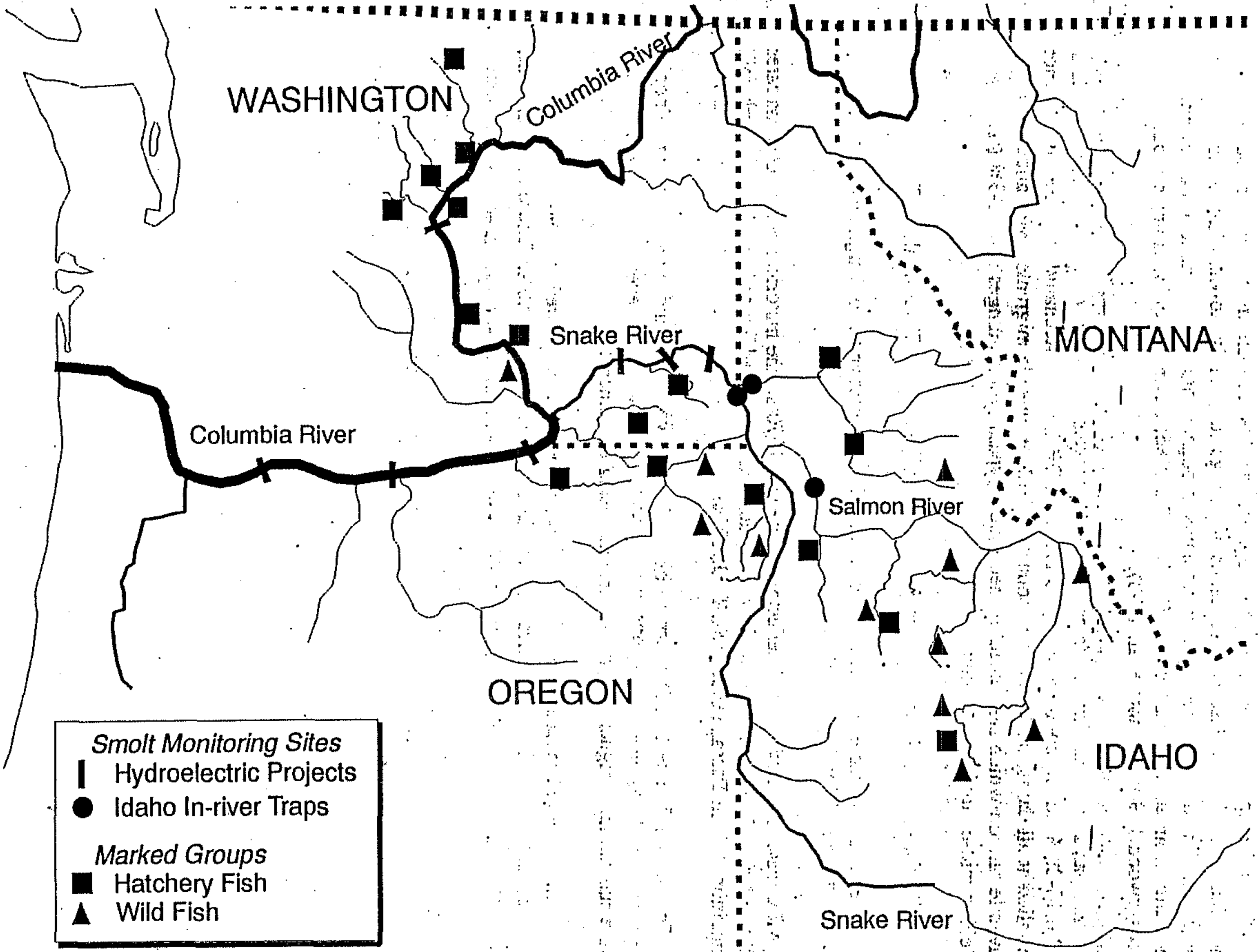
	CO	0	323	0.0%	0	134	0.0%	0	426	0.0%
	HSO	0	3	0.0%	0	15	0.0%	0	12	0.0%
	WSO	0	62	0.0%	0	127	0.0%	0	142	0.0%


WASHINGTON
Columbia River
MONTANA
Snake River
Columbia River
Salmon River
OREGON
IDAHO
Snake River
Smolt Monitoring Sites
Hydroelectric Projects
Idaho In-river Traps
Marked Groups
Hatchery Fish
Wild Fish

Testimony
file copy

May 16, 1994

PROJECT	NMFS REQUEST	CURRENT OPERATION
BON	68% spill (24 hrs)	Spill - 75 kcfs (day) - 120 kcfs(night) - (about ~~50%)~~ ~~47~~ 45%
TDA**	40% spill (24 hrs)	Spill - 40% (24 hrs)
JDA	33% spill (12 hrs)	Spill - 5% (12 hrs)
MCN**	48% spill (12 hrs)	Spill - 48% (12 hrs)
IHR**	25 kcfs (24 hrs)	Spill - 25 kcfs (24 hrs)
LMN	54% spill (12 hrs)	Spill - 35% (12 hrs)
LGS	48% spill (12 hrs)	Spill - 30 kcfs (12 hrs), about 35%
LWG**	78% spill (12 hrs)	Spill - 78% (12 hrs)

** Projects spilling NMFS requested levels and dissolved gas in area downstream of spillway does not exceed 120%.

CENPD-PE-WM May 11, 1994

MEMORANDUM FOR THE RECORDS
by Bolyvong Tanovan

SUBJECT: Total Dissolved Gas (TDG) Monitoring Needs

1. Current monitoring installations at Corps lower Snake and lower Columbia River projects include the following forebay and tailwater locations:

Project	Forebay	Tailwater	Location	Telemetry
1.DWR		x		x
2.LWG	x			x
3.LWG		x	.8 mi right bank	(H)
4.LGS	x			x
5.LGS		x	.7 mi Right Bank	(H)
6.LMN	x			x
7.LMN		x	.8 mi Left Bank	(H)
8.IHR	x			x
9.IHR		x	.8 mid-channel	(W)
10.IHR		x	3.6 mi Right Bank	x
11.IHR		x	7.1 mi Hood Park	x
12.MCQW	x		WA	x
13.MCQO	x		OR	x
14.MCN		x	1.4 mi Right Bank	(H)
15.JDA	x			x
16.TDA	x			x
17.BON	x			x
18.WRNO		x	Warrendale	x
19.SKA		x	Skamania	x
20.CWMW		x	Camas	x
21.KLAW		x	Kalama	x
22.WANO		x	Wauna Mill	x

(H) = Hynet Logger
(T) = Telemetry with Logger
(W) = Wireless deployed on buoy (logger)

FISH PASSAGE CENTER

2501 S.W. FIRST AVE. • SUITE 230 • PORTLAND, OR 97201-4752
PHONE (503) 230-4099 • FAX (503) 230-7559

MEMORANDUM

DATE: March 28, 1994

TO: FPAC

FROM: Larry Basham, FPC Larry

RE: Mainstem Adult Trapping Facilities - Recording Gas Bubble Trauma symptoms, head or other wounds noted on handled fish.

During the 1993 adult fish migration on the Columbia River, fairly high levels of spill were prevalent at all mainstem dams in mid to late May. Dissolved gas levels ranged as high as 141% saturation in the Snake River. Head injuries were recorded by WDW fish counters at the fish counting windows and at trapping sites. Few injuries of any type were noted at Bonneville Dam, increased injury rates at John Day Dam, and at Lower Granite Dam head injuries averaged about 9% of the total sample of adult salmon from mid-May through mid-July.

This year is not shaping up as a high flow year; however, high flow/spill conditions can sometimes prevail for short durations, as weather is not a controllable item. The FPAC recommended that an adult fish monitoring program be initiated or continued during 1994 at the mainstem trapping sites, and that records of fish condition be made available to the Fish Passage Center on a weekly basis. A standard reporting format should be used to record data from individual fish. A summary of sampled fish should be compiled weekly, and should be mailed or FAX'd to the FPC. The summary should include the following:

1. Sampling Dates for Week
2. Number of Fish Sampled Per Week
3. Number of Fish Rated Good to Excellent Condition
4. Number of Fish with Head Burns
5. Number of Fish with Gas Bubble Trauma Symptoms
6. Comments on Fish Condition or Adult Passage for the Week

Please observe the caudal, anal, and dorsal fin for presence of air embolisms. In addition, the roof of the mouth should be observed to assure no bubbles have settled in that area as well.

The attached data sheet can be duplicated and sent (fax preferred) to the FPC on Wednesday or Thursday of each week. Please call me at the Fish Passage Center, 503/230-4287, if you have questions regarding the information required for the weekly summary. Additional fish quality information can be sent with that listed above, but mainly, we are interested in monitoring adult fish for Gas Bubble Trauma symptoms and presence of head burns which may or may not be related to Gas Bubble Trauma symptoms. Some of the information may be used for the FPC weekly report.

cc: Jeff Fryer, CRITFC
Jerry Harmon, NMFS
Ted Bjornn, U of I Fisheries Coop Unit

ATTACHMENT 4

Gas Bubble Trauma Symptom Monitoring
Lateral Line and Gill Filament

1. On an every other day basis - thirty hatchery steelhead from the dissolved gas trauma monitoring sample will be randomly chosen and sacrificed by over-anesthetizing the fish.

2. These fish will be part of that day's sample for dissolved gas trauma monitoring and will be included in the sample statistics. In addition, the thirty (total) fish will be observed in-depth for lateral line and gill filament symptoms.

3. GILLS:

The gills should be examined first. First, hold the fish down under water and cut the gill arch. Gas bubbles may bubble up as the blood is released.

Take the fish from the water and clip a second gill arch, placing it on a slide. The size that we anticipate these fish to be will require that the individual filaments be removed from the arch with a scalpel, and then coverslipped with a drop or two of water for a wet mount examination. Examine the filaments under a compound microscope for evidence of gas bubbles in the gill capillaries.

This examination is crucial. Don't confuse round bubbles that happened to be caught under the coverslip for bubbles inside the blood vessels of the gills. You must focus up and down with the fine focus of the microscope to ensure that what you are looking at is truly inside the blood vessel. The bubbles actually inside will probably not be round, they will be elongated because they take on the shape of the gill capillaries themselves. Perfectly round bubbles should be discounted, as they are probably extraneous bubbles just caught under a filament or coverslip. This technique will take some practice.

LATERAL LINE:

This is by direct exam under the dissecting scope. Look for bubbles along the indentation of the lateral line. If none are apparent, peel back the skin of the fish to look between the skin and the muscle bundles for bubbles that may be in the indentation where the bundles meet each other. Examine both sides of the fish.

This is also a good opportunity to examine the eyes more closely under the dissecting scope for bubbles which may not be apparent to the unaided eye.

INTERNAL EXAM:

The fish can be opened carefully with a scalpel. Do not puncture too deeply into the fish as you are trying to preserve the swim bladder intact. As you open the fish, look for gas bubbles in the intestine, and see if the swim bladder is abnormally distended. This will take some practice in identifying. Once noted, the swim bladder can be tugged aside, and the surface of the kidney examined for visible bubbles under the membrane.

- Each site will be provided with a compound and binocular dissecting microscope to use for fish observation. Fish Passage Center Staff will arrange and provide training to Smolt monitoring Program crews. We request that at least two biologists from each site be made available for the training session.

387-94.mf

COLUMBIA BASIN FISHERY AGENCIES AND TRIBES

FISH PASSAGE CENTER
2501 S.W. FIRST AVE. • SUITE 230 • PORTLAND, OR 97201-4752
PHONE (503) 230-4099 • FAX (503) 230-7559

Attach 3

MEMORANDUM

DATE: May 11, 1994

TO: Smolt Monitoring Program Site Personnel

Michele DeHart

FROM: Michele DeHart

RE: Additional monitoring associated with gas bubble trauma

As you are all probably aware, additional spill is being provided this year to aid the juvenile migration. As part of this program, we have been asked to add an additional monitoring element into the gas bubble trauma monitoring that is now on-going. This element is designed to detect early symptoms of dissolved gas in fish. It will require sacrificing a number of fish, and the close examination of their gill filament and lateral line. Training and equipment will be provided at each site. The protocol that will be used for training and implementation is attached. The implementation of this monitoring on an alternate day basis will be initiated when dissolved gas levels reach 120%. As of this time, we do not know how the determination of dissolved gas levels will be determined. There are on-going discussions between NMFS and the operators. Therefore, we cannot tell you when the additional monitoring will begin. Be assured that we will notify each site with as much lead time as possible. The attached protocol has been reviewed and approved for implementation by the Fish Passage Advisory Committee.

We will be providing you with a separate data sheet and advice as to how the data should be transmitted to the FPC prior to implementation. If you have any additional questions, please contact Margaret Filardo at 230-4286 or Larry Basham at 230-4287.

ATTACHMENT 3

391-94.mf

1994 SNAKE RIVER SMP GAS BUBBLE SYMPTOMS

		LGR			LGS			LMN		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	HCH1	0	95	0	0	100	0	0		0
	WCH1	0	5	0	0	17	0	0		0
	CHO									
	HST	0	100	0	0	100	0	0		0
	WST	0	100	0	0	14	0	0		0
	WSO	0	9	0	0	6	0	0		0
05/12	HCH1									
	WCH1									
	CHO									
	HST									
	WST									
	WSO									
05/13	HCH1									
	WCH1									
	CHO									
	HST									
	WST									
	WSO									
05/14	HCH1									
	WCH1									
	CHO									
	HST									
	WST									
	WSO									
05/15	HCH1									
	WCH1									
	CHO									
	HST									
	WST									
	WSO									

ATTACHMENT 2

1994 LOWER COLUMBIA SMP GAS BUBBLE SYMPTOMS

		MCN			JDA			BON		
		# OBS	# SAM	% GBS	# OBS	# SAM	% GBS	# OBS	# SAM	% GBS
05/11	CH1	0	1246	0	0	113	0	0	101	0
	CHO	0	5	0				0	103	0
	HST	0	346	0	0	139	0	0	103	0
	WST	0	68	0	0	113	0			
	CO	0	958	0	0	118	0	0	102	0
	HSO	0	17	0	0	22	0	0	60	0
	WSO	0	286	0	0	132	0			
05/12	CH1									
	CHO									
	HST									
	WST									
	CO									
	HSO									
	WSO									
05/13	CH1									
	CHO									
	HST									
	WST									
	CO									
	HSO									
	WSO									
05/14	CH1									
	CHO									
	HST									
	WST									
	CO									
	HSO									
	WSO									
05/15	CH1									
	CHO									
	HST									
	WST									
	CO									
	HSO									
	WSO									

Dissolved Gas Symptoms

Site__________
Date__________ Batch #__________

Species: __________________ Sample Size: __________

No Evidence	< 50% in one fin	> 50% in one fin	Two or more fins	Fin(s) + Head
Totals:				

Species: __________________ Sample Size: __________

No Evidence	< 50% in one fin	> 50% in one fin	Two or more fins	Fin(s) + Head
Totals:				

Species: __________________ Sample Size: __________

No Evidence	< 50% in one fin	> 50% in one fin	Two or more fins	Fin(s) + Head
Totals:				

Species: __________________ Sample Size: __________

No Evidence	< 50% in one fin	> 50% in one fin	Two or more fins	Fin(s) + Head
Totals:				

Reporting GBS incidence to Fish Passage Center:

1. The sample season for GBS will be from April 15 through June 15 unless high flow/spill conditions exist prior to, or after, the normal sampling dates. The Fish Passage Center will inform the sampling sites of any change in this schedule.

2. On the individual sample days for GBS, the data should be sent to the FPC on the Smolt Monitoring Summaries. The information should be added to the Comment Section and include the number observed with symptoms and the number examined for each species, negative reports are also needed. The information should always be in this format: HCH1: x/y; WCH1: x/y; etc.

3. The individual tally sheets recording the GBS by species and categories, and appropriate comments should be mailed to the FPC on Friday of each week, and will be verified by FPC personnel on a weekly basis.

4. During the GBS monitoring season, the sites should indicate in the S/36 batch comments that either 1) there was no GBS monitoring, 2) there were no observations of GBS, or 3) what the GBS observations were.

FPC Reporting of GBS:

1. The FPC will report levels of GBS incidence in the FPC's Weekly Report that is mailed out each Friday to about 300 parties in the Columbia River Basin.

2. The FPC will further request that severe cases of GBS (fin(s) + head) at individual projects be documented by photo.

Protocol for Sampling Fish for Gas Bubble Symptoms at All Sampling Sites

1. The sample will consist of 100 fish per species per day. This sample will be taken 3 days per week. This sample will be composed of the same fish as used to determine descaling rates, weights, etc. When gas bubble symptoms are noted, then sampling will be accomplished on a daily basis at all sampling sites until the dissolved gas levels and associated gas bubble symptoms (GBS) are reduced to more normal levels.

2. When GBS first appear in the sample, a comparative sample will be taken at the separator of the following dams: Little Goose, Lower Monumental, and McNary. A sample of 100 fish of yearling chinook and steelhead will be obtained each day. Fish should be captured via a sanctuary dip net and transferred to the fish facility for examination. Samples should be taken twice during the 24 hour day. The purpose of this activity is to determine if GBS dissipate with time spent in the sample tank or raceways.

3. Individual fish will be examined for GBS in/on the fins, head, and eyes. Generally, first appearance of GBS is in the caudal fin.

4. The five classifications of GBS will be recorded. These classifications are:

   1. No Evidence = gas bubbles are not present in any fin.
   2. < 50% in one fin = gas bubbles are observed in less than 50% of the surface of one fin.
   3. > 50% in one fin = gas bubbles are observed in greater than 50% of the surface of one fin.
   4. Two or more Fins = gas bubbles are present in at least two of the fish's fins.
   5. Fin(s) + Head = gas bubbles are present in one or more of the fish's fin(s), plus the head area.

5. The Sequence to follow when inspecting a fish is to: 1) Inspect the fin area first, if no evidence is noted then, proceed to the next fish; 2) If only one fin has gas bubbles present, determine if 50% of the fin has bubbles, and record in the < or > 50% column, and proceed to next fish; 3) If a fish was noted to have gas bubbles in two or more fins, then look at the head for signs of bubbles; if no bubbles are noted in the head, record as two or more fins and proceed to the next fish. If bubbles were noted in the head area; and, 4) record as Fin(s) + head, and proceed to next fish.

   We can look for progression of GBS in the fish by using this sequence. Generally the progression is from the caudal fin to the anal or dorsal fin, and finally in the last stages to the head area on the fish.

Training:

1. Training of sampling personnel on recognition of gas bubble symptoms incidence will be completed prior to the fish passage season by experienced/trained personnel.

FISH PASSAGE CENTER
2501 S.W. FIRST AVE. • SUITE 230 • PORTLAND, OR 97201-4752
PHONE (503) 230-4099 • FAX (503) 230-7559

MEMORANDUM

FROM: Michele DeHart

DATE: March 30, 1994

TO: Smolt Monitoring Sites

RE: Gas Bubble Symptoms (GBS) Monitoring in 1994

Enclosed are the guidelines and the form for monitoring for symptoms of Gas Bubble Trauma. There are a few changes from last year, so please read through the protocol carefully. Starting on April 15, all sites excluding the traps will begin monitoring for GBS three days per week. As soon as any symptoms are seen, monitoring will be conducted daily until symptoms and dissolved gas levels are reduced. The Fish Passage Center will coordinate returns to three day sampling after a period of high dissolved gas levels.

For each day GBS monitoring is conducted, please fill out Dissolved Gas Symptoms data sheets. Use as many sheets as is necessary, depending on the number of species you sample. Use separate tally blocks for hatchery and wild of any species where it is possible to make this differentiation. Photocopies of the GBS data sheets should be mailed to the FPC weekly along with your handlogs.

Additionally, for each day during the GBS monitoring season (April 15 to June 15), you must indicate in the comments of each daily batch either 1) there was no GBS monitoring, 2) there were no observations of GBS, or 3) what the GBS observations were. If you are reporting GBS observations, use this format:

HCH1: x/y; WCH1: x/y; CH0: x/y; HST: x/y; WST: x/y; CO: x/y; HSO: x/y; WSO: x/y

where x is the number with GBS symptoms, and y is the number examined, which may be a subsample or the entire sample.

It is important to report the number observed with GBS and the number examined for *all* species, regardless of which are present at the time, or which species have any GBS. This information should be in the form of raw numbers, not percentages. Separate numbers should be reported for the hatchery and wild of a species, where that designation is being made. It is not necessary to specify the category breakdown of GBS symptoms in the daily batch comments.

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ATTACHMENT 1

We have advised the Fish Passage Advisory Committee that the data collected through the dissolved gas symptom monitoring will be used for management decisions in a manner analogous to the present model for descaling. When fish descaling increases at a project, the agencies and tribes are presented with the data, and at-site actions are prescribed first to remedy the situation. These may include, among other things, trash raking or screen cycling. If the descaling remains high, then additional (more consequential) actions are taken until descaling decreases. The FPAC will review dissolved gas symptom data on a regular basis, and if levels increase, actions will be taken to eliminate symptoms. Since the spill program in 1994 only includes voluntary spill, the reaction to symptoms can be immediate and confined to where symptoms are observed. We understand that dissolved gas levels will be considered on a daily average basis at several sites.

In summary, we believe the biological monitoring program is fully coordinated and in place at this time. This program was described and presented to the In-Season Management Team at the May 11, 1994 meeting. Please feel free to contact us regarding this operation if you have any questions.

Sincerely,

Michele DeHart

Michele DeHart
Fish Passage Center Manager

395-94.mf

will convene a group of regional experts to review the operation and recommend any changes to the program.

Reporting

Results of monitoring will be provided to the Fish Passage Center for inclusion in the weekly FPC report.

May 13, 1994

Draft

NATIONAL MARINE FISHERIES SERVICE

Gas Bubble Disease Monitoring and Management Program

A special spill operation started May 10, 1994 at Columbia and Snake River hydropower projects and is to continue through June 20, 1994. Spill will be managed in-season on a twice weekly basis. Decisions to increase or decrease spill levels and subsequent dissolved gas levels will be made by the Operations Group with the concurrence of the National Marine Fisheries Service (NMFS) at regularly scheduled meetings on Mondays and Thursdays of each week, or on an emergency basis if necessary. The decisions will be based on the results of biological and associated physical monitoring with the criteria described below added to the attached Fish Passage Center monitoring plan.

The current management action calls for spill levels necessary to pass 80% of the daily average juvenile migrants through non-turbine routes (spill, bypass, and sluiceway) at Bonneville, John Day, McNary, Lower Monumental, Little Goose and Lower Granite dams. Spill is capped at The Dalles and Ice Harbor dams. The incidence of gas bubble disease in migrant salmonids will determine whether these spill levels can be maintained through the remainder of the spring migrations.

Salmonid Monitoring

I. Juveniles

- A. Smolt Monitoring Program--Little Goose, Lower Monumental, McNary, John Day, Bonneville Dams
- B. Research Opportunities
    - 1) Fish Guidance Efficiency Studies -- Little Goose, McNary, The Dalles, and Bonneville Dams.
    - 2) Reservoir Studies -- John Day Reservoir, Little Goose Reservoir (awaiting ESA permit).
    - 3) Cage Studies -- below Priest Rapids, Ice Harbor, and Bonneville Dams.
- C. External, lateral line, and internal assessment for signs of gas bubble disease (GBD) to be made.

II. Adults

A. Trap Observations/Examinations

1) Bonneville Dam

2) Ice Harbor Dam (awaiting ESA permit modification)

3) Lower Granite Dam

B. External assessment for signs of GBD to be made.

Resident Biota Monitoring

A. Sampling below Priest Rapids, Ice Harbor, and Bonneville Dams

B. Cage studies with resident fish at same locations

C. External and lateral line assessment for signs of GBD to be made

Dissolved Gas Measurements

A. Total dissolved gas measured in forebays of all Columbia and Snake River Dams and at Warrendale, Oregon, will be reported as the average of the 12-hour period having the highest levels of dissolved gas for each location.

Actions Levels

Salmonids

Recommendations for alteration of spill regimes will be made when signs of gas bubble disease exceed 5% in juvenile salmonids and/or 2% in adult salmon at any location. If at any time unusual or unexpected events occur which would negatively impact survival of migrant salmonids, ramping of increased spill levels may be terminated.

Adjustment Criteria

If no signs of GBD are observed in juvenile or adult salmonids between Operations Group Meetings, spill will be increased at increments that result in 2.5% increases in total dissolved gas. In any case, spill will not exceed the originally requested amount necessary to achieve 80% Fish Passage Efficiency at Bonneville, John Day, McNary, Lower Monumental, Little Goose, Lower Granite dams or the upper limits of 40% of average daily flow at The Dalles Dam and 25 kcfs at Ice Harbor Dam. After 2 weeks of operation under the revised spill regime, the NMFS

COLUMBIA BASIN FISHERY AGENCIES AND TRIBES

FISH PASSAGE CENTER
2501 S.W. FIRST AVE. • SUITE 230 • PORTLAND, OR 97201-4752
PHONE (503) 230-4099 • FAX (503) 230-7559

May 12, 1994

Mr. J. Gary Smith
Acting Regional Director
National Marine Fisheries Service
7600 Sand Point Way NE
Seattle, Washington 98115-0070

Dear Gary:

The purpose of this correspondence is to advise you that the biological monitoring program for dissolved gas trauma symptoms is in place. The following is a description of the biological monitoring design and protocol that is currently in place for the monitoring of gas bubble trauma associated with increased dissolved gas due to spill. Monitoring has been occurring since the beginning of the fish passage season at all Smolt Monitoring Program sites including: Lower Granite, Little Goose, Lower Monumental, McNary, John Day, Bonneville and Rock Island dams. This has included sampling three times per week as described in the attached protocol (Attachment 1). On Monday May 9, all crews were advised to begin sampling for gas bubble symptoms on a daily basis. These data are sent directly to the Fish Passage Center on a daily basis, where they are summarized and stored electronically. The attached data sheets were developed (Attachment 2) to present data to interested parties on a regular basis. To-date several thousand fish have been observed and no gas bubble symptoms have been detected in the samples.

At the request of NMFS we were asked to include additional tasks into the gas bubble symptom monitoring program to address the presence of symptoms not observable in external monitoring. We consulted with Phyllis Barney, a pathologist for the USFWS, to develop a protocol for the detection of lateral line symptoms and gill observations. On Phyllis's recommendation we have included a task requiring the internal examination of the fish's organs (swim bladder, kidney and intestines) for symptoms. This protocol has been reviewed and approved (Attachment 3) by the agencies and tribes. The Smolt Monitoring Program Crews will be provided with all the necessary equipment, and the training of the crews is scheduled for May 12, 13 and 16.

In addition to the at-site monitoring, the NMFS will be conducting reservoir monitoring of both salmonids and other species below Ice Harbor, Priest Rapids and Bonneville dams. This research has been coordinated with the FPC in past years and we will continue to be provided with that data in-season.

Prior to the beginning of the migration season the FPC coordinated with all proposed adult sampling programs. Currently, fish are being handled and observed at Bonneville and Lower Granite dams. These data are being sent to the FPC (Attachment 4). The lead coordinators of these projects were notified on Monday, May 9, of the imminent implementation of the spill program and were asked to notify the FPC immediately of any symptoms detected in the samples. We also contacted Todd Kleist, WDFW, and asked him to alert all fish counters to observe adults for any detectable symptoms as they pass by the counting stations.

WEEKLY SUMMARY OF ADULT FISH MONITORING FOR GAS BUBBLE SYMPTOMS AND HEAD BURNS

Week of ______________________.

Sample Dates	# Sampled	# Good Condition	# Head Burns	# GBD
Total				

1. Examine each fish for quality and condition. Total to be recorded under # Sampled.
2. Record fish under # Good Cond., if there are no visible marks or injuries noted on fish.
3. Head burns would include all injuries from the top of the head (eye area) to the fleshy portion of the fish's back, and recorded under # Head Burns. The head will be scalped (skin removed) or attached in some cases. The head area may be exposed to the cartilege.
4. The fins should be examined for presence of air embolisms, then the head area (gill cover and eyes), and finally the roof of the mouth. If bubbles are found, record under # GBD.

<u>FAX or mail weekly summary to:</u>

Fish Passage Center
2501 SW First Ave, Suite 230
Portland, OR 97201-4752.
FAX #: (503) 230-7559

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DRAFT
SCIENTIFIC RATIONALE FOR IMPLEMENTING A SPILL PROGRAM TO INCREASE JUVENILE SALMON SURVIVAL IN THE SNAKE AND COLUMBIA RIVERS

The following summarizes the scientific basis for implementing a spill program during 12 nighttime hours at all Corps of Engineers dams on the mainstem Snake and Columbia Rivers to increase protection for 1994 spring outmigrating juvenile salmon. As concluded by the peer review team of independent scientists, "[t]ransportation alone, as presently conceived and implemented, is unlikely to halt or prevent the continued declined and extirpation of listed species of salmon in the Snake River Basin" (Mundy et al. 1994). Spill at transportation and collector dams, while continuing to transport those fish collected, addresses the substantial uncertainty associated with the effectiveness of the juvenile transportation program (TRG 1993; Mundy et al. 1994). A management approach when faced with uncertainty is to spread the risk between two choices. The spill program is designed to improve in-river passage survival and spread the risk by leaving a larger percentage of juvenile salmon migrating in-river. For the last several years, substantial spill for juvenile migrants has been implemented at all mid-Columbia PUD projects through settlements and stipulations.

The objective of the spill program is to safely guide 80% of the juvenile migrant salmon away from the turbines, the most harmful passage route at the dams, and pass them through mechanical bypass systems and over the spillways. Spill volumes will be controlled to avoid harmful levels of dissolved atmospheric gas in the river.

The spill program at the mainstem Corps dams was jointly coordinated and devised by fishery scientists from the National Marine Fisheries Service, the United States Fish and Wildlife Service, the Oregon Department of Fish and Wildlife, the Washington Department of Fish and Wildlife, the Idaho Department of Fish and Game, and the Columbia River Inter-Tribal Fish Commission. The spill program has been adopted for the remainder of the 1994 spring outmigration. This should be one of the major options, evaluated in the long term as part of an adaptive management approach, used to assist in improving juvenile survival with respect to recovery.

Fishery agencies and tribes have chosen a conservative approach to the implementation of the spill program. Where possible, based on real time and historical salmon migration patterns, spill is generally being confined to nighttime hours. This substantially limits economical impacts of spill because power demand is much less at night and river flows are lowered at night. An extensive program for monitoring the signs of gas supersaturation impacts in both juvenile and adult salmon has been established with trained biologists at each dam. The spill program can be immediately modified based upon the daily results of the monitoring program.

* Controlled spill as provided by the program, with the stringent monitoring protocols included, provides the best possible means of passage survival for downstream salmon migrants. Extensive studies at mainstem dams throughout the basin document that juvenile mortality from spill ranges from 0-3% (NWPPC 1986; Raymond 1988; Holmes 1952; Ledgerwood 1990; Iwamoto et al. 1993).

* Other passage routes through dams cause higher levels of mortality. Turbine passage causes from 10-20% direct mortality (NWPPC 1986; DFOP 1993). Mechanical bypass systems, not installed at all dams, only guide and collect 35-70% of juvenile migrants. Mortality to juvenile salmon which are guided by mechanical bypass systems ranges from 1-3% (D. DeHart mid-columbia testimony).

* Spill disperses predators from the forebay and tailrace areas (Faler et al.1988)

* There is considerable evidence that juvenile fish can detect and avoid high levels of gas supersaturation (Dawley et al 1975).

* After installation of the spill deflectors in the mid 1970's, the historical record demonstrates that better adult returns followed from juveniles which migrated under high flow and high spill conditions (Fish Passage Center SOR-19, 1994).

* Four of the five best adult return ratios for Snake River spring and summer spring chinook from 1974 to 1989 occurred in 1975, 1982, 1983, and 1984. Spill levels during these years were substantially higher than those currently being implemented.

* When compared to past years, the levels of spill being implemented in 1994 are substantially less than what occurred in the late 1970's and early 1980's. These levels are not, "unprecedented" as described by the federal operators.

* Levels of spill proposed for 1994 are considerably less than those that occurred in 1993, a year in which runoff levels late in the spring chinook migration resulted in high spill rates. In 1993 no fish with signs of impacts of gas supersaturation were detected through the Smolt Monitoring Program until spill levels greatly exceeded those proposed for 1994 . The monitoring program showed that in spite of high spill (which occurred during flows that were more than twice the levels anticipated for 1994) the observed impacts of dissolved gas on fish were minor (DFOP 1993; Appendix 6).

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Suite 1100
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Telephone: (503) 228-2525

Attorneys for DSIs

IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF OREGON

IDAHO DEPARTMENT OF FISH AND GAME, Plaintiff, v. NATIONAL MARINE FISHERIES SERVICE, <u>et al.</u>, Defendants.	)	Civil No. 92-973-MA (Lead Case) 93-1420-MA 93-1603-MA (Consolidated Cases) DECLARATION OF JAMES JAY ANDERSON

JAMES JAY ANDERSON declares:

1. I am an Associate Professor at the Fisheries Research Institute and Center for Quantitative Science in Forestry, Fisheries and Wildlife in the College of Ocean and Fisheries Science at the University of Washington. A copy of my curriculum vitae is attached as Exhibit 1. I am generally familiar with several computer models used to estimate the effects of the Federal Columbia River Power System on salmon. I am most familiar with, and was the architect and principal investigator for the

development of the CRiSP model used to model juvenile passage survival. I make this affidavit to demonstrate the effects of a planned increase in the amount of spill at the eight mainstem dams along the Columbia and Snake Rivers.

2. The CRiSP model contains parameters which attribute mortality to each of the three principal means by which juvenile salmon may pass a dam while migrating downriver: through a spillway, through a bypass system, or through the electric turbines. The CRiSP model also contains parameters which model the effects of transporting juvenile salmon around the dams. The CRiSP model is thus capable of predicting the net change in mortality to juvenile salmon arising from a change in operations that increases the percentage of water passing through spillways and decreases the percentage of water passing through turbines.

3. Although mortality to salmon passing through spillways is generally regarded as lower than mortality to salmon passing through turbines, increased spill tends to increase the percentage of dissolved gases present in water. This phenomenon, called gas supersaturation, has long been recognized to be a problem arising from the dams, because high levels of gas supersaturation are lethal to both juvenile and adult salmon.

4. The CRiSP model is the only computer model in existence which attempts to estimate the adverse effects of gas supersaturation caused by increasing spill at the hydroelectric projects along the Columbia and Snake Rivers. Thus the CRiSP model

is the only model that can provide an estimate of the balance between advantages to increasing spill and the disadvantage of increasing gas supersaturation. The model predicts effects from gas supersaturation based on the work of Dawley et al. (1976), using the relationships between gas supersaturation and survival developed through experiments in deep tanks.

5. I have been unable to obtain definitive documentation of the program to increase spills. It is unusual to have a program of this magnitude developed in haste, and implemented without any public review or scrutiny. As best I can determine, the U.S. Army Corps of Engineers, at the urging of the National Marine Fisheries Service (NMFS) and other parties, will change previously-planned operations to:

> (a) spill at The Dalles Dam to 40 percent 24 hours a day;
>
> (b) spill 25,000 cubic feet per second (25 kcfs) of water at Ice Harbor Dam 24 hours a day;
>
> (c) operate the remaining six dams to spill during the 12 nighttime hours (and 24 hours at Bonneville Dam) at the lesser of (1) the quantity of spill needed to meet 80% fish passage efficiency and (2) the quantity of spill producing a maximum 12 hour average dissolved gas concentration of 120% measured at the next downstream project; and
>
> (d) increase spill to meet 80% fish passage efficiency to the extent that there are no observed adverse biological effects of dissolved gas over and above 120% in increments of 2.5%.

I also understand that the Bonneville Power Administration has estimated the increase in spill at the eight mainstem projects to achieve 80% fish passage efficiency as follows:

	Current Spill	Increased Spill
Lower Granite	40% 12 hrs	78% 12 hrs
Little Goose	30% 12 hrs	48% 12 hrs
Lower Monumental	none	54% 12 hrs
Ice Harbor	25 kcfs 24 hrs	100% 12 hrs
McNary	none	48% 12 hrs
John Day	none	33% 12 hrs
The Dalles	30% 8 hrs	40% 24 hrs
Bonneville	180 kcfs 8 hrs 75 kcfs 15 hrs	same

6. I have run the CRiSP 1.4.5 model to compare current and the NMFS 80% FPE spill plans. Total system survival is 50% for current spill conditions and 37% under the NMFS plan. These estimates include survival of both fish that are transported to below Bonneville Dam and fish that migrated through the river system.

7. The survival of fish traveling in river is also adversely affected in the NMFS spill program. The total passage survival of in river fish decreased from 34% under current conditions to 17% under the NMFS plan. This is a decrease in fish survival of 50%.

8. The decreases with the NMFS plan are the result of decreased transportation and the high level of nitrogen supersaturation. In the current plan saturation is below 114% but it reaches to 139% under the NMFS plan. The percent of fish transported is also decreased under the NMFS plan. Current transport is 50%. Under the NMFS plan 37% of the fish are transported.

9. Attached as Exhibit 2 is a very brief report providing details of these analyses.

10. These results will tend to underestimate the adverse effects of the NMFS spill program for at least three reasons. First, the CRiSP model does not calculate adverse effects to salmon until the dissolved gas concentrations exceed 114%. Generally recognized water quality standards call for avoiding levels higher than 110% to protect fish; some research suggests that significant adverse effects begin at even lower levels. Second, the CRiSP model works with average gas supersaturation levels and does not take account of localized areas of much higher gas supersaturation levels associated with high average supersaturation rates. Third, the CRiSP model does not take account of adverse effects on returning adults, which tend to concentrate below dams where localized gas supersaturation levels are highest. The loss of returning adult salmon from gas supersaturation may have much greater consequences for the population of endangered and threatened salmon stocks than the loss of juvenile.

11. I understand that NMFS bases its rationale for the increases in spill at least in part on certain computer modeling results provided by the states and tribes. I have not seen these results. However, assuming that they are generated with the FLUSH model generally used by the states and tribes, they would not show the negative effects of gas supersaturation at all because the FLUSH model does not take account of the negative effects of gas supersaturation.

12. I declare under penalty of perjury that the foregoing is true and correct.

Executed on May 12, 1994

James J. Anderson

James Jay Anderson

April 1 1994

Curriculum Vitae for James Jay Anderson

Appointment

Associate Professor (WOT)
Fisheries Research Institute and Center for Quantitative Science in Forestry, Fisheries and Wildlife
College of Ocean and Fisheries Sciences
University of Washington, Seattle Washington 98195

Phone number

(206) 543-4772, 543-7848

e-mail

jim@fish.washington.edu

Social security number

537-44-4818

Previous appointments

Oceanographer, Dept. of Oceanography, University of Washington (1969-1979)
Principal Oceanographer, Fisheries Research Institute, UW (1979-80)
Adjunct Assistant Professor, Marine Sciences Research Center, State Univ. of New York (1977-1980)
Visiting Scientist, Institute of Oceanographic Sciences, Wormley England (1980)
Visiting Scientist, National Institute of Oceanology, Ambon Indonesia (seven visits between 1980-1983)
Visiting Scientist, Dept. of Biophysics, University of Kyoto Japan (1981)
Research Associate, College of Ocean and Fishery Sciences, UW ((1981-1982)
Research Assistant Professor, College of Ocean and Fishery Sciences, UW (1983-87)
Research Associate Professor, College of Ocean and Fishery Sciences, UW (1987-91)

Research Interest

Biomathematics, ecology, fisheries, oceanography, toxicology, fish protection at power plants, animal and human behavior, decision processes, ecosystem modeling.

Professional Activities

Journal activities

Associate Editor to The North American Journal of Fisheries Management (1988-1989)

Proposal Reviews

EPA Environmental Biology Review Panel
NSF Biological Oceanography, Physiological Processes
U.S. Geological Survey
Natural Environmental Research Council, Great Britain
EPA Cooperative research programs
NSF Psychobiology
Research and Evaluation Associates, Inc.
Bonneville Power Administration to technical work group
NSF Physiological Process section
NOAA Northwest Fisheries Center

EXHIBIT 1

Journal reviews

Journal of Marine Research
Limnology and Oceanography
Deep-Sea Research
Continental Shelf Research
American Naturalist
Mahasagar, the quarterly journal in Oceanography
International Symposium and Educational Workshop on Fish-Marking Techniques
North American Journal of Fisheries Management
Transaction of the American Fisheries Society
Canadian Journal of Fisheries and Aquatic Sciences
Northwest Environmental Journal (Illahee)

Consulting Activities

1975 NOAA, report on underway sampling systems
1983, 1984 Technical Arts Corporation, mathematical modeling
1984 Exxon Company, impact of off shore drilling
1985 Chelan Public Utility, expert witness on fish mortality at hydroelectric plants
1986 Coastal Climate Corporation, computer programming
1987, 1988 Bonneville Power Administration, consultant to technical work groups
1989 Great Saltbay Experimental Station, fish behavior literature review
1989 Envirex, Inc. fish diversion and protection
1989-1990 Montana Dept. of Fish Wildlife and Parks, ecosystem modeling
1989-1991 Bonneville Power Administration, consultant to develop fisheries research agenda
1990 City Council of Kennewick (WA), affects of bridge removl on salmon runs
1991/2 Army Corps, modeling fish behavior at dams
1993/4 Harza Northwest Consulting Engineers, Salmon passage modeling
1993/4 Pacific Northwest Project, Salmon passage modeling
1994 Chapman Consulting, Salmon passage modeling

Professional memberships

Sigma Xi
Western Society of Naturalists
Association of the Study of Animal Behavior
American Society of Limnology and Oceanography
American Association for the Advancement of Science
American Fisheries Society
Resource Modeling Association

Workshop and conference organization activities

Session chairperson at the Saanich Inlet workshop, Feb 1983

Coordinator for Ecological Risk Assessment Workshop University of Washington, Jul 1987

Session chairperson at the Conference on Fish Protection at Stream and Hydro-Power Plants Sponsored by Electric Power Research Institute, Oct 1987

Coordinator of the Bonneville Power Administration Survival Workshop, Friday Harbor Laboratories, Feb 1989

Organization committee for the Bonneville Power Administration Predator/Prey Workshop, Friday Harbor Laboratories, May 1989

Public service

Puget Sound water quality planning committee, ad hoc committee on nutrient studies, Mar 1987

University of Washington Saturday Alumni Lectures, Autumn 1989

Associate Editor North American Journal of Fisheries Management, 1989-1990

University Task Force on Salmon and the Columbia River System - represent the UW in a group of faculty from the University of Idaho, Oregon State University, Washington State University and University of Washington with interests and expertise relating to the Columbia River system.

Ravenna Creek Feasibility Study - joined with representatives of neighborhoods adjacent to Ravenna Creek and members of the Department of Landscape Architecture to consider the possibility of daylighting the creek from it's source to Portage Bay and possible restoration of it's salmon run.

Provide analysis and advice to the Snake River Endangered Species Recovery Team

Expert witness certified

Federal Energy Regulatory Commission Court - certified as a fisheries expert on issues of fish migration and dam passage

1989 Anderson, J., D. Dauble, and D. Neitzel. Proceedings of the Smolt survival workshop. Pacific Northwest Laboratory Publication, in press.

1989 Morison, R. and J.J. Anderson. Risk assessment-risk management: The need for a synthesis. R. Morison and J.J.Anderson presented at the Annual Meeting of the Society for Risk Analysis. San Francisco, CA. Oct. 30, 1989.

1990 Anderson. J.J. Assessment of the risk of pile driving to juvenile fish. Presented at the 15th annual members meeting and seminar of the Deep Foundations Institute. October 10-12, 1990, Seattle Washington.

1990 Ostrander, G.K., J.J. Anderson, J. P. Fisher, M. L. Landolt and R. M. Kocan. Decreased performance of rainbow trout emergence behaviors following exposure to benzo(a)pyrene. Fishery Bull. 88:51-55.

1990 Anderson, J. J. Mathematical models for fish bypass systems. Report to the Portland District of the Army Corps of Engineers.

1991 Anderson, J.J. Fish Bypass System Mathematical Models. WATERPOWER 91, Proceedings of the International Conference on Hydropower. July 24-26 1991 in Denver, Colorado.

1991 Feist, B. E., and J.J. Anderson. Review of Behavior Relevant to Fish Guidance Systems. Fisheries Research Institute, University of Washington. FRI-UW-9102.

1992 Anderson, J.J. A vitality based stochastic model for organism survival. In Individual-Based Models and Approaches in Ecology: Populations, Communities and Ecosystems. Editors DeAngelis and Gross. Chapman Hall, New York. p 256-277.

1993 Anderson., J.J. et al. Columbia River Salmon Passage Model CRiSP.1: Documentation for version 4, Release Date March 1993

1993 Nemeth R. and J.J. Anderson Response of juvenile salmon to light. In North American Journal of Fisheries Management. 12:684-692.

1993 Anderson. J.J. July Report to the Snake River Salmon Recovery Team on an Analysis of Spring and Fall Chinook Survivals using the CRiSP Mainstem Passage Model.

Invited Lectures and Seminars

1978 Water masses of the eastern tropical North Pacific. Dept. of Oceanography, Oregon State University.

1982 NSF/Indonesia Seminar on Marine Science, Jakarta Indonesia.

1982 A stochastic model for the size of fish schools. Dept. of Biophysics, Kyoto University

1983 Saanich Inlet Conference, Institute of Ocean Sciences Sydney, British Columbia.

1984 Probability distributions in biology. Estuaries Class 507, winter quarter.

1984 Probability models. Marine Sciences Research Center, State University of New York at Stony Brook

1984 A look at why and how animals form groups. Littorial Society of New York.

1984 Fish Schooling, New York City Sea Gypsies.

1984 The limitations and uses of microcomputers. Psychiatry Grand Rounds, St. Vincents Hospital, New York.

1885 A fish feeding model based on game and catastrophe theories. CQS/Biomath 597, Seminar Center for Quantitative Science, University of Washington.

1985 Model of fish feeding behavior. Marine Sciences Research Center, State University of New York, Stony Brook, N.Y. February 5

1985 Mathematical model of fish feeding behavior. Behavioral Ecology seminar, Simon Fraser University, March 6.

1985 Seasonal distributions of nutrients and chlorophyll in Puget Sound. University of Washington, Chemical Oceanography Lunch seminar.

1985 NITROP-85 Workshop. Bigelow Laboratory for Ocean Sciences, Booth Bay Maine, July 8-11.

1986 Ecological Risk Assessment Colloquium, Environmental Effects branch of the U.S. Environmental Protection Agency, Baltimore. Nov 10-14.

1987 Risk Assessment: Its context, theory and application, Fish Habitat Short Course, Colorado State University. Nov. 18.

1987 Presentation to Pacific Northwest Power Planning Council: Strategies for a five year work plan on reservoir mortality and water budget effectiveness evaluation. December.

1988 Panel member for discussion on uncertainty at ecological modeling in a regulatory framework, sponsored by the International Society for Ecological Modeling. U. of California at Davis. August.

1989 Fish Reservoir Interactions. North American Lake Management Society, Seattle, Sept.

1989 Rebuilding Fish Populations on the Columbia River. UW Alumni Seminar. Oct 14 1989.

1990 Symposium/workshop populations, community, and ecosystem: an individual perspective. Knoxville, Tennessee, May 16-19

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Evaluation of NMFS Spill recommendation

prepared May 11, 1994

by James J. Anderson, University of Washington

Introduction

This report describes an analysis of the proposed May/June 1994 spill program for the Snake River. The analysis uses the CRISP1.4.5 model with the most up to date calibrations including the NMFS survival study in 1993 and model parameters used in the System Operation Review.

The model runs used flows and temperatures from 1990, a year similar to observed and projected flows for 1994. The 1990 flows may be below the 1994 flows so in this respect the model runs underestimate nitrogen mortality affects.

Results specific to spring chinook are given in tables below which compare a base case using the current spill schedules, the NMFS proposed spill levels to achieve a 80% fish passage efficiency (FPE), a spills to meet exactly 80 FPE, and spills that limit nitrogen level to 120%. Table 1 gives total system survival and transportation percentages under the four scenarios. Table 2 through Table 5 give in river conditions including flow at dams, percent instantaneous spill at dams (spill was set at 12 hr per day except at Ice Harbor which spilled for 24 hr to a maximum of 25 kcfs), percent nitrogen saturation levels in pools behind dams, FPE at dams, and percent in river survival of fish to each dam.

The total system survival under transportation (Table 1) assumes transport survival of 80%. A document is in preparation detailing the calibration of transportation survival estimates (Anderson et al. in preparation). System survival is taken as the percent of fish released at the top of Lower Granite Reservoir that survive to the estuary.

Table 1 System survival and transportation percents under four plans

Scenario	system survival	percent transported
Current	50%	49%
NMFS plan	37%	34%
FPE = 80%	33%	16%
$N_2 < 120\%$	48%	40%

EXHIBIT 2

Table 2 Current conditions projected for May 20.

River segment or project	Flow (kcfs)	Spill % (hr)	Nitrogen in pool	FPE	In river survival
Estuary		-	112		36
Bonneville	232	50	107	70	39
The Dalles	216	30 (8)	105	52	42
John Day	212	0	106	72	46
McNary	208	0	107	70	51
Ice Harbor	61	25[a]	114	58	56
Lower Monumental	61	0	113	65	62
Little Goose	61	30 (12)	105	65	70
Lower Granite	61	40 (12)	105	67	82

a. 25 kcfs achieved under 24 hr spill

Table 3 Conditions under 80% FPE for May 20

River segment or project	Flow (kcfs)	Spill %	Nitrogen in pool	FPE	In river survival
Estuary		-	113		17
Bonneville	232	50	116	64	20
The Dalles	216	40	113	74	22
John Day	212	33	110	78	23
McNary	208	48	110	80	26
Ice Harbor	61	25[a]	139	84	33
Lower Monumental	61	54	125	83	62
Little Goose	61	48	112	75	72
Lower Granite	61	78	100	82	84

a. 25 kcfs achieved under 24 hr spill

Table 4 Conditions under exactly 80% FPE for May 20

River segment or project	Flow (kcfs)	Spill %	Nitrogen in pool	FPE	In river survival
Estuary		-	113		15
Bonneville	232	90	118	80	16
The Dalles	216	48	113	80	17
John Day	212	36	110	80	19
McNary	208	48	110	80	21
Ice Harbor	61	40[a]	140	80	27
Lower Monumental	61	47	129	80	58
Little Goose	61	60	111	80	72
Lower Granite	61	71	100	80	84

a. 25 kcfs achieved under 24 hr spill

Table 5 Conditions for keeping nitrogen below 120% and maximizing FPE up to 80% for May 20

River segment or project	Flow (kcfs)	Spill %	Nitrogen in pool	FPE	In river survival
Estuary		-	113		38
Bonneville	232	90	118	80	40
The Dalles	216	48	113	80	40
John Day	212	36	110	80	44
McNary	208	48	110	80	52
Ice Harbor Tailrace			121		56
Ice Harbor	61	25[a]	120	64	56
Lower Monumental	61	5	120	68	63
Little Goose	61	30	111	69	71
Lower Granite	61	71	100	80	84

a. 45 kcfs achieved under 24 hr spill

AFFIDAVIT OF WESLEY J. EBEL

STATE OF OREGON)
) ss.
County of Multnomah)

I, WESLEY J. EBEL, being first duly sworn, depose and say as follows:

1. I worked as a fishery research biologist for the National Marine Fisheries Service and its predecessors for 31 years, retiring in 1988 as Director of the Coastal Zone and Estuarine Studies Division formerly the Fish Passage Research Division. Since 1988, I have worked as a part-time consultant on fish passage research problems. I obtained a Ph.D. in Forestry and Wildlife Management from the University of Idaho in 1977.

General Effects of Gas Supersaturation

2. I have conducted a number of studies concerning the effect of gas supersaturation on juvenile salmon and other fish. Gas supersaturation arises when excess gas is dissolved in water; that is, an amount of gas over what the body of water would hold normally. In the Columbia and Snake Rivers, the process of spilling water over dam spillways concentrates atmospheric gases in the water in levels that exceed the norm. These excess levels are measured by percentages. Normal saturation is 100%. In the Columbia River, values as high as 148% have been recorded.

3. Gas supersaturation adversely affects fish in a number of ways. Excess nitrogen enters the circulatory system of the fish and diffuses out, causing gas bubbles or emboli in the circulatory system and gas bubbles under the skin. These gas bubbles have a number of adverse physical effects. Gas bubbles occlude blood flow in the gills, thus suffocating the fish. Gas bubbles also occlude the mouth and throat of the fish, and can cause blindness in the fish due to hemorrhaging or exopthalmia. The gas bubbles can also

result in overextension or rupture of the swim bladder, particularly in juveniles under 50 mm in length. Collectively, these symptoms are referred to as gas bubble disease.

4. Sublethal effects of gas bubble disease are not always evident as external visible symptoms. For example, Schiewe (1974) and Dawley and Ebel (1976) determined that sublethal effects such as decreased swimming performance and growth occurred at gas supersaturation levels as low as 106%. Poor swimming performance can result in increased predation by predators in the river.

5. Laboratory research conducted by several researchers showed that the threshold levels for supersaturation where mortality begins occurring is about 110 to 115% for juvenile salmonids, depending on size and species. In shallow water, laboratory experiments have shown that, for example, at 125% saturation, 50% mortality to chinook occurs in 13.6 hours. At 120%, 50% mortality occurs in 26.9 hours for chinook.

6. The depth of a fish in the water affects the level of gas supersaturation that the fish can tolerate. For example, each foot of depth compensates for approximately 3% excess saturation. Thus a fish at 3 feet of depth in water supersaturated at 120% will be subjected to the equivalent of a gas supersaturation level of only about 110%. Tests done in deep tanks showed that significant mortality still occurred. Dawley et al. (1976)

7. It does not appear that juvenile salmonids can detect and avoid supersaturation by sounding. Nevertheless, the normal depth distribution of salmon does compensate for some excess gas supersaturation. This compensating effect is limited by the fact that a significant portion of migrating juveniles travel in the upper 3 feet of the water column. For example, Smith (1973) found approximately 30% of juvenile chinook salmon in the upper three feet of the water column at Lower Monumental Dam. Dawley (1986) found similar

distributions of chinook the forebay of the The Dalles Dam.

8. I have been unable to obtain definitive documentation of the program to increase spills. It is unusual to have a program of this magnitude developed in haste, and implemented without any public review or scrutiny. As best I can determine, the U.S. Army Corps of Engineers, at the urging of the National Marine Fisheries Service (NMFS) and other parties, will change previously-planned operations to:

(1) spill at The Dalles Dam to 40 percent 24 hours a day;

(2) spill 25,000 cubic feet per second (25 kcfs) of water at Ice Harbor Dam 24 hours a day;

(3) operate the remaining six dams to spill during the 12 nighttime hours (and 24 hours at Bonneville Dam) at the lesser of (a) the quantity of spill needed to meet 80% fish passage efficiency and (b) the quantity of spill producing a maximum 12 hour average dissolved gas concentration of 120% measured at the next downstream project; and

(4) increase spill to meet 80% fish passage efficiency to the extent that there are no observed adverse biological effects of dissolved gas over and above 120% in increments of 2.5%.

9. I also understand that the Bonneville Power Administration has estimated the increase in spill at the eight mainstem projects required to achieve 80% fish passage efficiency as follows:

	Current Spill	80% FPE Spill
Lower Granite	40% 12 hrs	78% 12 hrs
Little Goose	30% 12 hrs	48% 12 hrs
Lower Monumental	none	54% 12 hrs
Ice Harbor	25 kcfs 24 hrs	100% 12 hrs
McNary	none	48% 12 hrs
John Day	none	33% 12 hrs
The Dalles	30% 8 hrs	40% 24 hrs
Bonneville	180 kcfs 8 hrs 75 kcfs 15 hrs	same

10. Assuming that current flows in the Columbia and Snake Rivers will remain at or exceed current levels (approximately 220 kcfs in the Columbia and 75 kcfs in the Snake), the spill percentages set forth in the preceding paragraphs cannot be achieved consistent with maintaining a gas supersaturation level of 120% or less.

11. I understand that the spill program calls for increasing spills until gas supersaturation levels reach 120% as measured at the next downstream project, and thereafter increasing the percentage of supersaturation until visible signs of gas bubble disease are apparent in migrating salmon. By the time gas supersaturation levels reach 120% at the next dam down, migrating salmon will have been exposed to that level for 2-3 days.

Monitoring Gas Bubble Disease

12. Monitoring for visible signs of gas bubble disease is unlikely to provide adequate protection for salmon. By the time gas bubble disease is widely apparent in either the juvenile or adult populations, it is likely substantial losses will have occurred. During the serious dissolved gas problems in the 1960s and 1970s, it was uncommon for large numbers of migrants to be observed with gas bubble disease symptoms.

13. I understand that the program may include monitoring of adult migrants as well as juveniles. There are no facilities for such monitoring except at Bonneville Dam and Lower Granite Dam. At Bonneville Dam, one would not expect to see many fish with symptoms, because they have just come from the ocean. Any fish that were adversely affected by gas bubble disease probably would not make it to Lower Granite Dam (the uppermost dam), making it also unsuitable as a monitoring site. It would make most sense to monitor adults at Ice Harbor Dam, where spill is proposed to be continuous and adult fish with symptoms are most likely to be observed.

Effects on Adult Salmon

14. Past research has shown that high spill at dams may lead to confusing tailwater currents that make it difficult for adults to find fishway entrances. Generally speaking, adult fish passage facilities were engineered on the assumption that a substantial portion of the flow would go through turbines. When spillway flows exceeded turbine flows at all the Snake River dams in the 1960s and 1970s, adverse tailwater currents and delays of adult migrants were observed. Junge (1966); Junge (1971).

15. If the proposed spill levels set forth in paragraph 9 at Lower Granite, Lower Monumental and Ice Harbor are implemented, confusing tailwater currents will occur, with accompanying delays of migrating adults. Moreover, spilling at the levels proposed will create gas supersaturation in the spillway side of the dam in excess of 130%. Adults exposed to these levels for extended periods of time will suffer the usual symptoms of gas bubble disease and die.

16. For example, in 1968, when excess water was spilled at John Day, adults were delayed for several days and a substantial mortality of chinook and sockeye was recorded. The State of Oregon estimated that over 20,000 adult chinook were lost. Beiningen and Ebel (1970). Meekin and Allen (1974) estimated that 6% to 60% of adult salmonids in the middle region of the Columbia River died between 1965 and 1970; carcasses of adult salmon were found in the river when gas supersaturation reached 120% or higher.

Other Reasons Increased Spill May Not Benefit Salmon.

17. I assume that the proposed increases in spill are intended to increase adult returns. In 1993, the best flows and spills occurred in more than a decade. The jack returns this year of spring chinook from that year's juvenile outmigration are the lowest on record.

This strongly suggests that a program of increasing flows and spills will have little positive effect on returns of adults.

18. It is also true that a program to increase spill will necessarily reduce the fraction of juvenile salmon which are transported. There are no data to support the notion that survival of juvenile salmon migrating in the river will exceed the survival of those transported. Indeed, the scientific evidence indicates that survival of juvenile salmon in the river will be less than those transported. For these reasons, the proposed spill program may reasonably be expected to reduce adult returns.

19. The proposed spill increase has been characterized as an experiment. It would be necessary to modify the proposed spill operation to gain scientifically meaningful data. A comparison between survival of fish passing a dam with no spill vs. one with spill could be made if spilling were kept at minimal levels at Lower Monumental. Survival could then be estimated for fish passing Lower Monumental (no spill) and for Little Goose or Lower Granite (spill). Various other scenarios could be developed but additional marked fish would be essential to measure the survival under spill conditions because of the lower recovery rate caused by spill at the dams where tag detectors are a part of the juvenile collection system. For this reason, researchers currently attempting to measure juvenile survival in the Snake River would have to be allowed to mark and recover substantially more fish.

Conclusion

20. In light of the foregoing facts, in my opinion the proposed spill program poses

unacceptable risks to migrating salmon in the Columbia and Snake Rivers and will result in lower survival rather than higher survival.

21. I declare under penalty of perjury that the foregoing is true and correct.

Wesley J. Ebel

Wesley J. Ebel

SUBSCRIBED AND SWORN to before me this 11th day of May, 1994.

OFFICIAL SEAL
ELIZABETH A. WRIGHT
NOTARY PUBLIC - OREGON
COMMISSION NO.008205
MY COMMISSION EXPIRES SEPT. 02, 1995

Elizabeth A. Wright
Notary Public for Oregon
My Commission Expires: Sept 2, 1995

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TOTAL DISSOLVED GAS REPORT FOR JOHN DAY
starting at 0019 13 MAY 1994

DATE	TIME	WA TM DEG F	BARO PRES	TD GAS PRES	GAS %	N2 PRES	O2 PRES	SPILL QS	TOT QR	NUMB GATES
0513	0100	057.7	0766.0	0855.0	111.6	689.0	174.0	032.1	204.0	+++++
0513	0200	057.0	0766.0	0854.0	111.5	689.0	168.0	032.0	203.8	+++++
0513	0300	057.6	0768.0	0855.0	111.3	691.0	167.0	032.1	204.1	+++++
0513	0400	057.2	0766.0	0853.0	111.4	689.0	169.0	032.1	203.5	+++++
0513	0500	057.6	0769.0	0852.0	110.8	684.0	173.0	032.2	202.7	+++++
0513	0600	057.2	0770.0	0852.0	110.6	692.0	166.0	032.1	212.4	+++++
0513	0700	057.7	0769.0	0852.0	110.8	689.0	168.0	031.3	216.8	+++++
0513	0800	057.6	0769.0	0849.0	110.4	681.0	173.0	001.9	221.6	+++++
0513	0900	057.7	0769.0	0851.0	110.7	677.0	178.0	001.8	225.7	+++++
0513	1000	057.7	0769.0	0849.0	110.4	681.0	172.0	001.8	226.6	+++++
0513	1100	057.9	0766.0	0852.0	111.2	683.0	173.0	001.8	224.3	+++++
0513	1200	057.6	0768.0	0851.0	110.8	687.0	169.0	001.8	224.5	+++++
0513	1300	057.9	0769.0	0851.0	110.7	681.0	174.0	001.8	226.7	+++++
0513	1400	057.7	0768.0	0853.0	111.1	691.0	167.0	001.8	226.9	+++++
0513	1500	057.9	0766.0	0852.0	111.2	687.0	169.0	001.8	224.9	+++++
0513	1600	057.7	0766.0	0853.0	111.4	684.0	172.0	001.8	226.4	+++++
0513	1700	057.9	0765.0	0853.0	111.5	680.0	179.0	001.8	225.2	+++++
0513	1800	057.9	0764.0	0854.0	111.8	687.0	173.0	001.8	225.0	+++++
0513	1900	058.1	0764.0	0855.0	111.9	691.0	169.0	002.9	225.1	+++++
0513	2000	057.9	0764.0	0858.0	112.3	684.0	175.0	033.3	229.0	+++++
0513	2100	057.7	0764.0	0855.0	111.9	689.0	172.0	034.0	224.5	+++++
0513	2200	057.7	0764.0	0857.0	112.2	687.0	174.0	033.1	226.4	+++++
0513	2300	057.6	0765.0	0857.0	112.0	688.0	173.0	033.1	225.5	+++++
0514	000	057.7	0763.0	0853.0	111.8	688.0	167.0	033.6	220.0	+++++
0514	0100	058.5	0765.0	0855.0	111.8	695.0	164.0	028.1	187.6	+++++
0514	0200	057.6	0764.0	0853.0	111.6	686.0	173.0	028.4	190.9	+++++
0514	0300	057.7	0760.0	0854.0	112.4	688.0	168.0	038.4	190.6	+++++
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TOTAL DISSOLVED GAS REPORT FOR MCNARY (OREGON)
starting at 0018 13 MAY 1994

DATE	TIME	WA TM DEG F	BARO PRES	TD GAS PRES	GAS %	N2 PRES	O2 PRES	SPILL QS	TOT QR	NUMB GATES
0513	0100	055.9	0763.0	0880.0	115.3	593.0	295.0	059.7	230.3	020.0
0513	0200	055.9	0763.0	0877.0	114.9	612.0	285.0	059.7	230.3	020.0
0513	0300	055.9	0763.0	0876.0	114.8	583.0	275.0	059.7	230.3	020.0
0513	0400	055.9	0764.0	0875.0	114.5	606.0	290.0	059.7	230.3	020.0
0513	0500	055.8	0763.0	0875.0	114.7	587.0	268.0	059.7	232.2	012.0
0513	0600	055.9	0763.0	0875.0	114.7	583.0	286.0	059.7	232.2	020.0
0513	0700	055.6	0764.0	0873.0	114.3	587.0	286.0	030.5	200.5	020.0
0513	0800	055.8	0765.0	0875.0	114.4	599.0	258.0	024.7	219.3	020.0
0513	0900	055.9	0769.0	0876.0	113.9	642.0	242.0	000.0	193.2	020.0
0513	1000	063.9	0760.0	0775.0	102.0	625.0	155.0	000.0	193.8	020.0
0513	1100	065.5	0763.0	0769.0	100.8	611.0	144.0	000.0	194.9	+++++
0513	1200	058.1	0760.0	0894.0	117.6	722.0	177.0	000.0	187.0	+++++
0513	1300	057.7	0760.0	0892.0	117.4	739.0	157.0	000.0	194.0	+++++
0513	1400	058.6	0760.0	0899.0	118.3	827.0	075.0	000.0	186.6	+++++
0513	1500	058.8	0759.0	0898.0	118.3	814.0	089.0	000.0	181.4	+++++
0513	1600	061.2	0759.0	0916.0	120.7	832.0	090.0	005.1	198.8	+++++
0513	1700	062.6	0759.0	0919.0	121.1	765.0	158.0	022.5	213.4	+++++
0513	1800	061.5	0759.0	0919.0	121.1	764.0	158.0	022.5	212.7	+++++
0513	1900	057.7	0758.0	0874.0	115.3	609.0	207.0	000.0	192.3	+++++
0513	2000	060.4	0758.0	0897.0	118.3	746.0	175.0	000.0	195.1	+++++
0513	2100	057.2	0758.0	0870.0	114.8	672.0	174.0	000.0	218.8	+++++
0513	2200	060.6	0757.0	0891.0	117.7	815.0	084.0	111.1	239.6	+++++
0513	2300	057.0	0758.0	0870.0	114.8	770.0	107.0	111.1	228.8	+++++
0514	000	056.5	0758.0	0858.0	113.2	743.0	124.0	111.1	229.1	+++++
0514	0100	056.7	0757.0	0858.0	113.3	744.0	122.0	111.1	228.8	+++++
0514	0200	056.8	0757.0	0862.0	113.9	770.0	100.0	111.1	228.8	+++++
0514	0300	056.7	0757.0	0860.0	113.6	768.0	098.0	111.1	228.8	+++++
0514	0400	+++++	++++++	++++++	+++++	+++++	+++++	111.1	228.8	+++++
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TOTAL DISSOLVED GAS REPORT FOR MCNARY (WASHINGTON)
starting at 0018 13 MAY 1994

DATE	TIME	WA TM DEG F	BARO PRES	TD GAS PRES	GAS %	N2 PRES	O2 PRES	SPILL QS	TOT QR	NUMB GATES
0513	0100	057.2	0763.0	0882.0	115.6	825.0	064.0	059.7	230.3	020.0
0513	0200	057.0	0763.0	0881.0	115.5	822.0	065.0	059.7	230.3	020.0
0513	0300	057.2	0764.0	0882.0	115.4	824.0	063.0	059.7	230.3	020.0
0513	0400	057.2	0764.0	0881.0	115.3	824.0	064.0	059.7	230.3	020.0
0513	0500	057.2	0764.0	0880.0	115.2	822.0	063.0	059.7	232.2	012.0
0513	0600	057.2	0764.0	0876.0	114.7	821.0	062.0	059.7	232.2	020.0
0513	0700	056.8	0764.0	0876.0	114.7	820.0	063.0	030.5	200.5	020.0
0513	0800	057.0	0765.0	0877.0	114.6	821.0	063.0	024.7	219.3	020.0
0513	0900	057.0	0765.0	0877.0	114.6	822.0	062.0	000.0	193.2	020.0
0513	1000	057.2	0765.0	0877.0	114.6	821.0	064.0	000.0	193.8	020.0
0513	1100	057.2	0765.0	0877.0	114.6	820.0	064.0	000.0	194.9	+++++
0513	1200	057.6	0764.0	0879.0	115.1	821.0	064.0	000.0	187.0	+++++
0513	1300	057.2	0763.0	0879.0	115.2	694.0	191.0	000.0	194.0	+++++
0513	1400	057.2	0761.0	0879.0	115.5	697.0	188.0	000.0	186.6	+++++
0513	1500	057.6	0763.0	0876.0	114.8	694.0	188.0	000.0	181.4	+++++
0513	1600	057.2	0761.0	0875.0	115.0	692.0	189.0	005.1	198.8	+++++
0513	1700	057.6	0761.0	0875.0	115.0	691.0	190.0	022.5	213.4	+++++
0513	1800	057.6	0760.0	0874.0	115.0	691.0	190.0	022.5	212.7	+++++
0513	1900	057.7	0759.0	0881.0	116.1	693.0	195.0	000.0	192.3	+++++
0513	2000	057.7	0759.0	0885.0	116.6	697.0	195.0	000.0	195.1	+++++
0513	2100	057.7	0760.0	0882.0	116.1	693.0	196.0	000.0	218.8	+++++
0513	2200	057.9	0760.0	0882.0	116.1	693.0	195.0	111.1	239.6	+++++
0513	2300	057.7	0758.0	0882.0	116.4	693.0	195.0	111.1	228.8	+++++
0514	000	058.8	0759.0	0886.0	116.7	697.0	197.0	111.1	229.1	+++++
0514	0100	059.2	0759.0	0887.0	116.9	697.0	197.0	111.1	228.8	+++++
0514	0200	058.6	0758.0	0884.0	116.6	695.0	195.0	111.1	228.8	+++++
0514	0300	058.6	0758.0	0881.0	116.2	693.0	194.0	111.1	228.8	+++++
0514	0400	+++++	++++++	++++++	+++++	+++++	+++++	111.1	228.8	+++++
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or proposed hydroelectric project that was previously certified by the Director of the Department of Environmental Quality according to section 401 (1) of the Federal Water Pollution Control Act P.L. 92-500, as amended:

(1) The director shall:

(a) Solicit and consider the comments of all affected state agencies relative to adverse impacts on water quality caused by changes in the project, according to sections 301, 302, 303, 306 and 307 of the Federal Water Pollution Control Act, P.L. 92-500, as amended.

(b) Approve or deny a certification of the proposed change after making findings that the approval or denial is consistent with:

(A) Rules adopted by the Environmental Quality Commission on water quality;

(B) Provisions of sections 301, 302, 303, 306 and 307 of the Federal Water Pollution Control Act, P.L. 92-500, as amended;

(C) Standards established in ORS 543.017 and rules adopted by the Water Resources Commission implementing such standards; and

(D) Standards of other state and local agencies that are consistent with the standards of ORS 543.017 and that the director determines are other appropriate requirements of state law according to section 401 of the Federal Water Pollution Control Act, P.L. 92-500, as amended.

(2) On the basis of the evaluation and determination under subsection (1) of this section, the director shall notify the appropriate federal agency that:

(a) The proposed change to the project is approved; or

(b) There is no longer reasonable assurance that the project as changed complies with the applicable provisions of the Federal Water Pollution Control Act, P.L. 92-500, as amended, because of changes in the proposed project since the director issued the construction license or permit certification. [Formerly 468.734; 1993 c.544 §2]

468B.048 Standards of quality and purity; factors to be considered; meeting standards. (1) The commission by rule may establish standards of quality and purity for the waters of the state in accordance with the public policy set forth in ORS 468B.015. In establishing such standards, the commission shall consider the following factors:

(a) The extent, if any, to which floating solids may be permitted in the water;

(b) The extent, if any, to which suspended solids, settleable solids, colloids or a combination of solids with other substances suspended in water may be permitted;

(c) The extent, if any, to which organisms of the coliform group, and other bacteriological organisms or virus may be permitted in the waters;

(d) The extent of the oxygen demand which may be permitted in the receiving waters;

(e) The minimum dissolved oxygen content of the waters that shall be maintained;

(f) The limits of other physical, chemical, biological or radiological properties that may be necessary for preserving the quality and purity of the waters of the state;

(g) The extent to which any substance must be excluded from the waters for the protection and preservation of public health; and

(h) The value of stability and the public's right to rely upon standards as adopted for a reasonable period of time to permit institutions, municipalities, commerce, industries and others to plan, schedule, finance and operate improvements in an orderly and practical manner.

(2) Standards established under this section shall be consistent with policies and programs for the use and control of water resources of the state adopted by the Water Resources Commission under ORS 536.220 to 536.540.

(3) Subject to the approval of the department, any person responsible for complying with the standards of water quality or purity established under this section shall determine the means, methods, processes, equipment and operation to meet the standards. [Formerly 449.086 and then 468.735]

468B.050 When permit required. (1) Except as provided in ORS 468B.215, without first obtaining a permit from the director, which permit shall specify applicable effluent limitations and shall not exceed five years in duration, no person shall:

(a) Discharge any wastes into the waters of the state from any industrial or commercial establishment or activity or any disposal system.

(b) Construct, install, modify or operate any disposal system or part thereof or any extension or addition thereto.

(c) Increase in volume or strength any wastes in excess of the permissive discharges specified under an existing permit.

(d) Construct, install, operate or conduct any industrial, commercial, confined animal feeding operation or other establishment or activity or any extension or modification thereof or addition thereto, the operation or conduct of which would cause an increase in the discharge of wastes into the waters of

United States Department of the Interior

FISH AND WILDLIFE SERVICE
911 N E 11th Avenue
Portland, Oregon 97232-4181

May 16, 1994

Fred Hansen, Director
Oregon Department of Environmental Quality
811 SW Sixth
Portland, Oregon 97204

Dear Mr. Hansen:

The National Marine Fisheries Service and U.S. Fish and Wildlife Service, with input from the State fishery agencies and Indian tribes, recently decided to increase spill at eight Corps of Engineer's dams on the Snake and Columbia rivers. The Corps of Engineers, with the concurrence of the Governors of the States of Oregon and Washington began implementing the spill program on May 10, 1994.

This action was taken because of the near total collapse of the spring chinook run to the upper Columbia and Snake rivers and because of the need to take extraordinary actions to attempt to increase the survival of the fish.

While we agree that there are risks associated with increase gas supersaturation, the levels that are occurring with the current spill program do not pose a serious risk. We are confident that the biological and physical monitoring program that has been implemented and the in-season management process will enable us to make modifications to the program if necessary and prevent impacts to the fish. The attached paper jointly developed by the Fish and Wildlife Service and other Federal and State fishery agencies and tribe's technical staffs, describes the scientific rationale for the spill program.

We are well aware of all of the risks associated with fish migration in the Columbia Basin. Turbine passage and the stress associated with fish collection and transport pose major risks to the survival of upriver runs. The spill program will create improved conditions for inriver migrants and spread the risks associated with turbine passage and transportation.

We strongly support the spill program and urge your support during this critical time.

Sincerely,

Acting Regional Director

Attachment

SCIENTIFIC RATIONALE FOR IMPLEMENTING A SPILL PROGRAM TO INCREASE JUVENILE SALMON SURVIVAL IN THE SNAKE AND COLUMBIA RIVERS

The following summarizes the scientific basis for implementing a spill program during 12 nighttime hours at all Corps of Engineers dams on the mainstem Snake and Columbia Rivers to increase protection for 1994 spring outmigrating juvenile salmon. As concluded by the peer review team of independent scientists, "[t]ransportation alone, as presently conceived and implemented, is unlikely to halt or prevent the continued declined and extirpation of listed species of salmon in the Snake River Basin" (Mundy et al. 1994). Spill at transportation and collector dams, while continuing to transport those fish collected by the mechanical bypass system, addresses the substantial uncertainty associated with the effectiveness of the juvenile transportation program (TRG 1993; Mundy et al. 1994). A management approach when faced with uncertainty is to spread the risk between two choices. The spill program is designed to improve in-river passage survival and spread the risk by leaving a larger percentage of juvenile salmon migrating in-river. For the last several years, substantial spill for juvenile migrants has been implemented at all mid-Columbia Public Utility District projects. As well, substantial controlled spill has been routinely implemented at Corps projects including Lower Monumental, Ice Harbor, The Dalles, and Bonneville Dams as an effective management strategy to increase juvenile salmon survival.

The objective of the spill program is to safely guide 80% of the juvenile migrant salmon away from the turbines, the most harmful passage route at the dams, and pass them through mechanical bypass systems and over the spillways. Spill volumes will be controlled to avoid harmful levels of dissolved atmospheric gas in the river.

The current spill program at the mainstem Corps dams was jointly coordinated and devised by fishery scientists from the National Marine Fisheries Service, the United States Fish and Wildlife Service, the Oregon Department of Fish and Wildlife, the Washington Department of Fish and Wildlife, the Idaho Department of Fish and Game, and the Columbia River Inter-Tribal Fish Commission. The spill program has been adopted for the remainder of the 1994 spring outmigration. This may be one of the major options, evaluated in the long term as part of an adaptive management approach, used to assist in improving juvenile survival with respect to recovery.

Fishery agencies and tribes have chosen a conservative approach to the implementation of the spill program. Where possible, based on real time and historical salmon migration patterns, spill is generally being confined to nighttime hours. This substantially limits economical impacts of spill because power demand is much less at night and river flows are lowered at night. An extensive program for monitoring the signs of gas supersaturation impacts in both juvenile and adult salmon has been established with trained biologists at each dam. The spill program can be immediately modified based upon the daily results of the monitoring program.

The following points further describe in detail the scientific rationale for initiating and continuing the program:

* Controlled spill as provided by the program, with the stringent monitoring protocols included, provides the best possible means of passage survival for downstream salmon migrants. Extensive studies at mainstem dams throughout the basin document that juvenile mortality from spill ranges from 0-3% (NWPPC 1986; Raymond 1988; Holmes 1952; Ledgerwood 1990; Iwamoto et al. 1993).

* Other passage routes through dams cause higher levels of mortality. Turbine passage causes from 10-20% direct mortality (NWPPC 1986; DFOP 1993). Mechanical bypass systems, not installed at all dams, only guide and collect 35-70% of juvenile migrants. Mortality to juvenile spring chinook that are guided by mechanical bypass systems ranges from 1-3% (Monk et al. 1991; Dawley 1991; FTOT annual reports; Krcma et al. 1986; and Brege et al. 1987).

* Spill disperses predators from the forebay and tailrace areas (Faler et al.1988)

* There is considerable evidence that juvenile fish can detect and avoid high levels of gas supersaturation (Dawley et al. 1975).

* After installation of the spill deflectors in the mid 1970's, the historical record demonstrates that better adult returns followed from juveniles which migrated under high flow and high spill conditions (Fish Passage Center SOR-19 1994).

* Four of the five best adult return ratios for Snake River spring and summer spring chinook from 1974 to 1989 occurred in 1975, 1982, 1983, and 1984. Spill levels during these years were substantially higher than those currently being implemented.

* When compared to past years, the levels of spill being implemented in 1994 are substantially less than what occurred in the late 1970's and early 1980's. These levels are not, "unprecedented" as described by the federal operators.

* Levels of spill proposed for 1994 are considerably less than those that occurred in 1993, a year in which runoff levels late in the spring chinook migration resulted in high spill rates. In 1993, no fish with signs of impacts of gas supersaturation were detected through the Smolt Monitoring Program until spill levels greatly exceeded those proposed for 1994 . The monitoring program showed that in spite of high spill (which occurred during flows that were more than twice the levels anticipated for 1994) the observed impacts of dissolved gas on fish were minor (DFOP 1993, Appendix 6).

IDAHO FISH & GAME
600 South Walnut
P.O. Box 25
Boise, ID 83707-0025

May 16, 1994

Oregon Department of Environmental Quality Commission
811 SW 6th Ave.
Portland, Oregon 97204

Dear Commissioners:

The Idaho Department of Fish and Game (Department) appreciates the opportunity to provide comment for consideration concerning the nitrogen gas supersaturation standard for the Columbia River. We believe National Marine Fisheries Service (NMFS) mandated spill level is within acceptable limits for inriver migrants this year.

Spill during 12 nighttime hours has been implemented at Army Corps of Engineers dams on the mainstem Snake and Columbia rivers to provide additional protection to outmigrating juvenile chinook and sockeye salmon. The salmon of the Snake River Basin in Idaho, northeast Oregon, and southwest Washington are currently listed as threatened and endangered species pursuant to the federal Endangered Species Act. The adult spring chinook salmon run returning to the Snake River Basin is the lowest on record. Only 600 wild spring chinook salmon are expected to pass Lower Granite Dam to return to the 4,000 miles of spawning habitat for these fish in the basin. This low runsize places only 1 female in each 14 miles of spawning habitat and represents about 2 percent of the spawner abundance that could be supported by Idaho's portion of the Snake Basin. These low numbers are of critical concern to our Department. Further concern is heightened by the prediction of declines possible next year. Providing additional protection for the smolts outmigrating in 1994 is critical to the future of Snake River salmon.

The spill program at the mainstem Corps dams was jointly coordinated and devised by the fishery scientists from the NMFS, the United States Fish and Wildlife Service, the Oregon Department of Fish and Wildlife, the Washington Department of Fish and Wildlife, the Columbia River Inter-Tribal Fish Commission, and our Department. Controlled spill as provided by the program is the best possible means of improving dam passage survival for salmon smolts. The stringent monitoring program associated with spill will ensure that the desired benefits will be achieved for the salmon.

Cecil D. Andrus / Governor
Jerry M. Conley / Director

Equal Opportunity Employer

Working for wildlife - since 1938

Our Department requests that the Oregon Environmental Quality Commission continue the variance from the state of Oregon for the standard in the mainstem Columbia River.

Sincerely,

for Jerry M. Conley,
Director

JMC:BB:alb

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Region
7600 Sand Point Way, N.E.
Bin C15700, Bldg. 1
Seattle, Washington 98115-0070

F/NW

Mr. William S. Wessinger, Chair
Environmental Quality Commission
121 S.W. Salmon - Suite 1100
Portland, Oregon 97204

Dear Mr. Wessinger:

I understand that the Commission is meeting today to review the question of a variance or modification to water quality standards affecting spill at hydroelectric projects operated by the U.S. Army Corps of Engineers on the mainstem Columbia and Snake rivers. As you know the National Marine Fisheries Service (NMFS) has requested and the dam operators have agreed to provide increased spill to improve the survival of downstream migrating juvenile salmon. I strongly urge your favorable consideration of this operation.

For your information, I am enclosing a brief review of the scientific rationale for this operation that was developed by technical staff of NMFS and other fishery agencies and tribes. Thank you for your assistance. If I can be of further assistance, please do not hesitate to call.

Sincerely,

Gary Smith

J. Gary Smith
Acting Regional Director

Enclosure

cc: Emery Castle
Henry Lorenzen
Carol Whipple
Linda McMahan

SCIENTIFIC RATIONALE FOR IMPLEMENTING A SPILL PROGRAM TO INCREASE JUVENILE SALMON SURVIVAL IN THE SNAKE AND COLUMBIA RIVERS

The following summarizes the scientific basis for implementing a spill program during 12 nighttime hours at all Corps of Engineers dams on the mainstem Snake and Columbia Rivers to increase protection for 1994 spring outmigrating juvenile salmon. As concluded by the peer review team of independent scientists, "[t]ransportation alone, as presently conceived and implemented, is unlikely to halt or prevent the continued declined and extirpation of listed species of salmon in the Snake River Basin" (Mundy et al. 1994). Spill at transportation and collector dams, while continuing to transport those fish collected by the mechanical bypass system, addresses the substantial uncertainty associated with the effectiveness of the juvenile transportation program (TRG 1993; Mundy et al. 1994). A management approach when faced with uncertainty is to spread the risk between two choices. The spill program is designed to improve in-river passage survival and spread the risk by leaving a larger percentage of juvenile salmon migrating in-river. For the last several years, substantial spill for juvenile migrants has been implemented at all mid-Columbia Public Utility District projects. As well, substantial controlled spill has been routinely implemented at Corps projects including Lower Monumental, Ice Harbor, The Dalles, and Bonneville Dams as an effective management strategy to increase juvenile salmon survival.

The objective of the spill program is to safely guide 80% of the juvenile migrant salmon away from the turbines, the most harmful passage route at the dams, and pass them through mechanical bypass systems and over the spillways. Spill volumes will be controlled to avoid harmful levels of dissolved atmospheric gas in the river.

The current spill program at the mainstem Corps dams was jointly coordinated and devised by fishery scientists from the National Marine Fisheries Service, the United States Fish and Wildlife Service, the Oregon Department of Fish and Wildlife, the Washington Department of Fish and Wildlife, the Idaho Department of Fish and Game, and the Columbia River Inter-Tribal Fish Commission. The spill program has been adopted for the remainder of the 1994 spring outmigration. This may be one of the major options, evaluated in the long term as part of an adaptive management approach, used to assist in improving juvenile survival with respect to recovery.

Fishery agencies and tribes have chosen a conservative approach to the implementation of the spill program. Where possible, based on real time and historical salmon migration patterns, spill is generally being confined to nighttime hours. This substantially limits economical impacts of spill because power demand is much less at night and river flows are lowered at night. An extensive program for monitoring the signs of gas supersaturation impacts in both juvenile and adult salmon has been established with trained biologists at each dam. The spill program can be immediately modified based upon the daily results of the monitoring program.

The following points further describe in detail the scientific rationale for initiating and continuing the program:

* Controlled spill as provided by the program, with the stringent monitoring protocols included, provides the best possible means of passage survival for downstream salmon migrants. Extensive studies at mainstem dams throughout the basin document that juvenile mortality from spill ranges from 0-3% (NWPPC 1986; Raymond 1988; Holmes 1952; Ledgerwood 1990; Iwamoto et al. 1993).

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testimony
file copy

NMFS Spill Request

Background

The National Marine Fisheries Service is requesting implementation of a spill proposal developed by the technical staffs of the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, in coordination with the State fishery agencies and tribes, in response to the decline of Snake River salmon listed under the Endangered Species Act. The revised estimate of the Columbia River spring chinook salmon run indicates that the expected number of adult returns is 19,000, down from an earlier estimate of 49,000. Of these fish, 600 to 800 are expected to pass Lower Granite Dam in the Snake River. This is approximately 10% of the recent 10 year average of annual spring chinook salmon counts at Lower Granite Dam; and this is the lowest run on record. 1994 jack returns indicate that the 1995 spring chinook run is also expected to be relatively small.

It is our expectation that implementation of this spill proposal will increase the downstream passage survival of listed juvenile Snake River spring/summer chinook salmon. The initial request for implementation of this spill proposal was outlined in a May 9th letter from Gary Smith of the National Marine Fisheries Service to Randy Hardy of the Bonneville Power Administration and General Ernest Harrell of the Army Corps of Engineers, following a May 7th conference call.

Initial Spill Request

The initial 12-hour spill request is intended to result in 80% Fish Guidance Efficiency, that is, 80% of the daily average passage of juvenile spring/summer chinook salmon migrants will pass hydroelectric dams via non-turbine routes at Bonneville, John Day, McNary, Lower Monumental, Little Goose, and Lower Granite dams. Spill is to be capped at 40% of instantaneous flow at The Dalles Dam and at 25 kcfs at Ice Harbor Dam. Also, daytime spill at Bonneville Dam will continue to be capped at 75 kcfs.

Initial spill levels to achieve 80% Fish Guidance Efficiency are based on the Fish Passage Center's System Operational Request number 94-19, dated April 26, 1994. Specifically, the following spill levels should be implemented:

at Lower Granite Dam

78% of instantaneous flow, from 1800-0600 hrs.

at Little Goose Dam

48% of instantaneous flow, from 1800-0600 hrs.

at Lower Monumental Dam

54% of instantaneous flow, from 1800-0600 hrs.

at Ice Harbor Dam

25 kcfs, 24 hrs. per day

at McNary Dam

48% of instantaneous flow, from 1800-0600 hrs.

at John Day Dam

33% of instantaneous flow, from 1900-0700 hrs.

at The Dalles Dam

40% of instantaneous flow, 24 hrs. per day

and, at Bonneville Dam

Through May 31:

68% of instantaneous flow, from 1/2 hour before sunset to 1 hour before sunrise

and 75 kcfs, from 1 hour before sunrise to 1/2 hour before sunset

From June 1 through June 20:

68% of instantaneous flow, from 1 hour after sunset to 1 hour before sunrise

and 75 kcfs, 1 hour before sunrise to 1 hour after sunset

The initial increased spill levels at these projects will be tailored so as not to exceed a maximum 12-hour average total dissolved gas level of 120% of saturation, as measured at mainstem Columbia and Snake river dam forebay and existing tailrace monitoring stations, and at Warrendale, below Bonneville Dam.

In-Season Management

Spill will be managed in-season on a twice weekly basis. Decisions to increase or decrease spill levels, and associated dissolved gas levels, will be made by the Operations Group, with the concurrence of the National Marine Fisheries Service, at regularly scheduled meetings on Monday and Thursday of each week, or on an emergency basis if necessary. State fishery agency and tribal input will also be considered prior to modification of spill levels. Spill modification decisions will be based on the results of biological and associated physical monitoring to be conducted during these spill operations. Biological monitoring will include monitoring of adult salmon passage conditions and tailrace conditions that migrant juvenile salmon encounter. Also, decisions to modify spill regimes to facilitate ongoing dam bypass research will be made by National Marine Fisheries Service research personnel.

After 2 weeks of operation under the revised spill regime, the National Marine Fisheries Service will convene monitoring experts to review the monitoring design and protocol, and to recommend any changes to the program. The complete biological monitoring program must be in place prior to implementing spill levels that would result in dissolved gas levels in excess of 120% of saturation, if such increases are necessary to achieve 80% Fish Passage Efficiency. Spill levels would be modified to achieve incremental increases in dissolved gas levels of 2.5%. Results of biological monitoring would continue to be considered during in-season management, and spill levels would be modified in response to observed gas bubble disease symptoms.

Specifically, recommendations to decrease spill levels ~~will~~ may be made if gas bubble disease symptom occurrence exceeds 5% in sampled juvenile salmonids, and/or 2% in adult salmon at any monitoring location. If, at any time, unusual or unexpected events occur which would negatively impact survival of migrant salmonids, implementation of further increases in spill levels may be terminated. In any case, spill will not exceed the amount necessary to achieve 80% Fish Passage Efficiency at Bonneville, John Day, McNary, Lower monumental, Little Goose, and Lower Granite dams, or the upper limits of 40% of instantaneous flow at The Dalles Dam and 25 kcfs at Ice Harbor Dam.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Region
7600 Sand Point Way N.E.
BIN C15700 Bldg. 1
Seattle, Washington 98115

MAY - 9 1994

Mr. Randy W. Hardy, Administrator
Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208

Major General Ernest J. Harrell
U.S. Army Corps of Engineers
North Pacific Division
P.O. Box 2870
Portland, Oregon 97208

Dear Mr. Hardy and General Harrell:

This letter confirms the request of the National Marine Fisheries Service (NMFS) during a May 7, 1994, conference call, to implement, at the earliest opportunity, a spill proposal at all eight dams in the Snake and lower Columbia River to increase the survival of listed juvenile Snake River spring/summer chinook salmon through June 20, 1994. I believe the proposal developed by the technical staff of the U.S. Fish & Wildlife Service and NMFS which was coordinated with the State fishery agencies and tribes, can be implemented within the flexibility of the inseason management procedure adopted in the 1994-1998 biological opinion for the Federal Columbia River Power System.

During the conference call, I indicated that we have sought the best technical advice available to formulate a proposal that would make more efficient use of available water to aid the migration of listed fish remaining in the river that are not transported in barges. The technical staff believes that the survival of fish can be increased from 5.2 to 10.5 percent if 80 percent of the fish can avoid being passed through turbines.

Essentially, discussion of the spill proposal and implementation request can be summarized as follows:

1) Immediately implement a 12-hour nighttime spill protocol at all projects, except The Dalles (spill 40 percent, 24 hours daily) and Ice Harbor (spill 25 kcfs for 24 hours daily), that does not exceed a maximum 12-hour average 120 percent dissolved gas levels. The objective of the spill protocol would be to achieve 80 percent fish passage efficiency (FPE).

Encl. 2

2) Convene monitoring experts to establish a biological monitoring design and protocol that would allow the controlled increase of dissolved gas levels above 120 percent in 2.5 percent increments to achieve the 80 percent FPE. The technical staff proposal established reviews every Monday and Thursday to determine whether incremental increases in allowable dissolved gas could be made and proposed measuring the dissolved gas levels at the next downstream project. These specifications must be reviewed before adoption. In addition, before any increase in dissolved gas level above 120 percent is permitted at any project, commitments for providing qualified biological monitoring personnel must be made and training completed to ensure that adequate safeguards are provided for detecting gas bubble disease in both juvenile and adult fish. It is also critical that the effectiveness of the spill proposal and biological impacts be monitored to determine if any changes in protocol will be necessary through the in-season management process. I have asked Dr. Michael Schiewe, NMFS' Northwest Fisheries Science Center, to provide guidance for this task.

3) The technical staff proposal addresses the remainder of the juvenile Snake River spring/summer chinook migration. I have asked the technical staff to review the applicability and biological benefits of extending the spill proposal to cover the Snake River fall chinook migration through July 31. NMFS will consider further recommendations following the review.

4) Concern about managing spill at levels of dissolved gas above current State water quality standards to meet the Environmental Protection Agency guidelines of 110 percent also was discussed. We have prepared letters to the Governors of Washington, Oregon, and Idaho requesting their assistance in obtain necessary variances to manage spill above the 110 percent dissolved gas levels. Verbal contact with the States indicates this request should not pose any problem.

An important issue that was not included in the May 7 conference call was our need to continue discussions on the identification of potential sources of additional flow augmentation water. During the last Fish Operations Executive Committee (FOEC) meeting, State representatives, other than Montana, were unable to comment on the potential for further drafting of reservoirs and the curtailment of irrigation water deliveries as potential sources of augmentation water. This issue is mentioned in the letters to the Governors. We will followup with the individual States in an effort to expedite our discussions at the next FOEC meeting.

We are fully aware of the burden these additional requests places on your agencies and appreciate the efforts you and your staffs are making to meet these difficult requests. I do not believe any of us could have forecasted the impact of the continued drought conditions and the abrupt decline of listed Snake River populations.

Sincerely,

Gary Smith

J. Gary Smith
Acting Regional Director

cc: BOR-J. Keys
FWS-M. Plenert

Memorandum

To: Brian Brown and Chris Ross, NMFS
From: Howard Schaller, ODFW and Paul Wilson, CBFWA
Date: May 13, 1994
Subject: Passage survival assessment for 1994 inseason options

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We are providing an assessment of two options for inseason management of the Federal Columbia River Power System during the 1994 spring migration period. The analysis was performed using the spring chinook FLUSH passage model. The analysis contrasted the overall impacts of the two operational options with respect to inriver and overall survival. The survival estimates apply only to the population migrating from May 1 through June 20. The survival for the portion of the population migrating prior to May 1 is not included in this estimate. Therefore, these survival estimates are based on the assumption that the measures in the options are implemented starting May 1.

The details of FLUSH model structure and underlying relationships are contained in previous model documentation that we have supplied to NMFS. However, we can provide you (upon request) with updated draft documentation for the spring FLUSH model.

The first option (Option 1) was a characterization of the all the Fish Passage Center System Operation Requests up to May 1, 1994 for the 1994 juvenile migration season. The estimated flows were based on the May 1 runoff forecasts and SOR operations. These include operations which provide an estimated average flow in the Snake River of 72.5 KCFS and an average flow in the Columbia River of 225 KCFS for the period May 1 - June 20. A spill program to achieve an 80% Fish Passage Efficiency (FPE) at all 8 projects was modeled. The resultant spill volumes and spill proportions are contained in Table 1. For this option it was assumed that all fish entering the bypass systems in the Snake River collector projects were transported. However, because of flow dependent (trigger of 220 KCFS at McNary Dam) FTOT rules regarding separator efficiencies, 80% of the bypassed fish were returned to the river. The resulting proportion of the initial population that is transported at all collector projects is in Table 2. This option was simulated using three transport model assumptions. A detailed description of these transport model approaches is contained in the State and Tribal Fishery Agencies "1994 ESA Section 7 Assessment Snake River Spring/Summer Chinook". The survival values for transported fish (derived from the 3 transport models) used in the simulations are shown in the footnotes of Table 2. The predator mortality reduction was assumed to be 12.5% for all simulations. Survival of fish migrating inriver and overall system survival are provided for the 3 transport models in Table 2.

In Option 2 the estimated flow was derived from the actions and runoff forecasts applied in the SSARR model runs of May 1, 1994. These include operations which provide an estimated average flow in the Snake River of 71.5 KCFS and an average flow in the

Columbia River of 200 KCFS for the period May 1 - June 20. The MOA spill program was modeled. The resultant spill rates and spill proportions are contained in Table 1. For this option it was assumed that all fish entering the bypass systems at all collector projects were transported. In this case the lower separator efficiency at McNary Dam was not triggered, because flows were below 220 KCFS in the Columbia River. The same transport models and predator mortality reduction level were used for simulations of Option 2. The transport survival estimates for this option, under the variable survival transport models, were lower due to lower water velocities in Option 2.

For comparison, a no transportation option (Option 3) was provided. This option is identical to Option 1 except there is no transportation.

The estimated survival of inriver migrants for Option 2 was approximately one half of the value estimated for Option 1 (Table 2). This is due to the combination of lower spill proportions, lower flow, and more fish being transported in Option 2. The last factor is due to a higher percentage of bypassed fish being transported rather than returned to the river.

The estimated survival of inriver migrants for Option 3 was greater than the value estimated for Option 1 (Table 2). The difference in this comparison can be solely attributed to the last factor in the above paragraph.

The estimated system survivals were higher in Option 1, with the exception of the simulations using the most optimistic transport survival assumption (Transport Model 2). The system survival estimates are sensitive to assumptions for transport effectiveness. The calculated Transport Return Ratio (TRR) simulated in the model for Option 2 and Transport Model 2 was 4.92:1 (Table 2). This TRR value is much higher than transport to control ratios estimated from experiments conducted in 1986 and 1989 for spring chinook in the Snake River.

The FLUSH model was designed to look at relative survival responses to differing management options. The survival results were intended be used in conjunction with life cycle models to put these relative survival changes in context.

CC: Earl Weber, CRITFC

Tom Cooney, WDFW

Charlie Petrosky, IDFG

Fred Olney, USFWS

Table 1. Project specific spill rates estimated by FLUSH

	Option 1		Option 2	
Project	Proportion Spill	Spill (KCFS)	Proportion Spill	Spill (KCFS)
LGR	0.546	39.5	0.000	0.0
LGO	0.429	31.1	0.000	0.0
LMO	0.429	31.1	0.000	0.0
IHR	0.130	9.5	0.300	21.4
MCN	0.333	75.0	0.000	0.0
JDA	0.286	64.3	0.000	0.0
TDA	0.328	73.7	0.100	20.0
BON	0.630	142.0	0.530	106.0

Table 2. FLUSH Passage Model results for Snake River Spring/Summer chinook
5-May-94

Transport Model 1/	Operation Alt. 2/	Inriver Survival	% Inriver Passing Bon. Dam 3/	% of Initial Population Barged	System Survival	Transport Survival	Calculated TRR 4/
2	Option 1	10.5%	2.8%	35.1%	17.7%	42.5%	2.55
2	Option 2	5.2%	0.1%	47.3%	20.1%	42.5%	4.92
3	Option 1	10.5%	2.8%	35.1%	10.3%	21.2%	1.27
3	Option 2	5.2%	0.1%	47.3%	9.4%	19.8%	2.29
4	Option 1	10.5%	2.8%	35.1%	8.2%	15.2%	0.91
4	Option 2	5.2%	0.1%	47.3%	6.8%	14.3%	1.66
N/A	Option 3	11.0%	11.0%	0.0%	11.0%	NA	NA

1/ Trans Model 2 fixed transport survival derived from 1986 TRR of 1.6:1
Trans Model 3 variable transport survival relative to H2O Travel Time
Trans Model 4 variable transport survival relative to H2O Travel Time

2/ Option 1 = SOR volume and flow levels; Spill to achieve 80% FPE at all projects; transport all bypassed fish
Ave Snake Flow = 72.5 KCFS; Ave Columbia Flow = 225 KCFS
Option 2 = Flow levels from SSARR for 5/1/94; MOU Spill levels no Spill at collector projects; transport all bypassed fish
Ave Snake Flow = 71.2 KCFS; Ave Columbia Flow = 200 KCFS
Option 3 = Same as Option 1 with no transportation

3/ Percent of the initial population which migrated inriver and survived to below Bonneville Dam

4/ Calculated TRR = FLUSH Estimated (Transport Survival / Inriver survival from Lower Granite Dam)

Predator Mortality Reduction = 12.5%

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
ENVIRONMENTAL & TECHNICAL SERVICES DIVISION
911 NE 11th Avenue - Room 620
PORTLAND, OREGON 97232
503/230-5400 FAX 503/230-5435

FEB 17 1994

F/NWO3

Greg
Please draft a response.
Detail out our process
and involve Greg Pettit
Andy Schaedel, Don Yon and
Robert Baumgartner in a revie
of the study design.
Thanks
Neil

William Sobolewski
Environmental Protection Agency
811 S.W. Sixth Ave.
Portland, OR 97204

Niel Mullane
Oregon Department of Environmental Quality
811 S.W Sixth Ave.
Portland, OR 97204

Eric Shlorff
Washington Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

Dear Messrs. Sobolewski, Shlorff and Mullane:

Thank you for attending our January 13, 1994, meeting regarding proposed dissolved gas research on the Snake and Columbia rivers. As a follow up to that meeting, we are providing you with our current draft research proposal for your review (see enclosure 1). As you may recall from this meeting, we are currently considering the option of manipulating spill to increase dissolved gas levels above the current standards. Such manipulation is not included in the current proposal; however, we are considering it because it would allow us more control over ambient test conditions. We also intend to combine this research with ongoing adult and juvenile salmonid monitoring at several dams to better estimate and evaluate the biological effects of spill/dissolved gas on migrating salmonids. These monitoring plans are enclosed (see enclosures 2 and 3). We would appreciate comments you may have on these research and monitoring efforts.

We are also hereby requesting that the state agencies provide us with detailed guidelines on obtaining a variance or modification to exceed your respective gas supersaturation standards (or water quality standards in general) for research purposes on the Snake and Columbia rivers (per our discussion at the January 13 meeting). Please include all the necessary steps, review periods, important dates, and limitations. We would also appreciate some estimation of how soon such a variance or modification may be obtained.

RECEIVED
FEB 17 1994
WATER QUALITY DIVISION
DEPT. ENVIRONMENTAL QUALITY

Unfortunately, we are working with a very limited time frame since the juvenile migration and the spill season intensifies in April and we are trying to complete research and management plans within the next few weeks. Please provide your response as soon as you can. If you have any questions regarding these enclosures or this request, please contact Gary Fredricks of my staff at (503) 230-5454.

Sincerely,

Brian J. Brown

for Merritt E. Tuttle
Division Chief

Enclosures

cc: Gary Chapman, EPA
Greg McMurray, ODEQ

DRAFT

PRELIMINARY PROPOSAL (COE) (FY94)

TITLE:	Evaluation of the Effects of Dissolved Gas Supersaturation on Fish and Invertebrates in the Mainstem Columbia and Snake Rivers
PROJECT LEADERS:	Earl M. Dawley and Margaret A. Toner National Marine Fisheries Service Northwest Fisheries Science Center Point Adams Biological Field Station P.O. Box 155 Hammond, Oregon 97121-0155 503-861-1853
ADMIN. OFFICER:	David M. Damkaer National Marine Fisheries Service Northwest Fisheries Science Center Coastal Zone and Estuarine Studies Division 2725 Montlake Boulevard East Seattle, Washington 98112-2097 206-860-3270
PROJECT DURATION:	1 January through 30 September 1994
SUBMISSION DATE:	February 1994

PROJECT SUMMARY

Increased spill to promote safe passage of juvenile salmonids over dams and in natural river flow has produced dissolved gas levels in the Columbia River Basin which often exceed the established maximum standard of 110% of saturation, and occasionally exceed 130%. In 1993, saturation levels of up to 140% were observed at Lower Monumental Dam when peak spills occurred because river flow on the Snake River exceeded powerhouse capacity or demand for power. Laboratory and field research indicate that dissolved gas levels of 130% of saturation or greater are an immediate and serious threat to aquatic organisms from gas bubble disease (GBD).

To assess GBD incidence among the aquatic biota when spill is occurring in the Columbia River Basin, weekly surveys and observations of fish and invertebrates will be conducted. Three sampling sites will be selected in each of three river reaches; the lower Snake River, mid-Columbia, and lower Columbia River. At each site, up to 100 individuals per species will be examined.

To assist in evaluating the threat of high levels of dissolved gas to the survival of each species, we will compare survey data to survival rates and GBD incidence of sampled individuals held in net pens in each river reach. From each weekly survey, 100 individuals per species (nonsalmonid) will be held for 4 days in ambient river water with one-half of the individuals held in shallow pens and one-half in large deep pens. When ambient dissolved gas levels exceed 120% of saturation, hatchery-reared fall chinook salmon will be included in the *in situ* holding assessment.

Data collected will provide a baseline understanding of the potential threat to aquatic biota from dissolved gas supersaturation produced as a result of spill at dams on the mainstem Columbia and Snake Rivers.

BACKGROUND

The U.S. Army Corps of Engineers (COE), Bonneville Power Administration (BPA), U.S. Environmental Protection Agency (EPA), and National Marine Fisheries Service (NMFS) have expressed concern regarding the possible detrimental effects of dissolved gas supersaturation on juvenile and adult anadromous fish and other biota of the Columbia and Snake Rivers. Spilling water at dams in the Columbia River Basin causes supersaturation of dissolved gas. The volume of spill during the spring has increased in recent years and may continue to increase as a result of efforts to improve fish-passage efficiency and survival by spill at dams.

Presently, the springtime levels of dissolved gas in the Columbia River Basin often exceed 110% of saturation, the maximum standard established by EPA, Washington State Department of Ecology, and Oregon State Department of Environmental Quality. Occasionally, saturation levels exceed 130%. Based on past observations of GBD in resident fish (Dell et al. 1974, Weitkamp 1974), mortality of caged juvenile salmonids (Ebel 1969, Ebel 1971, Meekin and Turner 1974, Weitkamp 1976, Blahm et al. 1976, Dawley 1986), diminished survival of migrating salmonids in the Columbia River Basin (Beiningen and Ebel 1970, Ebel 1971, Meekin and Allen 1974, Ebel et al. 1975, Ebel and Raymond 1976), and laboratory studies (Weitkamp and Katz 1975), dissolved gas levels of 130% of saturation or greater are an immediate and serious threat to aquatic organisms.

The effects of dissolved gas supersaturation from present-day hydropower operation on biota in the Columbia River Basin should be quantified. In 1993, operational procedures were established to monitor migrating juvenile and adult salmonids for signs of GBD at each of the dams on the lower Columbia and Snake

Rivers where migration monitoring occurred. Juvenile monitoring for GBD was conducted by the Fish Passage Center Smolt Monitoring Program, while adult monitoring was conducted by various fisheries agencies and the Columbia River Inter-Tribal Fish Commission. In addition, dissolved gas levels were monitored throughout the mid- and lower Columbia and lower Snake Rivers as part of the COE annual monitoring program. Also in 1993, a pilot program was implemented by NMFS to address the biological effects of gas supersaturation downstream from Bonneville Dam. Although signs of GBD were only occasionally observed, at certain times and locations and for certain species there was a high incidence of GBD. In that reach of river, NMFS developed procedures and established sampling locations which provided real-time observations of juvenile salmonids, resident fish, and aquatic invertebrates.

Because of the increased spill levels being requested to improve juvenile salmonid fish-passage efficiency through mainstem dams, NMFS proposes to assess some of the biological effects of ambient levels of dissolved gas supersaturation on resident fish such as peamouth chubs, suckers, and sticklebacks, and on invertebrates such as crayfish as well as on juvenile salmonids in the Columbia and lower Snake Rivers.

OBJECTIVES

The objectives of this study are: 1) to assess some of the impacts of ambient levels of gas supersaturation on the aquatic biota in the lower Snake and mid- and lower Columbia Rivers, and

2) to augment the existing database on the tolerance of resident nonsalmonid species to high dissolved gas levels. We propose to survey reservoir and free-flowing river reaches and conduct _in situ_ bioassays of the effects of dissolved gas using resident fish species, benthic and epibenthic invertebrates, and hatchery-reared salmonids. In the event of low gas supersaturation levels throughout the Columbia River Basin during the proposed study period, laboratory bioassays will be conducted with invertebrates and nonsalmonid fish species. The final product of research will be an analysis of the relationship between levels and duration of exposure to gas-supersaturated conditions and observed impacts on free-swimming and captive organisms. This study should be repeated annually during the spring freshet/juvenile salmonid outmigration to bracket a wide range of river flows and gas supersaturation levels.

METHODS

We propose a multiple year study. Beginning in 1994, we propose to assess the effects of ambient dissolved gas saturation levels and prevalence of GBD in juvenile salmonids, resident fish, and invertebrates in three river reaches and in test organisms (excluding migrant and resident salmonids) held for 4 days in net pens under ambient river conditions.

The river reaches to be sampled and rationales for their selection are as follows: 1) Priest Rapids Reservoir and the Hanford reach--effects of dissolved gas from spill throughout the mid-Columbia River will be represented here, and resident fish species were previously sampled for GBD (Dell et al. 1974). There is also a large resident population of juvenile fall chinook salmon in this reach that may be severely impacted by gas supersaturation; 2) Ice Harbor Reservoir and tailrace--effects of dissolved gas from spill from the lower Snake River dams will be represented in this reach; 3) downstream from Bonneville Dam--in a high flow year, spill volumes are expected to be high in this reach and no other biological sampling is being conducted. Within each of the three listed river reaches, three sites will be selected and sampled at regular intervals.

Sampling Intensity

Three sites within each of the three river reaches will be sampled once each week from April through June or July. If a high runoff and flow year is predicted, sampling will begin prior to any major spill (early April), and continue throughout the period of spill (probably through June at sites upstream from Bonneville Dam and through July at sites downstream from Bonneville Dam). At each site we will collect and examine for signs of GBD up to 100 individuals of the predominant taxa.

If total dissolved gas (TDG) saturation levels exceed 120%, and/or if GBD is observed in collected aquatic organisms, sampling effort will be increased to include additional sites in the affected river reach to augment observations of GBD.

Sampling Methods

Sampled organisms will include migrant salmonids and resident fish from nearshore, and benthic and epibenthic organisms collected in water depths of from 0.5 to 3.0 m. Gear will include 50-m beach and 7.5-m 2-person seines, fyke nets, hoop nets, traps, electrofishing equipment (if other methods prove ineffective), epibenthic sleds, and Ekman or Ponar samplers. Sampling will occur during daylight hours. Nighttime sampling will be conducted if deemed appropriate or if dissolved gas levels in net pens increase substantially at night.

Sampled organisms will be examined visually immediately for signs of GBD. Species identification (to the lowest practical taxon), life-history stage, fork length or total length, and location will be recorded. Dissolved gas saturation will be measured when biological samples are collected. Dissolved gas levels will also be obtained from the COE dissolved gas monitoring program.

<u>In situ</u> Bioassays of Dissolved Gas

Once each week, a subsample of up to 100 organisms per taxon of resident fish (excluding salmonids) and other invertebrates will be placed in net pens or cages located in each of the three river reaches. Evidence suggests that gas levels are lower nearshore than offshore in reservoirs or rivers. Resident fish and invertebrates may or may not be able to detect and avoid high gas levels. Thus, test organisms for use in <u>in situ</u> bioassay tests will be collected from an area near the location of the net pens. One-half of the organisms will be held in shallow water (0.25 m) cages and the other one-half will be held in 1.8- x 2.44- x 4-m deep net pens to allow free access to a depth of 4 m. Once each day during the 4-day holding period, test organisms will be brought to the surface, anesthetized and examined for signs of GBD. Any depth compensation occurring in these organisms will not be compromised because of the fairly short time that these organisms will be at the surface, since the physiological effects of high levels of gas supersaturation generally take several days to develop. Tests will terminate and organisms will be released at the end of the 4 days after final examination and recovery from the anesthetic. When dissolved gas levels are greater than 120% of saturation, 100-fish groups of hatchery-reared fall chinook salmon will be included as test organisms.

The results of these *in situ* bioassays will not be extrapolated to represent river-wide populations of the same taxon, but will provide comparative data relative to the occurrence and duration of supersaturation at the holding locations. Dissolved gas levels will be recorded continuously at the holding locations.

Laboratory Bioassays of Dissolved Gas

In the event of a low water flow year with little or no incidence of GBD, we propose to conduct laboratory dissolved gas bioassays using nonsalmonid aquatic species collected during river sampling. A mobile wet-laboratory with a supersaturation generator will be located at the NMFS Pasco Biological Field Station. Tests will utilize 100 organisms per taxon for 4-day periods held at constant and variable gas concentrations. Since different species exhibit differing tolerances to high levels of gas supersaturation, test conditions will be selected to bracket the expected range of tolerances of the collected test organisms. Invertebrate species will be included along with resident fish due to the paucity of information on their resistance and tolerance to high levels of gas supersaturation.

Data Analysis and Statistics

The outcome of this study is a model that can predict, within a 95% prediction interval of specified precision, what effects a certain spill regime with its resulting dissolved gas saturation level will have on juvenile salmonids and on other aquatic organisms in shallow-water habitats. The effects that we will be analyzing in our model are external signs of GBD and mortalities in the organisms held in net pens as well as the external signs of GBD observed in organisms sampled from the wild. To develop our model, we will determine the percent of individuals displaying signs of GBD and percent mortality for each species sampled resulting from exposure to ambient levels of dissolved gas saturation. We intend to use regression analyses to correlate observations of signs of GBD and mortality of organisms held in net pens at ambient dissolved gas saturation levels. We will need to make observations during different flow levels with their resulting levels of dissolved gas saturation in

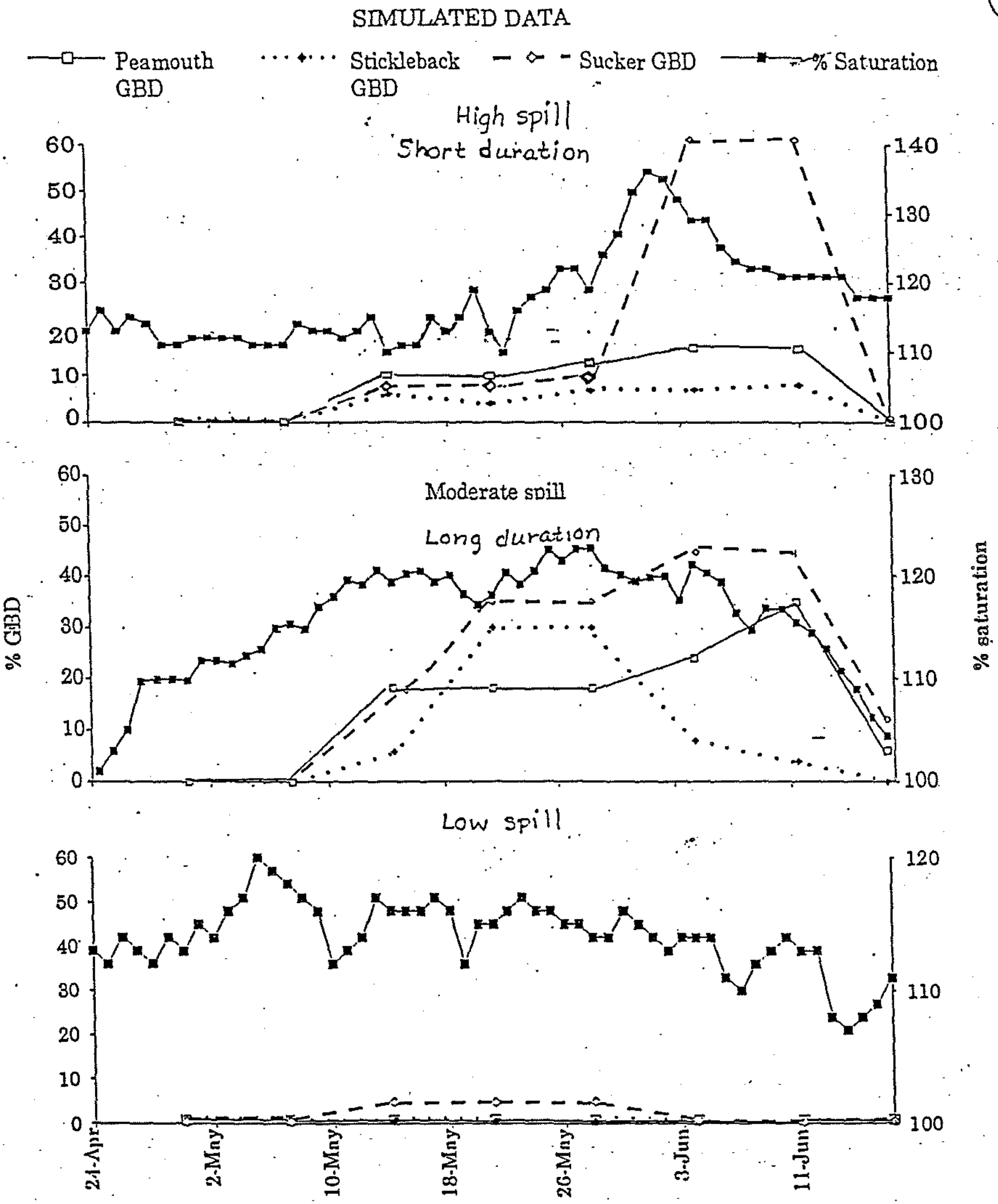

Figure 1.-- Daily average total dissolved gas % saturation during a high, moderate and low spill year (based on flows at Ice Harbor in 1986, Bonneville in 1993 and Warrendale in 1992 respectively) and data for occurrence of GBD signs in resident fish species contrived to depict what might be observed resulting from the three levels of spill.

order to obtain a sufficient number of observations. To illustrate the possible range and patterns of data we could expect for correlation, we developed Figure 1; a simulation based on the dissolved gas saturation values recorded by the U.S. Army Corps of Engineers in 1986, 1993, and 1992 for high, moderate, and low flows, respectively, and GBD sign prevalence adapted from observations by Dell et al. (1974) in the mid-Columbia River.

Limitations and Difficulties

Several years of sampling and *in situ* testing will be necessary to obtain the data set necessary to develop a model of the levels of gas supersaturation levels that constitute a threat to aquatic biota that could be used to formulate management decisions.

Expected Results and Applicability

Data collected will provide baseline understanding of potential threat to resident fish species and invertebrates from dissolved gas supersaturation resulting from spill at dams on the mainstem Columbia and Snake Rivers.

Facilities and Equipment

Three rafts and net pens will be fabricated for mobile in-river holding facilities. A mobile wet-laboratory will be outfitted for bioassays of dissolved gas supersaturation. Three dissolved gas recorders will be provided by the COE, North Pacific Division, Water Quality Section.

Reporting

Weekly summary reports will be provided to the COE and the Fish Passage Center. Data will be analyzed and a report prepared during the fall and winter.

Collaborative Arrangements

Dissolved gas monitoring data will be accessed daily from the monitoring network maintained by COE, North Pacific Division, Water Quality Section. Research activities will be coordinated with Washington Department of Fisheries, Washington Department of Wildlife, Oregon Department of Fish & Wildlife, COE Walla Walla and Portland Districts, Grant County Public Utility District, Battelle Northwest Laboratories, U.S. Department of Energy, and the Mid-Columbia Coordinating Committee.

KEY PERSONNEL

Margaret Toner	Principal Investigator
Earl Dawley	Project Manager
Stephen Grabowski	Program Manager

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From: Detailed Fishery Operating Plan - 1994
RE: Juvenile salmonid sampling

Protocol for Sampling Fish for Gas Bubble Symptoms at All Sampling Sites

1. The sample will consist of 100 fish per species per day. This sample will be taken 3 days per week. This sample will be composed of the same fish as used to determine descaling rates, weights, etc. When gas bubble symptoms are noted, then sampling will be accomplished on a daily basis at all sampling sites until the dissolved gas levels and associated gas bubble symptoms (GBS) are reduced to more normal levels.

2. When GBS first appear in the sample, a comparative sample will be taken at the separator of the following dams: Little Goose, Lower Monumental, and McNary. A sample of 100 fish of yearling chinook and steelhead will be obtained each day. Fish should be captured via a sanctuary dip net and transferred to the fish facility for examination. Samples should be taken twice during the 24 hour day. The purpose of this activity is to determine if GBS dissipate with time spent in the sample tank or raceways.

3. Individual fish will be examined for GBS in/on the fins, head, and eyes. Generally, first appearance of GBS is in the caudal fin.

4. The five classifications of GBS will be recorded. These classifications are:

    1. No Evidence = gas bubbles are not present in any fin.
    2. < 50% in one fin = gas bubbles are observed in less than 50% of the surface of one fin.
    3. > 50% in one fin = gas bubbles are observed in greater than 50% of the surface of one fin.
    4. Two or more Fins = gas bubbles are present in at least two of the fish's fins.
    5. Fin(s) + Head = gas bubbles are present in one or more of the fish's fin(s), plus the head area.

5. The Sequence to follow when inspecting a fish is to: 1) Inspect the fin area first, if no evidence is noted then, proceed to the next fish; 2) If only one fin has gas bubbles present, determine if 50% of the fin has bubbles, and record in the < or > 50% column, and proceed to next fish; 3) If a fish was noted to have gas bubbles in two or more fins, then look at the head for signs of bubbles; if no bubbles are noted in the head, record as two or more fins and proceed to the next fish. If bubbles were noted in the head area; and, 4) record as Fin(s) + head, and proceed to next fish.

    We can look for progression of GBS in the fish by using this sequence. Generally the progression is from the caudal fin to the anal or dorsal fin, and finally in the last stages to the head area on the fish.

Training:

1. Training of sampling personnel on recognition of gas bubble symptoms incidence will be completed prior to the fish passage season by experienced/trained personnel.

Reporting GBS incidence to Fish Passage Center:

1. The sample season for GBS will be from April 15 through June 15 unless high flow/spill conditions exist prior to, or after, the normal sampling dates. The Fish Passage Center will inform the sampling sites of any change in this schedule.

2. On the individual sample days for GBS, the data should be sent to the FPC on the Smolt Monitoring Summaries. The information should be added to the Comment Section and include the number observed with symptoms and the number examined for each species, negative reports are also needed. The information should always be in this format: HCH1: x/y; WCH1: x/y; etc.

3. The individual tally sheets recording the GBS by species and categories, and appropriate comments should be mailed to the FPC on Friday of each week, and will be verified by FPC personnel on a weekly basis.

4. During the GBS monitoring season, the sites should indicate in the S/36 batch comments that either 1) there was no GBS monitoring, 2) there were no observations of GBS, or 3) what the GBS observations were.

FPC Reporting of GBS:

1. The FPC will report levels of GBS incidence in the FPC's Weekly Report that is mailed out each Friday to about 300 parties in the Columbia River Basin.

2. The FPC will further request that severe cases of GBS (fin(s) + head) at individual projects be documented by photo.

DRAFT

PROPOSAL

ADULT FISH MONITORING PROGRAM - 1994

Introduction

During 1993, high flow/high spill conditions were present throughout the Columbia/Snake River Basin from mid to late May and into early June. Flows often exceeded the hydraulic capacity of the projects and uncontrolled spill or spill in excess generation needs occurred during daytime as well as nighttime hours. As a result of this spill, total dissolved gas (TDG) levels recorded at established monitoring sites exceeded 120% saturation for a one to two week period. High levels of spill can result in increased incidence of gas bubble trauma (GBT), passage delays, injuries due to fallback over spillways, scrapes and abrasions from debris, etc.

In 1993, head wounds were observed on adult salmon examined at the Lower Granite Dam trapping facility beginning shortly after the high flow and spill levels began. From May 18 through July 19, 2,660 chinook salmon were examined for marks, tags, and fish quality, of which 260 or 9.8% of the salmon had head burns. These head burns were not noted earlier in the season, i.e., prior to the onset of spill, nor had it been apparent during the past few years when little or no daytime spill occurred at Snake River Dams. Although head wounds were present, fish examined in the Lower Granite trap did not exhibit noticeable air bubbles in any of the fins (typical GBT symptoms). This led to speculation that head burns might be associated with injuries due to mechanical injuries associated with high flow and spill rather than a direct result of dissolved gas.

As a result of the high TDG levels in the river and the head burns noted at Lower Granite, efforts were initiated to routinely document GBT symptoms at fish counting stations, trapping sites, hatcheries, and from radio telemetry work. Available information on GBT symptoms, head wounds, and general fish condition will be summarized by the Fish Passage Center (FPC) and disseminated to interested parties.

1994 Monitoring Efforts

The fishery agencies and Indian tribes recommended that monitoring of adult fish be established at various sites in the Columbia Basin during the 1994 spring/summer migration (1994 DFOP, Appendix Table 5; Page 7,8). Extensive monitoring, including "hands on" sampling of salmon for condition factors such as GBT symptoms would be contingent upon whether high flow/spill was present in the system. The extent of the effort associated with the adult monitoring program for dissolved gas trauma symptoms will be dependent on the in-season total dissolved gas measurements.

1. When levels of TDG are below 120%, mainstem sampling for fish GBT symptoms will be as follows:

a. Ongoing sampling programs at Bonneville Dam and Lower Granite Dam incorporate an additional task to rate quality on those fish examined. A summary of fish quality will be provided to the FPC on a bi-weekly basis throughout the spring and summer chinook migrations by NMFS crews at Lower Granite, and CRITFC crews at Bonneville Dam. A standardized data collection sheet will be provided.

b. Ice Harbor Dam - Fish counters at the south ladders will observe fish for symptoms one hour a day on a 3-day per week basis, (preferably M-W-F). The fish counters should report this data to the WDW fish count supervisor who will fax the results to the FPC. Information should include mammal wounds, net marks, any injuries to the fish's body, and GBT symptoms. The count supervisor will be provided with a standardized data collection sheet which the fish counters will use to collect the data.

c. Normal TDG monitoring would be continued and upgraded at all established monitoring sites by the Corps of Engineers (COE), Bureau of Reclamation (BR), Idaho Power Company (IPC), and Public Utility Districts (PUD), and potentially new sites established as deemed necessary by CBFWA members. This information will be available on the CROHMS system on a daily basis.

2. When flow/spill levels increase to where TDG saturation levels exceed 120%, and are anticipated to continue based on flow forecasts, then the Monitoring program listed below should be followed. The monitoring will result in a more comprehensive evaluation for symptoms associated with increased TDG on adult fish migrating through the Columbia and Snake rivers.

a. The monitoring of TDG levels by the COE, BR, IPC, and PUD should be continued and upgraded as required, and new sites established at locations deemed necessary by CBFWA members. This information will be available on the CROHMS system on a daily basis.

Trapping and Sampling Sites

b. Bonneville Dam - "Hands-on" sampling of spring and summer chinook salmon will continue under the existing sampling programs. Fish condition will be recorded on each sampled chinook. Each chinook with any type of injury should be documented with video camera. Reporting of fish condition will be on a weekly or bi-weekly basis to the Fish Passage Center, where pertinent information would be disseminated to interested parties. Sampling will occur two days per week during periods when high TDG is present in the river.

c. Lower Granite Dam - Trapping of adult fish at LWG will allow the examination of fish on a daily basis throughout the spring and summer. All trapped chinook will be checked for fish condition, which includes head burns and GBT symptoms. Chinook that have injuries will be documented with video camera. The information will be provided to the FPC for dissemination to interested parties.

In addition, 5 to 10 hatchery chinook with the severe head burns will be sacrificed and sent to NMFS, USFWS, and State fish health labs to necropsy fish for disease, injuries, internal GBT symptoms, etc. to ascertain cause of head burns and sloughing of skin from the infected fish. Results of these findings will be provided to FPC for dissemination to interested parties.

d. John Day Dam - Adult salmon will be evaluated for presence of GBT symptoms during regular trapping of fish for radio tracking studies if that program continues in 1994. If no studies occur in 1994, then it is recommended that the Denil Fishway and associated trapping be accomplished 4-hours per day, three days per week to examine fish for GBT symptoms and head wounds. This sampling would be conducted by NMFS personnel familiar with operation of the trap and adult fish handling procedures. All injuries on adult salmon would be documented by video camera. Results would be provided to the FPC for dissemination to interested parties.

e. Ice Harbor Dam - Sampling will occur at the Ice Harbor south shore trap site three times per week for an eight hour time period, (preferably 9 a.m. to 5 p.m.). Sampling should include only delay within the trapping window, with no "hands-on" sampling required since the observer can ascertain fish condition within the confines of the trapping window. All results will be provided to FPC for dispersal to interested parties.

f. Priest Rapids - If needed, this site could be used to assess GBT symptoms. Recommended trap operation would be on a 3-day per week, four hours per day operation. Results will be provided to FPC for dissemination to interested parties.

Fish Counting Sites

a. A fish counting seminar for the fish counters will be held prior to the upstream salmon migration season. During this time, fish counters will be given training on recognition of head wounds, gas bubble symptoms, and injuries.. Slides and video footage will be available for the training session. Counters will be familiarized with data collection reports.

b. Monitoring of adult salmon for gross signs of gas bubbles and head wounds should routinely occur at all mainstem dams. The fish count supervisors may elect to check for signs of GBD for 1 to 2 hours per day rather than 16 hours per day. Daily fish counts should include incidence of GBT symptoms including those with head burns and made available to the adult fish count supervisor on a daily basis. The count supervisor should routinely provide this information to the FPC.

YAKIMA NEZ PERCE WARM SPRINGS UMATILLA

COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION

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Telephone (503) 238-0667
Fax (503) 235-4228

October 11, 1993

Bolyvong Tanovan
U.S. Army Corps of Engineers
North Pacific Division
Reservoir Control Center
P.O. Box 2870
Portland, Oregon 97208

Dear Dr. Tanovan:

The Columbia River Inter-Tribal Fish Commission (CRITFC) appreciates the opportunity to comment on the Corps Dissolved Gas Monitoring Program Plan of Action for 1994 (Plan). We have concerns with all aspects of mainstem water quality issues surrounding Corps hydroprojects as they impact our member tribes reserved treaty resources.

General Comments

We support efforts by the Corps to provide additional water quality monitoring at stations below Corps dams.

With respect to the issue of total gas pressure and spill for Ice Harbor Dam, the 1993 NMFS Biological Opinion for the Federal Columbia River Power System issued May 26, 1993 called for the Corps and the other action agencies to prepare an analysis of dissolved gas levels and fish condition to be completed before May 31, 1993. To our knowledge, this analysis has not been done. Because it is an integral aspect of the 1994 Plan, we request the analysis to be completed and the opportunity to comment on the analysis before the 1994 Plan is finalized.

We are very concerned that the Corps, as in 1993, will limit spill for salmonids solely on total gas pressure readings from limited stations below Corps dams, without real time assessment of salmonid condition. Spill is essential to mimimize mortality to juvenile fish as they pass through dams (Raymond 1988). It is well documented in the scientific literature (CBFWA 1993) that high levels of total gas pressure readings are not an inclusive indication of either chronic of acute symptoms of gas bubble trauma (GBT). The synergistic combination of many other variables such as fish size, stock, physiological condition, exposure time, depth, water temperature, turbidity and existing atmospheric pressure are responsible for the occurrence of GBT. We strongly recommend the Corps consider the effects of all these variables when analyzing the impacts of total gas pressure on salmonids. Further, we recommend the Corps manage spill on a real-time basis in consultation with the tribes according to fish condition information generated by monitoring at Corps projects by the Fish Passage Center.

In addition, we request the Corps, in close coordination with BPA, investigate ways to compensate for load distribution problems such as occurred in 1993 when the lack of a power market caused a shut down of turbines at Snake River Projects and the resulting forced spill cause levels of total gas pressure to exceed 130%. We request advance planning to be in place with respect to this serious problem before the onset of the 1994 juvenile migration season.

Finally, as a long term mitigative solution to the problem of total dissolved gas caused by Corps dams, we again request the Corps to expedite installation of flip lips at John Day, Bonneville, and Ice Harbor dams as was recommended in 1975 (Ebel et al. 1975).

Specific Comments

We support timely data distribution via the CHROMS network. This information, along with other water quality information and Fish Passage Center real-time monitoring of fish condition at dams should be used to manage spill at Corps projects.

We endorse Special Field Studies to be applied at as many projects as possible. In addition to monitoring planned below Ice Harbor, we strongly recommend similar work to be conducted below The Dalles Dam and Bonneville Dam in 1994, since spill is a chief passage route for juvenile salmonids at these dams. Horizontal and vertical mapping of the dissolved gas plume in reservoirs under specific project operational and environmental conditions and concurrent knowledge of exposure of juvenile salmonids to the plume is essential to ascertain the GBT impacts to salmonids. This information is also important as a data base to be utilized in a predictive model (Jensen et al. 1986)

We recommend the Corps funded transect studies below Ice Harbor and other Snake River dams be coordinated with existing transect work being conducted under the Snake River Water Temperature Control Project.

We recommend installation of telemetry dissolved gas monitoring stations below The Dalles and John Day Projects for 1994, as well as an additional station in the John Day pool. Millions of juvenile and adult salmonids pass through this section of the river and water quality parameters should be monitored.

We support the Corps maintaining backup monitoring equipment at certain projects so that monitoring will not be interrupted for more than a short time period. We recommend that the Corps provide backup equipment for all monitoring stations.

The CRITFC appreciates the Corps efforts and anticipates the Corps will continue to coordinate all aspects of 1994 dissolved gas monitoring with the tribes to whom the Corps has a trust responsibility to protect treaty resources. Should you have questions regarding these comments, please contact me at 731-1289.

Sincerely,

Bob Heinith
Fish Passage Biologist

cc Tribal biologists
Managers
FPAC/MLG
Soscia
Oregon DEQ
Washington DOE
EPA
Toole, NMFS

REFERENCES

Columbia Basin Fish and Wildlife Authority. 1993. Dissolved gas review and 1993 summary. Fish Passage Center. Portland, Oregon.

Ebel, W.J., H.L. Raymond, G.E. Monan, W.E. Farr, and G.K. Tanonaka. 1975. Effect of atmospheric gas supersaturation caused by dams on salmon and steelhead trout of the Snake and Columbia Rivers. United States Department of Commerce, National Marine Fisheries Service. Seattle, Washington. 111 pages.

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Mr. Bruce Lovelin
Columbia River Alliance
825 NE Multnomah, Suite 955
Portland, OR 97232
FAX 503-238-1554

May 11, 1994

re: NMFS/FWS staff recommendation for spill at Snake River and lower Columbia River dams.

Dear Bruce:

Spilling substantial quantities of water at each dam for 12 to 24 hours each day carries a considerable biological risk. As noted in the NMFS/FWS announcement you forwarded to me, any supersaturation above 120% carries a real risk of gas bubble disease in juvenile migrants, adult salmon, and resident fish. This risk will be exacerbated by supersaturation of essentially the entire migratory route from Lower Granite Dam to well-below Bonneville Dam. Both the duration and degree of supersaturation resulting from the proposed spill program are likely to greatly increase the risk of salmon losses due to gas bubble disease.

Monitoring biological conditions is unlikely to provide adequate protection for salmon. By the time gas bubble disease is widely apparent in either the juvenile or adult populations, it is likely substantial losses will have occurred. During the serious dissolved gas problems of the 1960's and 1970's, it was uncommon for large numbers of migrants to be observed with gas bubble disease symptoms. By the time such symptoms become obvious, it is likely many fish will be lost.

Monitoring for maximum levels of supersaturation should occur within several miles of each dam where water is spilled. As the water moves downstream, it will gradually lose some of the supersaturation. However, it is likely to remain sufficiently high to cause gas bubble disease if it is originally in the range of 130% or higher. Measuring 120% of saturation at a forebay location will indicate the fish were exposed to substantially higher levels in the shallow or tailrace areas.

If 130% of supersaturation is allowed to occur in any portion of the river for more than a few hours, it is likely both young and adult salmon will be adversely affected. How many fish will be lost will depend on both the duration and level of supersaturation. Since spill will be greatest at night when most fish pass the dams and fish will tend to remain with the large block of supersaturated water, it is likely many fish will be exposed to the highest levels occurring rather than the lower levels that may be measured downstream.

Supersaturation above 120% carries considerable risk. The attached Table 1 lists previous observations of salmon killed by supersaturation in the Columbia River.

Sincerely,

Don Weitkamp, Ph.D.
Principal

DW:sr

Table 1. Records of salmon mortalities caused by supersaturation

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Merrell, Collins and Greenough. 1971.

- location: Bonneville Dam
- date: 1955
- species: chinook—adult
- evidence: carcasses observed, estimated 16.8% of total run killed
- sat: unmeasured, mortality associated with high spill

Westgard. 1964.

- location: McNary Spawning Channel
- date: 1962
- species: chinook—adults
- evidence: GBD symptoms, 34% of adults
- sat: 119% (N_2)

Pauley, Fujihara and Nakatani. 1966. Pauley and Nakatani. 1967

- location: Rocky Reach Dam—aquaria and Priest Rapids Spawning Channel
- date: 1965
- species: chinook—juvenile and adults
- evidence: GBD gross symptoms and histopathology, adult mortalities
- sat: unreported

Meekin. 1971. Eble. 1969.

- location: Priest Rapids Dam
- date: 1966
- species: chinook, sockeye—adults
- evidence: mortalities
- sat: 120-130%

Beiningen and Ebel. 1970.

- location: The Dalles Dam, fish held for inspection
- date: 1968
- species: chinook, coho, sockeye, steelhead—juveniles and adults
- evidence: GBD symptoms up to one-half fish, high mortalities of juveniles held for inspection; estimated 20,000 adults killed, carcasses observed.
- sat: 123-143%

Bouck, Chapman and Schneider. 1970.
location: John Day Dam, Bonneville Dam
date: 1968, 1969
species: sockeye—adults
evidence: GBD symptoms—3 of 7 (1968), 13 of 129 (1969)
sat: 118% and above

Ebel. 1971. Raymond. 1970.
location: Ice Harbor Dam
date: 1970
species: chinook, steelhead—juvenile, adults
evidence: GBD symptoms—25-45% chinook, 30-58% steelhead; estimated loss 70% of chinook between Whitebind and Ice Harbor; symptoms in 30% of adults.
sat: 120-140%

Meekin and Allen. 1974.
location: mid-Columbia River (Wells to Priest Rapids Dams)
date: 1965-1970
species: chinook, sockeye, steelhead—adults
evidence: estimated 6-60% mortality; carcasses observed when saturation reached 120% or higher
sat: variable

GBD = gas bubble disease

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Effect of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River. Transactions of the American Fisheries Society 99:664-671.

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Observations on gas bubble disease in adult Columbia River sockeye salmon (*Oncorhynchus nerka*). Unpublished manuscript. Pacific Northwest Laboratory, Federal Water Quality Administration (US EPA), Corvallis, Oregon, 19p.

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Supersaturation of nitrogen in the Columbia River and its effect on salmon and steelhead trout. United States National Marine Fisheries Service Fishery Bulletin 68:1-11.

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Dissolved nitrogen concentrations in the Columbia and Snake rivers in 1970 and their effect on chinook salmon and steelhead trout. NOAA (National Oceanographic and Atmospheric Administration) Technical Report NMFS (National Marine Fisheries Service) SSRF (Special Scientific Report Fisheries) 646.

Meekin, T.K. 1971.
Levels of nitrogen supersaturation at Chief Joseph Dam under various spill conditions, phase 1. Report to United States Army Corp of Engineers, Contract NPSSU-71-796. Washington Department of Fisheries, Olympia, Washington.

Meekin, T.K., and R.L. Allen. 1975
Summer chinook and sockeye salmon mortality in the upper Columbia River and its relationship to nitrogen supersaturation. Washington Department of Fisheries Technical Report 12:127-153.

Merrell, T.R. Jr., M.D. Collins, and J.W. Greenough. 1971.
An estimate of mortality of chinook salmon in the Columbia River near Bonneville Dam during the summer run of 1955. Fishery Bulletin, United States Fish and Wildlife Service, 68:461-492.

Pauley, G.B., M.P. Fujihara, and R.E. Nakatani. 1966.
Salmon prespawning mortality studies at Rocky Reach Dam and Priest Rapids Dam, Washington from September to November 1965. Contract 13565-8, Washington Department of Fisheries, Biology Department, Battelle Memorial Institute, Pacific Northwest Laboratories, Richland, Washington.

Pauley, G.B., and R.E. Nakatani. 1967.
Histopathology of "gas bubble" disease in salmon fingerlings. Journal of Fisheries Research Board of Canada 24:867-871.

Westgard, R.L. 1964.

Physical and biological aspects of gas-bubble disease in impounded adult chinook salmon at McNary spawning channel. Transactions of the American Fisheries Society 93:306-309.

May 12, 1994

<u>Environmental Quality Commission</u>

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Ms. Carol A. Whipple
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Ms. Linda R. McMahan
The Berry Botanic Garden
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Re: **Special meeting of the Environmental Quality Commission regarding a request to temporarily modify Oregon's water quality standard for total dissolved gas on the Snake and Columbia Rivers.**

Dear Ladies and Gentlemen:

This Commission faces a pressing and serious issue of water quality in the Snake and Columbia Rivers, an issue that has arisen because the Corps of Engineers, at the request of the National Marine Fisheries Service, has begun spilling water in the Snake and Columbia Rivers to achieve 80 FPE (fish passage efficiency) for the current downstream migration of juvenile spring chinook salmon.

This precipitous action to increase spill is entirely voluntary, and not mandated by federal court order. Regrettably, these increased levels of spill will cause unacceptably high levels of gas supersaturation (water saturated with air at pressures exceeding one atmosphere) harmful both to juvenile and adult fish. Now, this Commission is being asked to allow this harmful condition to persist--gas saturation levels well above the current state standard of 105 percent for depths of two feet and 110 percent for depths below two feet, including disastrously high levels up to 130 percent for a period of seven days.

Pacific Northwest Generating Cooperative and Public Power Council urge this Commission to decline to continue to waive Oregon's water quality standard to permit these unacceptably high levels of total dissolved gases in the Columbia River. The **best scientific data** available indicate that, in the circumstances, waiving that standard would be clearly more harmful than beneficial to the listed spring chinook salmon and to other fish in the river, including steelhead currently migrating in river.

Gas supersaturation can kill both juvenile downstream, and adult upstream, migrants. According to a study by Drs. Dawley and Ebel, exposing **juvenile** spring chinook salmon and steelhead to 120 percent saturation caused 50 percent direct mortality in 1.5 days and 100 percent **direct** mortality in less than three days.

■U.S.E. P.A., Quality Criteria for Water 1986 (EPA 440/5-86-001), Gases, Total Dissolved. at p. 5 (discussing Dawley, E.M. and W. J. Ebel. 1975. Effects of various concentrations of dissolved atmospheric gas on juvenile chinook salmon and steelhead trout. Fishery Bulletin, 73:787-796.)

Besides direct mortality to juvenile salmonids from gas supersaturation, there are also **sublethal** effects. Dr. Schiewe found that the growth of juveniles was reduced at gas supersaturation levels of 106 to 120 percent, indicating a reduction in long term survival of these fish.

■Schiewe, M.H. 1974. Influence of dissolved atmospheric gas on swimming performance of juvenile chinook salmon. Transactions American Fisheries Society 103:717-721.

Not only does gas supersaturation adversely affect juvenile migrants, it also kills **adult** salmonids. For example, during the summer of 1968, gas levels at the tailrace of the John Day Dam were 123 to 143 percent, a condition that persisted for most of the adult upstream migration. Gas supersaturation at those levels resulted in significant adult mortality: thirteen sockeye and 365 chinook salmon were recovered dead in a single day.

■Dawley, E.M. and W. J. Ebel. 1975. Effects of various concentrations of dissolved atmospheric gas on juvenile chinook salmon and steelhead trout. Fishery Bulletin 73:787-796.

Moreover, as recently as April 20, 1994, experts in the field of gas supersaturation (including Dr. Wes Ebel) met to discuss the risks to salmonids inherent in large volumes of spill from gas supersaturation. At this meeting, **Dr. Ridler**, a noted researcher in gas supersaturation from the University of British Columbia, stressed that if the gas saturation standards in either the United States or Canada were revised based on current scientific data, they would be revised downward, not upward. He noted that environmental agencies in Canada are very concerned that sublethal effects of gas saturation have been ignored, and may be more important than acute mortality from gas supersaturation.

*Memorandum from Dr. Al Giorgi to John Stephenson dated 4/30/94 Re: Gas Saturation Workshop.

Attached is the affidavit of **Dr. Wes Ebel**, a retired biologist with NMFS, who is undisputedly one of the region's foremost experts on the effects of gas supersaturation on salmonids. As his affidavit indicates, "the proposed spill program [owing to gas supersaturation] poses unacceptable risks to migrating salmon in the Columbia and Snake Rivers and will result in lower survival rather than higher survival." **[Ebel affidavit, paragraph 19.]**

To further help the Commission fully understand this serious issue, we have also attached important studies on the adverse effects of gas supersaturation on salmonids, some of which were conducted by Dr.Ebel. Dr. Ebel will be available at the hearing before this Commission Monday to testify and answer any questions the Commissioners may have.

Very truly yours,

David E. Piper by R E J

David E. Piper
Pacific Northwest Generating
Cooperative

Robert G. Walton for

William K. Drummond
Public Power Council

AFFIDAVIT OF WESLEY J. EBEL

STATE OF OREGON)
) ss.
County of Multnomah)

I, WESLEY J. EBEL, being first duly sworn, depose and say as follows:

1. I worked as a fishery research biologist for the National Marine Fisheries Service and its predecessors for 31 years, retiring in 1988 as Director of the Coastal Zone and Estuarine Studies Division formerly the Fish Passage Research Division. Since 1988, I have worked as a part-time consultant on fish passage research problems. I obtained a Ph.D. in Forestry and Wildlife Management from the University of Idaho in 1977.

General Effects of Gas Supersaturation

2. I have conducted a number of studies concerning the effect of gas supersaturation on juvenile salmon and other fish. Gas supersaturation arises when excess gas is dissolved in water; that is, an amount of gas over what the body of water would hold normally. In the Columbia and Snake Rivers, the process of spilling water over dam spillways concentrates atmospheric gases in the water in levels that exceed the norm. These excess levels are measured by percentages. Normal saturation is 100%. In the Columbia River, values as high as 148% have been recorded.

3. Gas supersaturation adversely affects fish in a number of ways. Excess nitrogen enters the circulatory system of the fish and diffuses out, causing gas bubbles or emboli in the circulatory system and gas bubbles under the skin. These gas bubbles have a number of adverse physical effects. Gas bubbles occlude blood flow in the gills, thus suffocating the fish. Gas bubbles also occlude the mouth and throat of the fish, and can cause blindness in the fish due to hemorrhaging or exopthalmia. The gas bubbles can also

result in overextension or rupture of the swim bladder, particularly in juveniles under 50 mm in length. Collectively, these symptoms are referred to as gas bubble disease.

4. Sublethal effects of gas bubble disease are not always evident as external visible symptoms. For example, Schiewe (1974) and Dawley and Ebel (1976) determined that sublethal effects such as decreased swimming performance and growth occurred at gas supersaturation levels as low as 106%. Poor swimming performance can result in increased predation by predators in the river.

5. Laboratory research conducted by several researchers showed that the threshold levels for supersaturation where mortality begins occurring is about 110 to 115% for juvenile salmonids, depending on size and species. In shallow water, laboratory experiments have shown that, for example, at 125% saturation, 50% mortality to chinook occurs in 13.6 hours. At 120%, 50% mortality occurs in 26.9 hours for chinook.

6. The depth of a fish in the water affects the level of gas supersaturation that the fish can tolerate. For example, each foot of depth compensates for approximately 3% excess saturation. Thus a fish at 3 feet of depth in water supersaturated at 120% will be subjected to the equivalent of a gas supersaturation level of only about 110%. Tests done in deep tanks showed that significant mortality still occurred. Dawley <u>et al.</u> (1976)

7. It does not appear that juvenile salmonids can detect and avoid supersaturation by sounding. Nevertheless, the normal depth distribution of salmon does compensate for some excess gas supersaturation. This compensating effect is limited by the fact that a significant portion of migrating juveniles travel in the upper 3 feet of the water column. For example, Smith (1973) found approximately 30% of juvenile chinook salmon in the upper three feet of the water column at Lower Monumental Dam. Dawley (1986) found similar

distributions of chinook the forebay of the The Dalles Dam.

8. I have been unable to obtain definitive documentation of the program to increase spills. It is unusual to have a program of this magnitude developed in haste, and implemented without any public review or scrutiny. As best I can determine, the U.S. Army Corps of Engineers, at the urging of the National Marine Fisheries Service (NMFS) and other parties, will change previously-planned operations to:

(1) spill at The Dalles Dam to 40 percent 24 hours a day;

(2) spill 25,000 cubic feet per second (25 kcfs) of water at Ice Harbor Dam 24 hours a day;

(3) operate the remaining six dams to spill during the 12 nighttime hours (and 24 hours at Bonneville Dam) at the lesser of (a) the quantity of spill needed to meet 80% fish passage efficiency and (b) the quantity of spill producing a maximum 12 hour average dissolved gas concentration of 120% measured at the next downstream project; and

(4) increase spill to meet 80% fish passage efficiency to the extent that there are no observed adverse biological effects of dissolved gas over and above 120% in increments of 2.5%.

9. I also understand that the Bonneville Power Administration has estimated the increase in spill at the eight mainstem projects required to achieve 80% fish passage efficiency as follows:

	Current Spill	80% FPE Spill
Lower Granite	40% 12 hrs	78% 12 hrs
Little Goose	30% 12 hrs	48% 12 hrs
Lower Monumental	none	54% 12 hrs
Ice Harbor	25 kcfs 24 hrs	100% 12 hrs
McNary	none	48% 12 hrs
John Day	none	33% 12 hrs
The Dalles	30% 8 hrs	40% 24 hrs
Bonneville	180 kcfs 8 hrs 75 kcfs 15 hrs	same

10. Assuming that current flows in the Columbia and Snake Rivers will remain at or exceed current levels (approximately 220 kcfs in the Columbia and 75 kcfs in the Snake), the spill percentages set forth in the preceding paragraphs cannot be achieved consistent with maintaining a gas supersaturation level of 120% or less.

11. I understand that the spill program calls for increasing spills until gas supersaturation levels reach 120% as measured at the next downstream project, and thereafter increasing the percentage of supersaturation until visible signs of gas bubble disease are apparent in migrating salmon. By the time gas supersaturation levels reach 120% at the next dam down, migrating salmon will have been exposed to that level for 2-3 days.

Monitoring Gas Bubble Disease

12. Monitoring for visible signs of gas bubble disease is unlikely to provide adequate protection for salmon. By the time gas bubble disease is widely apparent in either the juvenile or adult populations, it is likely substantial losses will have occurred. During the serious dissolved gas problems in the 1960s and 1970s, it was uncommon for large numbers of migrants to be observed with gas bubble disease symptoms.

13. I understand that the program may include monitoring of adult migrants as well as juveniles. There are no facilities for such monitoring except at Bonneville Dam and Lower Granite Dam. At Bonneville Dam, one would not expect to see many fish with symptoms, because they have just come from the ocean. Any fish that were adversely affected by gas bubble disease probably would not make it to Lower Granite Dam (the uppermost dam), making it also unsuitable as a monitoring site. It would make most sense to monitor adults at Ice Harbor Dam, where spill is proposed to be continuous and adult fish with symptoms are most likely to be observed.

Effects on Adult Salmon

14. Past research has shown that high spill at dams may lead to confusing tailwater currents that make it difficult for adults to find fishway entrances. Generally speaking, adult fish passage facilities were engineered on the assumption that a substantial portion of the flow would go through turbines. When spillway flows exceeded turbine flows at all the Snake River dams in the 1960s and 1970s, adverse tailwater currents and delays of adult migrants were observed. Junge (1966); Junge (1971).

15. If the proposed spill levels set forth in paragraph 9 at Lower Granite, Lower Monumental and Ice Harbor are implemented, confusing tailwater currents will occur, with accompanying delays of migrating adults. Moreover, spilling at the levels proposed will create gas supersaturation in the spillway side of the dam in excess of 130%. Adults exposed to these levels for extended periods of time will suffer the usual symptoms of gas bubble disease and die.

16. For example, in 1968, when excess water was spilled at John Day, adults were delayed for several days and a substantial mortality of chinook and sockeye was recorded. The State of Oregon estimated that over 20,000 adult chinook were lost. Beiningen and Ebel (1970). Meekin and Allen (1974) estimated that 6% to 60% of adult salmonids in the middle region of the Columbia River died between 1965 and 1970; carcasses of adult salmon were found in the river when gas supersaturation reached 120% or higher.

Other Reasons Increased Spill May Not Benefit Salmon.

17. I assume that the proposed increases in spill are intended to increase adult returns. In 1993, the best flows and spills occurred in more than a decade. The jack returns this year of spring chinook from that year's juvenile outmigration are the lowest on record.

This strongly suggests that a program of increasing flows and spills will have little positive effect on returns of adults.

18. It is also true that a program to increase spill will necessarily reduce the fraction of juvenile salmon which are transported. There are no data to support the notion that survival of juvenile salmon migrating in the river will exceed the survival of those transported. Indeed, the scientific evidence indicates that survival of juvenile salmon in the river will be less than those transported. For these reasons, the proposed spill program may reasonably be expected to reduce adult returns.

19. The proposed spill increase has been characterized as an experiment. It would be necessary to modify the proposed spill operation to gain scientifically meaningful data. A comparison between survival of fish passing a dam with no spill vs. one with spill could be made if spilling were kept at minimal levels at Lower Monumental. Survival could then be estimated for fish passing Lower Monumental (no spill) and for Little Goose or Lower Granite (spill). Various other scenarios could be developed but additional marked fish would be essential to measure the survival under spill conditions because of the lower recovery rate caused by spill at the dams where tag detectors are a part of the juvenile collection system. For this reason, researchers currently attempting to measure juvenile survival in the Snake River would have to be allowed to mark and recover substantially more fish.

Conclusion

20. In light of the foregoing facts, in my opinion the proposed spill program poses

unacceptable risks to migrating salmon in the Columbia and Snake Rivers and will result in lower survival rather than higher survival.

21. I declare under penalty of perjury that the foregoing is true and correct.

Wesley J. Ebel

Wesley J. Ebel

SUBSCRIBED AND SWORN to before me this 11th day of May, 1994.

OFFICIAL SEAL
ELIZABETH A. WRIGHT
NOTARY PUBLIC - OREGON
COMMISSION NO.008205
MY COMMISSION EXPIRES SEPT. 02, 1995

Elizabeth A. Wright

Notary Public for Oregon
My Commission Expires: Sept 2, 1995

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TESTIMONY OF THE OREGON DEPARTMENT OF FISH AND WILDLIFE BEFORE THE ENVIRONMENTAL QUALITY COMMISSION REGARDING IMPLEMENTATION OF SPILL AT CORPS PROJECTS

MAY 16, 1994

1. My name is Ron Boyce, Columbia River Fish Passage Program Leader for the Oregon Department of Fish and Wildlife (ODFW). I will be providing comments on the spill program being implemented at the eight Corps projects on the lower Snake and lower Columbia rivers.

2. ODFW supports the spill program requested by the National Marine Fisheries Service (NMFS) which is designed to maximize survival of juvenile chinook and steelhead while minimizing impacts to aquatic species. The program provides for 12-hour nighttime spill at all projects to achieve a 80% fish passage efficiency up to 120% dissolved gas levels. This request is for all Corps projects on the lower Snake and lower Columbia rivers except Ice Harbor (25 kcfs for 24 hrs) and The Dalles (40% spill for 24 hrs).

3. This spill request is made in response to the critical need to increase the inriver survival of juvenile Columbia River chinook and steelhead. At extreme risk are Snake River spring chinook which are returning at historically low levels this year (adults and jacks at Lower Granite Dam are 11% and 6%, respectively of the 10-year average) with <u>only 600 wild spawners expected to escape this year</u> and even fewer next year. The returns of Mid-Columbia spring chinook are also at historical lows (19% of the 10-year average for adults and 3% for jacks at Priest Rapids Dam). The projections for escapement of Snake River and Mid-Columbia summer chinook look equally bleak. We must act now to reverse these trends to save these valuable stocks.

4. The spill program is designed to improve survival by increasing the passage of juveniles over spillways which has been shown to be the safest route past mainstem hydroelectric projects. Numerous studies conducted in the Columbia Basin have shown that fish survival is significantly higher for fish passed through spill (98%) than turbines (85%). Spilling fish will eliminate descaling, injury, and mortality associated with passage through screens, gatewells, collection galleries, dewatering screens, and transport conduits of mechanical bypass systems at 7 of 8 Corps projects and will help fish move quickly past the projects and reduce losses to predators.

5. The spill program will also improve survival by reducing the number of fish transported. The Independent Peer Review Team's recent report on studies of transportation in the Snake River found that there was inconclusive evidence to demonstrate the efficacy of transportation as a mitigative measure for recovery of federally protected Snake River chinook. Because there is great uncertainty associated transportation, the spill program

will allow more fish to migrate in-river than in the past when up to 90% of Snake River chinook and steelhead were transported each year.

6. The spill program will provide immediate and significant improvements in inriver survival of juvenile chinook and steelhead in the lower Snake and lower Columbia Rivers. For example, an analysis conducted by ODFW using the spring chinook FLUSH and transport models used in 1994 ESA Section 7 consultation indicates that the inriver survival of Snake River spring chinook would be doubled (5.2 to 10.5%) from implementation of the spill program. Although inriver survival would still be unacceptably low, these higher survivals will lower the risk of continued decline and possible extirpation of listed Snake River chinook.

7. It has been stated by the DSIs that the level of spill requested for this program will result in unacceptably high levels of dissolved gas and fish mortality. This statement is simply not true. The 1994 spill program is confined to nighttime hours and spills and dissolved gas levels will be much lower for example than those that occurred in 1993 where only 1-2% of fish at smolt monitoring sites exhibited signs of gas bubble disease (GBD) despite dissolved gas levels exceeding 120% up to 12 days and 125% for 4 days.

The DSIs have also stated that the low spring chinook jack returns observed this year can be attributed to the high dissolved gas levels observed in 1993. This is also not true since these high levels of spill and dissolved gas in 1993 occurred <u>after</u> the main fish migrations had occurred and <u>after</u> a majority of fish had been collected and transported. For example by the time the high spills and dissolved gas levels had occurred in the Snake in mid-May, nearly 90% of the chinook and steelhead had migrated and were transported below Bonneville Dam. According to ocean upwelling indices, the poor fish returns in 1993 are probably due to poor ocean conditions. We also believe that the low jack returns in 1993 in the Columbia River are in part due to the fact that the juveniles were transported rather than spilled at projects.

8. We support the biological monitoring program for GBD symptoms submitted to NMFS by the Fish Passage Center. With this program, spill levels for 80% FPE can be implemented while insuring impacts to juveniles and adults are minimized.

9. In conclusion, we recommend that the Commission adopts a 180 day variance in the State's dissolved gas criteria to allow the spill program to proceed throughout the duration of the spring and summer migration periods.

CRA
Columbia River Alliance *For Fish, Commerce and Communities*

May 11, 1994

Fred Hansen, Executive Director
Oregon Dept. of Environmental Quality
811 SW 6th Ave
Portland, OR 97204

Dear Mr. Hansen:

Please find enclosed a copy of the letter sent today, May 11, 1994, to the Washington Department of Ecology.

Based on the scientific information on "fish kill" occurring from gas supersaturation levels above 120 percent, we believe it is inappropriate for the state to grant a waiver of its own standards and authorize levels up to 130 percent. We request, therefore, that the state immediately rescind the waiver.

Thank you for your consideration.

Kindest regards,

Bruce J. Lovelin

Bruce J. Lovelin
Executive Director

Enclosure

825 NE Multnomah, Suite 955 • Portland, Oregon 97232 • (503) 238-1540 • Fax (503) 238-1554

CRA

olumbia River Alliance

For Fish, Commerce and Communities

May 11, 1994

Mr. Michael Llewelyn, Program Manager
Water Quality
Dept. of Ecology
PO Box 47600
300 Desmond Drive
Olympia, WA 98504-7600

State of Oregon
DEPARTMENT OF ENVIRONMENTAL QUALITY
RECEIVED
MAY 12 1994
OFFICE OF THE DIRECTOR

Re: <u>Administrative Order No. DE 94WO-218</u>

Dear Mr. Llewelyn:

I am writing in regards to the above cited Order issued by the Department of Ecology on May 10, 1994. The Order authorizes exceeding water quality standards for total dissolved gas under certain conditions to allow fish passage in the Columbia and Snake Rivers.

I have several concerns regarding Ecology's action in this matter which will be discussed below.

First, the water quality standard for total dissolved gas was promulgated for the very purpose of protecting aquatic life near dams. There is body of scientific studies clearly demonstrating that total gas supersaturation exceeding 120 percent is lethal to fish and other aquatic life. In fact, there are numerous cases of "fish kills" at gas supersaturation levels levels under 130 percent. (See enclosed memorandum from Dr. Don Weitkamp.) Ecology implicitly recognizes the lethal nature of supersaturation as demonstrated by Ecology's promulgation of the water quality standard in WAC 173-201A-030 (2) (c) (iii).

Yet, Ecology, without any public process or opportunity for comment by the scientific or public sectors, authorized total gas supersaturation up to 130 percent to "allow fish passage" along the Columbia and Snake Rivers. At best, it is ironic that Ecology is authorizing lethal levels of total gas supersaturation to help fish migration. At worst, Ecology has blindly accepted the National Marine Fisheries Service's (NMFS) representations that this proposal is beneficial and that the situation is an emergency, without full investigation, or even any direct discussions with NMFS's biologists at Sand Point to determine what real world impacts may be expected.

Ecology's Order specifically cites WAC 173-201A-110 as providing Ecology with the authorization to modify water quality standards. However, WAC 173-201A-110 (2) expressly states that:

> In no case will any degradation of water quality be allowed if this degradation significantly interferes with or becomes injurious to existing water uses or causes long-term harm to the environment.

825 NE Multnomah, Suite 955 • Portland, Oregon 97232 • (503) 238-1540 • Fax (503) 238-1554

Given that the very purpose of the total dissolved gas water quality standard is to prevent fish mortality, there is a presumption that exceeding the standard will cause fish death. It is unfathomable to understand how Ecology overcame that presumption and determined that allowing supersaturation to a level that is known to kill fish would not "interfere with or be injurious to" the beneficial use of fish migration. As a matter of law, Ecology's Order is contrary to its own regulations.

The second concern is Ecology proceeding without any public comment or hearing process. WAC 173-201A-070 (4) states that:

> Whenever waters are of a higher quality than the criteria assigned for such waters, the existing water quality shall be protected and pollution of said waters which will reduce the existing quality <u>shall not be allowed</u>, except in those instances where:
>
> > (a) it is clear, <u>after satisfactory public participation</u> and intergovernmental coordination, that overriding considerations of public interest will be served.

In this case, the existing water quality is of a higher quality than the criteria you are now allowing. Degradation of the existing water quality, notwithstanding the applicable criteria, can only be authorized after public participation.

I realize that WAC 173-201A-070 (5) acknowledges that short-term modifications of standards is authorized under WAC 173-201A-110 to respond to emergency situations, to accommodate essential activities and to otherwise protect the public interest. However, that acknowledgement does not authorize Ecology to circumvent the public hearing process. Except in the situation of an emergency, there is no reason why the public process requirement of WAC 173-201A-070 (5) should not be required before degradation of existing water quality is allowed. Furthermore, it is important to note that the Order modifies only the total dissolved gas standard. The Order does not modify the antidegradation standard established in WAC 173-20-070.

Therefore, unless this is truly an emergency situation (a proposition for which there is little, if any, evidence), it appears that Ecology has not complied with its public process requirements for issuance of this Order. Even if this particular situation was an emergency, the decision on whether a long-term modification should be granted is not an emergency and should be subjected to the public process.

The third concern is that the Administrative Order specifically requires that monitoring for total saturated gas "shall occur closest to highest dissolved gas source." Available information indicates that this monitoring is not occurring as required by the Administrative Order. It is our understanding that the monitoring stations are not located directly downstream at the "highest dissolved gas source" from the dam spillways. Instead, the existing monitoring stations are located in the forebay of the dams. Furthermore, if the water to be used in the bioassay is collected from these incorrect monitoring locations, the biomonitoring results will also not be accurate.

Because this monitoring is essential to determine compliance with the limits imposed in the Order, and even more importantly because the data collected will likely be used by Ecology to determine whether a long-term modification of the water quality standards should be granted, it is imperative to have accurate data at the proper locations.

Ecology must insist that the responsible party clearly demonstrate that monitoring is being conducted in the proper locations as required in the Order.

In summary, the bottom line is that this Order will in all likelihood result in fish death. The issuance of an Order with such significant consequence deserves more deliberation than a unilateral decision by Ecology based on the one-sided representations of the party seeking a waiver. Further, even if the Order was properly issued, the responsible party is not meeting the monitoring conditions imposed by the Order.

For these reasons, I urge Ecology to exercise its authority under RCW 90.48.240 to order the responsible party to immediately discontinue the discharges that are causing supersaturation of the water until:

(1) a proper public hearing process has been conducted, and

(2) the responsible party demonstrates that the monitoring stations are located in the areas closest to the highest dissolved gas sources.

Even if Ecology chooses to allow the discharges to continue under this seven-day Order, Ecology must provide for a public hearing before deciding on whether a long-term modification of the water quality standard should be granted. As you are aware, the State of Oregon is allowing public comment on its emergency rule on this same subject. I urge Ecology to follow Oregon's lead and hold a public hearing on this issue.

Thank you for your consideration of these concerns. If I can provide any further information, please do not hesitate to contact me.

Kindest regards,

Bruce J. Lovelin

Bruce J. Lovelin
Executive Director

Enclosure

Parametrix, Inc. [illegible]

5808 Lake Washington Blvd. N.E. Kirkland WA 98033-7350
206-822-8880 • Fax: 206-889-8808

Mr. Bruce Lovelin
Columbia River Alliance
825 NE Multnomah, Suite 955
Portland, OR 97232
FAX 503-238-1554

May 11, 1994

re: NMFS/FWS staff recommendation for spill at Snake River and lower Columbia River dams.

Dear Bruce:

Spilling substantial quantities of water at each dam for 12 to 24 hours each day carries a considerable biological risk. As noted in the NMFS/FWS announcement you forwarded to me, any supersaturation above 120% carries a real risk of gas bubble disease in juvenile migrants, adult salmon, and resident fish. This risk will be exacerbated by supersaturation of essentially the entire migratory route from Lower Granite Dam to well-below Bonneville Dam. Both the duration and degree of supersaturation resulting from the proposed spill program are likely to greatly increase the risk of salmon losses due to gas bubble disease.

Monitoring biological conditions is unlikely to provide adequate protection for salmon. By the time gas bubble disease is widely apparent in either the juvenile or adult populations, it is likely substantial losses will have occurred. During the serious dissolved gas problems of the 1960's and 1970's, it was uncommon for large numbers of migrants to be observed with gas bubble disease symptoms. By the time such symptoms become obvious, it is likely many fish will be lost.

Monitoring for maximum levels of supersaturation should occur within several miles of each dam where water is spilled. As the water moves downstream, it will gradually lose some of the supersaturation. However, it is likely to remain sufficiently high to cause gas bubble disease if it is originally in the range of 130% or higher. Measuring 120% of saturation at a forebay location will indicate the fish were exposed to substantially higher levels in the shallow or tailrace areas.

If 130% of supersaturation is allowed to occur in any portion of the river for more than a few hours, it is likely both young and adult salmon will be adversely affected. How many fish will be lost will depend on both the duration and level of supersaturation. Since spill will be greatest at night when most fish pass the dams and fish will tend to remain with the large block of supersaturated water, it is likely many fish will be exposed to the highest levels occurring rather than the lower levels that may be measured downstream.

Supersaturation above 120% carries considerable risk. The attached Table 1 lists previous observations of salmon killed by supersaturation in the Columbia River.

Sincerely,

Don Weitkamp, Ph.D.
Principal

DW:sr

Table 1. Records of salmon mortalities caused by supersaturation

---

Merrell, Collins and Greenough. 1971.
location: Bonneville Dam
date: 1955
species: chinook—adult
evidence: carcasses observed, estimated 16.8% of total run killed
sat: unmeasured, mortality associated with high spill

Westgard. 1964.
location: McNary Spawning Channel
date: 1962
species: chinook—adults
evidence: GBD symptoms, 34% of adults
sat: 119% (N_2)

Pauley, Fujihara and Nakatani. 1966. Pauley and Nakatani. 1967
location: Rocky Reach Dam—aquaria and Priest Rapids Spawning Channel
date: 1965
species: chinook—juvenile and adults
evidence: GBD gross symptoms and histopathology, adult mortalities
sat: unreported

Meekin. 1971. Eble. 1969.
location: Priest Rapids Dam
date: 1966
species: chinook, sockeye—adults
evidence: mortalities
sat: 120-130%

Beiningen and Ebel. 1970.
location: The Dalles Dam, fish held for inspection
date: 1968
species: chinook, coho, sockeye, steelhead—juveniles and adults
evidence: GBD symptoms up to one-half fish, high mortalities of juveniles held for inspection; estimated 20,000 adults killed, carcasses observed.
sat: 123-143%

Bouck, Chapman and Schneider. 1970.
location: John Day Dam, Bonneville Dam
date: 1968, 1969
species: sockeye—adults
evidence: GBD symptoms—3 of 7 (1968), 13 of 129 (1969)
sat: 118% and above

Ebel. 1971. Raymond. 1970.
location: Ice Harbor Dam
date: 1970
species: chinook, steelhead—juvenile, adults
evidence: GBD symptoms—25-45% chinook, 30-58% steelhead; estimated loss 70% of chinook between Whitebind and Ice Harbor; symptoms in 30% of adults.
sat: 120-140%

Meekin and Allen. 1974.
location: mid-Columbia River (Wells to Priest Rapids Dams)
date: 1965-1970
species: chinook, sockeye, steelhead—adults
evidence: estimated 6-60% mortality; carcasses observed when saturation reached 120% or higher
sat: variable

GBD = gas bubble disease

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FEDERATION OF FLY FISHERS

Conserving — Restoring — Educating Through Fly Fishing

Steelhead Committee
16430 72nd West
Edmonds, WA 98026

State of Oregon
DEPARTMENT OF ENVIRONMENTAL QUALITY
RECEIVED
MAY 13 1994
OFFICE OF THE DIRECTOR

May 14, 1994

Oregon Environmental Quality Commission
811 SW Sixth Avenue
Portland, Oregon

Gentlemen,

I regret that the Steelhead Committee of the Federation of Fly Fishers is unable to attend this short notice public meeting of the Oregon Environmental Quality Commission.

The Federation supports strongly the increased water released called for by the U.S. National Marine Fisheries Service to increase salmon smolt survival during this spring's migration window. Over the years, Bonneville Power Administration and the Corps of Engineers have refused to provide adequate flows for smolt migration. During that time, Columbia/Snake River salmon stocks have crashed. The scientifically based, peer-reviewed Detailed Fishery Operation Plan specifies increased flows as the preferred method of assisting smolt migration.

The Federation believes it is well past time to provide migrating salmon the water they need and to which they are entitled, as co-equals to other users of the hydro system, under the NW Power Act. You should not countenance attempts to scuttle the NMFS directed 1994 spills under the smoke screen of increased dissolved nitrogen. The Federation notes that predicted mortality from dissolved nitrogen is significantly lower than known mortality from barging and turbine passage.

The Federation also notes that dissolved nitrogen poses a serious obstacle to long-range salmon recovery plans. The per dam salmon mortality from all causes, including dissolved nitrogen, must be reduced dramatically and quickly which under-scores the pressing need to modify, on a priority basis, all Columbia/Snake River dams to provide for safe, in-river migration for juvenile and adult salmon. Oregon Environmental Quality Commission leadership and action in this critical arena is over due.

The Federation urges you to spend your time and intellectual energy on legitimate recovery actions rather than wasting your time and jeopardizing threatened salmon posturing for the Columbia River Alliance and direct services industry representatives.

Sincerely,

Pete Soverel
Chairman

Direct Service Industries, Inc.
925 LLOYD CENTER TOWER ▫ 825 N.E. MULTNOMAH STREET ▫ PORTLAND, OREGON 97232-2150 ▫ (503) 233-4445

State of Oregon
DEPARTMENT OF ENVIRONMENTAL QUALITY
RECEIVED
MAY 13 1994
OFFICE OF THE DIRECTOR

May 13, 1994

Honorable Ronald H. Brown,
Secretary of Commerce
14th Street & Constitution Avenue, N.W.
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Ms. Carol Browner, Administrator
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Mr. Chuck Clark
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Mr. Fred Hansen
Oregon Department of Environmental Quality
811 S.W. Sixth Avenue
Portland, Oregon 97204

Mr. Mike Llewelyn
Washington Department of Ecology
300 Desmond Drive
Olympia, Washington 98504-7600

Dear Sirs and Madam:

We have obtained a copy of a May 9, 1994 letter from National Marine Fisheries Service (NMFS) (copy enclosed) reporting a plan to increase dramatically spills at the eight mainstem dams on the Columbia and Snake Rivers. This plan will unquestionably reduce survival of migrating salmon in the Columbia and Snake Rivers by raising gas supersaturation levels, including Endangered Species Act (ESA) listed Snake River salmon.

We are enclosing herewith an Affidavit of Dr. Wesley J. Ebel, a well-respected and independent scientist who worked for NMFS for 31 years and personally conducted a great deal of research on the effects of gas supersaturation on migrating fish in the Columbia and Snake Rivers. His conclusion: "the proposed spill plan poses unacceptable risks to migrating salmon in the Columbia and Snake Rivers and will result in lower survival rather than higher survival".

We are also enclosing herewith the Declaration of James J. Anderson, the principal architect of the only computer model for assessing the effects of the Federal Columbia River Power System on migrating salmon that attempts to address the effects of gas supersaturation on salmon -- the Crisp model. His conclusion is that, giving every benefit of the doubt in favor of spill, the model shows survival decreasing, not increasing, under the plan.

Finally, we are also enclosing a scientific paper and letter from Dr. Don E. Weitkamp, providing a broad review of the scientific literature concerning the effects of gas supersaturation, and reaffirming that the proposed plan is likely to affect adversely migrating salmon in the Columbia and Snake Rivers.

We note that NMFS has purported to justify its decision on the results of the FLUSH model which, in substance, assumes that there are no effects to gas supersaturation and that transportation of fish does not work. Reliance upon a model that does not even consider the mechanism by which spill may kill fish is obviously arbitrary and capricious.

We understand that efforts may be underway to reframe the spill proposal as an experiment. This would require significant changes in the proposed operation. Unless there is little or no spill at Lower Granite, there will be no control against which to measure the effects of gas supersaturation. And without PIT tag detectors at Bonneville, it will be difficult to detect most of the spill mortality, which arises from extended exposure to an entire river of supersaturated water. The presently contemplated scope of monitoring for adverse effects of gas supersaturation is also inadequate to detect such effects. The monitoring of gas supersaturation levels is inadequate in geographic scope and the biological monitoring is essentially non-existent and seriously flawed.

We trust that NMFS and the Corps will consider this information and reconsider their decision. In addition to being contrary to the scientific evidence, the proposed action is also proceeding in violation of several federal statutes.

Most significantly, the proposed plan will violate the Clean Water Act (CWA). Recognizing that the spill plan would increase dissolved gas levels above the current water quality standards -- specifically set to protect Northwest salmon -- NMFS requested that the Washington Department of Ecology and the Oregon Environmental Quality Commission amend their water quality standards for total dissolved gas. The Washington Department of Ecology issued an administrative order which authorized total dissolved gas supersaturation up to 130 percent. Washington Administrative Order No. DE94-WQ218. The Oregon Environmental Quality Commission issued a temporary rule which likewise superseded the state's water quality standards to allow total dissolved gas concentration not to exceed 130 percent saturation. Oregon Temporary Administrative Rule 340-41-155.

States are required to adopt water quality standards which are consistent with the CWA. CWA § 303, 33 U.S.C. § 1313. One of the purposes of the Clean Water Act is to attain water quality which provides for the protection and propagation of fish, shellfish, and wildlife. CWA § 101(a)(2), 33 U.S.C. § 1251(a)(2). When a state revises or adopts a new standard, that standard:

> "[S]hall consist of the designated uses of the navigable waters involved and the water quality criteria for such waters based upon such uses. Such standards shall be such as to protect public health or welfare, and hence the quality of water and serve the purposes of this chapter. <u>Such standards shall be established taking into consideration their use and value for public water supplies, propagation of fish and wildlife</u>, recreational purposes, and agricultural, industrial, and other purposes, and also taking into consideration their use and value for navigation."
> 33 U.S.C. § 1313(c)(2)(A).

States must submit their new or revised water quality standards to the EPA for review and approval or disapproval. CWA § 303(c)(2), 33 U.S.C. § 1313(c)(2).

EPA reviews state water quality standards under 40 C.F.R. § 131.5 and for compliance with 40 C.F.R. § 131.6. The water quality standards adopted by Oregon and Washington to allow elevated levels of total dissolved gas are inconsistent with the requirements of the Clean Water Act and were not adopted to protect the designated water uses of the Columbia River. 40 C.F.R. § 131.5(a)(1), (2); 40 C.F.R. § 131.6(c). EPA regulations provide for state establishment of water quality criteria by (1) numerical values based on either: (i) EPA's criteria guidance developed under § 304(a) of the CWA; (ii) EPA's criteria guidance modified to reflect site specific conditions, or (iii) other scientifically defensible methods; and (2) narrative criteria or criteria based on biomonitoring methods where numerical criteria are unavailable or as a corollary to numerical criteria. 40 C.F.R. § 131.11(b).

Here, the EPA's own criterion guidance developed under § 304(a) of the CWA provides that

> "to protect fresh water and marine aquatic life, the total dissolved gas concentrations in water should not exceed 110 percent of the saturation value for gases of the existing atmosphere and hydrostatic pressures." EPA, Quality Criteria for Water 1986 (EPA 440/5-86-001).

Where, as here, the change in water quality standard facilitates a spill plan that will adversely affect migrating salmon in the Columbia and Snake Rivers, it cannot be sustained as consistent with the CWA. The magnitude and duration of NMFS' spill plan will negatively impact all riverine biota and possibly the estuarine biota as well.

Raising the gas supersaturation standard is also contrary to the antidegradation policy of 40 C.F.R. § 131.12. Both Oregon and Washington have adopted state antidegradation policies as required by 40 C.F.R. § 131.12. OAR 340-41-026(1); WAC 173-201A-070. Before allowing degradation and lowering of water quality, a state must assure that water quality is nevertheless adequate to protect existing uses fully. 40 C.F.R. § 131.12. Here, adoption of a water quality standard that will kill fish does not protect existing beneficial uses with respect to anadromous fish passage, salmonid spawning and salmonid rearing; it has the opposite effect.

Moreover, where high quality waters constitute an outstanding national resource, water quality shall be maintained and protected. 40 C.F.R. § 131.12(a)(3). The Columbia River flows through the Columbia Gorge National Scenic Area. Both Bonneville and The Dalles Dams are located within the scenic area. States may not lower water quality in waters of such exceptional recreational and ecological significance. Oregon and Washington have violated 40 C.F.R. § 131.12 by allowing the degradation of the water quality standard for total dissolved gas in the Columbia River.

Adoption of the water quality standard did not allow for adequate public participation under the CWA as required by 40 C.F.R. § 131.20(b) and state policies. To date, the water quality standard deviances have been adopted with no public participation.

We also believe that the National Environmental Policy Act (NEPA) requires an environmental impact statement to be prepared for this major federal action. To our knowledge, no such analysis has been conducted. Washington's State Environmental Policy Act (SEPA) would require an analysis of Washington's action to set aside its state water quality standards as well.

Finally, the proposed spill plan will also violate the Endangered Species Act by resulting in substantial additional unauthorized taking of Snake River salmon in violation of §§ 7 and 9 of that Act. The proposed action also violates that Act's direction to make decisions based on the "best scientific and commercial data available". 16 U.S.C. § 1536(a)(2).

We trust that the information provided will be of assistance in making decisions based on good science and in compliance with law.

Sincerely,

Nanci Tester (by [illegible])

Nanci Tester
Environmental Manager, DSI Inc.

PNUCC

PACIFIC NORTHWEST UTILITIES CONFERENCE COMMITTEE

State of Oregon
DEPARTMENT OF ENVIRONMENTAL QUALITY
RECEIVED
MAY 1 3 1994
OFFICE OF THE DIRECTOR

May 12, 1994

Governor Barbara Roberts
Oregon Governor's Office
State Capitol
Salem, Oregon 97310

Dear Governor Roberts:

I am writing this letter in response to the recent news that National Marine Fisheries Service is mandating high levels of spill at eight dams in the Snake and Columbia rivers, and your Department of Environmental Quality has approved it. PNUCC was shocked and troubled to hear this, not because NMFS wants to spill water, but because the amounts of spill they are suggesting will cause excessive and unnecessary levels of nitrogen supersaturation that can be deadly to fish. I was personally involved in the debates over acceptable nitrogen supersaturation levels in the 70s when the states of Oregon and Washington were deciding on the levels they would allow. Thus, I have intimate knowledge of this matter. At the time, several studies were done that unequivocally show that high levels of nitrogen supersaturation, caused by too much spill, kill fish. See the attached fact sheet that summarizes some of the study conclusions.

As you know, your current criterion for protecting freshwater and marine aquatic life limits the level of nitrogen supersaturation in the river to 110 percent. This standard has been in place for almost two decades. We are convinced that these spills and the resulting gas supersaturation levels you are allowing will harm and kill both adult and juvenile listed stocks of Snake River salmon if these high levels of nitrogen are maintained.

Both the states of Oregon and Washington have written waivers allowing the Corps of Engineers to operate the projects such that gas saturation levels can go as high as 130 percent. For the life of me, I cannot imagine why the NMFS or you would agree to such dramatic measures when much sound biological information exists proving that high nitrogen saturation levels are lethal. I can only guess that your advisors have been overwhelmed with the current hysteria and are overreacting to the dramatically low spring chinook returns, low water conditions, and pressure from the pending Judge Marsh proceedings.

You must stop this irresponsible action. We cannot afford to knowingly create a condition potentially lethal to salmon during this critical time. These actions will only compound the already difficult problem of increasing salmon survival. You must not allow gas saturation levels above the established 110 percent standard whenever it can be avoided. Your actions must be immediate. By the time we can monitor effects and detect harm to the fish, they will already be dead. Thank you for your attention in this matter. The fish cannot wait!

Sincerely,

Al Wright
PNUCC Executive Director

Attachment

cc: Governor Mike Lowry, State of Washington
Governor Cecil Andrus, State of Idaho
Governor Marc Racicot, State of Montana
Northwest Power Planning Council Members
Rod Ingram, Oregon Department of Fish and Wildlife
Fred Hansen, Oregon Department of Environmental Quality
Ted Kulongoski, Oregon Attorney General

SM103

Spill and Nitrogen Supersaturation

Fact Sheet

- Spill at dams can cause nitrogen supersaturation. (Lindroff, 1957)
- The federal and state EPA standard says that nitrogen supersaturation levels should not exceed 110 percent. (EPA 440/5-86-001, 1986)
- Gas bubble disease has been identified as a major problem affecting valuable stocks of salmon and trout in the Columbia River system. (Rulifson and Abel, 1971)
- When either juvenile or adult salmonids are confined to shallow water (1 meter), substantial mortality occurs at and above 115 percent total dissolved gas saturation. (Ebel, et al., 1975)
- When either juvenile or adult salmonids are free to sound and obtain hydrostatic compensation, substantial mortality still occurs when saturation levels (of total dissolved gases) exceed 120 percent saturation. (Ebel, et al. 1975)
- Exposure at 120 percent saturation for 1.5 days results in over 50 percent mortality for spring chinook and steelhead. (Dawley and Ebel, 1975)
- 115 percent nitrogen saturation is the threshold level where significant mortality began. (Dawley and Ebel, 1975)
- Gas saturation above 115 percent is acutely lethal to most species of salmonids, with 120 percent being rapidly lethal to all salmonids tested. (Bouck, et al., 1975)
- A decrease in lethal effect occurred when the nitrogen content fell below 109 percent even though the total gas saturation (oxygen and nitrogen) was at 119 percent. (Rucker, 1974)

Note: Citations available upon request.

PNUCC May 11, 1994

SM219

NORTHWEST
SPORTFISHING
INDUSTRY ASSOCIATION
P.O. BOX 4, OREGON CITY, OR 97045

May 15, 1994

FAXED
5/16/94
11:30A

State of Oregon
DEPARTMENT OF ENVIRONMENTAL QUALITY
RECEIVED
MAY 17 1994
OFFICE OF THE DIRECTOR

DEPARTMENT OF ENVIRONMENTAL QUALITY
The Environmental Quality Commission
811 SW Sixth Ave. Via FAX (503) 229 5850
Portland, OR 97204

RE: Continuation of Emergency Spillway release program

Dear Commissioners:

On behalf of the ***NORTHWEST SPORTFISHING INDUSTRY ASSOCIATION,*** I would like to express our strong support for the continuation of the emergency spill over the Columbia River dams during the outmigration period of juvenile salmon. ***NSIA*** is a trade organization representing hundreds of businesses and thousands of jobs in the Northwest dependent on and dedicated to healthy fishery resources.

The charters and guides, bait houses, marinas, marine suppliers, shopping centers, wholesalers, retailers, distributors, manufacturers, manufacturers representatives and "mom & pops" that NSIA represents, view the declining salmon and steelhead runs on the Columbia River as a driving force in **business closures and failures** in both sportfishing and commercial businesses along the west coast from northern California to Alaska. In addition, our businesses inland, from manufacturing to retailing accross the United States are severely impacted, by the loss of millions of salmon in the Columbia System.

Fishing closures and restrictions will continue to impact our economy with *hundreds of millions of lost dollars* until the operation of the hydro system is substantially altered for fish passage. Years of data collected and studied by the fish passage center have shown direct and substantial correlation between years of high flow and spill with increased adult returns.

According to the Detailed Fishery Operating Plan developed by the Columbia Basin Indian Tribes and the State and Federal Fish & Wildlife Agencies, there is no uncertainty in the NEED FOR INCREASED FLOWS AND REDUCED MORTALITY AT THE DAMS FOR JUVENILE PASSAGE AND SURVIVAL. The DFOP represents the best hope our industry and the salmon have for recovery based on a consensus of technical advisors in state, federal and tribal agencies.

We are facing an unprecedented crisis requiring measures that go far beyond what has been done for fish passage in the past. The DFOP emphasizes protection of all salmon stocks in the following manner:

- supports flexibility in hydro-system management to optimize migrant protection based on real time monitoring of biological, environmental and migratory stock conditions for daily in-season management
- emphasizes spill to maximize juvenile salmon survival based on 80% Fish Passage Efficiency
- Supports flexible dissolved gas supersaturating tolerance depending on biological and physical monitoring to optimize passage survival through improvements in dissolved gas monitoring systems

The spill program is the best recommendation that agencies could assemble to optimize survival of juvenile migrants. ODFW and other fishery analysts show that spill would double the survival of the juveniles migrating in river.

While dissolved gas can be a problem, this program is coupled with a detailed and effective monitoring program to detect and correct any occurrences of gas bubble trauma. As has been shown by Jensen, et al (1986) and Alderdice and Jensen (1985) GBT is related to other factors in addition to a particular "gas supersaturation standard". The factors contributing to GBT can also include: length of time of exposure, barometric pressure, compensation water depth, temperature, oxygen/nitrogen ratios, species, fish size, conditions and life history stage.

The current spill program is not expected to produce any dissolved gas levels that are not already commonly occurring in routine operations of these dams.

Perhaps the real issue of concern today, is not the "smokescreen" issue of gas bubble trauma. Without a doubt, there has been many time in the past where operation of the hydro-system was in violation if EQC standards. The real issue here in the minds of the board of directors of NSIA and the businesses that we represent is: How is it that it took a federal court case by the states and tribes to get the desperately needed spill for fish survival and enhancement? The agencies should have done this long ago.

This spill program is the first ray of light and hope for an industry that, until recent closures, generated a billion dollars in income to this region. The fish, and the industries I represent are waiting for the promises made when the dams went in to be kept.

Sincerely,

Liz Hamilton

Liz Hamilton
Executive Director

cc: Defazio, Furse, Wyden, Kopetski, Cantwell, Swift, Unsoeld, Dicks, McDermott, Kriedler, Hatfield, Packwood, Murray, Gorton, Stevens, Murkowski, Gov. Lowry, Gov. Roberts

NORTHWEST SPORTFISHING INDUSTRY ASSOCIATION

(Partial listing as of 5-15-94)

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NSIA **has been awarded an Environmental Quality Grant from American Sportfishing Association**

**PACIFIC COAST FEDERATION
of FISHERMEN'S ASSOCIATIONS**
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Habitat Director

Glen H. Spain
Northwest Regional Director

Mitch Farro
Director of Enhancement
Projects

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Fax: (503) 689-2500

DEPARTMENT OF ENVIRONMENTAL QUALITY
The Environmental Qualify Commission
811 SW Sixth Ave.
Portland, OR 97204

May 16, 1994
VIA FACSIMILE

RE: Emergency spillway release program

Dear Commissioners:

PCFFA is the largest organization of commercial fishermen on the west coast, representing thousands of working men and women in the Pacific Fleet. We are an industry group representing thousands of jobs and hundreds of millions of dollars to this region.

The future of salmon in the Columbia is of vital importance to our membership and our industry as a whole. Many recent salmon closures have been the direct result of the destruction of salmon runs in the Columbia, once the most productive salmon river in the world. Columbia River salmon swim far south and far north, and salmon fisheries throughout the coast including Alaska have been severely restricted each year in efforts to avoid taking threatened and endangered Columbia and Snake River fish, costing many tens of millions of dollars in lost opportunities each year.

We urge you to continue the emergency spills over the Columbia dams to increase salmon outmigration survival. While there are concerns with nitrogen supersaturation, it is also clear that many of these problems can be avoided with appropriate monitoring and timing. To date NMFS and the Corp. of Engineers have successfully kept gas saturation levels within biologically acceptable ranges, and there is no reason to believe they cannot continue to do so.

Claims of scientific uncertainty in the need for increased flows are bunk. These arguments are nothing more than a self-serving smokescreen raised by industries far less impacted than our own. **The scientific literature has clearly established a direct relationship between flow rates and smolt survival.** This relationship has been well established since the

handed out at mtg
file copy

work of Sims and Ossiander (1981) and confirmed in a number of other studies since then. Frankly it should come as no surprise that salmon need flowing water for their survival. Claims of "scientific uncertainty" on this point are hardly credible.

Likewise costs attributed to the program are largely mythical. We are already entering a period of lower demand for electricity as days get longer and warmer. During such low demand periods in the past spills have been quite common, up to 100% of inflow at times. Electrical production capacity often exceeds demand during such times. When that happens, water has to be released and turbines shut down in any event. Cost claims of $25 million or more are merely hypothetical "lost revenues" which often could not be realized in any event in the real world.

The Columbia River Alliance's grossly inflated estimates of rate increases are also utterly baseless -- even costs of $25 million or more can be easily absorbed in light of BPA's $3 billion annual sales. Any rate increases necessary specifically for this program would be very minor, probably on the order of 1% or less, if necessary at all. CRA's "freeze in the dark" doom and gloom rhetoric is just so much hot wind. Even modest conservation efforts could easily offset any actual power losses which might occur.

Furthermore, consider the costs to the region which have already resulted and which result every year from losses to the fishing industry of millions of salmon killed by the dams. The dams account for up to 90% of all human induced mortality. According to Power Planning Council figures and other studies, the hydropower system kills the equivalent of between 5 million and 11 million adults each year by its very existence -- fish that otherwise would be available for harvest. This means direct losses to the regional economy each year on the order of hundreds of millions of dollars! The hatchery stocks intended to replace these lost fish have proven less able to survive in the wild and more disease prone each successive generation and have largely collapsed. We need the genetic pool of these wild stocks to rebuild lost runs, and cannot truly replace them with artificial propagation. Restoring even a fraction of these wild runs will restore thousands of jobs and hundreds of millions of dollars to this region.

Even greater returns to the regional economy would occur once current catch restrictions imposed in the highly productive Alaskan fishery to avoid incidental catch of listed Snake River chinook can be relaxed. Alaskan fishermen lose many millions of dollars each year as a result of efforts to save these severely depressed wild stocks. Increasing these populations can only be accomplished, however, through increased outmigrant smolt survival rates. This requires increased flows. All other approaches have already been tried and have clearly failed.

Obviously anything that can be done to reconfigure the operation of the hydropower system so as to increase outmigrant smolt survival will amply repay the regional economy for whatever costs are incurred. Even a cost of $25 million or more, if understood in its true economic context, is relatively minor compared to the economic benefits this investment will likely generate. It is also only a fraction of the annual costs of barging and other transportation methods which have proven to be little more than costly boondoggles.

There have been accounts in the press indicating that "industry is opposed to continuing the spill program." This is untrue. Only some industries, such as the aluminum industies and irrigators, have opposed such measures. They have done so mainly to preserve power and water subsidies now provided to them at enormous government and taxpayer expense. The industry which has been most impacted -- the fishing industry -- strongly favors increased flow rates and spill programs such as currently are underway. These are investments in the future of the region which will be more than repaid in economic benefits over the next few years.

SINCERELY,

GLEN H. SPAIN
Northwest Regional Director
Pacific Coast Federation of
Fishermen's Associations

GHS/lt
Cc: Congressmembers:
    DeFazio
    Furse
    Wyden
    Kopetski
    Cantwell
    Swift
    Unsoeld
    Dicks
    McDermott
    Kreidler
  Senators:
    Hatfield
    Packwood
    Murray
    Gorton
    Stevens
    Murkowski

OREGON TROUT

May 16, 1994

MEMORANDUM

TO: Environmental Quality Commission

FROM: B.M. Bakke

SUBJECT: Temporary rule for TDG in Columbia River

Oregon Trout appreciates the opportunity to comment on the matter of the total dissolved gas standard for the Columbia River. On May 9, 1994, the Environmental Quality Commission adopted a temporary standard on TDG, allowing standard for nitrogen to increase from 110% up to 130% of saturation. This action was taken to allow an emergency spill of water over hydrodams to pass juvenile salmon.

According to National Marine Fisheries Service research conducted by Mr. Earl Dawley and Mr. Wes Ebel in 1975 (Studies on Effects of Supersaturation of Dissolved Gases on Fish, Final Report), 110% of saturation is probably the greatest amount of nitrogen supersaturation that can be justified, and it was based on studies like this one that the fish agencies sought adoption of the present standard.

I would like to share with you some findings from this study.

- The study was conducted by exposing fish to a specific level of nitrogen supersaturation for a specific period of time or until 50% of the test fish died.

- For 110% nitrogen supersaturation, the mortality did not reach the 50% level. (This means there were mortalities)

- For 118% nitrogen supersaturation, gas bubbles collected within 2-6 hours in the lateral line. The authors noted that this would have an adverse effect on survival.

- For 120% nitrogen supersaturation it took 8 days for salmon and steelhead to reach the 50% mortality level. The authors note that this level created functional blockage of gill capillaries, causing breathing stress in the fish.

To Protect and Restore Native Fish and their Ecosystems
Water Tower Building • 5331 S.W. Macadam • Suite 228 • Portland, Oregon 97201 • (503) 222-9091 • FAX (503) 222-9187

- For 130% nitrogen supersaturation, 50% of the fish died in 24 hours. Gas bubbles appeared in the lateral line within 2 hours of exposure. At 105% nitrogen supersaturation it took 24 days for gas bubbles to appear in the lateral line.

- The research found that steelhead were the most sensitive to gas supersaturated water followed by sockeye and then chinook. The Snake River sockeye is listed as an endangered species and the Snake River spring, summer, and fall chinook are listed as a threatened species. However, Oregon Trout has requested that the chinook be listed as endangered and the NMFS is reviewing the status of these fish. Steelhead have been petitioned for listing under the Endangered Species Act.

- Social interaction and turbid water caused fish to have trouble avoiding nitrogen supersaturated water by diving deeper in the water column.

- Exposure to 120% saturation for 1.5 days resulted in over 50% mortality, and 100% mortality occurred in less than 3 days. They also documented that the threshold level where significant mortalities begin occurring is at 115% nitrogen saturation.

- Bouck et. al. (1975) showed that gas supersaturated water at and above 115% total gas saturation is acutely lethal to most species of salmonids, with 120% saturation and above rapidly lethal to all salmonids.

RECOMMENDATION:

While Oregon Trout supports the use of spill as a means to improve the survival of juvenile salmon and steelhead at hyrdo dams on the Columbia and Snake rivers, excessive levels of nitrogen saturation could impair survival by gas bubble disease caused mortality. Also, adult salmon and steelhead do not recover from gas bubble disease. A standard for nitrogen supersaturation must be responsive to the survival of both juvenile and adult salmonids. It is Oregon Trout's recommendation that the standard of 110% of saturation for nitrogen be reinstated, since that is the threshold where increased mortality for salmonids begins. A threshold should be set at the point where there is some safety margin rather than at a point where there is measurable mortality. Every effort should be made to keep nitrogen below 120% of saturation. By using 110% as the threshold, actions should be taken to mediate increases above that point. An intensive monitoring program must be in place to make sure that excessive nitrogen and gas bubble disease are controlled.

COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION
729 N.E. Oregon, Suite 200, Portland, Oregon 97232
Telephone (503) 238-0667
Fax (503) 235-4228

TESTIMONY OF THE COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION

BEFORE THE

OREGON ENVIRONMENTAL QUALITY COMMISSION

AND THE

WASHINGTON DEPARTMENT OF ECOLOGY

Summary Statement of Position

The Columbia River Inter-Tribal Fish Commission (CRITFC) appreciates this opportunity to provide comments in strong support of the ongoing spill program to increase juvenile salmon survival through the Snake and Columbia river mainstem hydro-system. The CRITFC also supports temporarily amending or modifying Oregon and Washington water quality standards to allow total dissolved gas in the Columbia and Snake Rivers to exceed 110% saturation.

The CRITFC urges the Oregon Environmental Quality Commission (EQC) and the Washington Department of Ecology (WDOE) to either adopt temporary rules or issue variances amending their standards for total dissolved gas to permit spill of water at Columbia and Snake River Corps of Engineers projects to achieve 80 percent fish passage efficiency, for the duration of the 1994 juvenile salmon migration, at least through September 30, 1994. In achieving this 80 FPE goal, we support the use of biological monitoring, as proposed by the Fish Passage Center, to allow the controlled increase of total dissolved gas until the 80 FPE goal is achieved or until significant impacts on salmon are observed in accordance with the monitoring program; whichever is more protective of the salmon beneficial use. We also support requirements that hydroelectric project operators, upon the request of federal, state and tribal fishery managers, take immediate actions to reduce total dissolved gas levels if monitoring shows significant increases in fish mortality.

Introduction

It may seem ironic that traditionally strong advocates of strict adherance to water quality standards are now supporting "weakening" the standard for total dissolved gas. However, over the last 60 years, the Columbia River, once perhaps the most productive chinook producer in the world, has become so altered by human activities that only remnant runs of salmon remain. Numerous large hydroelectric projects have been constructed rendering the river so hazardous to salmon that "born again" advocates of total dissolved gas standards, such as the Direct Service Industries, argue that the best way to save salmon is to remove them from the river entirely and barge them downstream.

Given that the Columbia and Snake rivers have been so heavily altered by human activities, it is essential that the EQC and the WDOE take a practical approach in identifying and modifying water quality standards. The bottom line should be to do what is best to fully protect beneficial uses, in this case the salmon resource. Absent dam removal or dam re-configuration to mimic natural river flow during selected times,[1] the only way juvenile anadromous fish can reach the sea is: (1) through dam turbines; (2) through mechanical bypass systems and be bypassed to the river or transported via truch or barge; or (3) go over the dams via spill.

Until adult Snake River spring chinook runs crashed this year, the federal government's preferred method was to barge as many out-migrating juvenile salmon as possible. The federal water and power managers have avoided the use of spill as a solution because spilled water does not generate electricity. At various times, some federal water managers have also cited the need to comply with state water quality standards for total dissolved gas as justification for their refusal to spill water at the request of federal, state, and tribal fishery managers. The unfortunate irony is that the Columbia River system has been so altered by dams that the states' water quality criteria currently serve the interests of those wishing to maximize power generation, rather than the interests of the salmon the criteria were intended to protect.[2]

With the unprecedented decline in threatened adult spring chinook this year, and substantial uncertainty regarding the effectiveness of juvenile transportation, the federal government has now listened to the requests of Idaho, Oregon, Washington, and tribal fishery managers. It has rightfully decided that a carefully implemented and monitored spill program must be implemented in order to assure the survival of as many listed salmon as possible. Although it is likely that this spill program may result in violations of Oregon and Washington numeric criteria

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[1] This option is currently under study by the Corps of Engineers, in consultation with the federal, state, and tribal fish managers.

[2] For example, the Corps of Engineers routinely implements "forced spill" to deal with power load distribution problems, contrary to the recommendations of salmon managers.

for total dissolved gases, this spill program will enable significantly more listed salmon to survive, mature to adulthood, and spawn. The CRITFC firmly believes that implementation of this spill program is the best way to fully protect the salmon beneficial use.

Interest of the Columbia River Inter-Tribal Fish Commission

The Columbia River Inter-Tribal Fish Commission was created by the Confederated Tribes of the Warm Springs Reservation of Oregon, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes and Bands of the Yakima Indian Reservation, and the Nez Perce Tribe. These four tribes possess rights reserved by treaty with the federal government to take fish destined to pass their usual and accustomed fishing places. Among these fish are the anadromous species originating in the Columbia River and its tributaries.

The importance to the Commission's member tribes of their treaty-reserved right to take fish cannot be over-emphasized. The salmon are the heart of their culture and "not much less necessary to the existence of the Indians than the atmosphere they breathed."[3] It is indisputable that the right to take fish is meaningless unless there are fish to be taken. On this basis, the Commission and its member tribes have put their heart and soul into working with the state and federal regulatory system to rebuild Columbia basin anadromous fish runs so that the tribes would again be able to fully exercise their treaty rights to take fish as they once had. The tribes and their scientific experts have worked extensively with state and federal agencies to, among other things, decrease salmon mortality caused by Columbia and Snake river hydroelectric projects and to protect and improve water quality throughout the Columbia basin.

The tribes have not simply pointed fingers at others in order to rebuild the runs upon which their treaty rights depend. The tribes have not implemented commercial fisheries on summer chinook since 1964 or spring chinook since 1977. On these runs, the tribes' harvest has been restricted to low levels for ceremonial and subsistence purposes only.[4] Despite these efforts and sacrifices, the salmon runs have continued to plummet. Clearly, harvest restrictions alone will not rescue the salmon from their extremely disturbing decline. The tribes' treaty rights to take fish can only be restored if the anadromous fish beneficial use once again flourishes in the Columbia basin.

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[3] United States v. Winans, 198 U.S. 371, 381 (1905).

[4] A similar restriction on a rancher would only permit grazing cattle that would be consumed by the rancher and his extended family.

The Benefits of Spill to the Anadromous Fish Beneficial Use

Spill is the preferred alternative for dam passage and provides the best available protection for the anadromous fish beneficial use. As concluded by a peer review team of independent scientists, "[t]ransportation alone, as presently conceived and implemented, is unlikely to halt or prevent the continued decline and extirpation of listed species of salmon in the Snake River basin" (Mundy et al. 1994).

The spill program, developed by the federal, state, and tribal fishery managers, is designed to improve survival of salmon. The overall objective is to assure that 80 percent of the juvenile salmon reaching each dam will be spilled over the dam spillways thereby avoiding the extremely high mortalities caused by hydroelectric turbines. This is not some untried "experiment." For the last decade, substantial spill for juvenile migrants has been implemented at all mid-Columbia PUD projects through settlements and stipulations via the FERC re-licensing process. In addition, substantial controlled spill has been routinely implemented at Corps of Engineers projects, including Ice Harbor, The Dalles, and Bonneville dams.

Controlled spill and stringent monitoring protocols, as provided by the federal, state, and tribal fishery managers' program, will provide the best possible means of passage survival for migrating juvenile salmon. Extensive studies at mainstem dams throughout the basin document that juvenile mortality from spill ranges from 0-3 percent (Raymond 1988; NWPPC 1986; Holmes 1952; Ledgerwood et al. 1990). Spill also disperses predators from the forebay and tailrace areas thereby improving the chances of survival of salmon which are temporarily disoriented by being mechanically bypassed or run through dam turbines (Faler et al. 1988).

After installation of spill deflectors, the historical record demonstrates that better adult returns followed from juveniles which migrated under high flow and high spill conditions (Fish Passage Center SOR-19, 1994). Four of the five best adult return ratios for Snake River spring and summer chinook from 1974 to 1989 occurred in 1975, 1982, 1983, and 1984. It is noteworthy that spill levels during these years were substantially higher than those currently being implemented. The spill levels presently being implemented will not result in harm to the salmon beneficial use due to excessive total dissolved gas.

Past Spill Has Often Exceeded What Is Currently Proposed

When compared to past years, the levels of spill being implemented in 1994 are substantially less than what occurred in the late 1970's and early 1980's, or even the spill that occurred in 1993. The spill being implemented in 1994 is not "unprecedented" as alleged by some federal project operators and the Direct Service Industries.

For example, in 1993, high run-off late in the spring chinook migrating season forced dam operators to spill at rates considerably above those proposed for this year.[5] Juvenile salmon were inspected for signs of gas bubble trauma as part of the smolt monitoring project. No incidence of gas bubble trauma was observed until spill reached levels greatly in excess of those currently being implemented (DFOP; Appendix 6 1993). Since 1994 spill levels will continue to be far less than those experienced in 1993, and thorough biological monitoring is in place, we believe that implementing the spill program in 1994 will pose little risk of causing gas bubble trauma in adult and juvenile salmon.

Threat of Gas Bubble Trauma

As we understand it, the primary purpose of the total dissolved gas water quality standard is to protect the salmonid beneficial use by preventing mortality from gas bubble disease. As noted by a thorough review of the relevant scientific literature, "[h]igh levels of gas supersaturation are dangerous to migrating salmonids, and can cause gas bubble disease [trauma] a potentially lethal condition where dissolved gases in the blood come out of solution and form bubbles in various external and internal tissues." See Fish Passage Center, Impacts of Dissolved Gas Supersaturation on Columbia and Snake River Anadromous Fish (September 1993) at 1 (Hereinafter "FPC, Dissolved Gas Review").

It is well documented that spilling water over dams causes increases in total dissolved gas supersaturation. Id. How this impacts anadromous fish is related to a variety of factors. In its literature review, the Fish Passage Center concludes that:

> It is clear from a review of the literature that the impacts of dissolved gas [on] anadromous fish depend on a combination of factors: the level of supersaturation, exposure time, water depth and temperature, and fish

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[5] Although total dissolved gas reached levels far above those permitted by Oregon and Washington water quality standards, (DFOP; Appendix 6 1993), we are not aware of any attempts by either the federal water managers or the Direct Service Industries to seek variances or temporary rules from the EQC or WDOE. In contrast, the federal water managers and the Direct Service Industries appear to find compliance with state total dissolved gas standards to be extremely important when water that could be used for power generation is instead proposed for controlled spill to protect fish.

> condition. Intermittent exposure to high dissolved gas levels increases the ability of fish to tolerate supersaturated conditions, and does not necessarily result in gas bubble disease [trauma] or mortality. Adult and juvenile fish have been found to be sensitive to dissolved gas levels and will sound to compensate or otherwise avoid supersaturated conditions if given the opportunity. Except at very high levels of supersaturation (equal to or greater than 125% total dissolved gas), or when fish are not able to compensate by sounding, mortality occurs after exposure times on the order of many days to weeks.
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> The current debate over how to best protect fish from exposure to harmful levels of dissolved gas supersaturation must take into account that the Columbia river system and the response of fish to dissolved gas are complex, and also that the danger from dissolved gas is just one of a range of interconnected dam-related obstacles to safe fish passage. Management decisions regarding decreasing spill to reduce dissolved gas saturation levels must include a comparative risk assessment, since spill has been shown to be one of the safest ways to pass juvenile fish through dams.[6] In addition, the length of exposure, and constancy of dissolved gas levels must be considered in order to assess risk. It is safe to assume that most migratory fish will experience high dissolved gas on an intermittent basis in the river where their ability to sound should rarely be hampered, and should therefore have an increased chance of survival. In addition, high dissolved gas is associated with high spill, which usually is due to high flows. High flows result in rapid travel times for juvenile fish, which serve to reduce exposure time, a critical element in determining whether a fish will succumb to gas bubble disease.

See FPC, Dissolved Gas Review at 7.

Turbine and Mechanical By-Pass Mortality

As noted by the Fish Passage Center, the risk of gas supersaturation mortality caused by spill must be compared with the threat to the beneficial use posed by the other limited alternatives available to juvenile salmon originating in the Snake

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[6] United States Army Corps of Engineers. 1991. Bonneville scond powerhouse operation decision document. North Pacific Division, Portland, Oregon. p. A-7.

River who must somehow make their way past eight hydroelectric dams[7] in order to reach the sea.

Juvenile salmon that are neither trucked, barged, spilled, or mechanically bypassed must go through the turbines. Studies indicate that at each of these eight dams, approximately 10-30 percent of all juvenile salmon passing through the turbines are killed (NWPPC 1986; DFOP 1993; Raymond 1988).

Mechanical bypass systems such as fish screens, which have not been installed at all dams, guide and collect approximately 19-75 percent of all spring migrant juvenile salmon (Ceballos 1992). Of those spring migrant juvenile salmon that are guided and collected, approximately 1.5-2.5 percent die (Monk et al. 1991). Juvenile salmon not successfully guided and collected by mechanical bypass systems must go through the turbines and suffer the turbine mortality rate (10-30%) discussed above.

For summer migrant juvenile salmon, such as fall chinook, which are significantly more depressed than spring and summer chinook, mechanical bypass systems are much less effective. Mechanical bypass systems guide and collect only 8-35 percent of summer juvenile migrant salmon (Ceballos 1992). Mortality of those summer migrant that are successfully guided and collected in the mechanical bypass systems ranges from 2.4-9 percent (Dawley 1991; WDF 1992).

Transportation

Since 1985, over 25 million spring and summer chinook, over 140,000 subyearling chinook, and approximately 114,000 sockeye salmon have been transported from the Snake River at Lower Granite and Little Goose dams. Since these stocks continue to be on a declining trend, continuation of the transportation program should not be expected to reverse this trend. This conclusion is supported by Mundy et al. 1994: "[t]ransportation alone, as presently conceived and implemented, is unlikely to halt or prevent the continued decline and extirpation of listed species of salmon in the Snake River basin."

Transportation was thoroughly debated and rejected as the means for bypassing smolts around Priest Rapids and Wanapum dams in the mid-Columbia. After years of litigation, FERC Administrative Law Judge Grossman ruled that transportation would not provide for adequate survival of juvenile spring, summer, and fall chinook and sockeye salmon and, until adequate mechanical bypass systems could be developed and installed, ruled that substantial spill for spring and summer migrants must be implemented. <u>Grant County P.U.D. v. Washington Department of Fisheries</u>, Initial Decision at 25-26

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[7] Some fish in the upper Columbia must overcome nine dams.

(March 23, 1992).

Monitoring Adult and Juvenile Salmon

The federal, state, and tribal fishery managers are well aware of the potential threat to the anadromous fish beneficial use of gas bubble disease resulting from high levels of total dissolved gas. For this reason, they have directed the Fish Passage Center to establish an extensive program for monitoring juvenile and adult salmon (including steelhead) for signs of gas bubble trauma. The spill program can be immediately modified based upon the results of the Fish Passage Center's monitoring program.

The Temporary Rule and /or Variance Should Extend Through the 1994 Spring and Summer Juvenile Salmon Migrations

The Environmental Quality Commission should extend the temporary rule at least until September 30, 1994. Such an extension is consistent with ORS 183.335(6)(a), which allows temporary rules to be effective for a maximum of 180 days.

The Detailed Fishery Operating Plan (DFOP) developed by state and tribal fishery mangers, including ODFW and CRITFC, depicts the observed spring (yearling chinook, sockeye, steelhead) and summer (subyearling chinook) juvenile salmon migrations at each of the eight Corps of Engineer's dams on the mainstem Snake and Columbia rivers. Figure 4 in appendix 1-A of the DFOP shows that subyearling chinook are observed actively migrating through mid-September at Bonneville Dam. Likewise, Figure 2 in appendix 1-D of the DFOP shows that subyearling chinook are observed migrating at McNary Dam through mid-September. A copy of the DFOP is attached for your reference and inclusion in the record.

In order to protect the subyearling migration ODFW and CRITFC, through the DFOP, have recommended that spill be provided to achieve 80% FPE for "all migrants." DFOP at 5. Appendix 7 specifies the spill dates for spring and summer spill programs for each of the eight dams. The ending date for the summer spill program specified for each dam is August 31, 1994. At a minimum, any temporary rule/variance should be effective through August 31. However, since subyearling chinook are almost certain to be migrating through mid-September, it would be prudent to extend the administrative action until September 30.

The subyearling chinook include Snake River fall chinook, as well as summer and fall chinook populations from the mid- and lower-Columbia. For a variety of reasons, spill makes sense for subyearling chinook.

- Bypass systems (submersible traveling screens) have demonstrated relatively poor (8%-35%) guidance efficiencies at these projects. Thus, without spill most subyearling chinook will pass through turbines.

- No research has been undertaken to demonstrate the effectiveness of transporting the subyearling chinook listed under the ESA.

- Transportation of subyearling chinook directly from Lyons Ferry hatchery, located on the Snake River, produced excessively high stray rates and was discontinued.

- Spill has been shown to disperse predatory fishes in the tailrace of McNary Dam. Because summer is a period of heightened predator activity, predator dispersal should significantly benefit subyearling migrants, including those that have passed through turbines.

- Studies at Bonneville second powerhouse using subyearling chinook showed that the mortality associated with passage of the project via spill was not statistically detectable, compared to passage via turbines and bypass. In other words, spill is a safe route of passage by the dam.

Response to Affidavit of Wesley J. Ebel Submitted by DSI's

The Direct Service Industries (DSI's) have submitted an affidavit from their consultant, Wesley J. Ebel, in which he generally asserts that, in his personal opinion, exposure to increased gas supersaturation incidental to the proposed spill plan poses "unacceptable" risks to migrating salmon in the Columbia and Snake Rivers. We have reviewed Mr. Ebel's affidavit, and find many of his assertions and conclusions seriously flawed, or patently misleading. To support his opinions, Mr. Ebel selectively cites studies and scientific literature, and ignores studies and literature contrary to his opinion, which establish that the spill proposal will not harm migrating salmon.

Mr. Ebel also fails to show that the studies he cites to form his opinion, conducted under constrained laboratory conditions, apply to the **actual in-river environment**. Absent such a showing, Mr. Ebel's assertions and conclusions are extremely misleading. The following comments specifically address and refute assertions and conclusions Mr. Ebel makes in his affidavit.

- In paragraph 4 of his affidavit, Ebel states that sublethal effects, such as poor swimming performance, occur at dissolved gas levels as low as 106%. This conclusion is based on an experiment where decreased swimming performance was observed only after chinook were held in tanks only 0.25m deep for 35 days (Dawley and Ebel). The other study cited observed decreased swimming performance when fish were held in shallow tanks with 120% saturation.

- In paragraph 5, Ebel discusses mortality thresholds for juvenile salmonids established in laboratory experiments. Thresholds determined under laboratory conditions have limited application to in-river migrants, which are exposed to radically different conditions. Additional variables such as length of exposure, swimming depth, species and fish condition are critical in determining the impacts of dissolved gas on fish (Ebel et al. 1975; Weitkamp and Katz 1980; Jensen et al. 1986). The interplay between environmental and behavioral variables allows higher tolerance than is evident from bioassays (Bouck 1980).

- **There is no evidence that fish are impacted by 110% dissolved gas level in the Columbia and Snake Rivers.** Researchers have shown that even in shallow water, where fish cannot avoid gas supersaturation, fish can tolerate 110% total dissolved gas supersaturation for as long as 35 days (Dawley and Ebel 1975; Meekin and Turner 1974; Bouck et al. 1976; Bouck 1980; FPC 1993). The U.S. Army Corps of Engineers, in its 1986 Water Management Report, observed that although 110% was commonly exceeded, "there were no reported visible damages to fish."

- In paragraph 6, Ebel claims that significant mortality was observed in "deep tank" tests. This is misleading. Dawley et al. (1976) observed 4% mortality in "deep tanks" (2.5m) after 60 days, 67% mortality after 60 days at 124% saturation, and 97% mortality after 60 days at 127% saturation. However, when spring chinook were held in tanks 9-10 meters deep for 37 days at 133% saturation, **no gas related mortality was observed** (Dawley et al. 1975).

- In paragraph 7, Ebel concludes that juvenile salmonids cannot detect and avoid supersaturation by sounding. Ebel ignores studies that show that juvenile salmonids can detect and avoid gas supersaturation by moving both vertically and laterally. Dawley et al. (1975) followed vertical movement in juvenile salmonids in tanks of various depths, and noted that they would sound to avoid supersaturation, but judged that it was not sufficient to prevent mortality. Review of their results indicates that the ability of fish held at higher densities in intermediate depth tanks (2.5m) to sound to sufficient depths to prevent mortality was complicated by territorial interactions. However, it appears that fish held in reduced densities in tanks of 9-10 meters were able to sound to depths sufficient to prevent mortality.

- Bouck et al. (1976) reported that fish could avoid supersaturated water (from Meeker and Turner 1975).

- In tests by Weitkamp (1976), survival of juvenile chinook in cages that allowed fish to range from the surface to depths of 2, 3, and 4m increased substantially over fish held within 1m of the surface. This indicates that fish were able to sound to obtain hydroacoustic compensation.

- Alderice and Jensen (1985) tested juvenile salmon in 3m deep cages, and found that vertical distribution decreased as dissolved gas saturation increased up to 110-112%.

- Modelling by Jensen et al. (1986) indicated that "for the range of depth (0.1 to 1.0 m) modeled, fish appear to use a significant portion of the water column available to them, thereby finding protection against gas supersaturation."

- Stevens et al. (1980) found that coho, sockeye, and chinook salmon smolts and juvenile rainbow trout actively avoided supersaturation levels of 125 and 145%.

- Studies also show that juvenile chinook move laterally to avoid gas supersaturation. In tests where fish were able to move laterally between supersaturated and equilibrated water in a shallow trough, chinook avoided the supersaturated water. (Dawley et al.(1975).

- Adult spring chinook also avoid supersaturated water. Grey and Haynes (1977) used radio tags to follow adult in-river swimming depths. They found that the adult spring chinook spent 89% of the time below the critical zone (where they might be expected to be impacted by the dissolved gas levels) in supersaturated water. They also observed that under equilibrated conditions in 1976 and 1977, fish swam at significantly shallower depths than when supersaturation conditions existed.

- In paragraph 12, Ebel states that in years of serious dissolved gas problems in the 1960's and 1970's, it was "uncommon for large numbers of migrants to be observed with gas bubble disease symptoms." This is false. In 1968, 25-68% of each species of juvenile migrants were observed with "obvious signs of external symptoms of gas bubble disease," and large numbers of adults with easily detected symptoms (such as distended and bloody eyes) were observed (Beiningen and Ebel). Ebel speculates that substantial mortality will occur before any fish exhibit external symptoms of gas bubble disease. This is highly unlikely. Only acutely lethal dissolved gas conditions will cause mortality before any external symptoms are exhibited. Given that the river is a heterogenous environment, and that the tolerance to gas supersaturation is increased in the river environment due to hydrostatic compensation and intermittent exposure, we expect that any time an acutely lethal situation exists, a portion of the population would encounter less acute conditions, and would likely exhibit detectable external symptoms.

- In paragraph 16, Ebel refers to supersaturation conditions and observed mortalities at John Day dam in 1968 to support his conclusion that implementation of the spill proposal will kill adult chinook. The example has little relevance. Dissolved gas conditions in 1968 were extreme and will not be repeated in 1994. In 1968 all water passed over John Day dam, creating dissolved gas levels ranging from 123-143% throughout the entire migration period.

- In paragraph 17, Ebel hypothesizes that increased flows and spills do not have a positive effect on adult returns. The basis for his assertion is that even though 1993 outmigrants experienced the "best flows and spills in more than a decade," this years jack returns (which is a segment of the 1993 outmigrant group) are the lowest on record. Ebel's analysis and reasoning is flawed. Most of the spring chinook that outmigrated in 1993 did not experience the high flow and spill conditions (which were limited to a week in late May 1993). In fact, most of the fish were transported (82%). Moreover, 1993 was a below average runoff year (83% of the 30 year average, the eighth lowest in the last 25 years) (<u>See</u> Memorandum from Fred Olney, U.S. Fish and Wildlife Service). Ebel also fails to take into account the extremely poor ocean conditions which are believed to be the dominating factor affecting this year's poor returns.

- In paragraph 18, Ebel generally asserts that transported smolts experience greater survival than those migrating in-river. This assertion is undercut by Ebel's own argument in paragraph 17. In 1993, 82% of the outmigrants were transported (See FPC 1994 Annual Report). However, as Ebel himself has recognized, this year's jack return is the worst on record. It does not, in fact, appear that transportation is significantly beneficial.

Mr. Ebel's conclusions about the possible impacts of gas supersaturation on migrating salmon are severely compromised when the relevant studies and literature is more fully considered (it bears noting that Mr. Ebel co-authored some of the above mentioned studies that do not support his conclusions). Moreover, when it is recognized that actual in-river conditions are much different than laboratory conditions, many of the studies relied upon by Mr. Ebel have limited applicability. It appears that the "science" cannot empirically show that dissolved gas will or will not impact migrating salmon if the spill program is continued. Given this uncertainty, it must be determined which viewpoint is best serving the interests of the resource. In this case, any doubts should be resolved in favor of the agencies and tribes, which have a legal mandate to protect and restore the salmon resource.

Response to Affidavit of Jim Anderson Submitted by DSI's

Upon review of the Jim Anderson affidavit, we must highlight two mischaracterizations that pervade the document. The first is the implication that the FLUSH Model doesn't address gas supersaturation. The second is the implication that the CRiSP model provides a realistic assessment of the effects of gas supersaturation.

The FLUSH Model (Weber et al. 1992) was developed by the State and Tribal Fisheries Agencies to estimate mainstem passage survival under different management proposals. Gas supersaturation is addressed in two ways. First, from a management perspective, spill rates for all projects are calculated that do not exceed the models "spill caps." These caps are the maximum rates of spill achievable before gas supersaturation exceeds 120%. These spill caps are 65 KCFS and 235 KCFS in the Snake and Columbia Projects, respectively and were derived from relationships provided by the U. S. Army Corps of Engineers (1982). That the 120% level is appropriate appears to have been substantiated by the Smolt Monitoring Project in 1993, a year in which high runoff late in the spring chinook migration season resulted in high spill rates. Only when spill rates exceeded the FLUSH spill caps, and dissolved gas exceeded 120%, did any of the sampled smolts show external signs of Gas Bubble Trauma (GBT). The largest percentage of juveniles affected (18.6% observed with symptoms on one day) was at Lower Monumental dam, where dissolved gas concentrations exceeded 130% for four consective days, and reached a high of 141% (FPC 1994 Annual Report). Observations in 1993 indicate that 120% may be a conservative parameter.

The second way in which FLUSH takes supersaturation into account is through its reservoir mortality function. This function is based on system survival studies conducted by the National Marine Fisheries Service and included survival estimates for years when dissolved gas levels were high enough to induce Gas Bubble Trauma and increased mortality. Adding a separate spill-mortality function would double-count mortality attributable to gas bubble disease.

The assessment conducted by Anderson with the CRiSP Model to evaluate survival under different management proposals is unrealistic for at least two major reasons. First, much of the scientific community does not endorse CRiSP's assumption of a constant transport survival of 80%. Therefore, the tradeoffs between spill and transport presented in Anderson's affidavit incorporating this assumed transport survival rate are not well founded. In fact, the concern that transport actually has low effectiveness has prompted the scientific community to support a spread the risk policy.

The second reason the CRiSP Model produces unrealistic results is the way in which spill related mortality appears to be calculated. We note that despite participation by all modelers in a model comparison process, participants have not been provided with a detailed explanation of the CRiSP spill-mortality function. However, based on the Affidavit and my familiarity with the research on which Anderson's approach is derived, we gather that in CRiSP model simulations, fish exposed to dissolved gas levels in excess of 114% suffer very high if not total mortality. Additionally, it is our understanding that within CRiSP, once fish encounter dissolved gas levels in excess of 114%, mortality is instantaneous. This ignores important aspects of the research studies such as exposure times, and the possibility of avoidance by vertical or horizontal migrations. In any event, it is clear from side-by-side model comparisons that in CRiSP, spill produces reductions in survival that do not appear to be in agreement with smolt monitoring studies and research findings. In short, the spill-mortality function in CRiSP has not been calibrated to reflect available scientific information.

Analysis of the Applicability of the "Salt Caves" Decision to the Present Proceeding.

A recent Oregon Supreme Court case (Salt Caves) dealt with the EQC's refusal to waive the application of established Oregon water quality standards to the Salt Caves hydroelectric project on the Klamath River.[8] Because the opinion was only very recently released, and a superficial similarity of issues between the case and NMFS request may exist, we submit a brief analysis of the case, and its applicability to NMFS request to extend OTAR 340-41-155.

In Salt Caves, the court reviewed EQC's decision to uphold the DEQ's determination that a hydroelectric project did not comply with state water quality temperature standards. The EQC upheld DEQ's determination that raising the water temperature above the numeric limit was a violation as a "matter of law," even though the DEQ did not find that the temperature increase would harm the river's trout population, a beneficial use.[9] The

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[8] <u>City of Klamath Falls v. Environmental Quality Commission</u>, 318 Or. 532 (1994).

[9] <u>Id</u> at 537.

city of Klamath Falls argued that the DEQ must demonstrate that, not only was the numeric criterion violated, but also that the beneficial use was harmed, in order to find a violation of the water quality standard.[10] Alternatively, the City argued that the Commission erred in not exercising its discretion to waive the application of the standard to the specific project because it had not been proven that the beneficial use (trout) would be harmed.[11] Both of the city's arguments were based on the premise that the numeric standard was in fact established to protect a beneficial use, the fish population, so absent an affirmative finding by DEQ that the fish population would be impacted by exceeding the numeric standard, it would be "absurd" to rigidly apply the numeric standard to the project.[12]

The court upheld the EQC's determination that the project violated the temperature standard.[13] The court found that a rigid application of the numeric standard was consistent with the state's express policy of protecting fish, and a separate showing of harm to the fish was not necessary. The court stated that such an interpretation of the standard "merely increases the certainty that the trout . . . will not be harmed and that they will be protected."[14]

The current request to extend OTAR 340-41-155 is fundamentally different from the city's request in Salt Caves in two respects. First, in Salt Caves, the city argued that the project complied with established water quality standards. Alternatively, the city argued that even if the project did not comply with the water quality standards, the standards should not be enforced against the specific project. In short, the city argued that the project could be legally operated under the presently existing water quality standards. Conversely, in the present proceeding, operating the Columbia Basin hydroelectric projects to maximize salmonid survival will likely cause the established standard for dissolved gas to be exceeded. Therefore, the region's fishery management entities, including the ODFW, is requesting that the EQC exercise its statutory

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[10] Id at 541-45.

[11] Id at 545-48.

[12] Id at 541.

[13] Id at 541 (interpreting the temperature standard for the Klamath River, OAR 340-41-965(2)(b)(A)).

[14] Id at 547.

authority to promulgate a temporary alternative water quality standard which will be observed.[15]

The second crucial distinction is that in the Salt Caves case, the city argued that the numeric water quality standard should not apply because it could not be proven that the beneficial use that it was designed to protect, the trout population, would be harmed. Similarly, the Columbia and Snake Rivers dissolved gas standard was promulgated to protect the salmonid beneficial use.[16] However, in this proceeding, we are asking that a new temporary standard be adopted so that it may take affirmative action to benefit the beneficial use, the salmonid populations. Both procedurally and substantively, our request is wholly consistent with the letter and spirit of court's Salt Caves decision and the Clean Water Act.

Although the legal conclusions made by the court in the Salt Caves case have no relevance in acting on the request because of its different procedural posture, the case is instructive on how the EQC should exercise its authority to adopt water quality standards. The court stated that EQC rules should be in accordance with the policy of ORS 468B.015, which in part states it is the:

> policy of the state [t]o protect, maintain and improve the quality of the waters of the state . . . for the propagation of . . . fish and aquatic life . . . ."[17]

The court went on to characterize the EQC's rulemaking mandate as "broad." The EQC should exercise its broad discretion, and extend the temporary rule to give effect to the state's policy of

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[15] ORS 468B.048(1) grants the EQC the authority to adopt rules establishing water quality standards, and ORS 183.335(5) permits the EQC to adopt such rules on a temporary basis without full notice and comment procedure.

[16] However, strong scientific evidence indicates that salmonids are not impacted by dissolved gas concentrations at or exceeding the current 110 percent standard. See generally Fish Passage Memorandum from Michele DeHart, Fish Passage Center Manager, to Fish Passage Advisory Committee (Sept. 10, 1993) (Impacts of dissolved gas supersaturation on Columbia and Snake River anadromous fish).

[17] Id at 539.

protecting fish, and further, to protect the existing beneficial uses of the Columbia and Snake Rivers.[18]

It is undisputed among the region's state and federal fishery management agencies and tribes that spilling water at the hydroelectric projects in the Columbia Basin is the most effective mechanism to maximize safe passage past those projects. An incidental effect of spill, however, is an increase in dissolved gases in the river. The fishery management entities recognize that exposure to high levels of dissolved gas for extended periods may pose a risk to some fish. However, faced with the present emergency situation of historic low salmon populations, largely caused by hydroelectric development and operation, the fishery managers must immediately act to maximize salmon survival, and thus, preserve a beneficial use. It is necessary to extend OTAR 340-41-155 so that increased spill, a proven means to increase passage survival, can be lawfully continued.

Conclusion

For the forgoing reasons, the CRITFC respectfully requests that the EQC and WDOE to either adopt temporary rules or issue variances amending their standards for total dissolved gas to permit spill of water at Columbia and Snake River Corps of Engineers projects to achieve 80 percent fish passage efficiency, for the duration of the 1994 juvenile salmon migration, at least through September 30, 1994.

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[18] Additionally, ORS 468B.015(5) directs the EQC to "cooperate with other agencies . . . and the Federal Government in carrying out [the] objectives" of the state's water quality policy.

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
P.O. Box 47600 • Olympia, Washington 98504-7600 • (206) 407-6000 • TDD Only (Hearing Impaired) (206) 407-6006

May 10, 1994

J. Gary Smith
Acting Regional Director
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE
Seattle, Washington 98115-0070

Dear Mr. Smith:

Enclosed is Order No. DE 94WQ-218. All questions and correspondence relating to this document should be directed to Eric Schlorff, Department of Ecology, P.O. Box 47600, Olympia, Washington 98504-7600, (206) 407-6478.

This Order is issued to allow exceedance of the total dissolved gas criteria as shown in the surface water quality standards (Chapter 173-201A WAC) to allow fish passage on the Snake and Columbia Rivers. This order will be issued for one week after which we will reevaluate the effectiveness of the project.

Sincerely,

Michael T. Llewelyn
Program Manager
Water Quality Programs

ML:CM:sl
Enclosure

cc: Ernest J. Harrell
Honorable Mike Lowry
Honorable Barbara K. Roberts

RECEIVED
MAY 11 1994
WATER QUALITY DIVISION
DEPT. ENVIRONMENTAL QUALITY

Post-it™ brand fax transmittal memo 7671 | # of pages ▸ 4

To Greg McMurray	From Eric Schlorff
Co. Dept Enviro Qual	Co. Dept of Ecology
Dept.	Phone # 407 6478
Fax # 503 229-6124	Fax #

DEPARTMENT OF ECOLOGY

IN THE MATTER OF THE REQUEST BY	)	ADMINISTRATIVE
NATIONAL MARINE FISHERIES SERVICE	)	ORDER
FOR TEMPORARY MODIFICATION OF THE STATE	)	No. DE94-WQ218
SURFACE WATER QUALITY STANDARDS FOR	)	
TOTAL DISSOLVED GAS CRITERIA ON THE	)	
SNAKE AND COLUMBIA RIVERS	)	

To: J. Gary Smith
Acting Regional Director
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE
Seattle, Washington 98115-0070

National Marine Fisheries Service submitted a request for the U.S. Army Corps of Engineers, hereby referred to as the responsible party, to the Department of Ecology (Ecology) for temporary modification of the State's surface water quality standards for the purpose of exceeding water quality standards for total dissolved gas on the Snake and Columbia Rivers.

The responsible party is authorized to perform activities which will exceed water quality standards for total dissolved gas; any actions resulting in exceedance of water quality standards for total dissolved gas shall comply with the conditions listed in this Administrative Order.

The Department of Ecology retains continuing jurisdiction to make modifications hereto through supplemental Order if it appears necessary to protect the public interest. This includes protection of wildlife, aquatic, and wetland resources.

This Order is issued under the provisions of Chapter 90.48 RCW and WAC 173-201A-110.

The responsible party shall comply with the following conditions during all activities covered under this Order:

1. Name of Waterbody: Columbia River and Snake River

2. Locations: All federal dams on Columbia River below Grand Coulee Dam and all federal dams on the Snake River in Washington State.

3. A timing restriction is imposed for all activities resulting in exceedance of the water quality standards to the following period: Immediately upon issuance of this Order through May 18, 1994.

4. The responsible party shall obtain advance written approval from Ecology before making variations to this, and any, amended Order.

5. The responsible party performing the activities resulting in exceedance of water quality standards shall have this Administrative Order in possession and on site.

6. The responsible party shall allow an authorized representative of the Department of Ecology:

    - To enter the premises where activity resulting in exceedance of water quality standards is taking place.
    - To have access to and copy any records that must be kept under the terms of this Order.
    - To inspect any monitoring equipment or method of monitoring required in this Order.
    - To sample.
    - To inspect operations.

7. The responsible party shall provide a reasonable estimate of the time and location where these permitted activities will take place and an emergency telephone number where they can be reached immediately upon the request of Ecology. A message by voice mail or FAX shall suffice for this condition.

    Contact Name: Eric Schlorff Contact Number: (206) 407-6478

8.
    - The responsible party shall be responsible for monitoring. Monitoring shall be in place for total saturated gas when levels are in excess of 120 percent relative to atmospheric pressure.
    - Monitoring shall occur closest to highest total dissolved gas source.
    - Biological monitoring shall be conducted to show that total dissolved gas concentrations do not cause a significant increase in gas bubble disease related to mortality in salmon populations.
    - Total dissolved gas shall not exceed 130 percent relative to atmospheric pressure.
    - Total dissolved gas shall be measured at biological sampling sites.

Any failure to comply with this Order may result in the issuance of civil penalties or other action, whether administrative or judicial, to enforce the terms of this Order.

This Order may be appealed. Your appeal must be filed with the Pollution Control Hearings Board, P.O. Box 40903, Olympia, Washington 98504-0903 within thirty (30) days of your

receipt of this Order. At the same time, your appeal must also be sent to the Department of Ecology c/o The Enforcement Officer, P.O. Box 47600, Olympia, Washington 98504-7600; and to the Water

Quality Program, P.O. Box 47600, Olympia, WA 98504-7600. Your appeal alone will not stay the effectiveness of this Order. Stay requests must be submitted in accordance with RCW 43.21B.320. These procedures are consistent with Chapter 43.21B RCW.

DATED this 10 day of MAY, 1994, at Olympia, Washington

Michael T. Llewelyn
Program Manager
Water Quality Program

w:\section\wm\chris\94-spill.ord

May 15, 1994

Mr. William W. Wessinger, Chair
Oregon Environmental Quality Commission
121 S.W. Salmon , Suite 1100
Portland, OR 97204

Dear Mr. Wessinger:

Re: May 16, Meeting on Total Dissolved Gas Standards for the Columbia and Snake Rivers.

At the urging of Dr. Don Bevan, Chair, Snake River Salmon Recovery Team, I decided to get involved in this issue and am providing you with my concerns regarding this subject. I am recently retired and acting solely as a concerned citizen with some expertise in this matter. Regrettably, there has been little opportunity to prepare for this meeting, and the tentative agenda fails to provide equal time for both sides of the issue, hence this letter .

By way of introduction, my interests in gas bubble disease and gas supersaturation date back 35 years, to graduate school, where I earned a Ph.D. from the Department of Fisheries and Wildlife at Michigan State University. In my dissertation, I investigated physiological responses to low oxygen stress in fish, using nitrogen gas. Beginning in 1966, I was employed by the Division of Water Supply and Pollution Control of the U.S. Public Health Service (which later became EPA) at Corvallis, Oregon. I had the assignment of conducting research and other activities to generate water quality criteria that would protect Pacific salmon. In addition to researching salmon tolerances to various trade wastes and temperature, I also conducted extensive investigations on gas supersaturation, both in rivers and in the laboratory. In 1976, I transferred to the U.S. Fish and Wildlife Service in Seattle, WA., where I continued to investigate supersaturation, both in fresh water and sea water. In 1983 I transferred to the Division of Fish and Wildlife at the Bonneville Power Administration, where I retired recently as Senior Fisheries Scientist.

I have investigated gas bubble disease and gas supersaturation at numerous locations across the United States, and in Canada, England, Scotland, Norway, and Italy. I invented a means to measure total dissolved gas pressure in water, and I co-authored the associated analytical procedure that is now listed in the 18th edition of Standard Methods for the Examination of Water and Wastewater. In addition to scientific publications on gas bubble disease, I drafted the proposed water quality criterion that was later adopted by the National Academies of Science, and by the EPA. I also consulted with Mr. L. B. Day, who directed the Oregon Department of Environmental Quality, and he set the total dissolved gas (supersaturation) standard for Oregon.

I strongly believe that Oregon should neither grant a waiver, nor otherwise allow a relaxation of its water quality standard on gas supersaturation (total dissolved gas) for several reasons. Rather, Oregon should stringently enforce their existing standard. Here is why:

1. Any temporary increase in the gas supersaturation standard will surely establish precedence and invite further proposals to relax other water quality standards. The record shows that compliance with the existing supersaturation standard has been poor and generally not enforced. Thus the long term ramifications of a relaxation are likely to encourage further assaults upon an already difficult area, where federal-state jurisdiction and related responsibilities are both confusing and weak.

Another consideration is that all beneficial uses of water must be protected. In this regard, there has been a commercial effort to rear salmon in net pens in Young's Bay, to supplement naturally produced salmon and to create a terminal known-stock fishery. More of this is likely in the future. Based on my experience in Norway, salmon in net pens will be at risk if the gas levels are at or over 110%, and may be at risk at 105%. Thus, supersaturation can limit the use of Columbia River waters for aquaculture, a point already demonstrated by the US Fish and Wildlife Service.

2. The Columbia/Snake biota should not be put at additional risk. Between its mouth and the confluence of the Snake River, the Columbia occupies about 250,000 surface acres, which would be made lethal to an uncertain depth and for uncertain period, depending on the resulting gas pressures. In this reach, there is an extremely extensive assemblage both of native fishes, introduced fishes, amphibians, and invertebrates, whose ecology is complex and interrelated. The impacts of gas supersaturation on this biota are mostly unknown. Unfortunately, gas supersaturation can be predicted to have the most severe impact upon shallow water communities where, at this time of the year, reproduction and aquatic productivity is usually highest.

3. Gas supersaturation levels are difficult to predict and not readily controlled or dissipated. Gas supersaturation can occur by natural factors and these have produced a few fish kills of record, but typically go undetected. Man induced supersaturation usually occurs from spillage at dams or the warming of water, and its fish kills are equally difficult to detect. Gas levels from spillage depends on several factors, i.e., tail water height, depth of the stilling basin, velocity of the spill, presence of flow deflectors, gas level in arriving water, dilution from tributaries, solar heating, and discharges through the turbines. The biological effect of supersaturated gases is the same regardless of the source, but water laden with nitrogen gas accelerates gas bubble disease.

Unfortunately, river water that is supersaturated with atmospheric gases, tends to retain it. This is because rivers have a low surface to volume ratio, and because the diffusion pressure differential for each gas is relatively low. For example, I would expect water leaving the Bonneville area with total gases at, say 125 % of barometric pressure, to arrive near Astoria in the range of 115-120 %. This is only a small reduction in supersaturation from flowing 140+ miles, and much of this reduction can be explained by dilution from tributary flows.

If lethal levels of supersaturated water fill the reservoirs, there is considerable uncertainty that serious damage to adult salmon can be avoided. Further, once a reservoir is filled with dangerous gas levels, its effects will continue downstream for a considerable distance. But gas levels will likely be worse in the shallow water niches and sloughs than in the main stem due to solar heating, photosynthesis, or both. Here the impact is likely to fall on the nonsalmonid species and invertebrates.

4. Gas supersaturation at or over 120 % of barometric pressure is dangerous to juvenile and adult salmon, but the danger is difficult to demonstrate. Perhaps no subject is more confusing to lay persons and inexperienced scientists alike, than is gas bubble disease. This literature dates back to Sir Robert Boyle (Boyle's Law), and encompasses at least 200 publications, which range from wonderful to worthless. If an inexperienced person only reads this literature, they can find substance to support a wide variety of positions. The range of variability and difficulty of showing direct effects in rivers is true both for supersaturation and other pollutants. Even a knowledgeable scientist with extensive, specific experience in gas bubble disease will have difficulty estimating the safe limits, thus a cushion or safety factor is usually applied. In this case, it is commonly recognized that a supersaturation of 110% is not safe for shallow water organisms, but that it will protect most of the biota. At a supersaturation of 120 %, the safety factor is small to zero, hence the safe level becomes highly debatable and contingent upon a wide range of assumptions that are equally debatable. Therefore, it is extremely important to separate expert opinion, from the opinion of non-experts, no matter whether they are scientists, managers, or citizens.

Recently I organized and conducted a workshop on gas supersaturation, which was held here in Portland, April 19-20, 1994. In addition to various agency representatives, I invited a panel of scientists who have recognized expertise in gas bubble disease including Dr. Ebel, Mr. Dawley, and myself (see attachment 1). In the executive session, the panel of experts reached consensus that a gas supersaturation at or above 120 % would be a serious problem in the Columbia River. The proceedings of that workshop should be available within a month or so.

5. The burden of proof is upon those who would supersaturate. Many arguments for higher gas levels were presented in a manuscript from the Fish Passage Center (FPC), dated September 10, 1993, and titled "Impacts of dissolved gas supersaturation on Columbia and Snake River anadromous fish" (which was transmitted to you)." I found many errors and misconceptions in the FPC manuscript, and I am attaching a copy of my comments for your consideration. To their 9 pages, I wrote 16 pages of comments and corrections, concluding that, *"The FPC review is a rather unsophisticated product, and the omission of so much literature should warn the knowledgeable reader that the FPC review is heavily biased, ecologically incorrect, and should not be embraced.*

Some of the most commonly asked questions about supersaturation are listed below with my response. Literature citations can be provided upon request.

A. Would monitoring of external signs of gas bubble disease prevent significant damage to the salmon and the biota?

Response: No. Monitoring of gas bubble disease via externally evident lesions or signs, has several critical flaws. Any incidence of gas bubble disease among wild fish should be considered to be a serious situation for these reasons:.

1. External signs are slow to form, and rarely occur in all fish. For example, high levels of supersaturation (130 %) can kill fish without leaving externally evident signs of gas bubble disease. Even in protracted exposures, few if any salmon will develop "popeye" and dermal emphysema (bubbles) are rarely found in all species.

2. Externally evident signs disappear relatively soon if the fish are held in degassed water. Unless there has been a recent change in the holding circumstances, the smolts being observed for gas bubble disease may have been held in degassed water for periods up to 1-2 day prior to examination. This would tend to decrease the incidence of gas bubble disease drastically and makes the observations invalid.

3. Predation biases downward the apparent incidence of gas bubble disease in feral smolts. That is, as smolts become seriously disabled, they are rapidly eaten by predators and eliminated from the population. Unless the predator population is overwhelmed, the incidence of gas bubble disease will always seem low.

4. The most universal, rapid, and serious impact of gas bubble disease is emboli formation in the blood, which is not being monitored. Fish blood becomes saturated with gases within 2-4 hours, and emboli can cause hemostasis in the heart or other organs. For example, only 50 cc of air injected into a vein will cause hemostasis and cardiac failure in humans, while the same amount injected in skin or muscle will only cause discomfort. So if small amounts of air bubbles form in the blood of a fish, it can die from hemostasis and cardiac failure. None of this is being monitored, because it is technically difficult and not practical in the field.

5. There has been no validation and correlation of the incidence of externally evident signs of gas bubble disease in smolt samples, with its ultimate significance to survival in feral populations, or via sublethal effects such as immune suppression or parr reversion.

B. If supersaturation did kill fish, how evident would that be?

Response: Signs of gas bubble disease disappear soon after the death of the fish, thus eliminating the apparent cause of mortality. But in a river the size of the Columbia, one would not expect to find any dead smolts, and only 2-3 carcasses would show per 100 dead adults, which would be scattered long hundreds of miles of shoreline.

Therefore, gas bubble disease rarely produces evidence of a fish kill, unless there is massive mortality.

C. Would intermittent spill, hence intermittent exposures prevent damage?

Response: Not necessarily. Intermittent spill at all of the dams is likely to result in continuous exposure at some point downstream. Perhaps the Gasspill model can predict what would happen. On the other hand, intermittent exposure neither increases the inherent tolerance of fish to gas bubble disease, nor ensures increased survival. Mortality results when body burdens of gas continue to grow and this occurs under some conditions of intermittent exposure. In some of my tests, just as many fish were killed by intermittent exposure as continuous exposure, but it took more days of exposure.

D. Aren't fish protected from gas bubble disease by avoidance behavior?

Response: No. If that were true, we would not have had major kills of adult salmon in the Columbia River from gas bubble disease. While avoidance is theoretically possible, its likelihood seems very remote, and we cannot hypothesize how supersaturation would prompt avoidance . No one has proposed an stimulus-response mechanism that could explain active avoidance of supersaturation per se, and while avoidance has been reported, it appears to be related to confinement, and is unreliable.

Even if salmon seek depth while migrating in the reservoirs, all of the adults and most of the smolts must get into shallow water when passing dams. I have seen as high as 50 % of the adult sockeye passing Bonneville Dam with signs of gas bubble disease.

E. Does gas supersaturation cause sublethal effects to salmon?

Response: Yes. One sublethal effect is that gas supersaturation can block the flow of blood to the fish's eye. After an uncertain period of hemostasis, the eye becomes functionally blind. We have no evidence that blind fish continue to migrate or spawn, indeed, many of them probably die.

There are a whole spectrum of possible sublethal effects, some proven, but most have not been investigated. One of the most worrisome concerns is whether the stress from gas bubble disease suppresses the immune system and increases susceptibility to infectious diseases such as BKD (bacterial kidney disease). Another concern is whether the cumulative stress induces smolts to revert to nonanadromous parr stages in the fall after entering the ocean.

F. What benefits will result from experimental supersaturation of the Columbia?

Response: I really doubt that any valid conclusions can be drawn from this governmental misadventure, pro or con. The experimental design has little scientific merit, and the results are likely to be so variable and protracted that any proposed benefits will be impossible to discern. The main purpose of the "experiment" seems to a retrospective excuse for seeking control over river management. Clearly this approach is dangerous to the salmon, tremendously expensive, and irresponsible.

Field experimentation with gas supersaturation has been done extensively on the Big Horn River of Montana, below Yellow Tail dam. The study revealed that recruitment of rainbow trout was seriously depressed in this blue ribbon trout stream by supersaturation. If more field experimentation with gas supersaturation seems warranted, I recommend doing it on a much smaller stream, with no endangered species, no significant side channels and considerable potential for dissipating supersaturation via turbulence. *If there is no risk in the proposed experimentation, then an ideal location for it would be in the Deschutes River, below its first dam.*

I appreciate the opportunity to contribute to this effort and hope that you will give my concerns serious consideration. If I can provide further information or clarification, please do not hesitate to call me.

Sincerely,

GR Bouck

Gerald R. Bouck, Ph.D.

9691 SW Alsea Dr., Tualatin, OR. 97062. Phone 503 ÷ 692-4907

January 13, 1994

Comments on the Fish Passage Center's Review:

"Impacts of dissolved gas supersaturation on Columbia and Snake River anadromous fish"

by

Gerald R. Bouck

General Comments:

At first glance, the Fish Passage Center's (FPC's) effort appears to be an objective, unbiased review of the literature concerning dissolved gas supersaturation and its effects on all endemic Columbia River fishes. But the concern of the FPC document is essentially limited to salmonid smolts passing through reservoirs and spillways. There is no mention of smolts that must pass through the critical conditions in turbines and bypass systems, or of the juvenile fall chinook salmon and other species that rear along the edges of the river. The FPC report questions whether GBD stress increases susceptibility to infectious diseases or predation, because direct evidence is lacking. Concerns for adult salmon are dismissed based on avoidance, despite published reports wherein gas supersaturation killed feral adult salmon in the Columbia River. Eventually, it becomes evident that the FPC review was written in support of water spillage and monoculture policies, with little concern expressed for species diversity, or environmental protection for the entire Columbia / Snake River aquatic ecosystems. The FPC review's narrow perspective also omits concern for resident salmonids and other fishes, native or not, as well as omits concern for the myriad of invertebrates that fuel the food web and trophic levels. While the review does a credible job of listing some uncertainties in fish/supersaturation interactions, the list is by no means new or complete, and the relationships are not as clear or as simple as indicated. Certainly fish can stand some exposure to gas supersaturation, as can human divers. But there is no clear line to identify what is safe or unsafe, and a conservative approach is therefore warranted. Unfortunately, the FPC review exploits favorable data and uncertainty: any absence of data or variability is taken as support for higher gas levels. Perhaps this is because the review is incomplete and contains barely 25 viable, albeit older references, compared to 170 references in a more comprehensive review by Fidler and Miller (1993). The FPC review is a rather unsophisticated product, and the omission of so much literature should warn the knowledgeable reader that the FPC review is heavily biased, ecologically incorrect, and should not be embraced.

No comments were provided for the companion report "1993 Dissolved Gas Supersaturation", because a major element of it appeared to be FPC's side of a dispute.

Specific Comments on the FPC Review:

The following presents specific comments about selected concerns in the FPC Review. Comments are not presented on every concern.

FPC Introduction:

Para 1. There are some confusing terms here that merit clarification. Total Dissolved Gas (TDG) levels are either percentages of barometric pressure or some other reference pressure, i.e. standard pressure. In this case, the reference pressure is not clear but is presumed to be barometric pressure. Readers should recognize that until recently, these kinds of data were usually not standardized between studies, and this still causes significant confusion. (Standardized methods for this are presented in: Standard Methods for the Examination of Water and Waste Water, 17th Edition, 1989).

Strictly speaking, the gases are dissolved in both the blood, the tissues and the components thereof (1). Gases are more soluble in fatty tissues, and this variable is believed to alter tolerance to supersaturated gases in mammals (2, 32). Gases can be seen in the lipid-rich yolk material of supersaturated sac fry (28), but solubility in lipids may be less important in adult fish (33). Blood gases come into a pressure equilibrium between the environment and the tissues, via the respiratory and circulatory processes. Thus in supersaturated water, the pressures of inert gases in tissues will approach their environmental level (oxygen and carbon dioxide being exceptions), but the body burden of gases (total volume or mass) is expected to be greater in fatter animals (than lean ones of similar size) because lipid dissolves more gas than water. On this basis, fish rich in lipids such as salmon, probably take longer to fully supersaturate (and longer to degas) than lean fish. This could explain some individual and species differences in tolerance to gas supersaturation (6).

"-in various external and internal tissues." The biological term for the abnormal presence of gases or bubbles in tissues is emphysema. I assume this passage refers to emphysema in the skin, fins, etc. It should be noted that gas bubbles in the blood (gas emboli) are believed to be an earlier and more important sign of gas bubble disease than emphysema in tissues. Probably all fish have gas emboli in their blood soon after they become supersaturated, whereas externally evident emphysema require much longer to develop, are non-lethal, and form in some but not all individuals or species. In human divers, Behnke (3) believed that "bubbles form as soon as a state of supersaturation is initiated and that what appears to be a ratio of supersaturation tolerance is in reality an index of the degree of embolism that the body can tolerate."

Para. 2. Depth is not the controlling factor, rather, it is pressure. For example, despite the depth in a turbine bay, there is virtually no hydrostatic or atmospheric pressure immediately below the turbine blade (runner). That is important because it makes a major increase in the relative pressure of undissolved gases emboli, and the diffusion pressure differential of dissolved gases within the fish. According to the gas laws, these conditions would promote bubble formation and expand the size of existing gas emboli or emphysema.

"-pressure acts to keep dissolved gas in solution." should be gases (plural).

"-there is little agreement on a maximum level of TDG that fish can safely tolerate- - -." In general, I agree with this statement. The lack of precise limits is also true for human divers and as one result, diving tables apply liberal safety factors to compensate for the uncertainty (4). But the fact is, a great deal is known about the tolerances of trout in hatchery circumstances to supersaturation as described in three major reviews (5, 6, 7). Sockeye salmon fry showed signs of gas bubble disease, hemorrhages, necrosis, and mortality at a supersaturation ranging from 106-108% of barometric pressure (8). Atlantic menhaden all died within 24 hours when exposed to TDGP equal to 110% of barometric pressure (9). And 10-19 day old striped bass larvae experienced significant over-inflation of the swim bladder at TDGP as low as 103 % and mortality was increased at 106% ; they recommended TDGP levels below 101% for this life stage (10). Gas levels in the range of 103-105 TDGP were associated with episodes of infectious disease at the Fort Klamath Trout Hatchery (11). As one result, a TDGP of 110 % or lower should not be regarded as safe for all fishes in hatcheries or shallow water.

There is a need throughout the FPC review to be more specific, both regarding the generic term "fish" and in describing the exposure circumstances. The term "fish" includes all endemic species and life stages of fish in the river, not just smolts, and in some areas may include invertebrates. Misusing terms causes confusion and tends to mislead readers.

History of EPA criterion and DEQ Standards:

Para. I. This would have been a good place to describe the history of gas supersaturation studies in the Columbia. For example, the sighting of too many dead adult spring chinook below Bonneville prompted studies beginning around 1940, when powerhouse capacity was low and most of the river was spilled (12, 13). It took over 25 years of hard work by Fishery Agencies just to prove that the water was supersaturated and killing the fish (14-27), and this effort culminated in the present gas criteria. The lessons contained in these papers should not be forgotten.

The historical development of the gas supersaturation criteria merits expansion. It was begun under the 1968 Water Quality Act, which called for the establishment of specific water quality criteria. To reduce bias, EPA contracted with the National Academy of Sciences (NAS)/ National Research Council (NRC) in

1970(?) to draft appropriate Water Quality Criteria. NAS's Carlos Fetterolf requested a recommended criterion for supersaturation from fishery and environmental entities dealing with it in the Columbia Basin. They met in Richland, Washington, and recommended a standard of 110% of barometric pressure. NAS reviewed, and eventually adopted it. Subsequently, the 110 % of barometric pressure criterion was adopted by EPA, and then by several States. Currently the same criterion is used widely, and I believe it used in Norway and Scotland, and currently this is being considered for adoption by British Columbia. This is also the standard that is imposed by the Federal Energy Regulatory Commission upon the private hydro project operators.

The criterion was NOT based on shallow water studies as stated by FPC. As noted above, a criterion of 110% of BP couldn't have been justified because it can be lethal to some fish in shallow water. Rather, the criterion was based in part on the uncertainty, and upon the concern for organisms living in shallow water [such as the estimated 120,000 adult summer chinook that were killed by supersaturation below John Day Dam in 1968 (13, 24, 27). Thus the 110% standard represents a compromise which allows some supersaturation, but avoids the previously estimated carnage (12, 16, 24). Clearly, there is no magic "line in the sand" either for fishes and invertebrates, or for human divers, hence a safety factor must be emphasized.

There is no reason to debate "an allowable supersaturation mortality" for several reasons. Adequate *in situ* data are lacking for scientific comparison. Even if an acceptable level of mortality was set, there would be no way to monitor it in large rivers like the Columbia River. Large, dead adult salmon rarely become evident (12, 24). The finding of any visible dead smolts in the Columbia River would indicate a fish kill of such extreme proportions that it has overwhelmed the collective consumption capacity of available birds and fish predators. I speculate that a smolt mortality of say 25% / day would go undetected. (Note: the heavy mortality of smolts by slotted bulkheads in Lower Snake River Dams was discovered indirectly via an investigation of the seagulls' inability to fly in the area. Upon investigation, the seagulls were found to be glutted with dead smolts, that had not been obvious previously.)

Another reasons for keeping the present standard of 110% TDGP is the amount of shallow water niches in the Columbia River Ecosystem, which are used in part by ESA-listed fall chinook as rearing habitat. These shallow zones are also considered to be important for general aquatic productivity and specifically for endemic nonsalmonid fishes, which have been previously shown to exhibit gas bubble disease in the Columbia River (28).

Para. 3. While the publication by Rulifson and Abel (1971) was appropriate 20 years ago, it is of uncertain value now. Even then, it was a dated distillation of published reviews, and while it provided the basis for an agency policy in 1971, it is now nearly 25 years old. As in other cases, published reviews have merit, but the original articles must be evaluated, not the reviewer's opinion.

Para. 5. The FPC review correctly acknowledges that the 110% standard was intended to protect shallow water organisms. FPC goes on to conclude that the supersaturation standard is too low, based on two points: (1) because the standard is commonly violated; and (2) because FPC finds "no discernible impact on fish" (meaning unclear). This logic is hard to follow:-- if violating a legal standard justifies its liberalization in supersaturation, why not also in robbery? Also, since FPC provides no review of investigations on shallow water organisms, how can it be alleged that there was no discernible impact?

I don't think there was a "discrepancy" between the final and draft version of the Bouck *et al.* 1976 report. Rather, there was an expansion of the data when additional studies were completed. Anyone who cites a preliminary draft of a "gray literature" manuscript bears the burden of responsibility to ensure its appropriate use.

Para. 6. "Several researchers have found that even in shallow water, holding fish at 110% will not cause mortality." I agree that this is true in some cases, but it cannot be extended to all cases. Here the term "fish" encompasses all fish species and life stages (whether intended or not), and all conditions possible within the criterion of 110% of BP. As noted above, the published literature shows that gas supersaturations of less than 110% or less can damage or kill larval fishes such as striped bass and sockeye salmon (8, 9, 10). Further, I have investigated fish kills at levels as low as 105% of barometric pressure, both in the U.S. and Europe. Kills at this level are difficult to explain, and demonstrate the problem of assessing the risk in supersaturation. I speculate that other undetected gases (possibly intestinal gases) may be involved. That is, methane, hydrogen and other gases can be produced by bacteria in the gut of fish. In this case, the total gas pressures to which the fish are trying to equilibrate is equal to the sum of environmental gases plus the pressure of each individual intestinal gas (Dalton's Law of partial pressures). As a result, the TDGP that a fish might experiences under some circumstances could be higher than the level that was measured in the water.

Dissolved gas induced mortality

This section is devoted mostly to listing published times-to-death by various salmonids. Some confusing terms are included such as "deep tank survival ---in field tests" and "live-cage bioassays in natural river conditions." But the main issue here is that times-to-death are variable depending on circumstances, especially relative to compensatory hydrostatic pressure. More on this later.

Progression of gas bubble disease relative to mortality:

"monitoring migrants for signs of gas bubble disease (GBD) is a potentially important management tool for determining if dissolved gas levels are having an impact on the populations." I disagree with FPC for several reasons. First, monitoring smolts will not yield results that can be extrapolated to other lifestages or species. Secondly, one cannot predict the impact of gas supersaturation based on externally visible emphysema(29), in part because the first fish to die usually do not have emphysema (36). One can only report the incidence and location of externally evident signs, which unfortunately do not occur uniformly between species, within species or between body locations (36).

Thirdly, it is impossible to determine the ***prognosis*** of gas bubble diseased salmon via external lesions. Aside from the various technical difficulties, which span a wide range of physiological issues, there is no way of predicting future external interactions of gas bubble diseased fish with predators, turbines, and other potentially lethal factors. For example, if gas bubble disease causes debilitation and the debilitation results in the specimen being consumed by a predator, then the mortality must be credited to gas bubble disease, but this cannot be predicted in advance, nor proven from stomach contents.

External signs of gas bubble disease are easy to identify, but have potentially little value. Emphysema are not equally distributed between species, or gas levels; in one experiment, emphysema occurred in 20 % of the sockeye, 60 percent of the coho, and 80 % of the steelhead (36). Both dermal emphysema and air emboli, are usually pathognomonic (specific indicators of gas bubble disease), but exopthalmos (popeye) is infrequent, unreliable and can be caused by several factors (28, 36). Unfortunately, one cannot tell what portion of the population has gas bubble disease from emphysema or exophthalmus, and neither of these are rapidly appearing signs (38). The earliest, most subtle, and yet most threatening lesions are gas emboli in the blood(28), which can kill the fish before emphysema can form.

It is widely accepted that emboli grow from micro-bubbles (gas nuclei) in the blood. Criteria for their growth have been proposed (34), and in fish, emboli can accumulate to sizes that can block blood vessels (hemostasis) either in localized areas, or accumulate and block the cardiovascular system (35, 36, 37, 38, 39, 40). For example, hemostasis in the opthalmic artery at the optic rete probably accounts for the significant incidence of blinded fish observed in some instances of gas supersaturation (24, 27, 29). Hemostasis in small vessels probably produces localized lack of oxygen and nutrients with attendant cellular damage. Diminished blood flows probably accounts for reduced swimming ability in gas bubble diseased smolts (30), and resulting changes in blood chemistry (31). Although not proven, I speculate that the resulting cardiovascular perturbations and emboli may cause predisposition to infectious diseases or other problems, such as so called "head burn" of adult chinook.

Accurate identification of gas bubble disease *in a live population of fish* depends mainly on the ability to detect emboli within the blood vascular system (28), which in turn depends upon equipment not generally available to fishery biologists. Less desirable alternatives includes blood gas analyses, examination of gills for gas emboli and internal examination of sacrificed specimens. (It may be possible to modify and use Doppler blood flow equipment.)

The occurrence of visible emphysema in feral fish is noteworthy, primarily because it indicates an ongoing, unpredictable condition. That is, the body burden of dissolved hyperbaric gases *could* suddenly evolve into lethal air emboli and this *could* produce a massive hemostasis within a given fish. Unfortunately, it still isn't possible to predict which otherwise healthy sibling will die and which will survive gas bubble disease (personal observation by G.R. Bouck, based on extensive unpublished data). Predicting when and if Bends will happen is still a problem among human divers, despite diving tables and justifies liberal safety factors.

Sublethal and physiological effects:

This section in the FPC report cites some published sublethal and physiological effects of gas bubble disease, but mainly questions whether sublethal effects have any real significance to salmon. FPC states "no one has been able to directly document sources of indirect mortality and instead are left to infer that fish affected by gas bubble disease may be more susceptible to predation, disease, and delay." Relatively little effort has been focused on this concern, both because the difficulties of its study, and because this principle is so widely accept that its proposed funding has been neglected. **Therefore, the burden of proof is upon FPC to show that this widely held tenant is incorrect, or call for its investigation.**

Some sublethal effects of gas supersaturation have been noted. Fungal infections are believed to be a direct result of gas bubble disease (42). Supersaturation induced blindness, has been discussed earlier in this report, and was common among adult salmon in the 1960's and 1970's in the Columbia River (24,27) Blindness in adult salmon is believed to be essentially equal to death, if not directly from septicemia, then from dysfunctional migration /spawning.

FPC correctly notes that gas bubble disease in smolts seems to be reversible, but this is based almost entirely upon short- term survival studies (adults seem to be less flexible). For example, tolerance to sea water after gas supersaturation has been investigated only in terms of a few days post exposure. A much more critical examination would investigate the possibility of induced parr reversion the following autumn. Other informal observations support the concerns for sublethal effects. In several cases, the elimination of an annual cycle of gas supersaturation in a hatchery water supply was associated with the ending of a "follow on" pattern of infectious disease outbreaks in Oregon, Nevada, Michigan and Italy (41)

Currently the role of gas bubble disease relative to predation is being studied in laboratory tests by the National Biological Survey at Cook, and Montgomery Watson Co. and Battelle Labs, at Richland, WA. These laboratory results should be completed within a year. Predation studies are also underway in the Columbia River, but as designed, aren't likely to shed light on possible relationship to gas supersaturation. Still, the examination of recently ingested smolts by Nelson and coworkers, produced only a few percent with obvious physical injury (43), and raises questions why so many apparently healthy appearing prey were eaten. It is tempting to speculate that gas bubble disease may be involved in predation, but so far, the issue is unresolved.

Avoidance behavior:

The question here is whether avoidance behavior truly occurs in gas bubble disease of salmonid fishes. Avoidance-like behavior has been reported in some studies of supersaturation (16, 23,40,45), and could be protective if: (a) there is an active detection-avoidance response; (b) the avoidance response is not subject to stimulus exhaustion; and (c) there is opportunity to avoid or move away from supersaturation. The "avoidance response" of fish to supersaturation is variable, (5,6,44), and it is hard to rule out the possibility that test conditions in conjunction with supersaturation and confinement, may be responsible for the resulting behavior. Thus, it isn't clear why *O. mykiss* would "avoid" gas supersaturation in some cases, but not in other cases (44,45). Whatever the cause of variability, avoidance may not be an option for shallow water organisms such as juvenile fall chinook, or for migrating salmon passing the confining conditions of turbines, bypass systems, and fish ladders.

The avoidance stimulus-response mechanism remains unknown for supersaturation, but it is not likely to be based directly on the total dissolved gas pressure. This is because most rivers and experiments have well mixed water, with total dissolved gas pressures similar from surface to benthos. In this case, stimulus exhaustion would be expected to result from continuous exposure. Alternatively, if supersaturation stimulated avoidance by diving, via increased gas pressure in the swim bladder, the immediate effect of sounding would be counterproductive and raise the gas pressure in the swim bladder. It would take less energy and be more directly remedial to relax the pneumatic duct of physostomous fishes and thereby decrease both the pressure in the swim bladder and the excess buoyancy.

Individual gases in supersaturation are also unlikely to stimulate avoidance. Carbon dioxide gas is unlikely to exert any gas pressure because it is chemically transformed into dissolved bicarbonate and carbonate. Nitrogen and noble gases are essentially inert, at least at the low pressures in surface water. There are oxygen cells in rainbow trout *Oncorhynchus mykiss* gills, but hyperbaric oxygen pressure in lakes and raceways is not associated with avoidance behavior such as sounding or movement to lower oxygen pressures.

I speculate that the stimulus-response mechanisms for fish in supersaturated water is more likely to be found in some form of internal irritation, or damage (called pain in Bends patients), or in organ dysfunction resulting from emboli and emphysema. Supersaturation seems more likely to stimulate avoidance by causing irritation, dysfunction, or even damage. For example, blood vessels are highly innervated and they may be stimulated by the physical passage of emboli, or if the emboli stretch the vessel wall. If sufficient emboli form, these can diminish the flow of blood and cause hypoxia, hypercapnia, cardiovascular perturbations, cellular damage, and irritation or "pain."

Thus avoidance behavior, while potentially protective, seems uncertain and unreliable. For example, why didn't the adult summer chinook avoid the supersaturation during the fish kill at John Day Dam in 1968 by sounding, instead of being killed by it? Why were adult Atlantic salmon *Salmo salar* killed by gas supersaturation in a Norwegian stream, and in net pens in a fjord, when they could have avoided it (46)?

In summary, avoidance behavior has never solved a pollution problem and allows damage to the ecosystem.

Depth distribution of fish:

Most of the data cited by FPC provide a "snap-shot" of fish migrating through the water column, but do not describe the dynamics or the end result. How much time do individual adult salmon spend at these depths? In one case, radio tagged adult spring chinook reportedly spent 89% of their time below the critical zone for bubble formation (47). Yet this may not be adequate to ensure their safety because the supersaturation at John Day Dam in 1968 killed an estimated 18,000-20,000 adult chinook (24). Unfortunately, adult salmon cannot pass over dams without getting into the shallow depths of fishways.

FPC's review reports that GBD was not observed in the fish ladders on Snake River Dams last year, during significant periods of supersaturation. Yet when this was investigated at Bonneville Dam (27), the following was reported:

1969: At least 10 % of 129 adult sockeye salmon.

1972: 49 % of 55 adult sockeye salmon; 40 % of 5 adult steelhead;
26 % of 35 American shad, and none observed in lampreys.

GBD was readily apparent in captured adult salmon 20 years ago, but currently it seems difficult to find signs of GBD in adults that have traveled further during similar gas levels. Several explanations are possible, including increased heritable resistance to this disease (50), and different operational conditions. But at present, adequate data seems lacking to indicate the most likely explanation.

FPC also believes that most smolts migrate well below the danger zone. On the other hand, while smolts were reported to be in the top 3.5 m, most smolts were reported to be in the top 1 m (48, 49).

Intermittent exposure:

"Intermittent exposure increases the ability of fish to tolerate exposures to supersaturation conditions." I believe FPC did not mean this as stated; I am unaware of any evidence that repeated, intermittent exposure will build up physiological resistance to the onset or severity of GBD. To my knowledge, prior intermittent exposure to supersaturation has not been reported to increased tolerance to higher levels or longer periods of supersaturation. Rather, intermittent exposures to supersaturation, can produce extensive mortality (23,45,52).

During intermittent exposure, organisms may still acquire excessive body burdens of gases that can come out of solution and cause gas bubble disease (mild) or hemostasis (severe) in fish (Bends in human divers). Within certain limits of intermittent exposure, a *dangerous* body burden of gases may not occur, but the limits are critical. These limits have not been defined for salmon, but depend on the severity of conditions in the intermittent exposure. As a result, different intermittent exposure conditions have different implications.

In true intermittent exposure, the total dissolved gas pressure intermittently rises and falls over selected periods that are repeated, potentially from intermittent spillage at dams. In these tests, the hydrostatic pressure compensation, hence depth, is held essentially constant and is not allowed to compensate for the hyperbaric component of the gases. During the supersaturation phase, the organism becomes equilibrated with hyperbaric gas pressures and this may become lethal, depending on the circumstances. Gases dissolve in and saturate tissues, creating a body burden that may or may not be eliminated before the next exposure to hyperbaric gases. During the normal saturation phase, the total dissolved gas pressure in the water is lowered to barometric pressure (or lower). When this happens, the *in vivo* gas burden tends to diffuse out of the fish's tissues, into the blood, and back into the water. Gases are lost slower than they are gained (6), as evidenced by decompression tables, but the limits are not defined for migrating salmonids.

A second type of "intermittent exposure" is intermittently gaining and losing hydrostatic pressure compensation, during a relatively constant level of supersaturation. This can be accomplished by intermittently moving up or down in the water column, and thereby intermittently suppressing or promoting bubble formation. The tolerance of salmon to this should be at least twice the time required to saturate the fish with the supersaturated gases, or 2 X 2 hr (or more)= 4+ hr (53). At or below compensatory depth, no bubbles are possible (similar to a corked bottle of champagne). When the fish rises in the water column (such as when it reaches a dam), and swims vigorously, the result is analogous to removing the cork from the bottle and agitating it. It isn't certain if or when any bubbles will form, before the fish dives again and thereby "corks" the bottle via hydrostatic pressure. *In vivo* bubble formation is difficult to predict, impossible to control, and depends on numerous physical factors.

In a river, fish experience a much more complicated circumstance than is presented by most studies. Some fish will experience intermittent compensation, and others may experience intermittent supersaturation, or some combination of both.

Conclusions:

I find most of the FPC's conclusions are at odds with my experience, or do not address the entire issue. For example, intermittent exposure to high dissolved gas levels *can* kill fish and will *not* increase their *ability* to tolerate supersaturation as stated. While some intermittent exposures may not kill, other intermittent exposures will kill fish. Adult and juvenile "fish" *will not necessarily* sound volitionally or otherwise avoid supersaturation, as implied, and the published "fish kill" reports support this. I agree with FPC that it can take "many days to weeks" to kill the 50th percentile at low gas levels, but it does not take very long to kill 20 % of the smolts in the range of 120-124% TDGP, and time to death seems irrelevant for resident aquatic organisms. I also agree with FPC that management should apply a comparative risk assessment, but it should be applied to the entire aquatic ecosystem. The risk from supersaturation must be compared not only for the salmon, but also the nonsalmonids and the myriad other species in the river, especially in the shallow, eutrophic zone.

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MEMORANDUM
30 April, 1994

To: John Stevenson, PNUCC staff, and interested members
From: Al Giorgi AG
Subject: Summary of key issues discussed at AFS, EPA, COE, and BPA sponsored, Gas Saturation Workshop - 19,20 April, 1994.

In this summary, I try to concentrate on those issues that are of central concern, and provide commentary where appropriate.

Background: The workshop started by presenting some background information. Dr. Wes Ebel gave a history of the gas saturation (GS) problem in the Snake/Columbia Rivers. As we are aware high spillage rates in the 1960s increased GS substantially. As more turbines came on line and flip lips were installed the problem subsided. Some participants suggested that head lesions observed in 1993 were due to GS, i.e. blisters lysing. However, some weren't so sure, since other symptoms were not apparent. Bouck speculated that emboli could block blood flow to the eyes, temporarily blinding fish, and that the lesions may be a result of fish running into objects. More rigorous inspection of adults is required. Ceballos noted that the lesions definitely developed during passage from JD to LGR Dam, as evidenced by clean fish that were radio-tagged at JD and observed with lesions upstream.

COE Model: Tanovan from the COE briefly described that agency's GASSPILL model. He noted that the model predictions were truthed at within 10% of actual GS levels. However, the model is still somewhat coarse in that timesteps are long, shortterm changes in GS associated with brief spill periods are not well reflected.

Unmeasured Effects, Physical Environment: A&T representatives suggested that spill restricted to peak night passage hours would have less effect on the average daily GS. This may be so, however some pointed out that concentrated spill may greatly supersaturate a specific cell of H2O, which could maintains it's integrity as it moves downstream. If smolts remain in this cell as they migrate they may be subjected to high GS for extended periods. Monitoring for such dynamics is warranted. This raises the issue as to whether salmonids can sense GS and actively avoid it by actively swimming laterally or vertically(sufficient depth can compensate GS). Earl Dawley, Ebel note no such behavior in salmonids, nor did Dr. Bob White (MSU) observe such for trout. Dr Fidler said he has seen some information that may suggest rainbows may detect and move from GS.

Species Vulnerability: Dr. Ray Beamesderfer after reviewing the fish community, concluded that anadromous salmonids and lamprey were most vulnerable to GS, due to the time period they migrate and depth distribution. Dr. Fidler noted that early life stages, larvae, were most sensitive to GS effects. With regard to invertebrates, GS effects are somewhat different. On the Bighorn R. investigators observed that shallow water benthic insects(nymphs and larval stages) formed internal bubbles that buoyed them in the water column, and they were swept downstream. This could have implications with regard to critical rearing habitat for subyearling chinook foraging in the littoral zone throughout the Columbia system. In the context of ESA, any intentional activity, e.g. voluntary spill, that perturbs important features (prey items for Snake R. falls in this case) of critical habitat may be deemed inappropriate. It may be advisable to investigate the occurrence of this phenomenon in the Snake/Columbia rivers.

Also, the high sensitivity of fry stages raises the question as to potential effects on pre-emergent fry, particularly in the Hanford Reach. It is possible that spillage in the Mid Columbia is creating GS levels sufficiently high to cause substantial mortality to this productive wild stock.

EPA GS Standards: The GS standard in US waters is not to exceed 110%. Individual sate standards in the NW are; OR, 105% < 2 ft, 110% > 2ft; ID no clear standard with regard to dam discharge; WA recognizes EPA standard but there are provisions for temporary allowances to exceed it. In 1986 EPA asked the COE to conduct bioassays because of the high GS associated with dam. That did not occur. Apparently the existing EPA were to be adhered to. The EPA speaker noted that the EPA is regularly violated and that if EPA and/or the states do not actively enforce it they are vulnerable to lawsuits. He also noted the standard is to protect all species in the waterways, not just salmon.
The participants suggested that perhaps new standards were warranted and queried how this might be pursued. No clear procedure was apparent to me.

British Columbia Standards: Dr. Fidler, a noted researcher on GS, said that the standards in BC are similar to US, 110% > .7 m. However, he stressed that if the standards in either the US or BC were revised they would certainly be downward, not upward as desired by some parties in this region. He noted that there is real concern in their environmental agencies that the sublethal effects associated with GS have been ignored, and may be more important than observed acute mortality as measured with lab bioassays. Compromised or debilitated organisms will likely not perform well in a natural setting. For example, due to the small pneumatic duct, young juvenile salmonids cannot readily equilibrate their swim bladder volume as it rapidly overinflates with high GS. They may rupture resulting in direct mortality, or swimming behavior may be altered subjecting them to increased predation.

Risk Assessment: There was a panel discussion about how to best perform risk assessment for anadromous species. Several central issues deserve attention. John McKern noted that existing spill survival estimates do not reflect gas effects since water was only spilled during the test periods. Gas effects may offset any spill passage survival benefits. this needs to be considered in any future evaluations. EPA stressed they are concerned about all species, not just anadromous fish. Matt Mesa (NBS) noted that we have no assessment of the cumulative effects of serial stress conditions experienced during downstream passage. Effects measured in the lab with fresh test animals may not reflect the same level of gas-related effects as incurred by migrants passing turbines and bypass systems. If the migrants are compromised by other passage conditions, GS may have a more pronounced effect. He challenged the group to design evaluations that reflect this. A number of the participants stated that monitoring obvious external symptoms was inadequate. Bubbles in capillaries are a major concern. Also, bubbles forming on the lateral line are common, suspected to interfere with sensory processes, and are difficult to detect with casual inspection. With regard to the ESA stocks, intentionally exposing them to known stressful conditions may be unacceptable and unlawful. The balance between survival advantage associated with spillway passage and resultant gas effects is critical to overall stock survival. Both adult and juvenile stages must be evaluated. Some suggested we need to develop technological tools to detect the formation of bubbles in the blood. Fidler implied this was unnecessary since we already know that bubbles form at levels at 118% saturation. He also recommended that the Fraser River may provide baseline information representing an undeveloped system.

FPC Monitoring of GS Effects: In the past the SMP has monitored for symptoms in smolts and will continue to do so. Fish are inspected for external symptoms such as exopthalmia and bubbles in fins. M. Filardo noted that in 1993 they observed that at times the incidence of symptoms appeared to subside at downstream sites, indicating recovery during migration. However, some cautioned that the pattern may reflect mortality in route. Margaret noted that the PI did not change much from previous years, an indication of no great GS loss. Dr. Fidler cautioned that the PI if it is an appropriate survival index reflects all combined sources of smolt mortality, and GS effects cold have been quite large but were balanced by increased spill passage survival. The point is it is the net survival through the system that is of concern. If spill enhances survival at the dam but causes conditions that kill smolts it high levels in the reservoir what have we accomplished? The FPC will start examining adults this year at BON, IH, LGR.

Spill-equivalent survival: Fidler repeatedly stated that the risks associated with intentionally spill large volume of water are real. I would add that the only sensible way to provide high spill-equivalent passage survival, without spilling water in volumes that create GS problems is to develop a prototype surface/vertical slot forebay collector and test it as soon as is reasonably possible.

BPA funded GS study: Enclosed is a study outline for a 1994 investigation to be conducted jointly by Fidler and Colt.

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Workshop Agenda, April 19-20, 1994

GAS SUPERSATURATION RESEARCH NEEDS
at

The Columbia River Room, Coliseum Red Lion, Portland, Oregon
(behind the Coliseum, south off Broadway Blvd)

Sponsored by the Portland Chapter of the American Fisheries Society, the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, and the Bonneville Power Administration, Portland, Oregon.

Objectives

1. Review present and probable future supersaturation circumstances on the Columbia and Snake Rivers.
2. Provide peer review and comment on existing gas supersaturation research projects.
3. Have experts on gas supersaturation list and prioritize the additional research needs.
4. Provide a record of the meeting and update the 1980 AFS report on "Atmospheric Gas Supersaturation: Educational and Research Needs (TAFS 109:769).

April 19, 1994

Background Information:

8:15a Welcome and Introductions

8:30a Historical and Current Supersaturation in the Columbia and Snake Rivers.
Dr. Wesley J. Ebel, (retired) NMFS, Seattle, WA.

8:50a Projected Gas Levels for Hydro Operations in the Columbia and Snake Rivers.
Dr. Bolyvon Tanovan, US COE, Portland, OR.

9:10a Anadromous and Resident Fish Assemblages in the Columbia and Snake Rivers of Concern to Supersaturation. Dr. Ray Beamesderfer, ODFW, Oregon City, OR.

9:30a Break

10:00 The Regulatory Frame of Reference: Bill Young, Oregon Department of Environmental Quality; Bill Sobolewski, EPA, and .TBA, Washington Dept of Ecology, Olympia, WA.

Group Discussion on General Concerns and Research Needs:

10:30a How Does One Set Standards for Gas Supersaturation in Rivers?
Columbia Basin Management Considerations by -Gary Fredricks, NMFS, Portland,

11:30 Lunch

12:30p What are the Analytical and Monitoring Needs (Biological and Instruments)?

1:00p What Are the Concerns and Research Needs for Anadromous Fish Relative to Gas Supersaturation?

What species are at risk, why, what life stage, and under what circumstances?

2:00p What Are the Concerns and Research Needs for Resident Fish and Invertebrates Relative to Gas Supersaturation?

What species are at risk, why, what life stage, and under what circumstances

3:00p Break

Review of Current Research or Related Activities:

3:30p Study Plan: Determination of Total Dissolved Gas Effects on Salmon and Other Aquatic Species from Spill at Nontransport projects in the Lower Columbia and Snake Rivers. Jim Athern, and Rudd Turner, Corps of Engineers, Portland, Or.

Discussion and Comments

4:30p Study Plan: Biological Monitoring of Supersaturation in the Columbia River. Earl Dawley, NMFS, Hammond, OR.

5:00p Discussion and Comments
5:30p Adjourn

April 20, 1994

8:00a Smolt Monitoring for Gas Supersaturation. TBA. Fish Passage Center, Portland, OR..

8:30a General Discussion and Comments.

9:00a Study Plan: Effects of Supersaturation on Predation of Smolts. Matt Mesa, US Biological Survey,Cook, WA.

9:30a. General Discussion and Comments

10:00a Break

10:30a Study Plan: Allowable Levels of Gas Supersaturation for Fish Passing Dams. John Colt, Montgomery Watson Co., Bellevue, WA.

11:00a General Discussion and Review Comments

11:30a Lunch

/ 12:30p Executive Session to Consolidate and Prioritize Research Needs.

/ 3:30p BFO's, After Thoughts, and Public Comments (written comments will be encouraged).

5:00p Adjourn

Invited Experts on Gas Supersatuation

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Introduction

The development of the Columbia and Snake rivers for hydropower has led to a host of obstacles to the safe migration of anadromous salmon and steelhead trout. One problem that fishery managers and hydropower operators have long recognized is that of high concentrations of atmospheric gases, primarily nitrogen, becoming entrained in water passing over spillways at dams, causing supersaturation at well above the normal range for a free flowing river. Total dissolved gas (TDG) levels routinely exceed 110% and can reach 120 to 140 percent over long periods and long stretches of the river during periods of high flow and spill. High levels of dissolved gas supersaturation are dangerous to migrating salmonids, and can cause gas bubble disease (GBD), a potentially lethal condition where dissolved gases in the blood come out of solution and form bubbles in various external and internal tissues (EPA, 1976). Published accounts of observed mortality include Ebel (1971), who reported that widespread GBD in Snake River adult and juvenile chinook and steelhead due to high spill has caused substantial losses of fish, and Beiningen and Ebel (1970), who described high mortality of juveniles and adults due to high spill at John Day Dam in 1968. Based on Snake River survival estimates from 1966 to 1975, Ebel et al. (1975) concluded that there had been 40 to 95% mortality of juvenile fish, a major portion of which was due to supersaturation during high flow years, when most of the fish and water pass over spillways at dams instead of going through the turbines, and travel times are fast.

The fact that spill directly causes increases in TDG supersaturation or maintenance of high levels is well established (Ebel et al., 1975). However, the relationship between the level of gas supersaturation in the Columbia and Snake rivers and resulting effects on migrating adult and juvenile salmonids is not as well understood, due to the large area and complexity of the river system. How a fish will be affected by dissolved gas supersaturation depends on a variety of factors, including the level of supersaturation, length of exposure, swimming depth, water temperature, species, fish condition, life stage, and the ratio of oxygen to nitrogen partial pressures (Ebel et al. 1975, Weitkamp and Katz 1980, and Jensen et al. 1986). Depth is an especially important consideration, since for any given level of supersaturation, fish will be affected most at the surface and less at depth, since hydrostatic pressure acts to keep dissolved gas in solution. Efforts to protect fish from exposure to high dissolved gas levels have focused on determining a threshold supersaturation level to be applied to all river conditions, species and ages of fish that, when exceeded, creates unsafe conditions for migratory fish. This approach was initiated in the 1970's with the establishment of state and federal dissolved gas water quality standards. Currently, there is little agreement on a maximum level of TDG that fish can safely tolerate, and it has become clear that the debate has important management implications. This review examines the history of the dissolved gas standards and provides background on several critical questions and issues that must be considered in management decisions regarding the relationship between dissolved gas supersaturation and salmonid survival in the Columbia and Snake rivers.

History of EPA criterion and DEQ standards

In an effort to ensure good water quality for migrating salmonids and other aquatic organisms, the federal and state governments have set standards for limits on the allowable level of supersaturation. In 1972, Washington and Idaho set preliminary water quality standards for maximum permissible levels of dissolved nitrogen at 110 percent for the Columbia and Snake rivers; Oregon adopted a 105 percent standard. Blahm et al. (1973) commented that "these preliminary standards were established without the benefit of adequate biological information concerning the effects on fish of dissolved nitrogen in combination with other dissolved gases, water temperature, exposure time, and swim depths." In 1976, the Environmental Protection Agency published a criterion for TDG concentrations of no more than 110 percent for freshwater and marine environments. Oregon Department of Environmental Quality has since revised their standard to 105 percent for waters of less than 2 feet in depth, and 110 percent except in a 10-year, 7-day average flood (Oregon Administrative Rules, November 1987, Chapter 340, Division 41, p. 8).

The EPA criterion was based on shallow water studies, notably Ebel et al. (1975), Dawley and Ebel (1975), and an unpublished 1975 version of Bouck et al. (1976). There appear to be some discrepancies between the published and unpublished versions of the Bouck et al. study, because the EPA paper cites a finding by Bouck et al. that "water at and above 115 percent total gas saturation is acutely lethal to most species of salmonids, with 120 percent saturation and above rapidly lethal to all salmonids tested", whereas the 1976 published version found that "some mortality occurred among sensitive fish at dissolved gas levels of 110 to 115% of barometric pressure when they were restricted to shallow water" and noted that "these and higher gas levels may be safe for wild fish if they sound to compensatory depths." Another citation used in the justification for the EPA criterion is the conclusion of Dawley and Ebel (1975) that there is a threshold where "significant mortalities" begin occurring at 115% nitrogen saturation (111% TDG) at 15° C in water 0.25 m deep. This has been widely used in justifying or supporting a 110% standard. The observed mortalities of juvenile fish under these conditions in the study were 50% steelhead mortality and 7% chinook mortality after 35 days. This illustrates the need to explicitly define a critical time period and what level of mortality would be considered "significant". Studies investigating the effect of gas supersaturation on fish survival have varied widely in their determinations of critical periods: from four hours, the time estimated for a fish to pass through a plume of highly supersaturated water (Backman et al., 1991), to over two months (Blahm et al., 1973). A major problem with the debate about what constitutes a safe level of TDG supersaturation is that there is no agreement on what, if any, level of mortality is acceptable. This is complicated by the situation in the Columbia River basin, where the level of acceptable impact changes as river conditions vary.

Another EPA report that recommended a 110% nitrogen saturation criterion was a 1971 paper by Rulifson and Abel. From a review of the literature, they concluded that nitrogen supersaturation above 105% causes gas bubble disease in fish, and levels above 120% are lethal. The first conclusion was based on two sources (Harvey and Cooper 1962 and Shirahata 1966), who agreed that levels of less than 110% lead to GBD. Shirahata found that rainbow trout fry in shallow water need less than 111% nitrogen saturation for survival. Other researchers they cited indicated that GBD occurred at between 110 and 120% (Rucker and Tuttle 1948, Rucker and Hodgeboom 1953). They all reportedly agreed that over 120% dissolved nitrogen is lethal.

Alderdice and Jensen (1985), recommended that in order to prevent acute mortality of juvenile salmonids and adult sockeye in the Nechako River, TDG levels should be kept below 110%. The determination for adult sockeye was based on a study by Nebeker et al. (1976), which established a lethal threshold for adult sockeye at 114% TDG at 12° C in water 0.6 m deep. The determination for juvenile salmonids was based on a literature review and the results of modelling based on past research (Jensen et al., 1986), from which they deduced a boundary region between chronic and acute GBD risk of 108 to 116% TDG. The modelling done by Jensen et al. (1986) had a large area of uncertainty around the predicted 50% mortality curve at TDG saturations less than 125%, due to the large variation in research results and the large number of factors affecting how fish are affected by dissolved gas supersaturation.

The 110 percent TDG standard is generally considered conservative, and was adopted with the protection of shallow water organisms in mind. Given that 110 percent TDG is routinely exceeded in the Columbia and Snake rivers, with no discernable impacts on fish, it is generally agreed by most researchers and agencies that the standard is too low to be useful when applied to migrating salmonids in the Columbia river system. At a January 16, 1990 meeting at the EPA Oregon operations office in Portland, Oregon, Earl Dawley of the National Marine Fisheries Service (NMFS) said that the 110%

criterion was only useful for shallow waters. Jim Athearn of the COE commented that there have been no significant TDG related problems during the period 1985 to 1988, although 110% TDG was often exceeded. In addition, the 1986 COE Water Management Report indicated that in spite of the high levels of dissolved gas in excess of the 110% standard observed in 1986, "there were no reported visible damages to the fish."

Several researchers have found that even in shallow water, holding fish at 110% will not cause mortality. Dawley and Ebel (1975) observed no mortality of juvenile steelhead and chinook held at 110% nitrogen, 15° C in tanks 0.25 m deep for 35 days. Meekin and Turner (1974) determined that 112% nitrogen is not a harmful level when oxygen is at less than 100% saturation. Bouck et al. (1976) found that long term exposure of adult spring chinook salmon to 110% TDG had no adverse impact on fertilization and hatching of eggs. Most studies did not test fish at 110% TDG, since insignificant mortality usually resulted, especially if fish were allowed to sound, and instead began bioassays at 115% and up. Bouck (1980) concluded that field studies investigating the 110% criterion "support the contention that 115% saturation would be safe for wild salmonids in the Columbia River." He also noted that given information from laboratory research on acute lethality due to dissolved gas, and given that dissolved gas supersaturation below Bonneville Dam during the spring runoff season has often been in the range of 125% TDG since Bonneville was built, salmon should have disappeared from the Columbia River 25 years ago. He concludes that "obviously, interplay of behavioral and environmental variables allows higher tolerance to supersaturation than is evident in laboratory bioassays." Other researchers have suggested that limits could be defensibly set as high as 120% TDG (Weitkamp and Katz, 1980).

Dissolved gas induced mortality

There have been a number of laboratory and *in situ* studies designed to determine the effects of various levels of dissolved gas concentrations on salmonids. Most took the approach of measuring time to a chosen level of mortality, usually 50 percent. Ebel et al. (1975) reviewed several of these studies and concluded that for juveniles and adults, substantial mortality occurs at 115% TDG after 25 days exposure in shallow water, and when allowed to sound and obtain hydrostatic compensation, substantial mortality occurs at supersaturation levels greater than 120% TDG after more than 20 days exposure.

Blahm et al. (1973) tested juvenile chinook and coho over 72 days in 3 tanks of Columbia River water: an equilibrated control, and tanks 1 m and 2.5 m deep. Control mortality was 2.2% for chinook, and 4.1% for coho, where TDG was between 97 and 106% 85% of time, with a high of 109%. In the 1 m tank, they observed 98.2% chinook and 80.1% coho mortality at TDG saturation greater than or equal to 120%. In the 2.5 m tank at the same TDG concentrations, they saw 8.7% chinook and 4.2% coho mortality.

Dawley et al. (1975) found that in shallow tanks at 130% nitrogen saturation, all species tested reached 50% mortality in 24 hours and no species reached 50% mortality at 110%. They did an initial series of tests in deep tanks where high mortality was observed (100% chinook mortality at 124 and 127%), but thought that the high density of fish to water and the limited depth of the tanks may have affected the results, after observing some territorial interactions when fish were trying to compensate for TDG levels with vertical movement. A second round of deep tank tests in tanks 9-10 m deep at reduced population densities yielded no steelhead mortality in 7 days at 130% TDG (27% with GBD symptoms) and no dissolved gas related juvenile spring chinook mortality in 37 days at 133% nitrogen (10% with GBD symptoms).

As mentioned above, Dawley and Ebel (1975) tested fish in shallow tanks (0.25 m) at 15 °C and 115% nitrogen (111% TDG) and saw 50% steelhead and 7% chinook mortality in 35 days. They also observed greater than 50% mortality in less than 1.5 days at 120 and 125% nitrogen saturation in the shallow tanks.

Blahm (1975) noted that deep tank survival was better than shallow tank survival in field tests in the Columbia River at Prescott, Oregon, with prevailing fluctuating dissolved gas levels. He concluded that shallow water tests are "not representative of all river conditions that directly relate to mortality of juvenile salmon and trout in the Columbia River."

Bouck et al. (1976) tested different developmental stages of fish in shallow water, and measured the number of hours to 20% mortality at different dissolved gas levels. At 115% TDG, it took adults 309, smolts 154 and parr 125 hours to reach 20% mortality; at 120% TDG, it took adults 48, smolts 41 and parr 53 hours to reach 20% mortality; at 125% TDG, it took adults 18, smolts 17 and parr 24 hours to reach 20% mortality. They observed that the response curve (mortality vs. time) of fish put into water with high dissolved gas levels took the form of a sublethal period, a period of log-linear mortality, and a period of protracted survival.

Weitkamp (1976) found in live-cage bioassays in natural river conditions in the mid-Columbia River that at 120% TDG, significant mortality (53% mortality in 10 days, 90% of survivors had GBD) was seen only in fish groups held within 1 meter of surface. Fish allowed to sound up to 4 m did not suffer mortality in any of the tests at TDG ranges of 119 to 128%.

On May 29, 1990, a fire in the powerhouse at John Day Dam resulted in large amounts of spill for several days during the high flow period of the spring migration. This had the effect of greatly increasing dissolved gas saturation levels below John Day. Daily average TDG saturations at The Dalles Dam jumped from below 110 to above 125% for 5 days (May 30-June 3), and slowly declined to previous levels over a period of two weeks. Dissolved gas saturations at Bonneville Dam and Warrendale (below Bonneville) showed a similar trend, although peaks at those sites were a few percentage points lower. At The Dalles Dam, smolt monitoring efforts observed percentages of the sample with GBD symptoms of 2 to 17% from May 31 to June 4; 110 fish with GBD were observed out of 2,042 sampled altogether. At Bonneville Dam, GBD symptoms were evident in fish from June 1 through June 12. Percentages of fish observed with external signs of GBD during that time period ranged from 50% to less than one percent of the total sample. Steelhead were the most affected, and on June 3, 75% of the steelhead sampled had GBD. Subyearling chinook were the least affected– less than 5 fish out of 7,024 fish sampled June 1-12 were observed with signs of GBD. Yearling chinook were affected in low percentages (5% or less for four days), and sockeye and coho were intermediately affected.

Progression of gas bubble disease relative to mortality

Since it is clear that the impact that dissolved gas is having on fish at any given time cannot be simply determined from gas saturation measurements, monitoring of migrants for signs of gas bubble disease (GBD) is a potentially important management tool for determining if dissolved gas levels are having an impact on the populations. Therefore, it becomes important to understand the relationship of external symptoms of GBD to mortality and other ill effects of dissolved gas supersaturation.

External signs appear to be a good indicator of when dissolved gas levels are impacting fish in sublethal laboratory environments. In acutely lethal environments, fish may die before external signs appear. Meekin and Turner (1974), Weitkamp (1975) and Bouck et al. (1976) found that a small portion of mortalities which died in a short time had no external signs of GBD. This was more common in acute saturations (140%), but also occurred in more chronic situations. External GBD symptoms are most severe when conditions are marginally lethal, allowing longest survival (Bouck et al., 1976). Mortality does not necessarily accompany the presence of GBD symptoms, as demonstrated by Dawley (1975) in tests where no mortality occurred but 10 to 27% incidence of GBD was seen in fish held in deep tanks at 130 to 133% TDG over 7 to 37 days. Also, juvenile fish with external symptoms that do not die during exposure to high TDG levels will recover if returned to 100% saturation (Meekin and Turner 1974, Blahm 1973, Weitkamp 1974, Knittel et al. 1980). Dawley and Ebel (1975) found that fish returned to 100% saturation after exposure to 125% nitrogen, exhibited no delayed mortality due to prior exposure to high dissolved gas and saw external signs disappear after 15 days. Adults, on the other hand, are thought not to be able to recover (Ebel et al., 1975). However, this hypothesis has not been tested directly, and appears to be an inference drawn from the fact that high TDG can cause blindness in adults. Another finding of note is that after death, external signs of GBD disappear in adults after 24 hours (Ebel et al., 1975).

When migrants were monitored at dams for signs of GBD, GBD symptoms were observed to coincide with periods of high dissolved gas levels. In 1970, at Ice Harbor Dam, 25 to 45% of juvenile chinook migrants had external symptoms, and mortality for the entire population was estimated to be 30%. In 1971, 10 to 32% had external symptoms, and the survival for that year was estimated at 50% (Ebel et al., 1975). Dawley (1986) reported that in 1986, when dissolved gas levels exceeded 120% in late May and early June, GBD symptoms were observed in juvenile migrants at McNary Dam (mild symptoms 1-7% daily) and at Bonneville Dam (1% mild one day on coho, 3 days around 15% on steelhead), but not at John Day. No adults examined at McNary had signs of GBD. He concluded that there were minimal impacts of supersaturation on migrants during that time.

Sublethal and physiological effects

In addition to direct mortality, any sublethal effects of exposure to high dissolved gas levels must also be considered. There is evidence that swimming performance, growth and blood chemistry are affected (Dawley and Ebel, 1975), although no one has been able to directly document sources of indirect mortality, and instead are left to infer that fish affected by gas bubble disease may be more susceptible to predation, disease and delay. Dawley and Ebel (1975) found that 35 days exposure to 110% nitrogen (106% TDG) decreases the swimming ability of juvenile chinook, that growth was affected in steelhead and chinook at nitrogen saturations of 105, 110, and 115%, and that blood chemistry was affected at 115%.

Dawley et al. (1975) reported that fish stressed with high levels of dissolved gas had less swimming stamina than unstressed fish (an average of 17 minutes swimming time in supersaturated water versus 25 minutes in equilibrated conditions). They also did extensive tests of blood chemistry in a variety of fish under a variety of conditions, with largely inconclusive results. They did notice differences in the way steelhead and chinook respond to stress, and that the one change in blood chemistry that was present in most tests was a depression of chloride, which was observed in steelhead and chinook at 120% nitrogen saturation. They reported that several blood characteristics (albumin, calcium, phosphate and potassium) consistently change in a particular direction in response to nitrogen stress, and that their laboratory results were similar to results of field experiments. Another result that may have implications for fish survival is their observation that gas bubbles in the lateral line can block its function. When fish are allowed to recover from GBD, function of the lateral line returns.

Bouck et al. (1976) tested whether juvenile salmonids stressed by high dissolved gas were less able to transition successfully from freshwater to saltwater, and found that surviving high TDG saturations did not affect their ability to survive a direct transfer to seawater.

Avoidance behavior

Several researchers have reported that some species of anadromous fish are able to actively avoid or compensate for supersaturated conditions. The research falls into two categories: investigations of lateral avoidance, and studies of changes in depth distribution as related to dissolved gas saturation level.

In the first category, Dawley et al. (1975) observed that chinook avoided supersaturation, but steelhead did not in tests where juvenile fish were able to move laterally between supersaturated and equilibrated halves of a shallow trough. Stevens et al. (1980) tested several species of juvenile salmon and trout for avoidance of supersaturated water in a shallow tank. They found that coho, sockeye and chinook salmon smolts and juvenile rainbow trout actively avoided supersaturated water at levels of 125 and 145% TDG, but were less consistent in avoiding 115% TDG. Steelhead were not able to consistently avoid supersaturated water and suffered higher mortality. Territorial interactions displayed by the steelhead may have influenced these results. Sockeye were the quickest to avoid supersaturated conditions, perhaps aided by schooling behavior, and avoided supersaturated water within two hours.

Dawley et al. (1975) followed vertical movement in juvenile chinook and steelhead, and noted that they would sound to avoid supersaturation, but judged that it was not sufficient to prevent mortality. However, from reviewing their results, it seems that fish were able to sound to depths sufficient to prevent mortality when tested in very deep tanks (9-10 m) at reduced population densities, whereas in initial tests in tanks of intermediate depth (2.5 m) at higher densities, territorial interactions complicated the ability of fish to reside at depths sufficient to prevent mortality. They also observed that in turbid conditions, fish stayed in shallower water, and the depth distribution changed between day and night, even when tanks were lighted at night. Bouck et al. (1976) reported that juvenile chinook could avoid supersaturated water, whereas coho, which have a higher tolerance than chinook, showed no preference (from Meeker and Turner, 1975). In tests by Weitkamp (1976), survival of juvenile chinook in cages that allowed fish to range from the surface to depths of 2, 3 and 4 m, increased substantially over fish that were held within 1 m of the surface, indicating that fish were able to sound to obtain hydrostatic compensation. However, in 20 day tests at 120% to 128% TDG, mortality in the 0-2 and 0-3 m volitional cages was greater than in 1 m deep cages held at 1-2 and 2-3 m depth, indicating that fish did swim above compensation depths. Alderdice and Jensen (1985) tested juvenile salmon in 3 m deep cages and found that the mode of vertical distribution decreased as dissolved gas saturation increased up to 110-112% TDG; above those concentrations, the mode was above compensation depth. Modelling by Jensen et al. (1986) indicated that "for the range of depth (0.1 to 1.0 m) modelled, fish appear to use a significant portion of the water column available to them, thereby finding protection against gas supersaturation."

Less research has been done on avoidance abilities of adult fish. Grey and Haynes (1977) used radio tags to follow adult in-river swimming depths, and found that spring chinook adults spent 89% of the time below the critical zone (where they might be expected to be impacted by the dissolved gas levels) in 1976 in supersaturated water. They also observed that under equilibrated conditions in 1976 and 1977, fish swam at significantly shallower depths than in supersaturated conditions.

Depth distribution of fish

Since the effect of dissolved gas supersaturation on fish depends on the depths at which they swim, several researchers have done depth distribution studies. It is important to keep in mind that fish have been found to be sensitive to dissolved gas levels, and their depth distribution may change under different dissolved gas saturation conditions. Weitkamp (1974) cited a 1974 depth distribution study that found that 88% of chinook juveniles were between 2 to 4 m; for steelhead, 11% were between 0 and 2 m, 37% were between 2 and 4 m, and 42% were at 4 to 5 m depth; 20% of coho were found at 0 to 2 m and the remaining 80% were between 2 and 4 m. Dawley et al. (1975) reported that 58% of chinook juveniles and 36% of steelhead were at depths of 0 to 12 feet, and of these, 80% were between 0 and 6 feet.

Intermittent exposure

Intermittent exposure increases the ability of fish to tolerate exposure to supersaturated conditions. Dawley et al. (1975) found that intermittent exposure led to higher survival. Weitkamp (1976) found that fish held within 2 m of the surface for 16 hours per day had significant mortality only when TDG levels were at or above 125%, and found that fish survival improved with intermittent exposure (provided by raising and lowering the test cages) over constant exposure to surface levels.

The shape of the response curves of exposure dependent fish mortality measured by Bouck et al. (1976), indicate that there is an initial period when no mortality occurs, even at high TDG saturation levels. Knittel et al. (1980) found that the tolerance of juvenile steelhead for supersaturated conditions increased if they were allowed to remain at a compensatory depth. They longer the steelhead remained at depth, the higher their tolerance for surface conditions. They estimated that the minimum time necessary at 3 m depth to fully recover from exposure to TDG supersaturation in the range of 125 and 130% is 2 to 3 hours, and the minimum time to recover from 120% is 1 to 2 hours. In fish held for five days in live cages in The Dalles reservoir in 1985 where there was a diurnal pattern of 8 hours of TDG near 120%, 8 hours below 110% and intermediate levels during the remaining time, Dawley (1986) observed no mortality attributable to dissolved gas. He noted that spilled water (high dissolved gas) had a passage time through the reservoir of 16 to 20 hours and appeared to move as a distinct mass. All of these observations support the conclusion that exposure to high levels of dissolved gas supersaturation for time periods on the order of hours may not adversely affect fish.

Conclusions

It is clear from a review of the literature that the impacts of dissolved gas anadromous fish depend on a combination of factors: the level of supersaturation, exposure time, water depth and temperature, and fish condition. Intermittent exposure to high dissolved gas levels increases the ability of fish to tolerate supersaturated conditions, and does not necessarily result in gas bubble disease or mortality. Adult and juvenile fish have been found to be sensitive to dissolved gas levels and will sound to compensate or otherwise avoid supersaturated conditions if given the opportunity. Except at very high levels of supersaturation (≥ 125% TDG), or when fish are not able to compensate by sounding, mortality occurs after exposure times on the order of many days to weeks.

The current debate over how to best protect fish from exposure to harmful levels of dissolved gas supersaturation must take into account that the Columbia river system and the response of fish to dissolved gas are complex, and also that the danger from dissolved gas is just one of a range of interconnected dam-related obstacles to safe fish passage. Management decisions regarding decreasing spill to reduce dissolved gas saturation levels must include a comparative risk assessment, since spill has been shown to be one of the safest ways to pass juvenile fish through dams (COE, 1991). In addition, the length of exposure, and constancy of dissolved gas levels must be considered in order to assess risk. It is safe to assume that most migratory fish will experience high dissolved gas on an intermittent basis in the river where their ability to sound should rarely be hampered, and should therefore have an increased chance of survival. In addition, high dissolved gas is associated with high spill, which usually is due to high flows. High flows result in rapid travel times for juvenile fish, which serve to reduce exposure time, a critical element in determining whether a fish will succumb to gas bubble disease.

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1993 Dissolved Gas Supersaturation

Introduction

Dissolved gas supersaturation and its effects on anadromous fish in the Columbia River Basin was a critical issue in 1993. High flows in the Snake and Columbia rivers forced more uncontrolled spill than has occurred during the past low flow years and led to high dissolved gas supersaturation levels. In addition, with the listing of Snake River chinook and sockeye under the Endangered Species Act, the system bore closer scrutiny than in past years, and the new responsibilities of the National Marine Fisheries Service (NMFS) with respect to in-season management were in the process of being worked out. In past years, the U.S. Army Corps of Engineers (COE) has used dissolved gas levels and the possible detriment they inflict on fish to justify refusal to provide spill for fish passage. The recommendation of the regional fishery management agencies and tribes to provide spill sufficient to ensure 80% spring and 70% summer fish passage efficiency (FPE) was criticized as potentially causing damage to fish. Partly in response to this criticism, a system wide monitoring plan for tracking the effects of dissolved gas on migrating juvenile salmon and steelhead trout was implemented in 1993. In a letter from J. Donaldson of the Columbia Basin Fish and Wildlife Authority (CBFWA) to Major General E.J. Harrell of the COE North Pacific Division (COE-NPD) dated February 5, 1993, the agency and tribal plan to monitor smolt condition for gas related problems was described. Their goal was to combine biological observations with dissolved gas monitoring in order to begin the development of the baseline necessary for dissolved gas management in the Columbia and Snake river systems. This in-season management role was not recognized by the COE, who on several occasions ignored the advice of the agencies and tribes with respect to managing spill to provide the safest migration conditions for fish, particularly at Ice Harbor and Bonneville dams. The COE instead relied on agreements made with NMFS in justifying their actions.

The smolt monitoring program observed some impacts on juvenile fish from the high dissolved gas levels that occurred during the period of peak flows in the latter part of May. Daily average total dissolved gas (TDG) saturations exceeded 120% for one to twelve days at all monitoring stations (where data were available) except Lower Granite Dam. The highest levels of daily average dissolved gas recorded were at Lower Monumental Dam, where 130% was exceeded for 4 days (May 17-20), and an instantaneous high (one hourly reading) of 141% was observed. Saturations at John Day, The Dalles and Bonneville exceeded 125% for one to two days. Unfortunately, reliable dissolved gas data were not always available, and several stations, including Ice Harbor, Priest Rapids, McNary North shore and Warrendale, were out of service during the high flows in the last two weeks in May. Dissolved gas measurements from Rock Island and Rocky Reach dams were unavailable for the most of the spring migration.

During the period when the highest dissolved gas saturations occurred, low incidence of mostly mild external signs of Gas Bubble Disease (GBD) were observed on juvenile migrants. The largest proportion of juveniles affected was observed at Lower Monumental, where 18.6% of the sample had signs of Gas Bubble Disease (GBD) on one day-- May 20. With the exception of Lower Granite Dam, where no GBD was seen, the rest of the monitoring stations recorded low percentages (typically 1-2%) of the daily sample affected with mild symptoms of GBD for 2 to 19 days out of the spring migration season. Based on smolt monitoring program observations, it is apparent that the impacts of high dissolved gas saturation on fish were minor in 1993. The results of sampling done downstream of Bonneville by the National Marine Fisheries Service also indicated minor impacts. For detailed descriptions and plots of GBD monitoring observations along with flow and dissolved gas information for Lower Granite, Lower Monumental, McNary, John Day and Bonneville dams, refer to the appendix.

Dissolved gas conditions in the Snake and Columbia rivers in 1993

The levels of dissolved gas supersaturation coming into the system, i.e. daily average measurements from the forebays of Lower Granite and Grand Coulee dams, varied throughout the spring migration season. The range was particularly wide at Grand Coulee, where saturation levels fluctuated from around 100% to a high of 127% total dissolved gas (TDG) saturation. Dissolved gas levels seen in the mid-Columbia reach between Grand Coulee and Wells dams usually did not vary much, and high levels were either maintained when spill was occurring in the mid-Columbia, or sometimes decreased from high levels if there was no spill. Saturation at Priest Rapids Dam was usually somewhat higher than at the upstream dams. The Snake River at Lower Granite was always less than 110% saturated, and did not vary much during the season (see figure A-2); therefore dissolved gas supersaturation increases in the lower Snake River were caused solely by spill at the lower Snake dams.

At the end of April, when collection of dissolved gas data started, mid-Columbia TDG saturation levels varied between 104% and 109%, Snake River levels were between 100% and 103%, and lower Columbia levels were between 102% and 108%, except for the Warrendale site below Bonneville, which recorded levels of 110% to 111%.

During the first two weeks in May, dissolved gas saturation began to increase as flows increased. Priest Rapids in the Columbia, Lower Monumental in the Snake River, and the lower Columbia stations all recorded levels generally above 110%, and neared 120% saturation.

In the last two weeks of May, flows peaked at levels far above those seen in the past several years of drought. Since the high flows exceeded the hydraulic capacity of the dams, high amounts were spilled, and dissolved gas saturation reached the highest levels of the season. In addition, dissolved gas saturation of water coming into Grand Coulee was higher than normal, reaching a daily average high of 127% saturation. This high saturation was maintained through the mid-Columbia reach, although the peak lasted only a day or two at each site (data were not available for Rocky Reach or Rock Island). In the Snake River, high dissolved gas levels were created by spill at the lower Snake dams. At Little Goose, average saturation ranged from 107% to 120%, with five days greater than 115%. At Lower Monumental Dam, average saturation reached 133%, and ten days during this period were above 125% (see figure A-3). In the lower Columbia, most daily averages were greater than 115%, 120% was exceeded for five to twelve days, and saturations reached a high of 127% for one to two days at all three dams below McNary (see figures A-4,5,6).

The beginning of June saw a decrease in dissolved gas supersaturation in the Columbia and Snake rivers, although for the first week in the Snake and lower Columbia, levels still ranged between 110% and 120%. Dissolved gas saturation in the mid-Columbia during June stayed mostly under 110%. By the end of June, few daily averages above 110% were observed in the river system.

Reasons for spill

During periods of high flow there were correspondingly high spill volumes. The spill occurred due to flow in excess of the hydraulic capacity of the projects, or as a result of overgeneration. Overgeneration spill typically occurs during light load hours (nighttime and weekends) when the hydrosystem is generating the maximum amount it can sell. The excess flow is spilled.

Spill volumes were exacerbated by project operations during 1993. Some projects had hydraulic capacities that were less than usual because of units being out of service. At some projects this was a result of mechanical failures, while at others the reduction in hydraulic capacity was due to the conduct of research projects. Extended length screens were being tested for their fish guidance efficiency at Little Goose and McNary dams. This caused a limited hydraulic capacity at these projects during most of the high flow periods. The research units were brought back in service during the highest flow and spill period in an effort to decrease dissolved gas concentrations. In addition, at Little Goose Dam equipment related to a research project was located in a spillbay equipped with a flip lip. This caused proportionately more spill to pass through the spillbays without flip lips and concentrated the spill volume into fewer spillbays until the equipment was removed. All of the above conditions contributed to the high dissolved gas levels in the Columbia and Snake rivers in 1993.

Monitoring for Gas Bubble Disease

In 1993, a systematic program for monitoring migrating fish for signs of Gas Bubble Disease (GBD) was implemented at Smolt Monitoring Program sites. Previously, monitoring sites had informally recorded observations of GBD symptoms. In addition, in 1993 the National Marine Fisheries Service sampled salmonids as well as several other species and recorded incidence of GBD at several sites below Bonneville Dam. The monitoring program showed that in spite of high spill, the observed impacts of dissolved gas on fish were minor. Almost all observations of GBD occurred during the last two weeks of May, the period of peak flows, when several monitoring sites observed low incidence of GBD. Symptoms were generally mild; most observations consisted of bubbles in less than 50% of the surface area of one fin. The daily proportions of the sample visibly affected by GBD were generally well under 5% and mostly in the range of 1 to 2%, with the exception of Lower Monumental Dam, where proportions were above 5% on four days and on one day 18.6% of the sample was affected (see appendix figures and tables). On a site visit to Lower Monumental Dam on May 18, Larry Basham of the Fish Passage Center (FPC) observed five dead steelhead in one of the holding raceways, all with gas bubbles in their fins, and concluded that dissolved gas levels were at least high enough to begin causing mortality to juvenile fish. Dissolved gas levels reached higher levels at Lower Monumental than any other monitoring site, exceeding 130% for three out of the four days when more than 5% of the sample had GBD. These high levels, as discussed above, were a function of project operations at Little Goose.

When symptoms were seen on juvenile fish at smolt monitoring sites, higher proportions of steelhead had visible evidence of GBD as compared to salmon. Below Bonneville, very few steelhead were sampled, and symptoms were seen most often on coho, even though chinook were sampled in far greater numbers than any other salmonid. For detailed descriptions of observations at each smolt monitoring site, refer to the graphs and text in the appendix.

Fish counters at sites noted any observations of adult fish condition that could be related to GBD. The Washington Department of Wildlife reported in a July 21 memo that a few fish were observed with GBD symptoms at McNary, although in most instances it was unclear whether the injuries observed resulted from GBD. They concluded that their observations did not either support or disprove impacts of dissolved gas on adult fish. There were no known observations of GBD in adult spring/summer chinook trapped at Lower Granite Dam and in the Tucannon River in 1993. However, there were a significant number of adult fish seen in 1993 with "head burns", a condition where a portion of the cranial area is missing skin and often harboring a fungal infection. It is not known whether the head burns result from exposure to high dissolved gas levels or from physical impact, but are clearly related to high flow and spill conditions. Fish with head burns were not observed to have any other evidence of gas bubble disease.

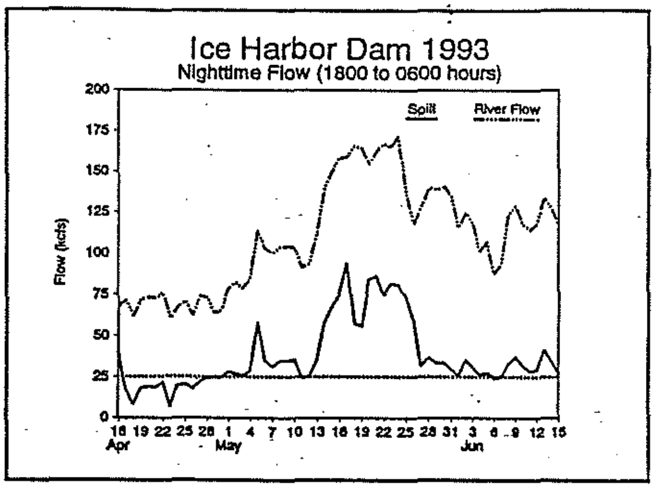
Controversy over the use of dissolved gas standards in 1993

Although the 110% standard for dissolved gas saturations in the Columbia and Snake rivers set by the states and described in an EPA criterion has been in place for over twenty years, it is commonly exceeded, usually due to spill caused by flows in excess of hydraulic capacity of the dams on the river. In 1993, there was debate over the appropriateness of using a standard level of dissolved gas supersaturation that, when exceeded, would lead to the curtailment of spill. CBFWA, in a letter to Major General E.J. Harrell of the COE-NPD on February 5, 1993 recommended that the data on fish condition collected by the smolt monitoring program, in conjunction with dissolved gas monitoring, be used to guide in-season decisions concerning spill at each project. They pointed out that use of the 110% criteria has been criticized as inappropriate by reviewers (Weitkamp and Katz 1980, Ebel et al. 1975, and COE 1986), and is also problematic when considering common sense observations such as the fact that dissolved gas levels coming into the system have exceeded 110%, and would therefore require the system not to spill at all. In addition, dissolved gas saturation at the Warrendale site, which is used to govern Bonneville spill operations, often exceeds 110% with no spill at Bonneville. The letter also pointed out inconsistency in the criteria, noting that the Bonneville operations document refers to a 120% dissolved gas criterion, while the Fish Passage Plan mentions 110% in the Bonneville section and 120% at the other projects (e.g. The Dalles and John Day).

In 1993, criteria for dissolved gas saturation levels were used in an unprecedented fashion by the COE to limit spill for fish passage. The fishery management recommendations made by the agencies and tribes in 1993 were designed to provide the safest conditions for migrant fish and took into consideration the benefits for fish passage provided by spill and the possible detriment caused by higher dissolved gas levels. During May and June, the COE limited nighttime spill at Bonneville Dam based on concern about dissolved gas levels. This limitation was made over the objections of the agencies and tribes, and in spite of their requests to spill sufficiently to achieve 80/70% FPE. The COE asserted that NMFS, in their ESA role, had concurred with their action, although there was some confusion about whether NMFS actually agreed or not. At that time, flows were on the decrease, there was no evidence that dissolved gas saturation was particularly high, and biological monitoring below Bonneville did not indicate that a major problem existed. The COE did not provide a biological analysis for their action.

The other major example of the use of a dissolved gas criterion to limit fisheries spill was the debate surrounding spill at Ice Harbor Dam in 1993. The Biological Opinion (May 26, 1993) submitted by NMFS on the operation of the Federal hydropower system set "fundamental spill for Ice Harbor Dam ...at 25 kcfs from 1800-0600 hours, from April 15 until an analysis of dissolved gas levels and fish condition can be completed by the BPA, COE and NMFS." This action replaced the measure in the 1993 COE Fish Passage Plan which specified 60% spill at Ice Harbor during the nighttime hours of the spring migration. The required analysis of dissolved gas impacts on fish was directed to be completed before May 31, 1993, but this deadline was not met. To this date, no analysis has been circulated. NMFS also required that spill be "managed to minimize periods where gas supersaturation levels exceed 110 percent, unless otherwise requested by NMFS."

On Friday, April 16 at 1700 hours, the spill program designed to provide the 70% FPE standard agreed to by the COE and NMFS at Ice Harbor Dam was terminated by a decision coordinated by Jim Athearn (COE), Merritt Tuttle (NMFS), and Gayland Arp (BPA). Only spill in excess of hydraulic capacity was authorized. The decision was prompted by concern about exceeding EPA limits after observing some hourly readings below Ice Harbor of greater than 130% (conversation between Margaret Filardo, FPC and Chris Ross, NMFS, 4/16/93). However, the COE and NMFS had no biological evidence that fish were being impacted to justify their decision, and an examination of the conditions present in the system when the decision was made raised serious questions about whether there was even a remote chance that fish were being endangered.



During that period, flows at Ice Harbor were averaging 60-65 kcfs, and at these flows and high spill levels in the past, evidence of GBD has never been observed at McNary Dam, and had not been observed at McNary in 1993 at that time. Daily dissolved gas averages were not alarming (111.2% for 4/15), and research has shown that it is extremely unlikely that levels of 110 to 115% present a danger to migrating salmonids. To address concerns about possible impacts on adult fish, Rudy Ringe of the Idaho Cooperative Fisheries Unit relayed to Chris Ross, NMFS (as conveyed to M. Filardo, FPC by Brian Brown, NMFS) that he never saw evidence of GBD in any of the over 500 adult fish he trapped in 1992 at Ice Harbor during the spill season.

To rectify the situation, the state fishery management agencies and Indian tribes repeatedly requested that spill be allowed to exceed the 25 kcfs cap to provide 80/70% FPE when dissolved gas conditions were not dangerous for fish as determined by biological observations and saturation data (SORs #93-9, 12, 17, 21 and 42). The COE repeatedly refused to honor the requests, citing their agreement with NMFS to a 25 kcfs cap (Letters from B. Tanovan, COE-NPD to M. DeHart, FPC: May 4, 20 and June 30).

In summary, the COE and NMFS made a decision to implement a spill cap at Ice Harbor based solely on a few high hourly readings of dissolved gas at a station four miles below the project, with no biological evidence demonstrating impacts on fish, that had the negative impact of reducing fish passage efficiency at the project. This decision was made over the repeated objections of the agencies and tribes, and could not be construed to be in the best interest of the juvenile migration. Although a written justification for this action was requested through the Fish Passage Center by the agencies and tribes, none was received.

Quality of dissolved gas data from stations downstream from Ice Harbor Dam

The fact that decisions which reduced FPE at Ice Harbor Dam were being made based on data from dissolved gas saturation gauges downstream from the project that were not part of the COE's standard electronic reporting system prompted the Fish Passage Center to acquire and review the data. In an addendum to the 1992 Dissolved Gas Monitoring report, the COE described problems they have had with the newly installed downstream monitors. In addition, they commented that "evaluation of the data collected in the tailwaters shows these shore-based stations log TDG levels that are not representative of those measured in the main channel." In 1993, Tom Miller (COE-NPW), who was the primary person involved in the collection of the downstream data, also relayed concerns about the quality of the data. They have had problems with keeping the gauges in place and free of sand, since they are anchored in pipes resting on the bottom of the reservoir at depths of about 15 feet. They were also concerned about groundwater intrusion affecting dissolved gas readings, and about calibration, after observing that transects in the region of the downstream gauge yielded different readings than those recorded by the gauge during the same period.

The 1993 hourly data supplied to us by the COE were highly variable, and seemed problematic. From the downstream shore station data, it would appear that spill sometimes acted to reduce dissolved gas levels in the tailwater. Also, during hours with no spill, differences measured between tailwater and forebay saturations covered a startling range, showing increases as high as 25% and decreases of up to 5% saturation. The data used by the COE in justifying the 25 kcfs spill cap show a general increase in saturation level as spill increases, as expected, but the variation in saturation level for any given amount of spill was as much as 25% saturation. We would expect any analysis of the effect of spill on dissolved gas levels to take forebay saturation into account.

Conclusions

Low incidence of gas bubble disease was observed in juvenile anadromous fish during the period of highest flow and spill during the spring migration. The impact of dissolved gas supersaturation was minimal, as evidenced by monitoring results and supported by the fact that based on cumulative passage distributions, there was no indication fish were being eliminated from the system in significant numbers. The high levels of dissolved gas were not necessarily caused by fishery spill, but rather by a combination of overgeneration and excess hydraulic capacity spill. Everything possible was done in the system to decrease the spill level, but in spite of these efforts, substantial amounts were spilled at all projects and concentrations of dissolved gas increased. We anticipate, based on the 1993 experience, that the implementation of the agency and tribal 80/70 spill program for fish passage would result in insignificant impacts from gas bubble disease and would provide for optimal survival of migrating salmonids.

The application of dissolved gas criteria to limit spill for fish passage as occurred at Ice Harbor Dam in 1993 is not appropriate and is not supported by research. Hourly peaks of high dissolved gas have not been shown to be significant in impacting fish; the literature indicates that exposure time is a critical factor and that fish survival is improved by intermittent exposure as opposed to constant exposure to high TDG saturations. The management of spill to control dissolved gas must address the benefits of spill for fish passage and the potential for adverse impacts from dissolved gas. Biological monitoring along with improved dissolved gas data collection should be used as the basis for determining actions to reduce spill and benefits of spill passage. Lastly, fish travel time through a reach must be considered because the length of exposure to high levels of dissolved gas is the major factor in determining the impacts the high levels will have on fish.

Appendix

Dissolved gas saturation and Gas Bubble Disease in juvenile fish at Smolt Monitoring sites

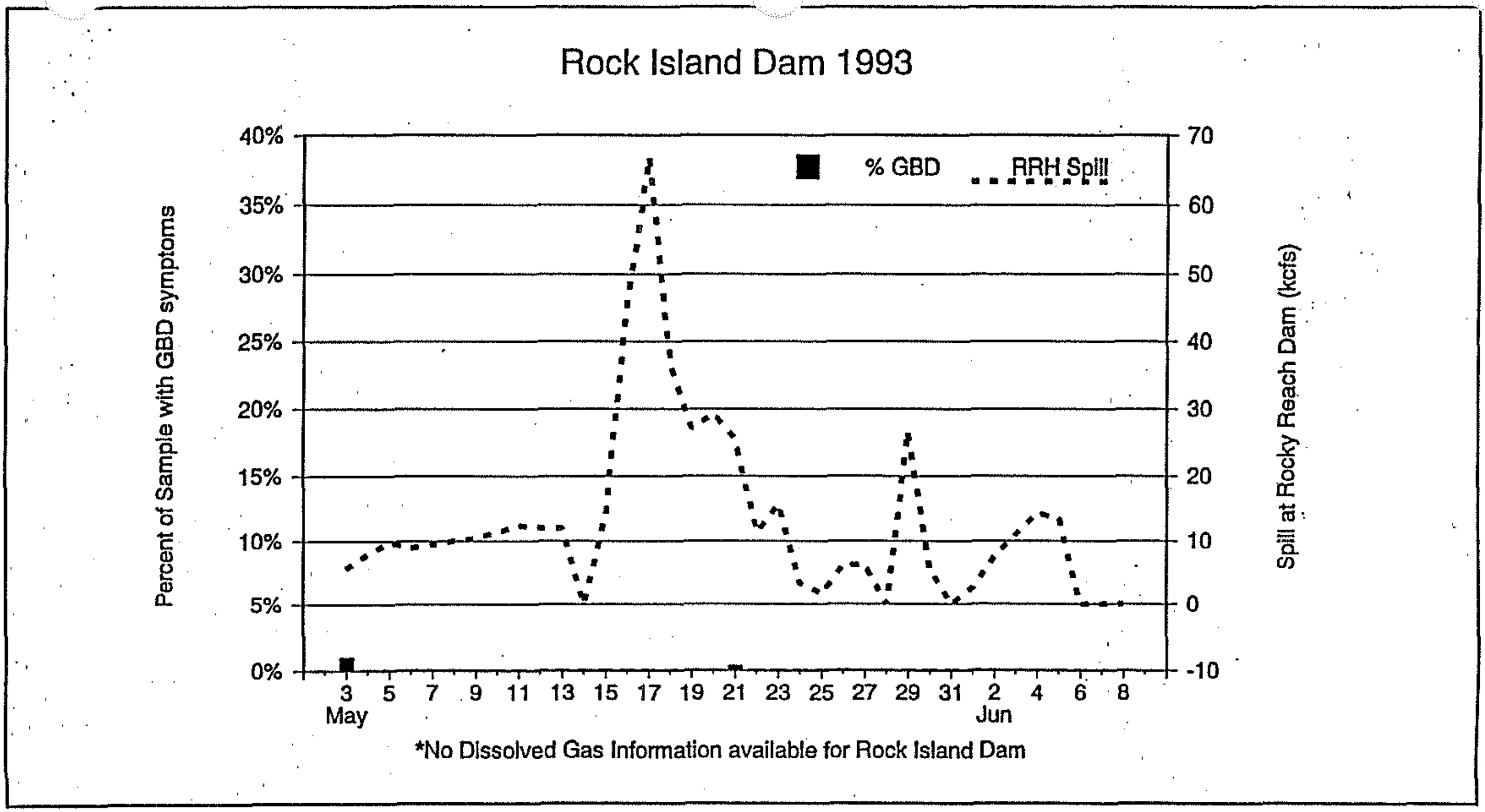


Figure A-1. Rock Island Dam

Fish were observed with GBD symptoms on 2 days at Rock Island Dam, on May 3 (2% of sockeye, or 1% of the sample) and on May 21 (1.2% of chinook, or 0.4% of the sample). No dissolved gas saturation information is available for Rock Island for May. The observations of GBD on May 3 are not likely a result of ambient river conditions, since dissolved gas levels around that time at Wells, Chief Joseph and Grand Coulee dams varied between 103 and 109%, and spill at Rocky Reach Dam was low in early May (6-8 kcfs). Spill at Rocky Reach was higher around May 21, with a peak daily average of 67 kcfs on May 17, and levels of about 30 kcfs the few days afterward.

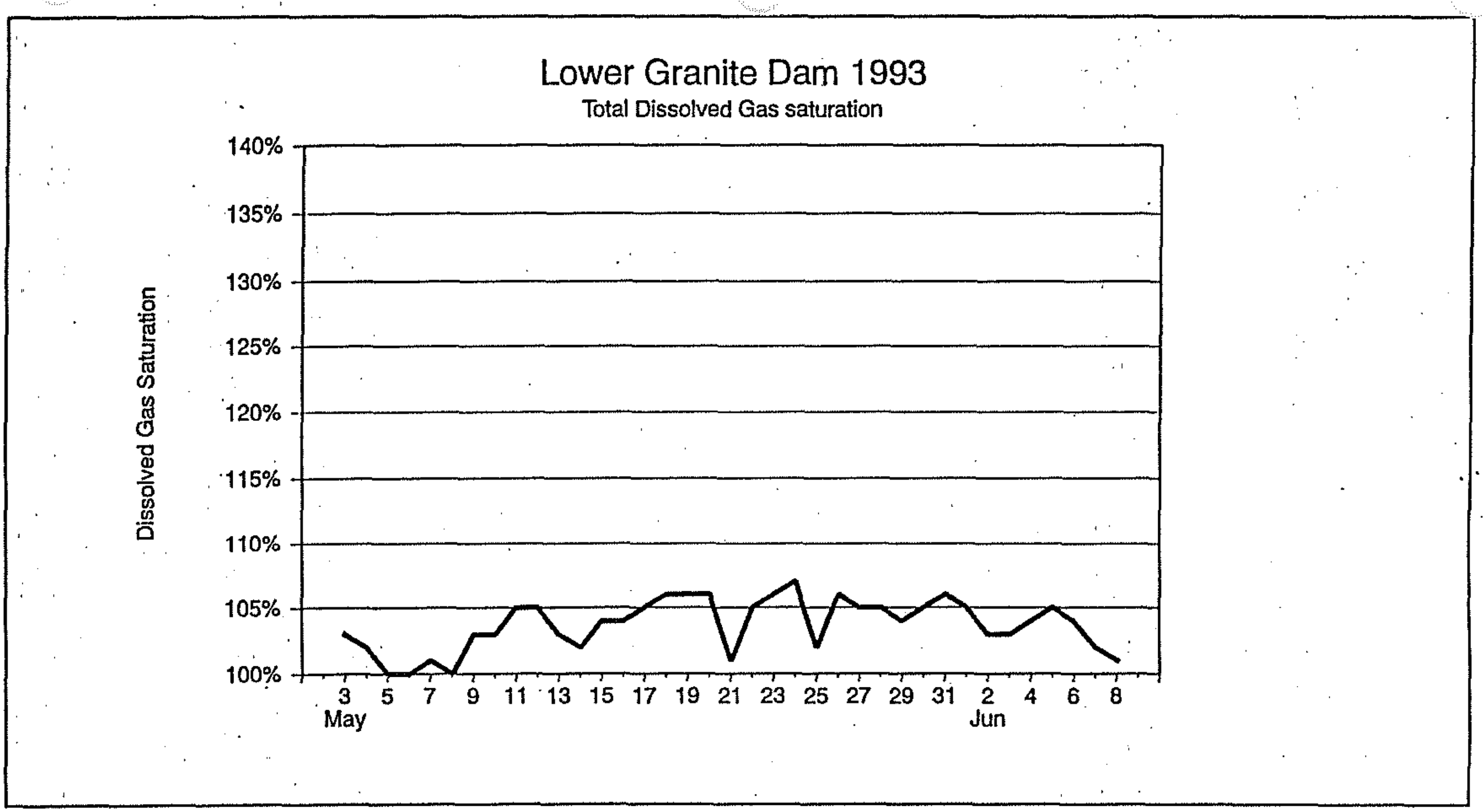


Figure A-2. Lower Granite Dam
No observations of GBD symptoms.

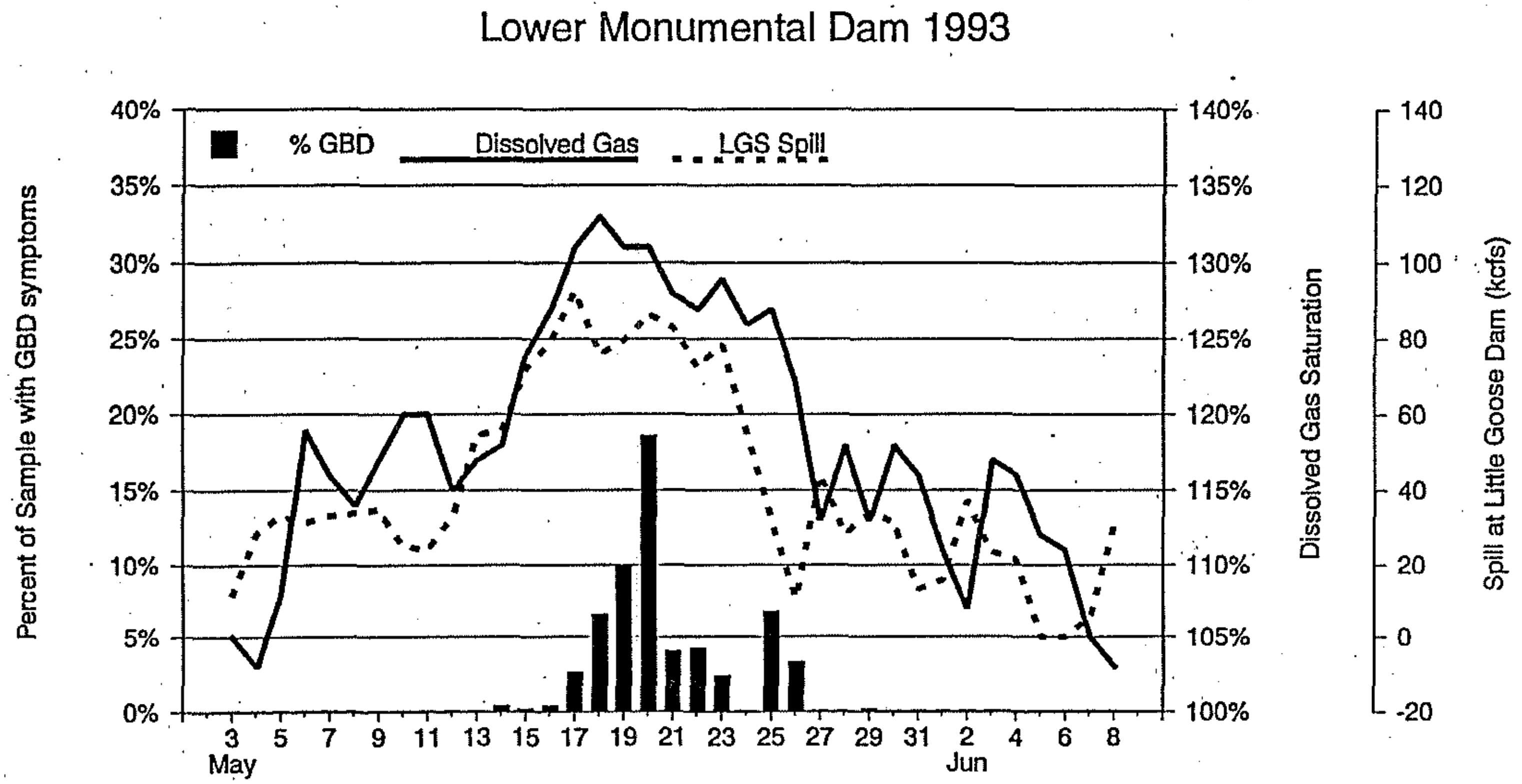


Figure A-3. Lower Monumental Dam

The highest percentages of the sample with GBD throughout the entire system were observed at Lower Monumental Dam, with a peak of 18.6% of the sample on May 20. Lower Monumental Dam also had some of the highest dissolved gas levels of any of the monitoring sites, exceeding 130% for 4 days beginning May 17. GBD symptoms were first seen on May 14, and last seen on May 29. The most frequent category of GBD symptoms observed were bubbles in less than 50% of the caudal fin. The second most common type were observations of bubbles in the caudal and other fins, and the least frequent were observations of bubbles in greater than 50% of the caudal fin. Two wild steelhead sampled on May 16 had severe symptoms of GBD. Symptoms were seen in steelhead (highs of 18% and 19% for hatchery and wild, respectively), chinook yearlings (daily maximums of 15% for hatchery and 12.5% for wild), and a few sockeye. Operations limitations at Little Goose Dam during the period of peak flows contributed to the dissolved gas problems at Lower Monumental Dam. Two units were out of service for FGE testing, which reduced the hydraulic capacity of the dam and forced more spill. In addition, one spillbay equipped with a flip lip was unusable because of research equipment installed in it for NMFS survival study purposes. This caused proportionately more spill to pass through the spillbays without flip lips and concentrated the spill into a smaller area, which likely resulted in higher dissolved gas levels than if all the spillbays had been usable. Spill levels at Little Goose during the period when GBD was observed ranged from a daily average of 10.8 to 92.9 kcfs, and averaged 61.4 kcfs.

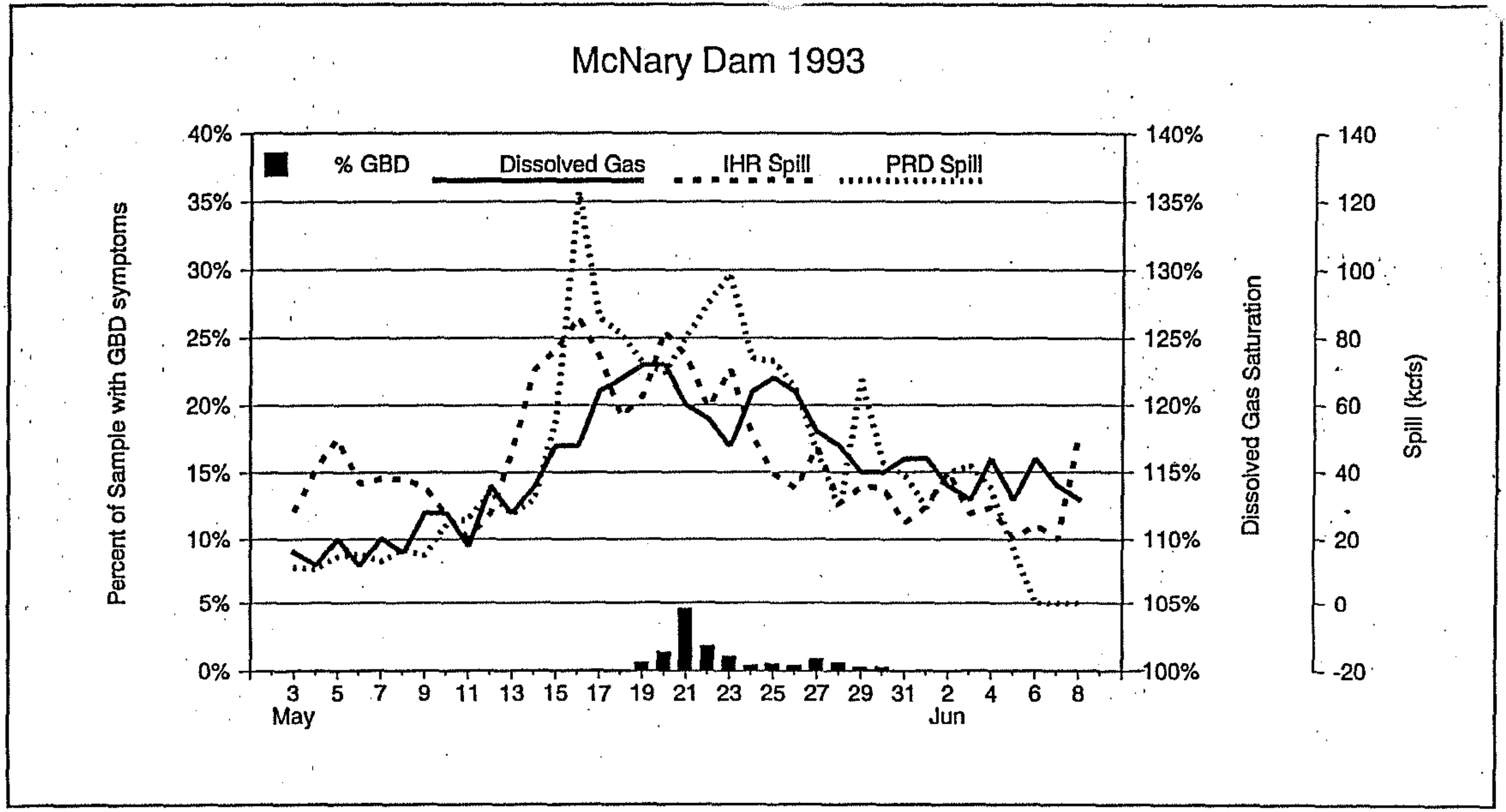


Figure A-4. McNary Dam
Low incidence of GBD symptomatic fish was seen May 19 through May 31 at McNary Dam. Daily incidence varied from 0.1% of the sample to 4.6% of the sample on May 21. The daily average dissolved gas high during this period was 123% for two days, May 19 and 20. Spill at Ice Harbor during the period when fish were affected ranged from around 30 to over 80 kcfs; spill at Priest Rapids Dam was mostly over 80 kcfs during the time when the highest frequencies of GBD symptomatic fish were seen. The most frequent category of GBD symptoms observed were bubbles in less than 50% of the caudal fin. The second most common type were observations of bubbles of bubbles in greater than 50% of the caudal fin, and the least frequent were observations in the caudal and other fins. Symptoms were seen in steelhead (highs of 8% and 14% for hatchery and wild, respectively), coho (maximum 7%), sockeye (maximums of 9% and 2% for hatchery and wild, respectively) and chinook yearlings (maximum 5% of daily sample).

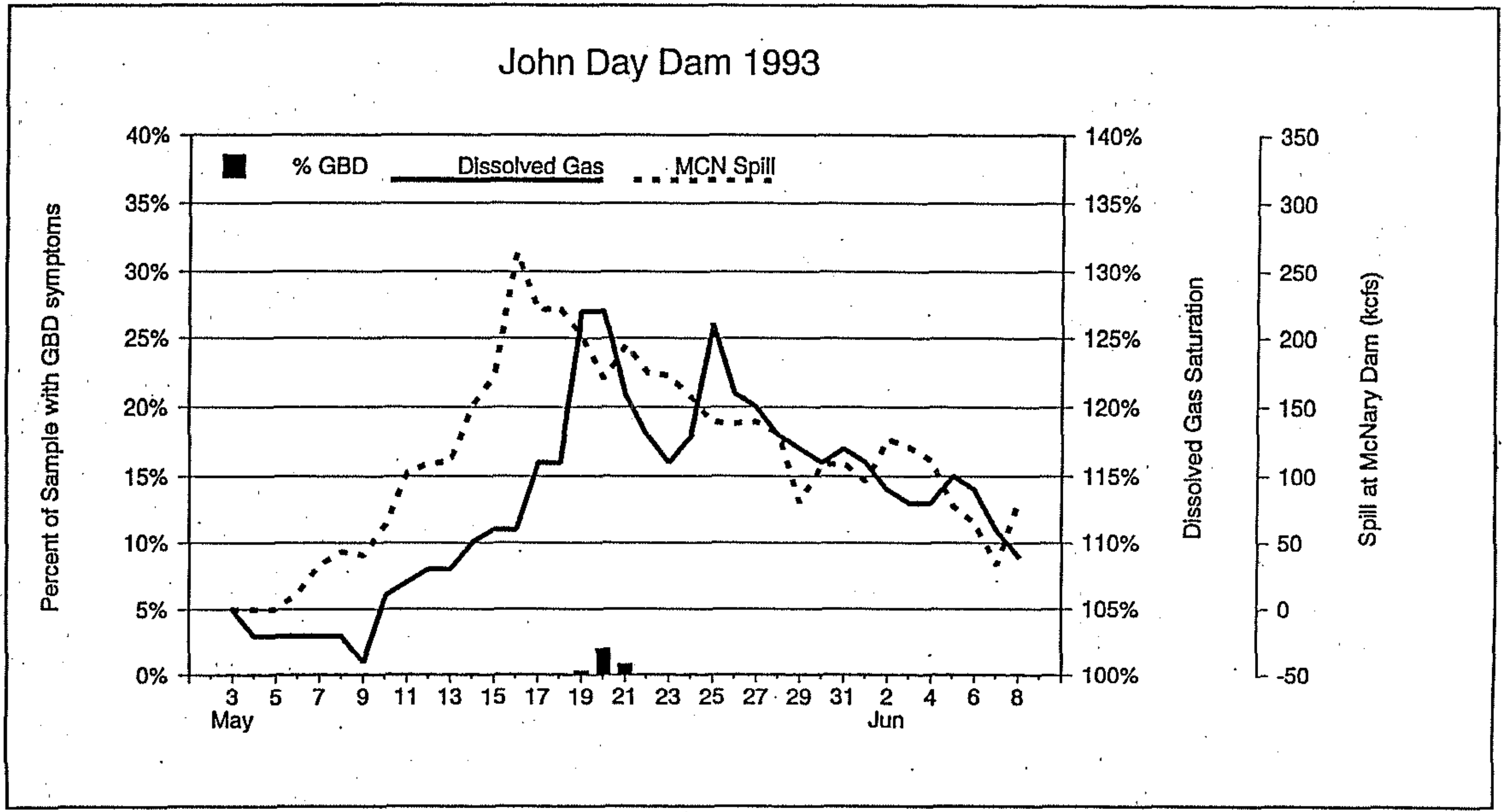


Figure A-5. John Day Dam

Low incidence of GBD symptoms was observed on 5 days at John Day Dam, May 19-21, when several fish were observed with symptoms, and on May 27 and 31, when one steelhead was seen with signs of GBD each day. The peak was 2% of the sample on May 20. Dissolved gas daily average saturations on May 19-21 were 127%, 127% and 121%, up from daily averages of 108% to 116% the preceding several days. Signs of GBD were most often observed in steelhead; the peak daily percentage of steelhead with GBD was 3%. GBD was also observed in chinook and coho (1% each on May 20).

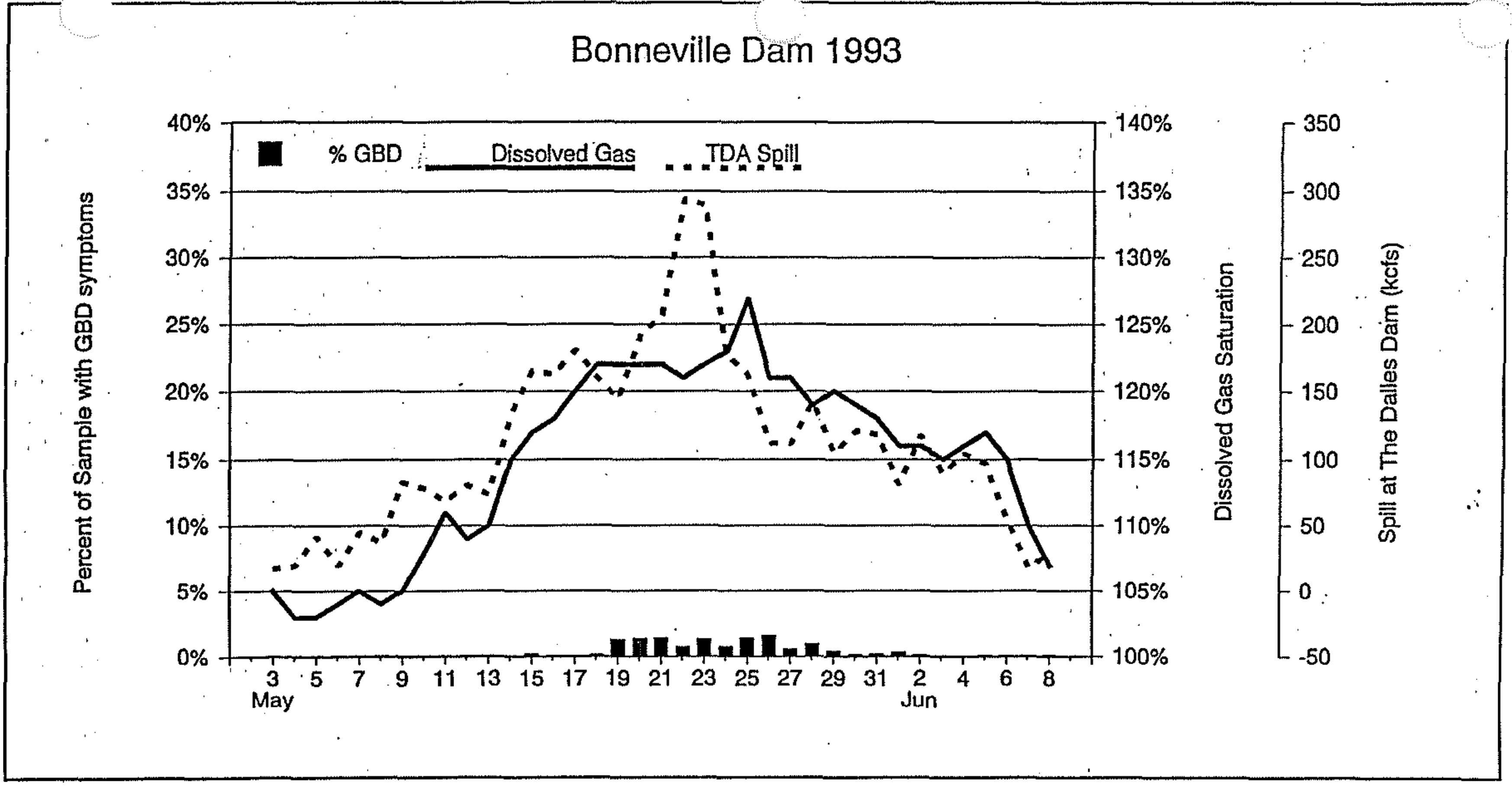


Figure A-6. Bonneville Dam

Low incidence of GBD symptoms in fish was observed on 19 days during the period beginning May 15 and ending June 8. This comprised the longest time span over which GBD observations were made at any monitoring site. The highest percentage of the daily sample with evidence of GBD was 1.6% on May 26. Daily average dissolved gas saturation during the period when most GBD symptoms were seen were above 120%; the high was 127%. GBD was seen mostly in steelhead (daily highs of 8% and 11% for hatchery and wild, respectively), sometimes in coho (maximum of 3%), less often in chinook yearlings and sockeye (1% of sample or less), and almost never in chinook subyearlings. Bonneville was the only site that observed GBD symptoms in subyearlings at all.

Below Bonneville:

The National Marine Fisheries Service reported that 24 salmon and steelhead were observed with mild symptoms of GBD below Bonneville Dam out of 1,863 sampled from May 6 to June 16. A similar proportion of other species sampled were observed to be affected. Two out of 26 coho with bubbles in less than 50% of the caudal fin were sampled at the Rooster Rock station (RM 130) on May 19. 11 out of 17 coho sampled at the Rooster Rock station (RM 130) on May 21 had bubbles in the anal fin, and 2 out of the 17 had bubbles in less than 50% of the caudal and anal fins. Also on May 21, 1 out of 68 chinook and the only coho sampled at the Lemon Island station (RM 111.8) had anal fin bubbles. 1 out of 102 chinook, the only coho, and 1 out of 35 peamouth sampled at the Puget Island station (RM 46.3) on May 22 had bubbles in their anal fins. On May 25, at Rooster Rock, 2 out of 4 coho and 1 out of 5 steelhead sampled had bubbles in the anal fin. 2 out of 7 coho sampled at the Hump Island station (RM 59.7) on June 9 had signs of GBD; one had bubbles in the anal fin and the other had bubbles in less than 50% of the caudal fin. Three non-salmonids were also observed to have evidence of GBD, out of approximately 1,500 sampled. On June 1, one out of 24 sculpin sampled at the Beacon Rock station (RM 142) had bubbles in the eye and 2 out of 12 stickleback had bubbles on the posterior half of the body on the side above the lateral line.

Table A-1.

1993 Bonneville Dam Smolt Monitoring Program Gas Bubble Disease Incidence

Date	All Species	Yearling Chinook	Subyearling Chinook	Hatchery Steelhead	Wild Steelhead	Coho	Wild Sockeye
5/15	0.2%	0.0%	0.0%	0.0%	4.8%	0.0%	0.0%
5/16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5/17	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%
5/18	0.1%	0.0%	0.0%	0.4%	1.1%	0.0%	0.0%
5/19	1.3%	0.6%	0.0%	2.9%	8.0%	0.4%	0.0%
5/20	1.3%	0.0%	0.0%	2.9%	6.5%	1.9%	0.0%
5/21	1.4%	1.1%	0.0%	5.1%	11.1%	2.0%	0.0%
5/22	0.8%	1.0%	0.0%	2.0%	4.0%	1.0%	0.0%
5/23	1.3%	0.4%	0.0%	5.0%	7.1%	1.6%	0.0%
5/24	0.8%	0.3%	0.0%	2.5%	5.5%	1.3%	0.0%
5/25	1.4%	0.3%	0.0%	6.9%	7.3%	2.7%	0.0%
5/26	1.6%	0.4%	0.0%	7.3%	4.3%	1.7%	0.4%
5/27	0.5%	0.2%	0.0%	1.2%	0.5%	1.9%	0.7%
5/28	1.0%	0.2%	0.0%	8.2%	2.5%	1.9%	0.6%
5/29	0.4%	0.0%	0.0%	0.0%	10.2%	0.0%	0.5%
5/30	0.1%	0.0%	0.0%	1.5%	0.0%	0.0%	0.0%
5/31	0.2%	0.0%	0.2%	1.3%	0.0%	0.5%	0.0%
6/1	0.3%	0.1%	0.2%	3.0%	0.0%	0.0%	0.0%
6/2	0.1%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
6/3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6/4	0.1%	0.0%	0.0%	1.7%	0.0%	0.0%	0.0%
6/5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6/6	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6/7	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6/8	0.1%	0.0%	0.0%	2.7%	0.0%	0.0%	0.0%

Table A-2.

1993 John Day Dam Smolt Monitoring Program Gas Bubble Disease Incidence

Date	All Species	Yearling Chinook	Hatchery Steelhead	Coho
5/15	0.0%	0.0%	0.0%	0.0%
5/16	0.0%	0.0%	0.0%	0.0%
5/17	0.0%	0.0%	0.0%	0.0%
5/18	0.0%	0.0%	0.0%	0.0%
5/19	0.3%	0.0%	0.5%	0.0%
5/20*	2.0%	1.0%	3.0%	1.0%
5/21	0.8%	0.0%	1.0%	0.0%
5/22	0.0%	0.0%	0.0%	0.0%
5/23	0.0%	0.0%	0.0%	0.0%
5/24	0.0%	0.0%	0.0%	0.0%
5/25	0.0%	0.0%	0.0%	0.0%
5/26	0.0%	0.0%	0.0%	0.0%
5/27	0.0%	0.0%	0.1%	0.0%
5/28	0.0%	0.0%	0.0%	0.0%
5/29	0.0%	0.0%	0.0%	0.0%
5/30	0.0%	0.0%	0.0%	0.0%
5/31	0.0%	0.0%	0.2%	0.0%
6/1	0.0%	0.0%	0.0%	0.0%
6/2	N/A	N/A	N/A	N/A
6/3	0.0%	0.0%	0.0%	0.0%
6/4	N/A	N/A	N/A	N/A
6/5	0.0%	0.0%	0.0%	0.0%
6/6	0.0%	0.0%	0.0%	0.0%
6/7	N/A	N/A	N/A	N/A
6/8	0.0%	0.0%	0.0%	0.0%

*Percentages for May 20 are estimates.

Table A-3.

1993 McNary Dam Smolt Monitoring Program
Gas Bubble Disease Incidence

Date	All Species	Yearling Chinook	Wild Steelhead	Hatchery Steelhead	Coho	Wild Sockeye	Hatchery Sockeye
05/18	0.0%	0.0%	1.2%	0.0%	1.0%	0.0%	0.0%
05/19	0.6%	0.6%	1.7%	1.4%	6.9%	0.3%	0.0%
05/20	1.4%	0.7%	5.3%	4.3%	5.1%	0.8%	0.0%
05/21	4.6%	5.1%	9.2%	8.4%	7.2%	2.2%	8.7%
05/22	1.8%	1.9%	14.3%	1.3%	1.7%	1.0%	7.7%
05/23	1.1%	1.4%	7.5%	2.2%	0.0%	0.5%	0.0%
05/24	0.4%	0.1%	5.6%	3.0%	0.0%	0.0%	0.0%
05/25	0.5%	0.0%	4.7%	2.3%	1.6%	0.2%	0.0%
05/26	0.4%	0.0%	4.3%	1.8%	1.3%	0.2%	0.0%
05/27	0.9%	0.2%	7.1%	4.5%	1.3%	0.5%	0.0%
05/28	0.6%	0.1%	1.1%	3.1%	0.4%	0.7%	0.0%
05/29	0.3%	0.0%	0.0%	1.2%	1.2%	0.5%	0.0%
05/30	0.3%	0.2%	0.0%	1.4%	1.0%	0.0%	0.0%
05/31	0.1%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%

Table A-4.

1993 Lower Monumental Dam Smolt Monitoring Program Gas Bubble Disease Incidence

Date	All Species	Hatchery Yearling Chinook	Wild Yearling Chinook	Hatchery Steelhead	Wild Steelhead	Sockeye*
05/14	0.4%	0.0%	0.0%	0.0%	4.8%	0.0%
05/15	0.2%	0.0%	0.0%	0.0%	2.8%	0.0%
05/16	0.4%	0.0%	0.0%	0.0%	4.9%	0.0%
05/17	2.6%	4.8%	0.0%	2.3%	4.0%	0.0%
05/18	6.6%	8.6%	0.0%	6.9%	4.8%	100.0%
05/19	10.0%	15.2%	6.8%	8.6%	10.8%	100.0%
05/20	18.6%	18.3%	12.5%	18.4%	23.8%	100.0%
05/21	4.0%	9.8%	7.1%	2.5%	0.0%	0.0%
05/22	4.2%	2.2%	0.0%	4.7%	6.8%	0.0%
05/23	2.4%	1.5%	3.0%	2.3%	4.1%	0.0%
05/24	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
05/25	6.8%	0.0%	0.0%	8.9%	0.0%	0.0%
05/26	3.3%	0.0%	0.0%	3.9%	4.7%	0.0%
05/27	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
05/28	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
05/29	0.2%	0.0%	0.0%	0.6%	0.0%	0.0%

*Sockeye sample sizes were 0 to 2 fish.

Table A-5.

1993 Rock Island Dam Smolt Monitoring Program Gas Bubble Disease Incidence

Date*	All Species	Yearling Chinook	Sockeye
04/28	0.0%	0.0%	0.0%
04/30	0.0%	0.0%	0.0%
05/03	1.0%	0.0%	2.0%
05/05	0.0%	0.0%	0.0%
05/07	0.0%	0.0%	0.0%
05/10	0.0%	0.0%	0.0%
05/14	0.0%	0.0%	0.0%
05/17	0.0%	0.0%	0.0%
05/19	0.0%	0.0%	0.0%
05/21	0.4%	1.2%	0.0%
05/24	0.0%	0.0%	0.0%
05/26	0.0%	0.0%	0.0%
05/28	0.0%	0.0%	0.0%
06/02	0.0%	0.0%	0.0%
06/07	0.0%	0.0%	0.0%
06/09	0.0%	0.0%	0.0%

*Days where information was unavailable not included in table.

COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION
729 N.E. Oregon; Suite 200, Portland, Oregon 97232
Telephone (503) 238-0667
Fax (503) 235-4228

MEMORANDUM

TO: GREG MCMURRY, OREGON DEPARTMENT OF ENVIRONMENTAL QUALITY

FROM: BOB HEINITH, CRITFC, FISH PASSAGE BIOLOGIST

DATE: SEPTEMBER 13, 1993

RE: REVIEW OF MAINSTEM COLUMBIA RIVER DISSOLVED GAS STANDARD

Recommendations

1. The Columbia River Inter-Tribal Fish Commission (CRITFC) believes the mainstem Columbia River dissolved gas standard, as set by the states of Oregon and Washington, precludes protection of the tribes' federally reserved salmon resources. The majority of the state and federal agencies of the Columbia Basin Fish and Wildlife Authority (CBFWA) also have similar concerns with respect to the protection of anadromous fish migrating through the Columbia River hydrosystem and the current dissolved gas standard.

2. The CRITFC and CBFWA recommend the extant dissolved gas standard be modified to allow flexibility for fishery management purposes during the anadromous fish migration periods on a real time basis as conditions warrant.

3. We request the Department of Environmental Quality coordinate a review and modification of the standard with the CRITFC and other CBFWA agencies.

Background

In 1993, management of Columbia Basin hydrosystem for the protection and safe passage of salmon stocks, both listed and not listed under the Endangered Species Act, has been directed by the 1993 National Marine Fisheries Service Biological Opinion for the hydrosystem (BIOP). In turn the BIOP was formulated from 1993 biological assessments from the "action agencies", including the Corps of Engineers. A key part of the Corps biological assessment was based upon the real time operation of the hydrosystem during salmon migration periods, which was directed by the Corps 1993 Fish Passage Plan. The plan contained operational constraints to spill as a primary mode of juvenile fish passage, because such spill would create in river dissolved gas levels in excess of levels already exceeding the EPA standard of 110%.

In 1993, a majority of the agency and tribal members of the Columbia Basin Fish and Wildlife Authority, including the USFWS, ODFW, IDFG, and CRITFC, proposed management of spill for juvenile passage to be conditioned upon real time monitoring of effects gas bubble disease (GBD) on juvenile and adult salmonids at the dams. Actual monitoring revealed only very limited, isolated occurrences of GBD at a few dams during limited periods of extremely high **forced spill** when the dams experienced load distribution problems. At these times, total dissolved gas levels exceeded 130%. The daily proportion of juvenile migrant GBD occurrence during this period ranged from 1-5% at all Snake River Projects except Lower Monumental, where for four days GBD proportions were greater than 5%. During the rest of the juvenile migration, GBD proportions averaged between 1-2%, and adult symptoms averaged less than 1%. (CBFWA 1993 Attachment 1; WDW 1993).

Despite this evidence, the Corps and NMFS rejected the fishery agency and tribal recommendation, and instead conditioned voluntary spill upon total dissolved gas levels measured by an incomplete physical monitoring system in the hydrosystem reservoirs. In this manner, 1993 voluntary spill levels at dams were substantially decreased over 1992 levels despite favorable flow, water quality and fish condition.

It has been well documented in the scientific literature that direct spill mortality for juvenile and adult salmon which fall back over the dam (0-2%) is much lower as compared to direct mortality through the turbines or through mechanical bypass systems (10-15%). Thus, any potential increased mortality due to elevated total dissolved gas levels remains substantially below mortality incurred through passage routes other than spill.

It has also been well documented in the scientific literature that high levels of total dissolved gas are not an inclusive indication of levels of acute or chronic GBD. The combination of many other variables, including fish size, stock, physiological condition, exposure time, water temperature, turbidity, and existing atmospheric pressure, are responsible for GBD.

Despite only isolated findings of GBD during high flows in 1993, the Corps is proposing similar spill management in their draft 1994 Fish Passage Plan, **solely based upon the EPA and states 110% standard.**

Attachment 1

REFERENCES

CBFWA. 1993. Dissolved gas review and 1993 summary. Fish Passage Center. Portland, Oregon.

WDW. 1993. July 21, 1993 Memorandum from T. Kleist, adult fish supervisor to members of the FPDEP Operations and Maintenance Subcommittee.

COLUMBIA BASIN FISHERY AGENCIES AND TRIBES

FISH PASSAGE CENTER

2501 S.W. FIRST AVE. • SUITE 230 • PORTLAND, OR 97201-4752
PHONE (503) 230-4099 • FAX (503) 230-7559

MEMORANDUM

DATE: September 10, 1993

TO: FPAC
CBFWA Liaison Group

Michele DeHart

FROM: Michele DeHart

RE: Dissolved Gas review and 1993 summary

In response to a request from FPAC, we have completed a review of the literature pertaining to dissolved gas standards for the Columbia and Snake rivers, and an assessment of 1993 dissolved gas saturation conditions and impacts on fish. The document includes a review of the application of dissolved gas standards with respect to spill management in 1993.

We were also asked to review the specific spill management and dissolved gas data at Ice Harbor Dam in 1993. We received the data from the Corps of Engineers, and are aware of the verbal recommendations they made to NMFS regarding Ice Harbor spill management. However, the COE has not provided a written analysis based on the information they collected, which provided the basis for Ice Harbor management decisions. We will review and provide comments to you when that written report is produced.

If you have any questions, please contact Lucy Bernard of my staff at (503)230-4291.

602-93.lab

To

Bill Masters

[redacted]

Curriculum Vitae

WESLEY J. EBEL

1. Present Address

107 NW 185th
Seattle, WA 98177
Phone 206-542-2978

2. Education

1953 - B.S. degree, University of Nevada
1959 - Graduate work in Limnology, University of Minnesota Biological Station
1963 - Completed extension course from Portland State University
1975-76 - Graduate work in statistics, University of Washington
1978 - PhD, University of Idaho

3. Work Experience

A. Current Position: 1988 to present, Fishery Research Consultant.

B. Last Full-Time Position: 1977-1988

(1) Division Director
Division of Coastal Zone and Estuarine Studies
Northwest Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

(2) Position Classification: Fishery Biologist (Research-Administration)

(3) Description of research I was conducting.

As Director of the Coastal Zone and Estuarine Studies Division, I was responsible for providing, through research, the information necessary for the protection, enhancement, and optimum utilization of the fisheries resources of the coastal zone and estuaries of the Pacific Northwest. I was primarily concerned with broad policy development for the Division's research efforts in the Columbia River Basin, and the development of fishery enhancement and stock identification techniques as areas of increasing potential and national interest. Research in the

Columbia River Basin was conducted to assess the effects of dams and other water resource developments on the migration and survival of the anadromous fishes and on the ecology of the Columbia and tributary rivers; to determine causes of fish losses; to develop systems to protect fish from hazardous conditions resulting from water use and development; and to evaluate the effectiveness of protective actions. Research in fisheries enhancement was centered on techniques designed to improve current husbandry practices to improve survival of hatchery stocks and to develop new strategies for enhancement of depleted stocks. Research in stock identification was focused on improvements in genetic stock identification procedures for use in management under the U.S./Canada Salmon Treaty.

The research activities under my supervision were and are of concern to many groups, including international, federal, and state agencies, as well as industry, recreational fishermen, and the public. I had to be familiar with the aims and organization of such groups and have sufficient knowledge of their current and contemplated programs and needs to direct the research programs of the Division to be responsive to the needs of these groups.

C. Earlier Professional Experience

1957-1958	Ann Arbor, Michigan Laboratory, Bureau of Commercial Fisheries. Collected fishery biological data and specimens at various sea lamprey control installations, at fishing ports, and from streams on which control devices are maintained, including: collection of fishes, lamprey and invertebrates, and fishes on spawning grounds; making routine limnological observations including temperature, water chemistry, and volume of stream flow.
1958-1959	Ann Arbor, Michigan Laboratory, Bureau of Commercial Fisheries. As assistant area supervisor, supervised operation of sea lamprey control device on shoreline of western and northern Lake Michigan. Analyzed and prepared data collected for reports. Recommended, planned, and carried out changes in construction and design of installations to improve efficiency. Conducted stream surveys using electrical shockers and other equipment. Developed a back-pack shocker for lamprey larvae

surveys. A report was published in Progressive Fish Culturist in April 1961.

1959-1961	Operated bioassay laboratory used to determine concentrations of larvicide to be used in treatment applications. Knowledge of water chemistry, preparation of standard solutions, and bioassay procedure necessary. Assisted in supervision of chemical treatment crews which involved accurate analysis of chemical concentrations with critical adjustments of chemical feeding equipment.
1961-1962	As chemical control supervisor, scheduled and supervised setting up of chemical feeders and analysis laboratory. Operated bioassay laboratory, measured stream volumes and conducted stream surveys. Compiled and analyzed data reports. Prepared cost accounting, and began a study to determine effect of chemical treatments on benthos organisms which resulted in publication in 1968 (SSR No. 572) by Richard Torblaa. I developed a dye detector during this period which I reported in the Great Lakes Fishery Commission Report No. 4, September 1962.
1962-1965	Transferred from Great Lakes region to West Coast to work with team of scientists studying the effect of reservoirs on salmon migrations as a part of the overall fish passage program. I was assigned to the limnology project at Brownlee Reservoir in 1963. The purpose of this project was to determine the physical, chemical, and biological characteristics of reservoirs and water impoundment areas, especially in relation to the distribution and behavior of migrating salmon. This project terminated in 1965. Results were published in 1969 in Fisheries Bulletin, Vol. 67, No. 2. This report was used extensively by both state and federal agencies in making decisions involving the construction of High Mountain Sheep Dam. As a result of this report and other information, a decision was made not to build the dam.
1965-1974	The Brownlee Reservoir studies were terminated in 1965. I was transferred to Seattle and assigned as Program Leader of the Transportation of Juvenile and Adult Salmon Studies, in addition, I was assigned a nitrogen study. This program made the following progress:

1) Developed an automatic magnetic tag detection system which detects and automatically separates adult fish tagged with magnetic wire tags. Published in Fish. Res. Board of Canada, 1969, Vol. 26:3083-3088. 2) Determined that transportation of wild and hatchery juvenile chinook around danger areas can increase survival; and that homing of naturally migrating chinook salmon and steelhead was not affected. Report published in American Fish. Soc. Transactions, 1970 and in NMFS Fish. Bull. 71(2):549-563, 80(2):491-505. 3) Determined that thermal branding can be used successfully to evaluate returning adult spring and summer chinook salmon. Marine Fisheries Review - 1974. 4) Perfected magnetic tagging process so wild salmonids can be tagged successfully. Marine Fisheries Review - 1974. 5) Verified losses between dams resulting in conclusive evidence for mitigation purposes. NWAFC, Proc. Rep., 1979, 39 pp.

Nitrogen studies resulted in numerous investigations and reports which led to solutions to the problem of supersaturation of atmospheric air and have made fishery scientists throughout the west coast cognizant of the importance of supersaturation in relation to gas bubble disease and fish survival. Reports published in Fish. Bull. 5, SSRF, and special reports.

1975-1976 Served as Deputy Director of the Coastal Zone and Estuarine Studies Division. With the Director, was primarily concerned with broad policy development for the Division's research effort in both the Columbia Basin and the development of Aquaculture (fisheries enhancement) as an area of increasing national and international potential. Shared with Director the responsibility for formulating research plans and goals and in critically reviewing the results and recommendations forthcoming these actions. I shared with Director the responsibility for analysis of research needed, anticipating the social and economic trends; initiation of exploratory research to access probability of success of major effort; preparation of research programs for definition of objectives, schedules, manpower, and budget requirements; conduct of research after review and approval of Center Director, NMFS Headquarters Washington; and reviewed progress to meet all Center service and scientific requirements.

1977-1988 As Director of the Coastal Zone and Estuarine Studies Division, I was responsible for providing, through research, the information necessary for the protection, enhancement, and optimum utilization of fishery resources of the coastal zone and estuaries of the Pacific Northwest. I was primarily concerned with broad policy development for the Division's research efforts in the Columbia River Basin and the development of fisheries enhancement techniques as an area of increasing potential. Research in the Columbia River was and still is conducted to assess the effects of dams and other water resource developments on the migration and survival of anadromous fishes and on the ecology of the Columbia and tributary rivers; to determine causes of fish losses; to develop systems to protect fish from hazardous conditions resulting from water use and development; and to evaluate the effectiveness of protective actions.

Because of the complexities of the program and its close relationship with other agencies, I was often expected to lead a coordinated effort to maintain or enhance fishery resources. Accordingly, I had to exhibit a high degree of originality and have training and experience in the theory and application of fishery biology, biometrics, and oceanography. I also had to have a working knowledge of engineering as it applies to the design, construction, and operation of gear to assess, sample, and culture fish populations. I also was familiar with considerations involved in the construction and operation of hydroelectric dams. This required significant extension of existing theory and methodology.

I was responsible for analysis and reporting of research results including designing programs to anticipate social and economic trends, initiation of exploratory research to assess probability of success and cost/benefits, definition of program objectives, schedules, manpower and budget requirements, conducting the research after review and approval of Center Director, NMFS Headquarters in Washington, and allocation of funds and review of progress to meet all NOAA, NWAFS, and scientific requirements.

4. Memberships - Professional Associations

American Institute of Fishery Research Biologists (AIFRB)
American Fishery Society
Pacific Fishery Biologist (PFB)

5. Significant Research Accomplishments

Determined the physical, chemical, and biological characteristics of reservoirs and water impoundment areas, especially in relation to the distribution and behavior of migrating salmon. This report was used extensively by both state and federal agencies in making decisions involving the construction of High Mountain Sheep Dam. As a result of this report and other information, a decision was made not to build the dam.

Developed an automatic magnetic tag detection system which detects and automatically separates adult fish tagged with magnetic wire tags.

Determined that downstream survival of both hatchery and wild juvenile chinook salmon can be increased by transportation around danger areas; and that homing of adult naturally migrating chinook salmon and steelhead are not affected.

This work has lead to the implementation of a mass transport effort on the Snake and Columbia Rivers; adult runs in the Snake River are being maintained at this time by a collection and transportation system developed as a result of this work.

Perfected the magnetic tagging process so that wild salmonids with a wide range of size variation can be successfully tagged.

Verified losses between dams resulting in conclusive evidence for mitigation purposes.

Determined that stress factors caused by diversion and collection of juvenile chinook salmon at Little Goose Dam and other dams needs to be eliminated before optimum benefit can be achieved by a collection and transportation system.

The nitrogen studies resulted in numerous investigations and reports which have lead to solutions to the problems of supersaturation of atmospheric air and gas bubble disease, and have made fishery scientists throughout the U.S. cognizant of the importance of supersaturation of nitrogen gas in relation to gas bubble disease and fish survival. The studies have resulted in the following accomplishments:

(1) Completed surveys of nitrogen gas levels from Grand Coulee, Washington, to Astoria, Oregon. Seasonal cycles of levels and cause of the supersaturation were determined.

(2) Studies of nitrogen and effects on fish in the vicinity of John Day Dam in 1968 revealed that substantial losses to both juvenile and adult salmon occurred and that gas bubble disease caused by nitrogen was a major factor.

(3) Other experiments concerning timing of releases of hatchery progeny in the Columbia River revealed that significant loss to hatchery populations occurred if releases were made during high nitrogen. These experiments have resulted in the acceptance of an entirely new concept for release of hatchery progeny in the lower Columbia River and timing of releases took into account the levels of nitrogen supersaturation.

(4) Studies concerning the effect of supersaturation on a salmonid's tolerance to temperature increase revealed that a salmon's tolerance to temperature increases is lowered when a fish has been stressed by gas bubble disease. Results of this report have contributed to the decision by the authorities to require thermal power plants to provide for cooling of discharge water. This information also was used to adjust temperature tolerance standards now in existence.

(5) Other studies designed to help find solutions to the problem of supersaturation of atmospheric gas led to the installation of spillway deflectors on key dams, and for the present, the problem is essentially solved in the Columbia River. These studies also provided key information ont he establishment of gas standards by EPA and the states for the Columbia River.

(6) Studies on the effect of collection and transportation of juvenile salmonids has led to the installation and operation of major collection and transportation systems at three Columbia River dams. The operation of these systems has been instrumental in restoring viable runs of chinook and steelhead in the upper Columbia River drainage.

6. Scientific Honors and Awards

1970 - Special Achievement Award
1971 - Superior Performance
1971 - Best paper in AFS Transaction for 1970
1972 - Special Achievement Award
1972 - Nominated for Federal Employee of the Year Award
1973 - Special Achievement Award
1974 - Special Achievement Award
1975 - Unit Citation of Research Division
1975 - Outstanding publication in Fish Bulletin for 1973

7. Consultant Services

a) Battelle Northwest Laboratories on analysis techniques for dissolved nitrogen.

b) EPA and other state environmental control agencies on establishment of dissolved gas standards.

c) U.S. Army Corps of Engineers on data needed and the parameters to include in mathematical model contract for Water Resources Engineers of California.

d) State and federal fisheries officials concerning losses of fish related to nitrogen supersaturation and other causes.

e) Biologists from Washington and Oregon concerning problems of automatic detection and separation.

f) U.S. Army Corps of Engineers and state agencies on requirements for bypass, collection, and transportation systems for use at dams.

8. Task Force Assignments

Columbia River Fisheries Technical Committee
Columbia River Thermal Effects Technical Advisory Committee
Nitrogen Task Force
Former Chairman, Research Subcommittee of the Fish Passage Development and Evaluation Program (FPDEP)
Statistical Committee for Mid-Columbia River Studies
Research Needs Committee for FPDEP
Research Needs Committee for Columbia Basin Fish and Wildlife Authority (CBFWA)

9. Publications

Braem, R. A., and W. J. Ebel.
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Ebel, W. J.
1962. A photoelectric amplifier as a dye detector. Great Lakes Fish. Comm., Tech. Rep. 4:19-26.

Ebel, W. J., and R. W. Pearson.
1968. Are Columbia upriver salmon stocks doomed? Fish Business 3(11):1-8, 1968.

Raleigh, R. F., and W. J. Ebel.
1968. Effects of Brownlee Reservoir on migrations of anadromous salmonids. Amer. Fish. Soc., Proc. Reservoir Fish. Resource Symp., Athens, GA., April 5-7, 1967:415-443.

Ebel, W. J., and C. H. Koski
1968. Physical and chemical limnology of Brownlee Reservoir, 1962-64. U.S. Fish. Wildlife Serv., Fish. Bull. 67(2):295-335.

Durkin, J. T., W. J. Ebel, and J. R. Smith.
1969. A device to detect magnetized wire tags in migrating adult coho salmon. J. Fish. Res. Bd. Can. 26(11), 1969:3083-3088.

Beiningen, K. T., and W. J. Ebel.
1969. Supersaturation of dissolved nitrogen in the Columbia and Snake Rivers, Data Report, 1965-1969. Bur. Comm. Fish Data Rep. Series.

Ebel, Wesley J.
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Pugh, J. R., A. B. Groves, and W. J. Ebel.
1969. Experimental tank to stimulate certain reservoir conditions. J. Fish. Res. Bd. Can. 26(7), 1969:1956-59.

Ebel, Wesley J.
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