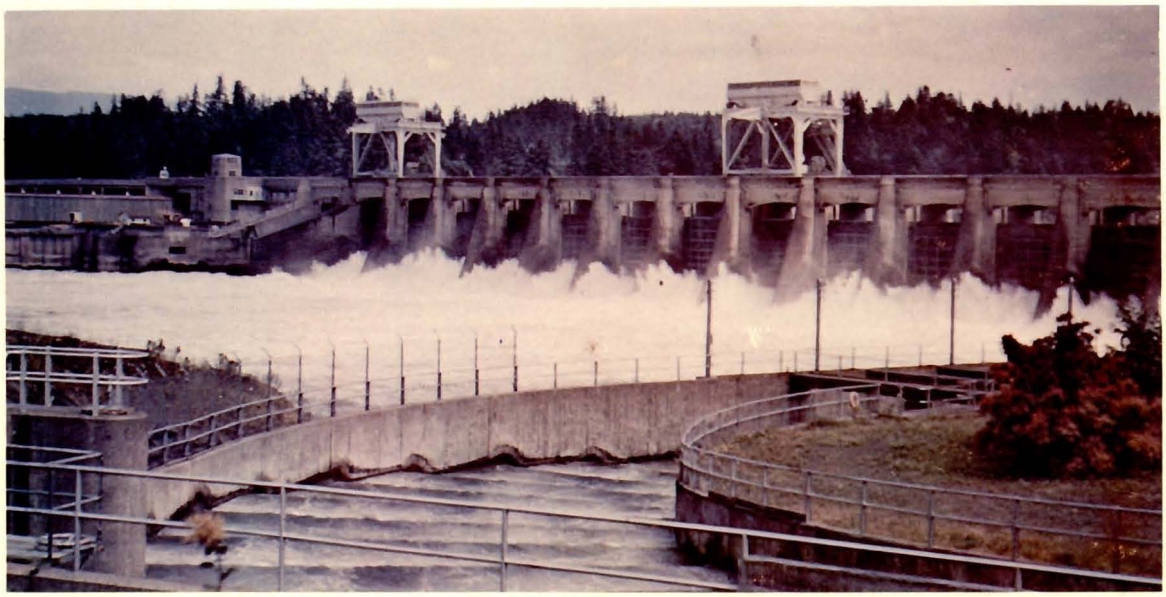
COLUMBIA RIVER



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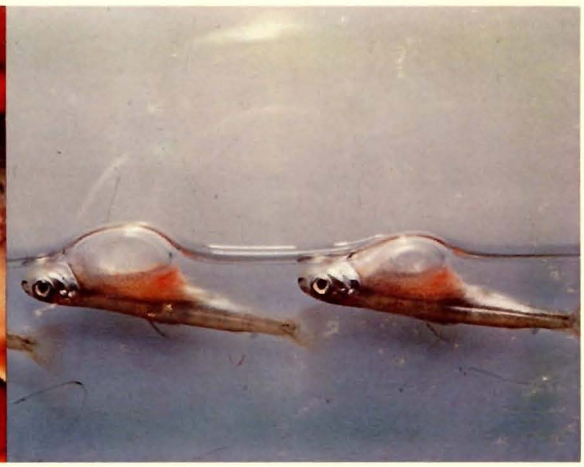

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COVER

(Top photo) Air entrainment (supersaturation) from spilling at Bonneville Dam

(Bottom left photo) Adult steelhead trout with symptoms of gas bubble disease

(Bottom right photo) Juvenile chinook salmon with symptoms of gas bubble disease

NORTHWEST FISHERIES CENTER
PROCESSED REPORT
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EFFECT OF ATMOSPHERIC GAS SUPERSATURATION CAUSED BY DAMS ON SALMON AND STEELHEAD TROUT OF THE SNAKE AND COLUMBIA RIVERS

(A Review of the Problem and the Progress Toward a Solution, 1974)

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EFFECT OF ATMOSPHERIC GAS SUPERSATURATION CAUSED BY DAMS ON SALMON AND STEELHEAD TROUT OF THE SNAKE & COLUMBIA RIVERS, 1974

EXECUTIVE SUMMARY

INTRODUCTION

Dams constructed on the Columbia and Snake Rivers in the past decade have impounded most of the free flowing sections of these rivers and created a water condition that in high flow years is deadly to migrating salmon and steelhead trout. With high spills, the water becomes supersaturated with atmospheric gases to levels that are lethal to fish. In response to this problem, a major research effort is in progress which seeks to define the effects of supersaturation on fish and to develop methods of reducing supersaturation caused by dams. This report summarizes the present status of the research and the relation of our current information to the anadromous resources of the Columbia and Snake Rivers. Although our most complete information is on the salmon and steelhead runs of the Snake River, it is logical that the conclusions apply as well to the stocks of the upper Columbia River and to a lesser degree, to the runs entering the Columbia River below the Snake River.

RECENT TRENDS IN THE SNAKE RIVER SALMON AND STEELHEAD TROUT POPULATIONS

A superficial examination of available data would seem to indicate that there was no serious decline in chinook salmon and steelhead trout runs to the Snake River until 1974. However, an analysis of adult returns by the year of juvenile outmigration shows that the Snake River runs have been declining since 1969. An in depth analysis of survival rates of juvenile populations migrating downstream reveals that the primary cause of the declining runs can be attributed to losses of juveniles caused by dams. The specific factors causing the losses vary depending on river flows. During higher flows when most of the fish and water pass over spillways at dams, most losses result from exposure to atmospheric gas (primarily N_2) supersaturation. During low flows, when most of the fish and water pass through turbines at dams, losses are primarily turbine-predator related.

SUPERSATURATION OF NITROGEN: ITS SOURCE AND ITS EFFECTS ON FISH

Several conclusions regarding the effect of supersaturation of atmospheric gas on fish in the Columbia River System can be made from the laboratory and field data presented. The main conclusions reached are:

1. Supersaturation of atmospheric gas has exceeded 130% over long stretches of the Columbia and Snake Rivers during several years since 1968.

2. When either juvenile or adult salmonids are confined to shallow water (1 m), substantial mortality occurs at 115% Total Dissolved Gas (TDG) saturation after 25 days exposure.

3. When either juvenile or adult salmonids are allowed the option to sound and obtain hydrostatic compensation either in the laboratory or in the field, substantial mortality occurs when saturation levels (TDG) exceed 120% saturation after more than 20 days exposure.

4. On the basis of survival estimates made in the Snake River from 1966 to the present, we conclude that juvenile fish losses ranging from 40 to 95% do occur and a major portion of this mortality can be attributed to fish exposure to supersaturation of atmospheric gases during years of high flow.

5. 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 to supersaturation.

In summation, there is ample evidence, both laboratory and field, that adult and juvenile salmon and steelhead are jeopardized by gas bubble disease in the Columbia River Basin. The severity of the disease and its consequences depend on the level of supersaturation, duration of exposure, temperature of water, general physical condition of the fish, and the swimming depth the fish maintains.

REMEDIAL MEASURES

When it became apparent in 1970 that supersaturation of river water with atmospheric gas due to spilling at dams was a substantial problem to both adult and juvenile stocks of fish in the Columbia and Snake Rivers, the U.S. Army Corps of Engineers took the lead role in devising methods to reduce supersaturation. Systems investigated were: use of head water storage to control flow during the spring freshet season; installation of additional turbines to reduce spilling; use of slotted bulkheads in skeleton bays to reduce spilling; and installation of spillway deflectors to reduce air entrainment during spilling.

All of these methods are useful in helping to provide solutions to the problem of supersaturation, but spillway deflectors were determined to be the most effective way to reduce supersaturation.

To determine the benefit that will be achieved by installing spillway deflectors, the dissolved gas concentrations that will occur with and without additional spillway deflectors are estimated for various flows. The year 1975 was used as the base year and estimates of gas concentrations and losses for that year were done assuming spillway deflectors and turbines scheduled for 1975 would be completed by April. Estimates of dissolved gas levels for 1980 (Project A) consider all of the scheduled turbines and spillway deflectors in the Snake River System and the spillway deflectors at Bonneville and McNary Dams in the Columbia River. Estimates for 1980 (Project B) consider all of the turbines and spillway deflectors for Project A plus spillway deflectors at John Day Dam.

Estimates of mortality attributable to exposure of juvenile chinook and steelhead to supersaturation of nitrogen are made from the estimates of dissolved nitrogen levels that will occur with spillway deflectors installed as scheduled for 1975 and as indicated for 1980 (Projects A and B).

It is obvious from the analysis that a substantial reduction in levels of supersaturation and in losses of fish will occur with spillway deflectors installed as described in both Project A and B.

ALTERNATIVES, COSTS AND BENEFITS

Without any remedial projects, and considering only the Snake River fish stocks, losses of juvenile salmonids will result in a total loss of 2 million adult chinook salmon and steelhead during the period 1976 to 2000. In terms of 1974 dollars, this represents a loss in the range of $47.2 to $126.9 million in net economic yield to our society in the next 24 years. These are conservative estimates. Furthermore, the continued loss of both juvenile and adult salmon and steelhead to gas bubble disease, if not corrected, can seriously affect the very survival of these valuable resources.

Project A (spillway deflector installation at Little Goose, Ice Harbor, McNary, and Bonneville Dams) is expected to result in a savings of 1.7 million adult chinook salmon and steelhead during the period 1980 to 2000. In terms of 1974 dollars, this represents a total net benefit of $40.7 to $109.7 million. These are conservative estimates. Project A will cost $9.1 million. At a discount rate of 5-7/8% the ratio of net benefit to project cost ranges from 2.28 to 6.15. The economic efficiency criterion is more than met by this project.

Project B (spillway deflector installation at John Day Dam) is expected to result in an additional saving of 22.5 thousand adult chinook salmon and steelhead during the period 1980 to 2000 and represents a total net benefit of $0.6 to $1.5 million in terms of 1974 dollars. These are conservative estimates. Project B will cost $4.8 million. At a discount rate of 5-7/8% the ratio of net benefit to project cost ranges from 0.07 to 0.17. This is less than the minimum criterion of unity (1.0) in benefit to cost.

RECOMMENDATIONS

The two main factors considered in formulating recommendations from the information contained in this report were: (A) the impact of the recommendation on survival of fish and (B) the relation of costs associated with the recommendations to the economic benefits to be derived.

On this basis we recommend:

1. Spillway deflectors be installed at Little Goose, Ice Harbor, McNary, and Bonneville Dams (Project A) as soon as possible.

2. Spillway deflector installations be deferred at The Dalles and John Day Dams at this time subject to review if conditions at a later date indicate reasonable benefits can be obtained.

These recommendations assume that maximum power load will be programmed during the spring run-off period for the turbines at John Day Dam. Less than 85% of full operation, however, would result in unacceptable levels of supersaturation downstream from John Day Dam. If so, this would change our current evaluation of Project B.

In our opinion, if the recommended spillway deflectors are installed and if the turbines scheduled for installation by 1980 are actually in and programmed to their capacity, the problem of supersaturation in high flow years will be for all practical purposes under control for anadromous migrants in the Snake River.

We feel obligated to point out again, however, that the supersaturation problem is associated with high flow years, but substantial mortality also occurs during low flow years from turbine-predator related problems. Current data indicate that two low flow years in succession could eliminate upper river stocks of salmonids. To insure survival of these stocks so that maximum benefit from spillway deflectors can be achieved, the young migrants must be protected in low flow years. We, therefore, further recommend that the U.S. Army Corps of Engineers provide and maintain the capability to collect and transport juvenile salmonids from Little Goose and Lower Granite Dams for release below Bonneville Dam and, that the development and refinement of turbine intake screening systems be continued.

EFFECT OF ATMOSPHERIC GAS SUPERSATURATION CAUSED BY DAMS ON SALMON AND STEELHEAD TROUT OF THE SNAKE & COLUMBIA RIVERS, 1974

INTRODUCTION

Dams constructed on the Columbia and Snake Rivers in the past decade have impounded most of the free flowing sections of these rivers and created a water condition that in high flow years is deadly to valuable stocks of anadromous salmon, Oncorhynchus spp., and steelhead trout, Salmo gairdneri. With high spills, the water becomes supersaturated with atmospheric gases to a level that is lethal to fish. In response to this problem, a major research effort is in progress which seeks to define the effects of supersaturation on fish and to develop methods of reducing supersaturation caused by dams. This report summarizes the present status of the research and the relation of our current information to the anadromous resources of the Columbia River.

Salmon and steelhead resources of the Columbia River have in the past produced as much as 50 million pounds of fish in one year for consumption. Today, production is estimated at between 25 to 30 million pounds (Appendix Table A-4). Even in today's depressed state, the contribution of the Columbia River resources to our commercial and recreational fisheries is of a magnitude far greater than most people realize:

> Columbia River salmon and steelhead represent an annual value of $22.5 million to commercial fishermen, and nearly $77.2 million at the retail level. An average of 42% of the chinook salmon, O. tshawytscha, and 73% of the steelhead taken annually by the United States commercial fisheries are of Columbia River origin (Appendix A and B).
>
> Columbia River salmon and steelhead represent an annual "net economic value" of $15.2 to $53.9 million to sport fishermen. An average of 54% of the chinook salmon and 33% of the steelhead taken annually by sport fishermen along our Pacific Coast are of Columbia River origin. Estimates of annual expenditures by sport fishermen on these fish range from $34.1 to $72.7 million (Appendix A and B).
>
> The social and economic well being of port cities, such as Ilwaco and Westport, Washington, and Astoria, Oregon, depend in large part on the salmon of the Columbia River.

The millions of people that annually come to visit the fishways and fish rearing facilities in the Columbia River Basin attest to the aesthetic experience of witnessing the life cycle of the salmon. For many, the salmon and steelhead have become symbols of the quality of life in the Pacific Northwest. Over 5 million "visitor days" are recorded annually, more than at the Grand Canyon or at Yellowstone Park (Appendix Table A-3).

The great majority of Columbia River fish are affected by the huge dams built for hydroelectric power, navigation, irrigation, and flood control. The upper river runs, because they must pass through a long sequence of dams (Figure 1) are most severely affected. This review addresses itself to the salmon and steelhead runs of the Snake River where we have our most complete information, but it is logical that the conclusions apply as well to the stocks of the upper Columbia and to a lesser degree, to the runs entering the Columbia River below the Snake River.

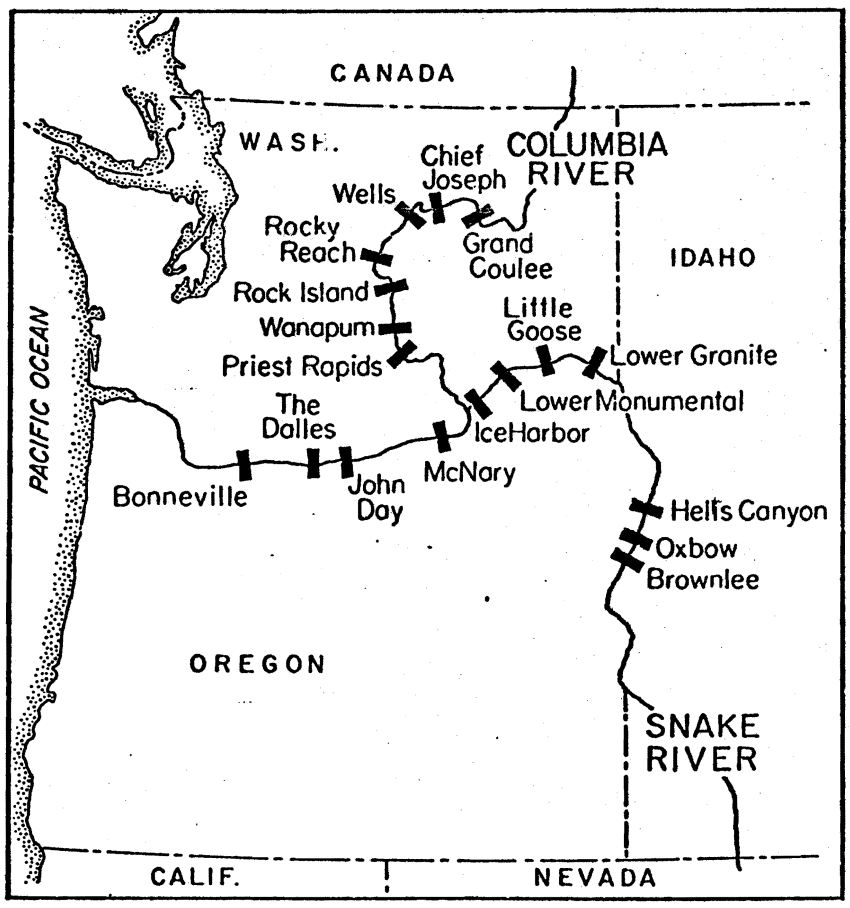


Figure 1.--Main stem dams in the Columbia River Basin

RECENT TRENDS IN THE SNAKE RIVER SALMON AND STEELHEAD TROUT POPULATIONS

A superficial examination of available data (Top panels-Figures 2 and 3) indicates that there was no serious decline in chinook salmon and steelhead trout runs to the Snake River until 1974. However, an analysis of adult returns by year of outmigration shows Snake River runs have been declining since 1969. Greatly increased releases of chinook salmon and steelhead fingerlings from hatcheries, combined with an above-average survival in the ocean of chinook migrating downriver in 1970, have masked the real effect of new dams and impoundments on survival of juveniles migrating downriver. The adult run of spring chinook and steelhead migrating up the Columbia River each year consists of progency from 3 separate years of juvenile downstream migrations; therefore, one very successful juvenile outmigration in any given year can result in that year class dominating the adult run for several years. Returns in 1974, not influenced by the fish that migrated in 1970, are dangerously low.

The percentage of adults returning from known populations of juvenile chinook salmon and steelhead migrating downriver each year reflects the status of fish passage conditions in the Snake and Columbia Rivers. While total numbers of both chinook and steelhead smolts increased significantly starting in 1970 (Middle panels - Figures 2 and 3), adult return percentages of both species have declined at an alarming rate since 1969 (Bottom panels - Figures 2 and 3). Prior to installation of recent dams and resulting reservoirs in the Snake River (1964 to 68), returns of chinook averaged about 4%. In 1969, with the completion of Lower Monumental Dam, adult returns from that year's juvenile population dropped to 3.5%, and to 3.2% in 1970, after the completion of Little Goose Dam. Since that time, adult returns from juvenile populations migrating downstream have declined sharply to 2.2% from juveniles migrating downstream in 1971 to 0.8% from those migrating downstream in 1972. We estimate that only 0.3 to 0.4% will return from those migrating downstream in 1973. Steelhead runs show a similar decline from 5 to 6% through 1966 to: 2.5% in 1969, 2.1% in 1970, 1.4% in 1971, 1.0% in 1972, and an estimated 0.2 to 0.3% in 1973.

Cause of Decline

The analysis that follows will show that the drop in adult return percentages reflects losses of juveniles due to fish passage problems in the Snake River--not to adult losses at dams, nor to ocean mortality, nor to increased fishing pressure in the ocean, nor even to the river gillnet fishery.

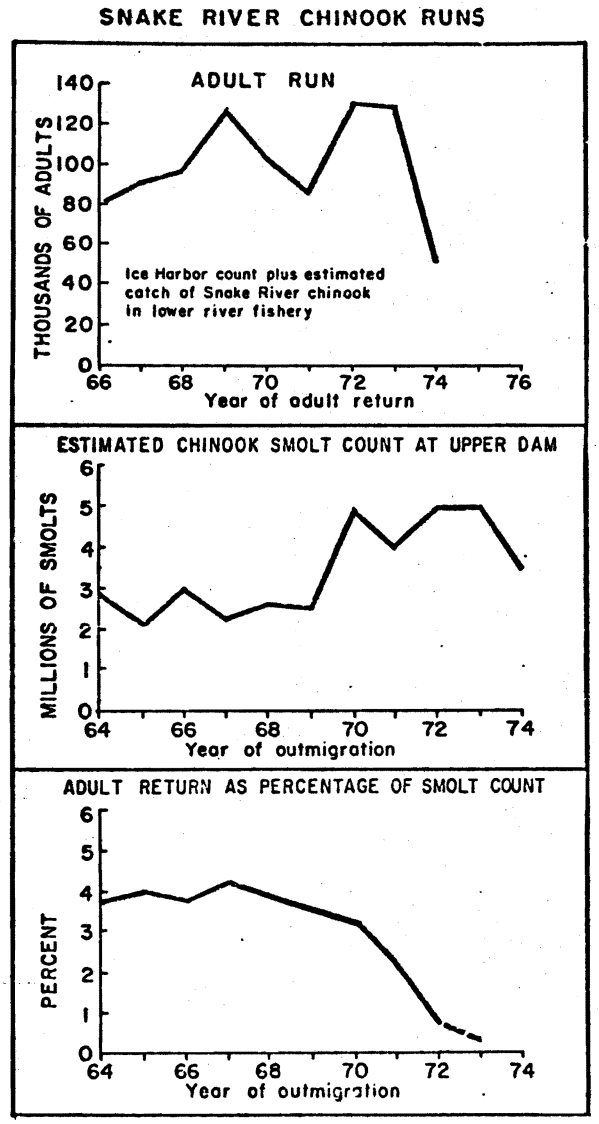


Figure 2

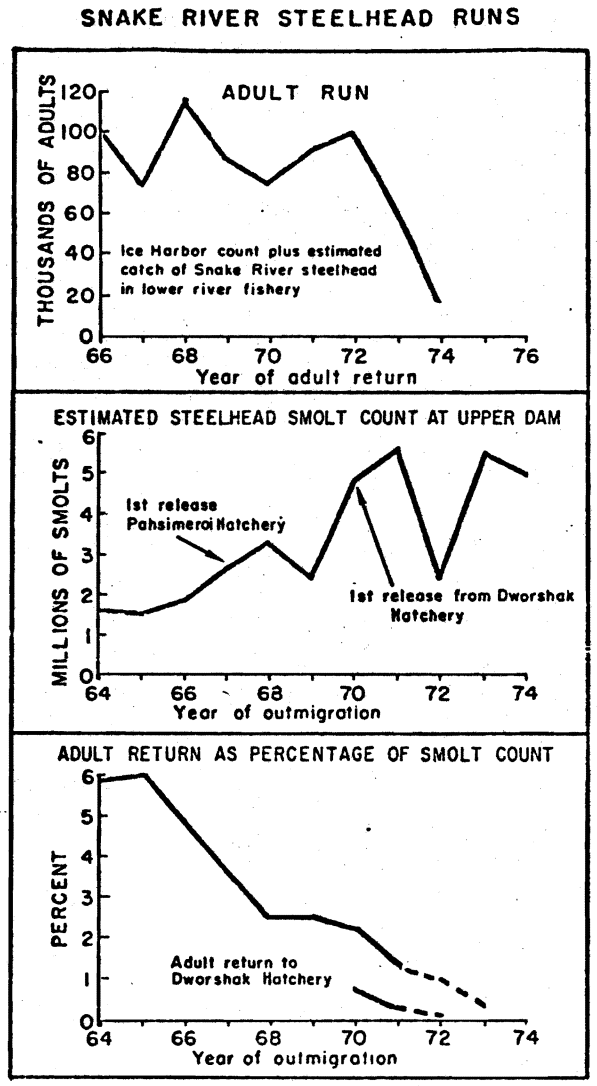


Figure 3

(Upper panels) Snake River adult chinook salmon and steelhead runs by year of return.
(Center panels) Estimated count of juvenile chinook salmon and steelhead (smolts) arriving at the uppermost dam in the Snake River.
(Bottom panels) Adult chinook salmon and steelhead returns as percentage of juvenile count.
(Source: Raymond, 1974)

If the declines in fish populations since 1969 were due to increased fishing pressure in the ocean, then chinook should be the only species showing a drop, since there is no significant harvest of steelhead in the ocean. If the decline were due to the river fishery, then it would have to be due to unreported catches since both sport and commercial fisheries are included in adult return calculations. The decline is not due to losses of adults at dams. Data from the Fish Commission of Oregon* show that losses of adults in recent years (1970 to 1973) were no higher than losses in 1968 or 1969.

An analysis of adult returns in relation to numbers of smolts passing Little Goose Dam and numbers of Snake River smolts passing The Dalles Dam (Figure 4) isolates the primary cause of declining adult runs to juvenile losses between Little Goose Dam and The Dalles Dam. Significant declines in adult return percentages from both chinook and steelhead smolts passing the upper dam began in 1967 (Bottom panels - Figures 2 and 3). In contrast, adult returns from Snake River smolts passing The Dalles Dam (except chinook in 1970) have been consistently between 5 and 7% over the years sampled (Table 1). Although some loss no doubt occurs below The Dalles Dam, it has not changed since 1966 and therefore is not responsible for the recent decline in adult returns.

Causes of Juvenile Losses

Primary causes of juvenile losses vary depending on river flows. During higher flows when most of the fish and water pass over spillways at dams, most losses result from exposure to atmospheric gas (primarily N_2) supersaturation. During low flows, when most of the fish and water pass through turbines at dams, losses are primarily turbine-predator related. Due to differences in timing of the outmigrations of juvenile chinook and steelhead, chinook may not be subjected to the same passage conditions as steelhead during their downstream migration (chinook migrations are generally 10 days earlier than steelhead). As a result, their survival as juveniles and the subsequent adult return will vary depending on river flows and passage conditions encountered from year to year.

Specifics on juvenile survival, timing, and migration rate as related to river flows and downstream passage conditions encountered each year will be discussed in the section on effects of N_2 supersaturation on juveniles.

* Data compiled from commercial and sport fisheries statistics by Burnie Bohn, Oregon Fish Commission, Clackamas, Oregon

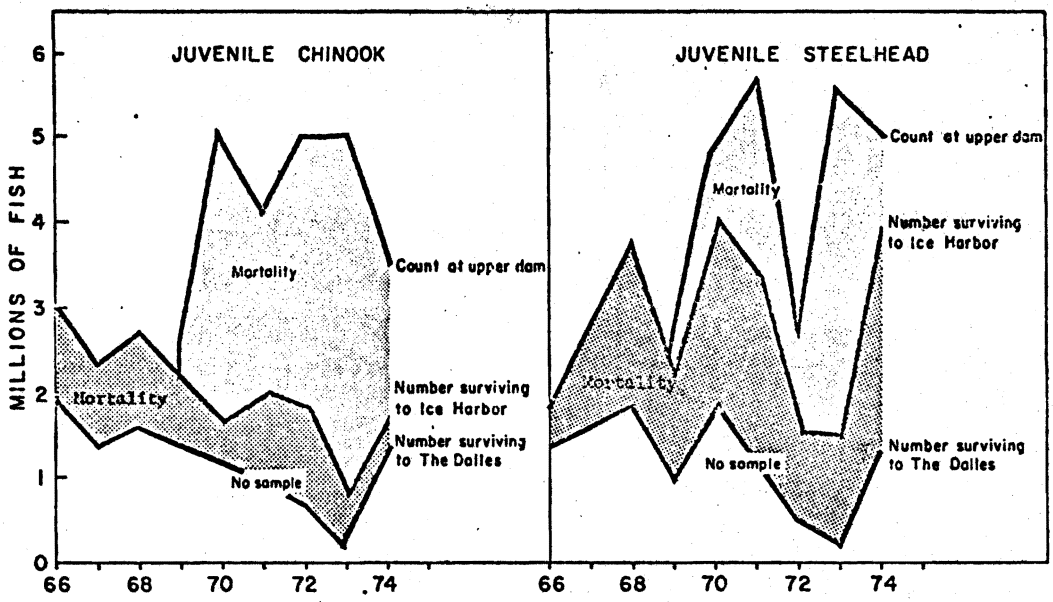


Figure 4.--Estimated number of juvenile chinook salmon and steelhead surviving to Ice Harbor and The Dalles Dams. (Source: Raymond, 1974).

Table 1.--Percentage of adults returning to the Snake River from estimated numbers of smolts passing The Dalles Dam (1966-74).

CHINOOK

Year of migration	Millions of smolts to The Dalles	Thousands of returning adults	Return (%)
1966	1.9	132	6.9
1967	1.4	97	6.8
1968	1.6	104	6.5
1969	1.4	87	6.2
1970	1.2	162	13.5
1971 1/	-	90	-
1972	0.75	38	5.1
1973	0.25		
1974	1.4		

STEELHEAD

Year of migration	Millions of smolts to The Dalles	Thousands of returning adults	
1966	1.4	86	6.1
1967	1.6	97	6.1
1968	1.9	91	5.1
1969	1.0	66	6.6
1970	1.9	103	5.4
1971 1/	-	76	-
1972	0.5	26	5.2
1973	0.22		
1974	1.35		

1/ No sampling at The Dalles, 1971. Source: Raymond (1974).

SUPERSATURATION OF NITROGEN: ITS SOURCE AND ITS EFFECT ON FISH

Supersaturation of nitrogen was first recognized as a potential problem to anadromous fish in the Columbia River in 1965 when levels as high as 125% of saturation were recorded. A comprehensive study (Ebel, 1969) of dissolved gas levels done in 1966-1967 throughout the Columbia from Grand Coulee Dam to the estuary at Astoria, Oregon substantiated that high levels of dissolved gases occurred throughout the study area (Figure 5) during the spring and early summer when high flows occur. The study also showed that water plunging over spillways was the main cause of supersaturation and that little equilibration occurred in the reservoirs associated with the dams. Subsequent studies conducted by Roesner and Norton (1971) and Meekin and Allen (1974) substantiated the earlier data of Ebel. Sufficient data are now available to establish air entrainment coefficients and rating curves for most of the dams on the Columbia and Snake Rivers; reasonably accurate predictions of the level of supersaturation that might occur downstream from a given dam during a specified flow are now possible. Thus, the mechanisms involved in creating supersaturation in the Columbia and Snake Rivers are at this time well understood.

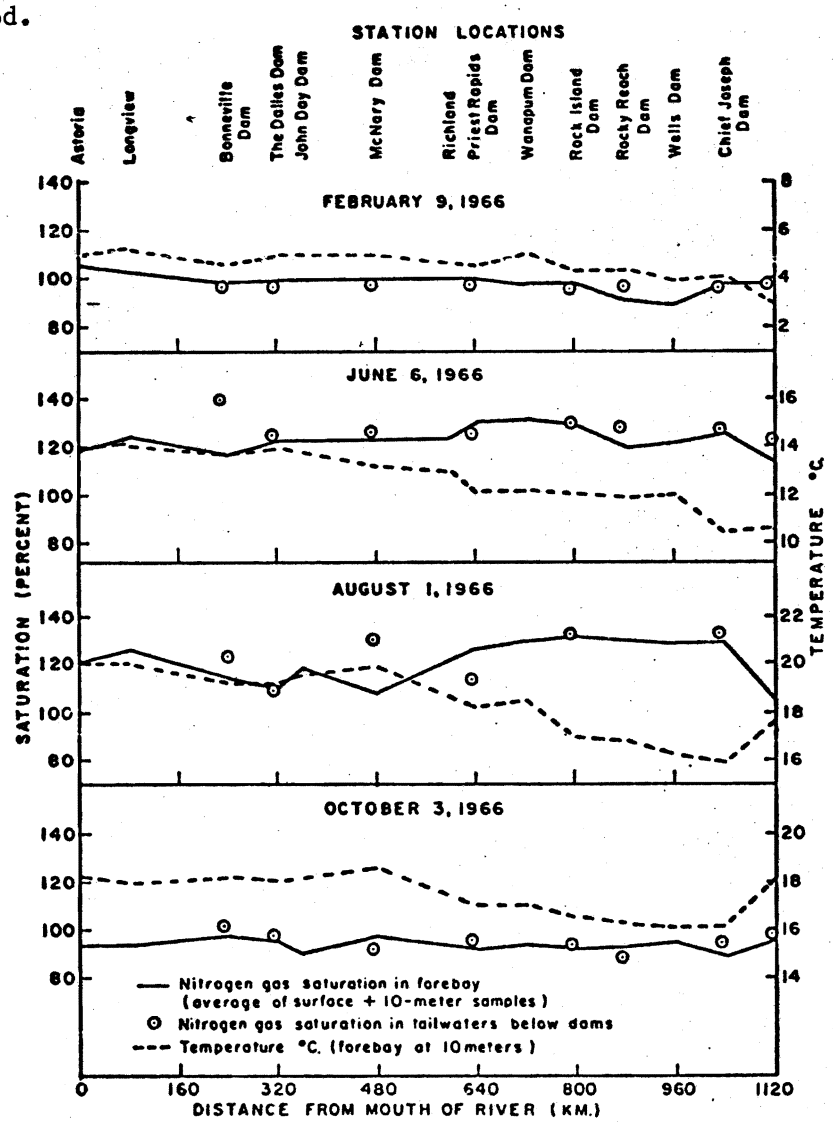


Figure 5.--Saturation of dissolved nitrogen and temperature of samples in Columbia River from Astoria to Grand Coulee Dam, February to October 1966. (Source: Ebel, 1969).

A substantial impact from supersaturation of N_2 on fish populations, however, was not documented until John Day Dam was placed in operation in 1968. During the spring of that year heavy spillway discharge at the dam caused abnormally high (123 to 143%) supersaturation downstream (Figure 6) and substantial mortalities of both adult and juvenile salmonids were recorded (Beiningen and Ebel, 1970). Continued evidence that a substantial problem for both juvenile and adult salmon and steelhead existed in the Columbia drainage (Ebel, 1971; Raymond, 1970) prompted a large scale research effort to (1) measure the effects of supersaturation of dissolved gases on fish and (2) develop methods of reducing levels of supersaturation caused by dams.

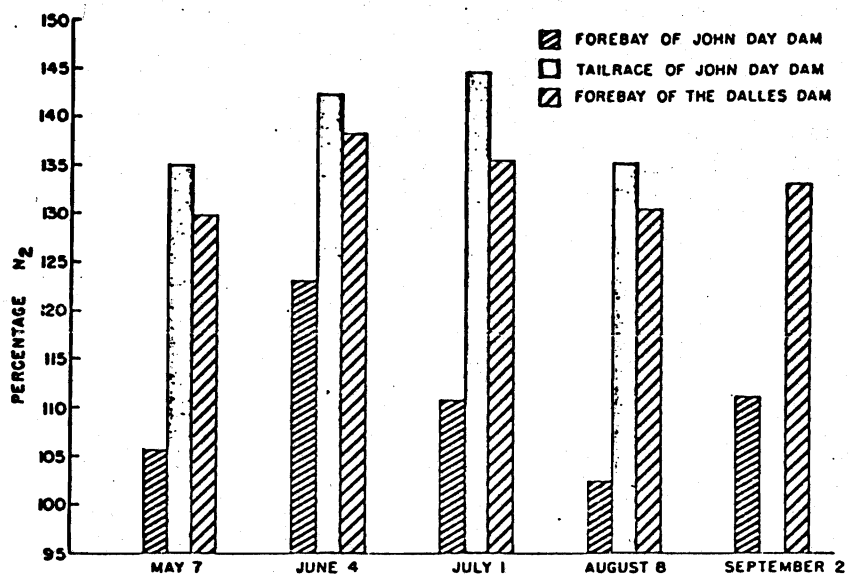


Figure 6.--Comparison of percentage saturation of dissolved nitrogen in forebay of John Day Dam with tailrace of John Day Dam and The Dalles Dam forebay, May-September 1968. (Source: Beiningen and Ebel, 1970).

Effects of Supersaturation on Juvenile Salmonids

Supersaturation of atmospheric gas (mainly nitrogen) in waters of the Columbia and Snake Rivers was well documented by 1970 as a serious problem to valuable stocks of salmon and steelhead. There was sufficient evidence that gas bubble disease resulting from this supersaturation caused both direct and indirect mortalities. However, precise data on tolerance of various species of salmonids to various levels of supersaturation of atmospheric gases was unknown.

Several investigators recorded the lowest level observed during various experiments where mortalities occurred from gas bubble disease; however, very little attention was given to determining precise tolerance levels or effect of sublethal exposure on performance. Harvey and Cooper (1962) indicated 108 to 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 resident freshwater form of S. gairdneri, whereas the steelhead trout is the anadromous form of the species) 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 the record, thus making the results incomplete for critical applications. The extent of the costs involved in alleviating the supersaturation problem in the Columbia and Snake Rivers will depend on the degree of protection required to afford a safe environment for the aquatic biota. It is imperative, therefore, that regulatory and corrective measures established to govern the level of saturation be based upon a thorough understanding of the effects of dissolved gases on aquatic organisms.

Presently available laboratory and field research data defining the effects of supersaturation on juvenile salmonids and some nonsalmonids present in the Columbia drainage are summarized as follows:

Laboratory Studies

Research (Figure 7) was undertaken to define the effects of various levels of dissolved gases on several species of fish (primarily juvenile salmonids) by the National Marine Fisheries Service (NMFS), Bureau of Sportfisheries and Wildlife (BSFW), Battelle Northwest Laboratories (BNW), and the Environmental Protection Agency (EPA).

NMFS centered their research on smolting size juvenile spring chinook and steelhead, fall chinook fry, and juvenile and adult squawfish, Ptychocheilus oregonensis. Dawley and Ebel (in press) found that exposure of juvenile spring chinook and steelhead to 120% saturation for 1.5 days resulted in over 50% mortality; 100% mortality occurred in less than 3 days. They also determined that the threshold level where significant mortalities begin occurring (Table 2) is at 115% saturation nitrogen and argon (111% total gas saturation).

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

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 at 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.

Similar results on mortality rates of juvenile coho salmon, O. kisutch, were obtained in bioassays conducted by Nebeker (1973) and Rucker (1974). Rucker also determined that smaller coho (3.8 to 6 cm) were more resistant than larger coho (8 to 10 cm) at the same gas concentration. In addition, he determined the effect of individual ratios of oxygen and nitrogen and established that a drastic decrease in lethal effect occurred when the nitrogen content fell below 109% saturation even though total gas saturation remained at 119% saturation, indicating the importance of determining the concentration of the individual components (O_2 and N_2) of the atmospheric supersaturation.

An additional study was done by NMFS in 1974 to more accurately define the benefit that stocks of fish might receive by sounding into deeper water levels (hydrostatic compensation). An experiment was conducted where juvenile fall chinook salmon and steelhead mortality rates could be compared when they were exposed to various levels of N_2 in deep and shallow tanks. This study (Dawley et al., 1975) showed that by providing chinook and steelhead the option to sound in deep tanks, their ability to survive was increased, particularly at the lower levels of supersaturation. However, substantial mortality, still occurred in fish tested in deep tanks when the concentrations exceeded 120% (Figure 8). It is apparent from this study and similar field studies that depth of migration or hydrostatic pressure must be considered when estimating probable loss from N_2 for fish populations migrating in the Columbia or Snake River. Calculations of estimated mortality discussed later in this report take this into consideration.

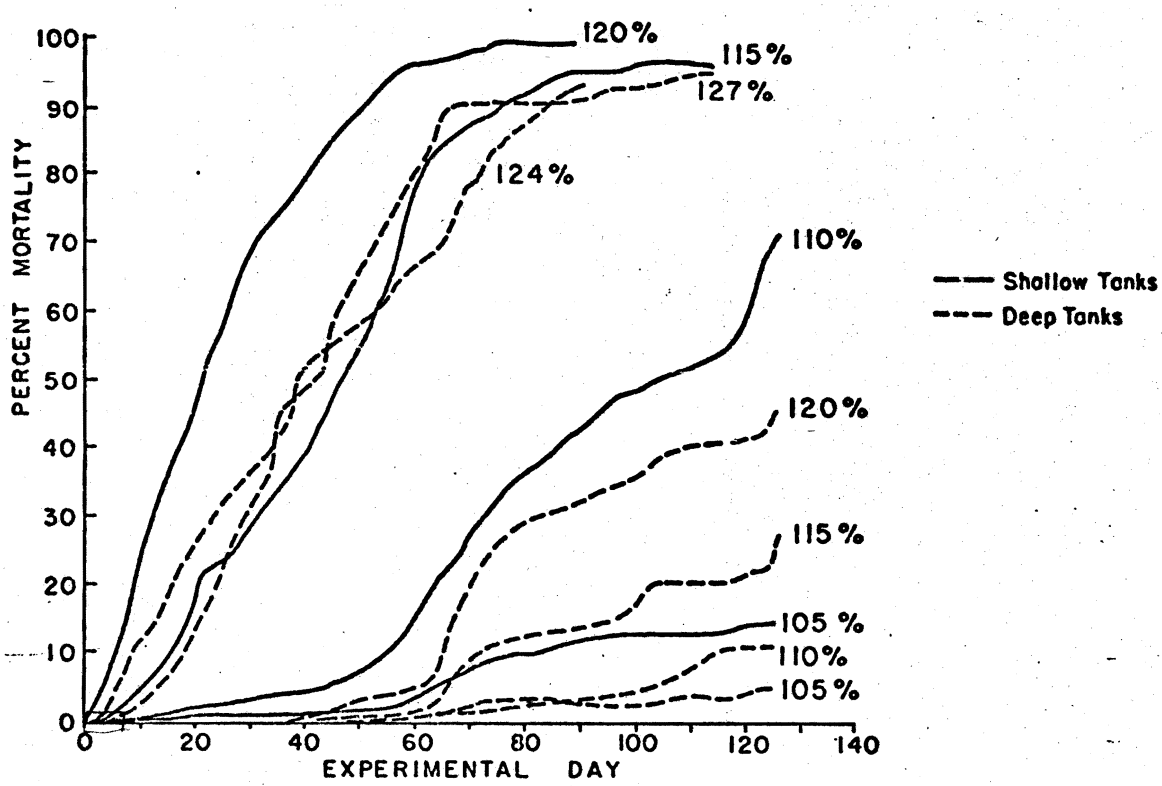


Figure 8.--Mortality versus time curves for juvenile fall chinook exposed to various concentrations of dissolved atmospheric gas in shallow (0.25m) and deep water (2.5m) tanks at 10°C. (Source: Dawley et al; 1975).

1. Sublethal Exposure

Experiments conducted by Schiewe (1974), Dawley and Ebel (in press), and Dawley et al. (1975) to determine the effect of sublethal exposure to supersaturated water on swimming performance and growth indicated that swimming performance of chinook was adversely affected when chinook were exposed for various sublethal periods to concentrations ranging from 106 to 120% saturation. These data indicate that survival would no doubt be lower than normal in a natural river environment where numerous hazards are encountered.

2. Effect of Supersaturation on Resident Fish

Most of the information regarding effect of supersaturation on resident fishes endemic to the Columbia River was obtained primarily from bioassays conducted at BNW (Fickeisen et al., 1973). Eleven different resident species were studied and a differential tolerance among the various species tested was noted. Carp, Cyprinus carpio; smallmouth bass, Micropterus dolomieui; and catfish and bullheads, Ictalurus spp. were the most tolerant; whitefish, Prosopium williamsoni and rainbow trout the least tolerant. The threshold tolerance level for rainbow trout was about 110% saturation--identical to that found by Dawley and Ebel (in press) for anadromous steelhead and chinook.

Field Studies

Numerous field studies have been conducted by state, federal, and private fishery research groups to obtain information on effect of supersaturation of atmospheric gas on juvenile salmonids in the Columbia and Snake Rivers. Live cage, migration rate, timing, and survival studies were of particular significance because they have been done over a range of river conditions for several consecutive years. Incidence of symptoms of gas bubble disease in juvenile migrants arriving at Ice Harbor and The Dalles Dams was also determined for several years. Data are therefore available from studies done during periods of low, intermediate, and high levels of supersaturation.

1. Live Cage Studies

The first live cage studies conducted in the middle Columbia River (Ebel, 1969) indicated that 6 to 16% mortality occurred in populations of juvenile coho and chinook held in a deep (surface to 6 m) cage when concentrations of N_2 ranged from 118 to 143%. Mortality ranged from 10 to 100% in fish held in shallow cages (surface to 1 m deep). Similar tests done in the lower Columbia River (The Dalles forebay) by Beiningen and Ebel** in 1969 resulted in a mortality range for juvenile fall chinook of 25 to 30% in the deep cage and 95 to 100% in shallow cages. At this time N_2 concentrations ranged from 126 to 145% of saturation. Another live cage test done later by Ebel (1971) in the forebay of Ice Harbor Dam on the Snake River resulted in a range of mortality from 45 to 68% in the deep cage where fish could sound to 4.5 m. In these tests both hatchery and wild stocks of juvenile spring and fall chinook were used as test animals. Nitrogen concentrations ranged from 127 to 134% of saturation.

** Kirk T. Beiningen (presently employed by the Oregon Fish Commission, Clackamas, OR, and Wesley J. Ebel, NMFS, Seattle, WA.

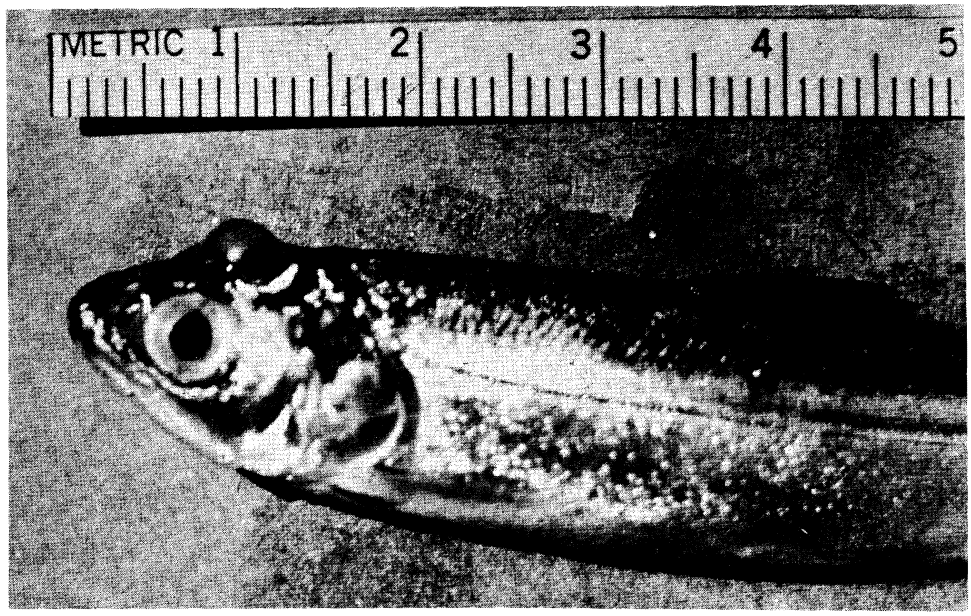
Finally, a similar live cage test was again conducted in the Wanapum area of the Columbia in 1974 by Weitkamp***. No mortality occurred in his deep cage, but nitrogen levels never exceeded 125% during these tests.

It is obvious from these live cage studies that various levels of mortality occur depending on the location, level of nitrogen supersaturation and stock of fish used. Of particular significance, however, is the fact that substantial mortalities occurred even in the deep cages, which allowed fish to sound when concentrations exceeded 125% saturation. Nearly 100% mortality occurred in surface cages used in all the tests.

Similar studies were conducted by (Blahm et al., 1973). In his studies, ambient Columbia River water was pumped into 1 m and 3 m deep tanks, and mortality was recorded as dissolved gas concentrations in the river changed from a low of about 106% in April to a high of 130% in June. Substantial mortality of both juvenile chinook and coho salmon occurred in the shallow (1 m) tank, in the deep (3 m) tank mortality did not begin until dissolved nitrogen centrations approached 125% near the termination of the test in June. Nitrogen concentrations did not exceed 125% saturation except for about 1 day at the termination of the test. These data substantiate other laboratory and field data where high levels of mortality were recorded in fish held in shallow water at dissolved gas levels as low as 115%, and substantial mortality does not occur where juvenile salmon are allowed the option to sound until concentrations exceed 120 to 125% of saturation.

Observations of gas bubble disease symptoms in juvenile migrants (Figure 9) in the Columbia River were first noted in 1966 (Ebel, 1969) from samples of fall chinook and coho netted from gatewells. These symptoms persisted throughout July and August when levels of nitrogen as high as 137% were recorded. Subsequent observations of symptoms were made from samples taken in gatewells at The Dalles Dam in 1968 and at Ice Harbor Dam each year since 1969 (Ebel, 1971; Ebel, Krcma, and Raymond, 1973; Ebel, Raymond et al., 1971, 1973). These data generally show that during periods when nitrogen levels are high the incidence of symptoms is also high, particularly on the later migrants (Figure 10). Incidence of symptoms cannot be directly transferred into percentage mortality, but we believe they are an indication of the degree of stress a population is suffering from exposure to supersaturation of atmospheric gas. For example, in 1970 the incidence of symptoms of gas bubble disease on chinook migrants examined at Ice Harbor Dam ranged from 25 to 45%; the survival of chinook (Raymond, 1970, 1974) passing from the Salmon River to Ice Harbor Dam was estimated to be 30%. In 1971, incidence of gas bubble disease ranged from 10 to 32% during the main portion of the migration; survival was estimated at 50%.

*** Donald E. Weitkamp, Parametrix Inc., Seattle, WA., Unpubl. data.



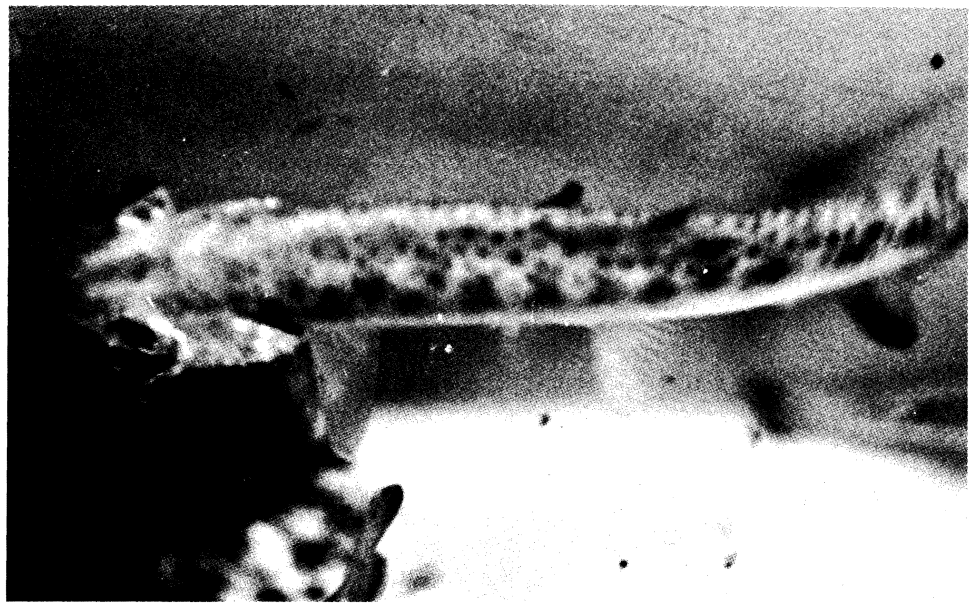


Figure 9.--Gas bubble disease symptoms observed on juvenile fish sampled at The Dalles Dam. (Upper) Gas blister on juvenile coho salmon; photo source - Beiningen and Ebel (1970). (Lower) Bilateral exophtalmia on juvenile chinook salmon.

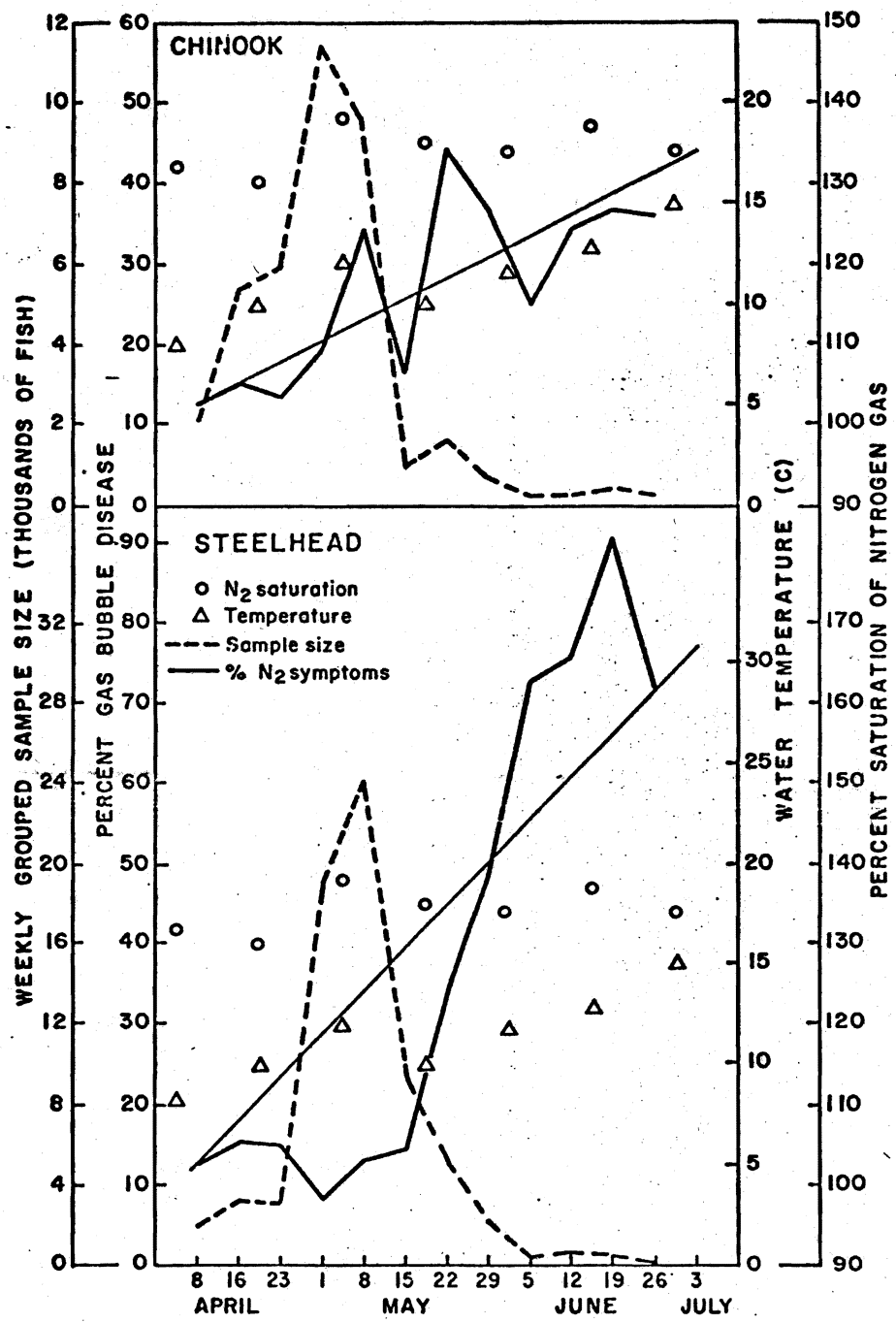


Figure 10.--Percentage gas bubble disease symptoms in juvenile steelhead and chinook in relation to nitrogen concentrations and temperature of tailrace water samples at Lower Monumental Dam. Sample size reflecting the magnitude of the migrating populations is also shown. (Source: Ebel et al., 1971).

2. Relationship between survival estimates (juvenile chinook and steelhead) and supersaturation of atmospheric gases

Research on the migrations of juvenile salmonids from the Salmon River (the main spawning tributary of the Snake River) as far downstream as The Dalles Dam has been conducted since 1966. The object of the research has been to measure the effects of new dams and impoundments on juvenile timing, migration rate, and survival. A general decline in survival of downstream migrants has occurred since 1967. This decline is attributed to four main factors: passage through turbines, delays in migration, predation, and supersaturation of nitrogen.

In this section of the report, losses or decrease in survival of juvenile salmonid populations attributable to excessive exposure to supersaturation of atmospheric gases (N_2) will be defined. The results obtained from data collected in 1966-67 provided a basis for comparing migrations after John Day (1968), Lower Monumental (1969), and Little Goose Dams (1970) were completed. Details of methods, experimental design and statistical calculations are contained in annual progress reports (Raymond, 1967, 1968, 1970; Park and Bentley, 1968). Fish at each of the sampling sites from the Salmon River to The Dalles Dam were given separate marks to identify the sampling site and the time of release. Subsequent recovery of these marked fish (Figure 11) at dams provided the necessary data for the measurement of survival. Juvenile chinook salmon and steelhead trout which represent 95% of the outmigration from the Snake River were the primary species studied.

3. Migration Rate

Travel time or migration rate is related to river velocity; i.e., the higher the water velocity the higher the rate of fish migration. Raymond (1968b-1969) determined that juvenile chinook moved only one-third as fast through McNary and John Day reservoirs as through free-flowing stretches of river. Calculations made for impoundments in the Snake River indicated similar delays. Migration rates of both chinook and steelhead are similar. These are shown (Table 3) for low, moderate, and high river flows through both free-flowing and impounded sections of the Snake and Columbia Rivers. These data become particularly important when estimating the length of time fish are exposed to supersaturation of atmospheric gas.

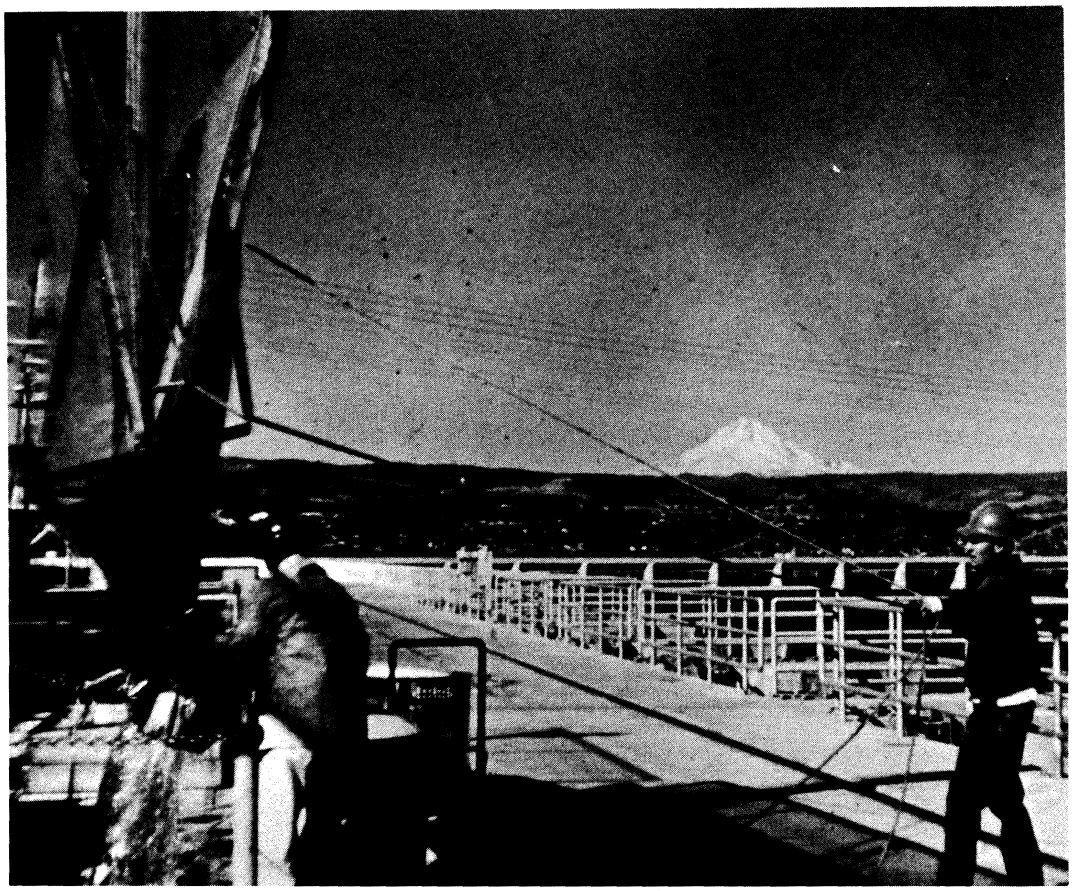


Figure 11.--(Upper) Sampling for juvenile migrants at the turbine intake gatewell of a dam with a specially designed dip net. (Lower) Purse seining for juvenile migrants near Little Goose Dam.

Table 3. Travel time[1/] estimates in days for Snake River juvenile chinook and steelhead trout to travel from the Salmon River to the estuary.

Stretch of River	Flow[2/] Low	Moderate	High
Salmon River to Lewiston (115 miles)-free-flowing	8	5	3
Lewiston to Lower Granite Dam (35 miles)-impounded	7	4	2
Lower Granite to Little Goose Dams (40 miles)-impounded	8	5	3
Little Goose to Ice Harbor Dams (63 miles)-impounded	13	8	4
Total Snake River	36	22	12
Ice Harbor to The Dalles Dams (143 miles)-impounded	29	18	10
The Dalles Dam to the Estuary (192 miles)-like free flowing	13	8	6
Total Columbia 335 miles	42	26	16
Grand Total	78	48	28

1/ Travel time based on following migration rates:

	Low	Moderate	High
free-flowing	15m/day	25m/day	34m/day
impounded	5m/day	8m/day	15m/day

2/

low flow	Snake River		30-50,000 cfs	Columbia River	150-180,000 cfs
med flow	"	"	80-100,000 cfs	" "	200-300,000 cfs
high flow	"	"	120-180,000 cfs	" "	350-500,000 cfs

4. Timing of peak migration

Peak migrations generally occur between late April and late May with the chinook peaks preceeding the steelhead peak outmigration by 3 to 14 days (Table 4). The arrival of peak migrations to The Dalles Dam is now 10 to 20 days later than it was before the recent dams (John Day, Little Goose, and Lower Monumental) impounded large stretches of the river. This later arrival of peak migrations is caused by a reduction in the migration rate in the impounded stretches of the river to about one-third of that measured in free-flowing stretches. The late arrival of the peak migrations of Snake River stocks has resulted in increased exposure to supersaturation during some high flow years. In years prior to 1968, the peak migration of juvenile chinook from the Snake River usually entered the Columbia River before flows in the Columbia had peaked and hence were not subjected to the highest levels of supersaturation in the Columbia. With a 10 day later arrival they often become subjected to the highest levels of supersaturation in both rivers. Recent differences (since 1970) in timing between years and between species are attributable to annual variability in water temperature, stream flow, and--particularly in the case of steelhead smolts--time of release from hatcheries.

Table 4. Comparison of timing of the migration peak of juvenile chinook salmon and steelhead trout at Ice Harbor Dam on the Snake River 1966-74.

	CHINOOK		STEELHEAD		
Year	Peak of Migration	River Flow at Peak	Peak of Migration	River Flow at Peak	Timing Dif. No. of Days
1966	5/4	65,000	5/11	108,000	7
1967	5/10	93,000	5/22	148,000	12
1968	5/10	53,000	5/21	90,000	11
1969	4/28	107,000	5/12	165,000	14
1970	5/13	88,000	5/25	175,000	12
1971	5/4	188,000	5/8	204,000	4
1972	5/12	122,000	5/22	186,000	10
1973	5/21	87,000	5/24	78,000	3
1974	5/6	157,000	5/13	140,000	7

5. Survival estimates

Survival of juvenile populations of chinook and steelhead from the Salmon River to Ice Harbor Dam was about equal and was estimated to be about 90% (Figure 12) in the years prior to 1968. Survival between Ice Harbor and The Dalles Dams was reduced to about 60% during the years prior to 1968, largely because of fish passage through the turbines of Ice Harbor and McNary Dams (N_2 levels were not critical through this stretch of river until 1969). After 1968, survival rate of the two species declined and was no longer equal. The data indicate that the decline in survival of both species during high-flow years can be attributed primarily to increased exposure to supersaturated water. Knowledge of the timing and migration rate, depth distribution (Figure 13), and dissolved gas concentrations makes it possible to estimate the percentage loss that can be attributed to exposure to supersaturation. Figure 14 provides a pictorial representation of the relationship between surface supersaturation, exposure time, depth of fish, and hydrostatic compensations. Table 5 provides an example of the method used to calculate the percentage loss of chinook attributable to exposure to supersaturation of atmospheric gas (nitrogen) in 1970. Similar calculations were used to estimate losses attributable to supersaturation in other years.

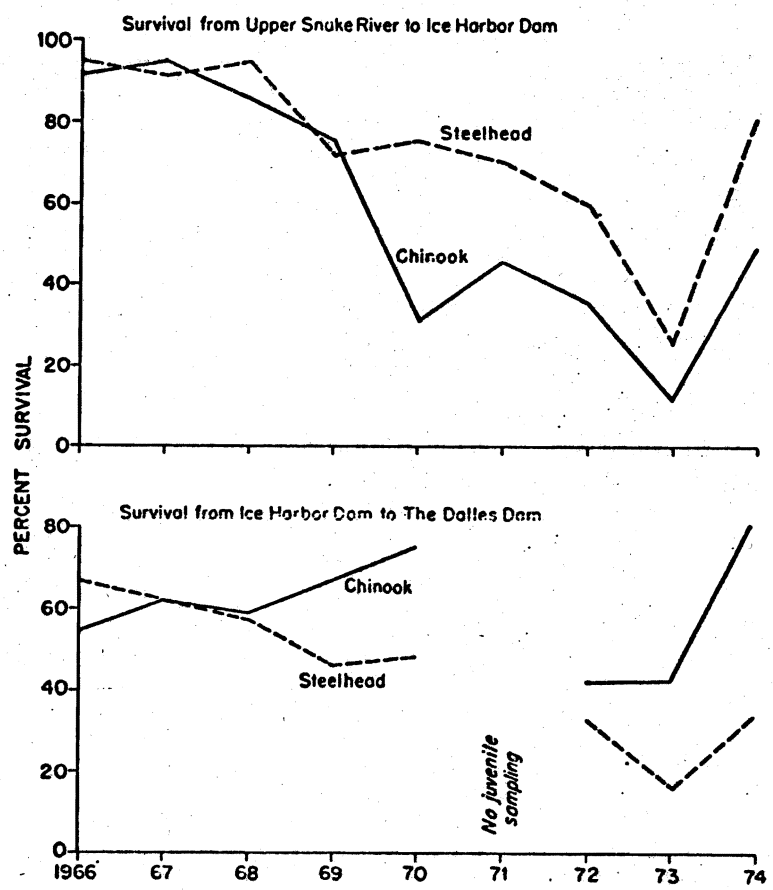


Figure 12.--Survival of juvenile chinook salmon and steelhead from the upper Snake River to Ice Harbor Dam and The Dalles Dam.

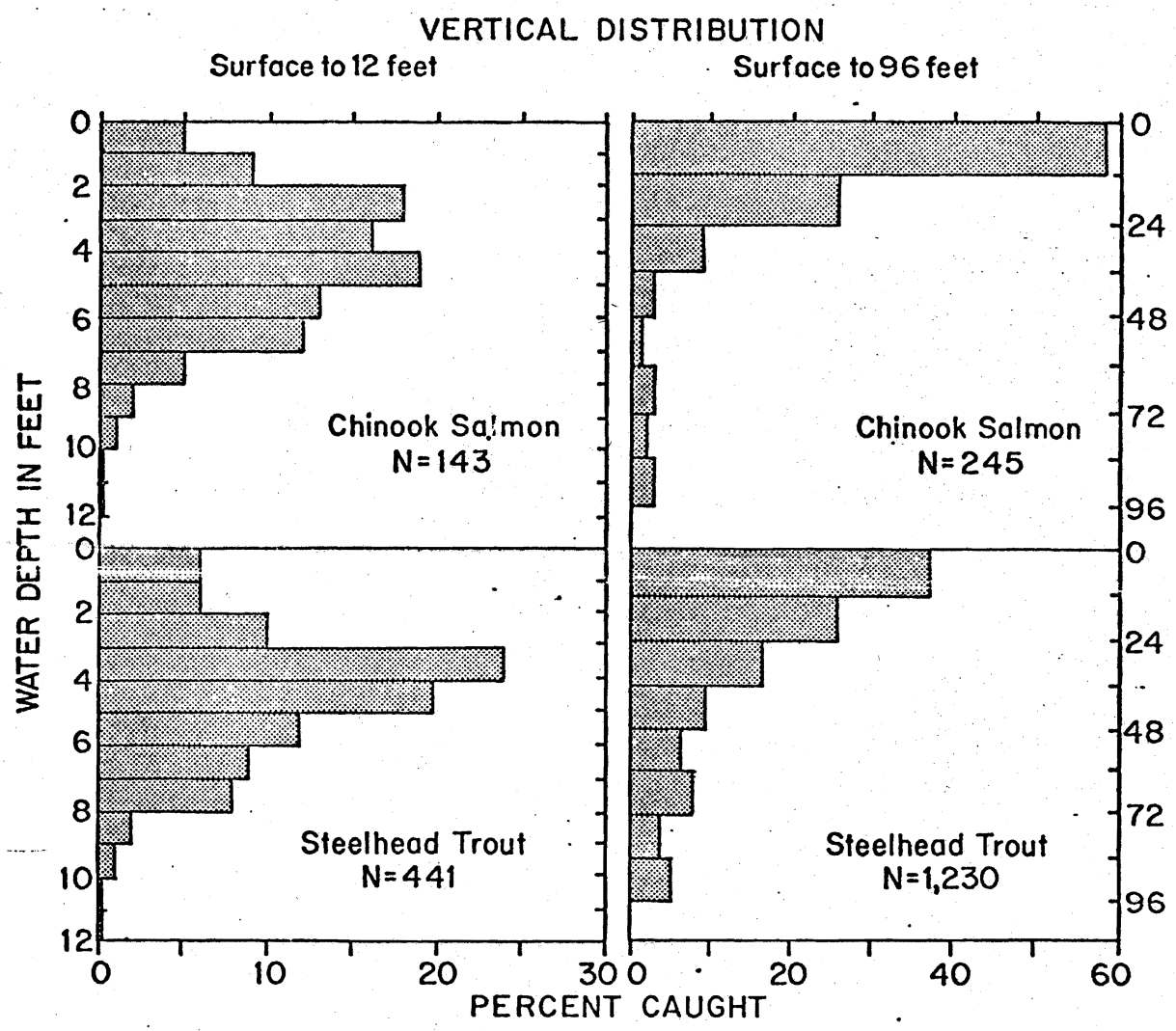


Figure 13.--Vertical distribution of juvenile chinook salmon and steelhead caught in the forebay of Lower Monumental Dam, 1973. (Source: Ebel, 1973).

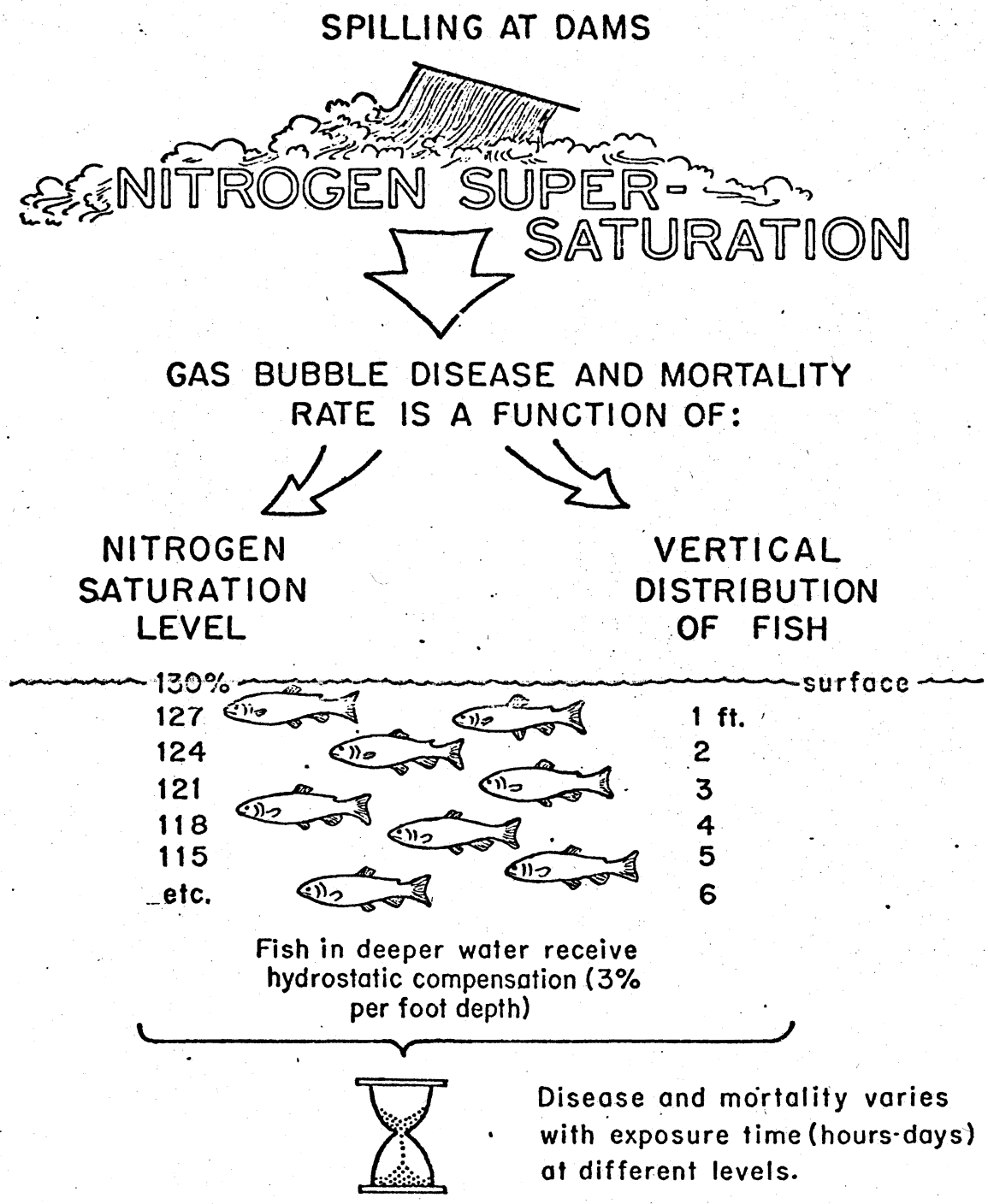


Figure 14.--Generalized representation of cause and effect relationship in gas supersaturation-gas bubble disease-fish mortality.

Table 5. Estimated mortality of juvenile chinook salmon from exposure to supersaturated atmospheric gas in the Snake River, 1970. (Ebel, 1973).

Percentage migration 1/	Depth distribution (feet)	Gas level (% sat.)	Depth compensated level (% sat.)	Exposure time (days) 3/	Percentage mortality 4/	Total mortality of group (%)	Portion of 5/ total migration
34	0-5	135	120	3	100	34.0	
11	5-7	135	114	3	0	0.0	1/3
					Subtotal	34.0	
34	0-5	135	120	14+	100	34.0	
11	5-7	135	114	14+	30	3.3	2/3
					Subtotal	37.3	

Summary of estimates:
1/3 of migration, 34.0% loss
2/3 of migration, 37.3% loss
weighted average, 35.2% total estimated mortality

1/ Determined from depth distribution study.

2/ Computed from prevailing gas concentration minus hydrostatic pressure compensation as determined by average depth of migrants.

3/ Determined from migration rate and timing data. The first 1/3 of the migration was subjected to 3 days exposure to levels of 135% or greater; the remaining 2/3 of the migration was subjected to 135% or greater for 14 days.

4/ Percentage mortality as determined from exposure time and bioassay research.

5/ Portion of migration subjected to this loss as determined by timing of migration.

Survival estimates from the upper Snake River to The Dalles Dam for juvenile populations of chinook and steelhead migrating down the Snake and Columbia River are shown in Figure 15. Survival differences noted between the Snake River stretch of the migration and the Columbia River stretch between Ice Harbor and The Dalles Dams are indicated in Figure 12. Both figures are referred to frequently throughout this section.

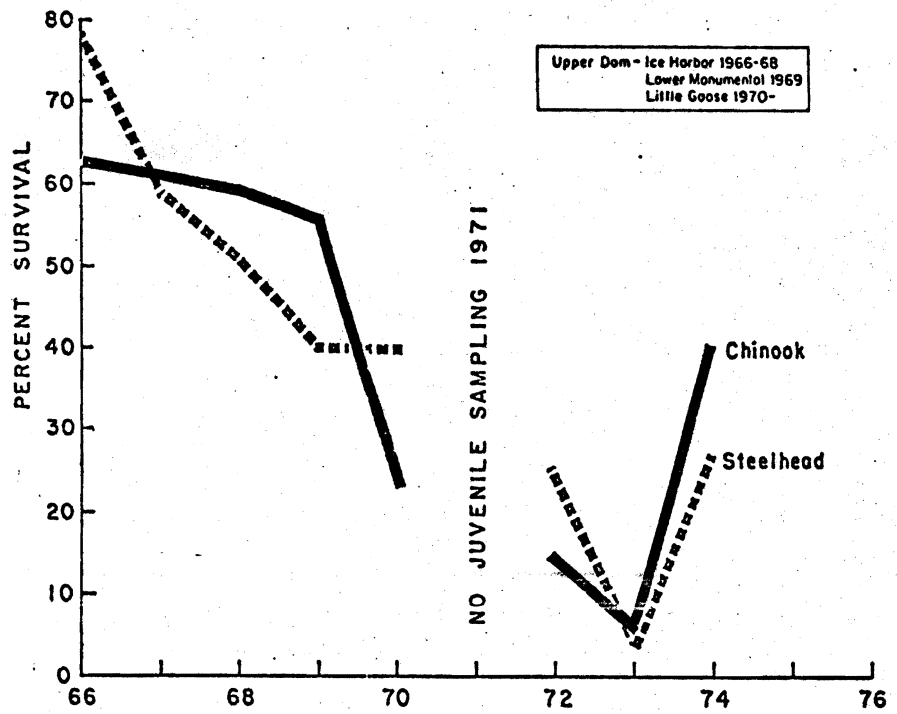


Figure 15.--Survival of Snake River juvenile chinook salmon and steelhead from the upper dam down to The Dalles Dam, 1966-74. (Source: Raymond, 1974).

Survival of both chinook and steelhead smolts during migration down the Snake River to Ice Harbor Dam declined from over 90% through 1968 to about 70 to 75% in 1969. It is believed that N_2 levels above 130%, appearing for the first time in the Snake River after completion of the Lower Monumental Dam, were largely responsible for the decline. Survival of chinook smolts from Ice Harbor Dam to The Dalles Dam in 1969 was slightly higher than in the previous years (67%). Conversely, steelhead survival through this stretch of river dropped significantly to 46%. The lower steelhead survival was attributed to increased exposure to higher N_2 supersaturation in the Columbia River. Most of the chinook migrated downstream in April and early May when flows were 80 to 100,000 cfs in the Snake River and about 300,000 cfs in the Columbia River. Steelhead migrations were nearly 2 weeks later when flows exceeded 166,000 cfs in the Snake and 440,000 cfs in the Columbia River. Thus, even though a larger portion of the steelhead migrated deeper they were exposed longer to a higher level of supersaturation and consequently suffered a higher mortality than the chinook in this stretch of the river in 1969.

Estimated survival of juvenile chinook and steelhead from the upper Snake River to The Dalles Dam in 1970 was 24 and 40%, respectively. However, with respect to area of loss, survival of juvenile chinook and steelhead was markedly different in 1970 for the two species. Most chinook mortalities occurred in the Snake River while most of the steelhead did not succumb until reaching the Columbia River. Differences can be related to length of exposure and differences in depth (vertical) distribution and tolerance to N_2 supersaturation. Most chinook migrated during Snake River flows of 50 to 100,000 cfs during the first 20 days of May. Travel time was 8 to 13 days from Little Goose to Ice Harbor Dam, and N_2 levels exceeded 130% saturation. Survival of chinook smolts to Ice Harbor Dam was 32%.

Data by Ebel (1971) indicate that losses from nitrogen are directly related to exposure time. He found that fish held in surface cages all died within 48 hours; 50% of the fish held in a 0 to 4.5 m volitional cage, where fish were allowed to seek their own depth, died in 7 days (127 to 134% saturation). If chinook were traveling near the water surface as indicated from depth distribution studies (Smith, 1974) and were exposed to high nitrogen from 10 days to 2 weeks as indicated by the data on timing of migration, most of the 68% mortality measured could be attributed to gas bubble disease caused by prolonged exposure to high levels of supersaturated nitrogen as fish migrated down the Snake River to Ice Harbor Dam. In contrast to high losses in the Snake River, mortality of chinook between Ice Harbor and to The Dalles Dams was only 25%, most of this was believed to have been turbine related. There was little spilling at Columbia River Dams which resulted in relatively low levels of supersaturation in the Columbia River during the chinook outmigration.

On the other hand steelhead smolts migrated between the 15th of May and the 5th of June; this was 2 weeks later than chinook and in river flows of 160 to 200,000 cfs in the Snake River and 350 to 400,000 cfs in the Columbia River. During their migration N_2 levels increased to over 140% in the Snake River and 127 to 139% in the Columbia River. With the higher flows, travel time was much faster—4 days in the Snake River and 10 days in the Columbia River. Estimated survival was 75% down the Snake River, sharply declining to 48% in the Columbia River. Although gas concentrations were higher in the Snake River during this period, exposure time (4 days) was short; and since a larger portion of the steelhead migrate at deeper levels, the loss to Ice Harbor Dam was only 25%. However, a 10-day additional exposure in the Columbia River from Ice Harbor to The Dalles Dams in supersaturated water was sufficient to cause an additional 52% loss, resulting in a 60% total loss.

Measurements of survival of juvenile chinook and steelhead to The Dalles Dam were not conducted in 1971 because sampling of juvenile populations for marks was discontinued that year. Measurements of survival from the Salmon River to Ice Harbor Dam indicated that survival of chinook was 45% and steelhead, 70%. The Snake River flow was extremely high in 1971 (180 to 200,000 cfs during the peak of the migration of both steelhead and chinook), and the majority of the mortality was attributed to exposure of the populations to supersaturation of nitrogen gas. The relationship between time (exposure), supersaturation of nitrogen, and survival is shown in Table 6. Slower moving fish migrating during lower flows in 1970-71 survived at a lower rate (25 to 37%) than those traveling at a faster rate during higher flows (50 to 52%). The table also indicates that a flow control effort for 3 days between April 21 and April 30 reduced dissolved gas concentrations to 109% for about 3 days and increased survival from 25 to 37%.

Table 6. Relationship between travel time, supersaturation of nitrogen, and survival of juvenile chinook salmon from the Salmon River to Ice Harbor Dam 1970-71.

	Travel Time (days)	Period of Migration	Nitrogen 1/ % Saturation	Survival %
1970	25	4/19 - 5/13	130	25
	12	5/14 - 5/31	136	50
1971	26	4/7 - 5/31	109-131 2/	37
	13	5/4 - 5/19	135	50

1/ N_2 levels - Lower Monumental Forebay

2/ N_2 109% during flow control period 4/27-29

Survival of Snake River juvenile chinook and steelhead populations to The Dalles Dam in 1972 was 15 and 25%, respectively. Survival to Ice Harbor Dam in the Snake River was 35 and 60%, respectively. We believe differences in timing between chinook and steelhead in 1972 accounts for the higher survival calculated for steelhead down the Snake River. Slotted bulkheads installed in skeleton bays to reduce N_2 in the river caused significant losses to juveniles (Long, 1973). Most of the chinook migrated when the bulkheads were in place, whereas, the peak steelhead migration occurred 10 days later—after many of the bulkheads had been removed. After removal of the bulkheads, N_2 levels exceeded 130% through most stretches of the Snake and Columbia Rivers. A total of 14 days exposure (based on migration rate) to nitrogen level of this magnitude would have caused at least 36% of the 75% loss of steelhead measured from Little Goose to The Dalles Dams in 1972.

Catastrophic losses in 1973 were primarily turbine-predator related and resulted from passage of nearly the entire juvenile migration through the powerhouses of dams. Net survival to The Dalles Dam was only 4 to 5% for both species. Supersaturation of nitrogen was not a factor in 1973 because there was little or no spilling at most dams.

Downstream survival of chinook and steelhead in 1974 to The Dalles Dam increased from the low of 4 to 5% in 1973 to 40% for chinook and 27% for steelhead. Nearly two-thirds of the 60% loss for chinook in 1974 was attributed to exposure to supersaturation of atmospheric gas. The major factor causing the loss of steelhead in 1974 cannot be estimated because of a disease problem**** in stocks of steelhead released from Dworshak Hatchery, which now accounts for one-half to three-fourths of the juvenile steelhead migrating down the Snake River. A combination of loss from exposure to supersaturated atmospheric gases and disease no doubt occurred.

Experiments to measure the effects of supersaturation of atmospheric gas on juvenile fall chinook migrants in the lower Columbia River have also been conducted and these show that losses as high as 40%***** have been attributed to exposure of these stocks to high levels of supersaturation. For example in 1970, fall chinook (Sims, 1975) released from Spring Creek Hatchery in April before supersaturation was high survived at a rate of about 90%. Releases in late May and June after gas saturation levels increased suffered a 50% loss.

**** Verbal communication, Einer Wold, former fish pathologist at Dworshak Hatchery, Ahsahka, ID.

***** Verbal communication, Kirk Beiningen, Fish Commission of Oregon, 17330 SE Evelyn St., Clackamas, OR., 97015.

The Fish Commission of Oregon conducted similar experiments in 1969 and concluded that losses exceeding 50%***** occurred during periods of supersaturation.

In summation, losses of juvenile chinook and steelhead migrating from the Salmon River to The Dalles Dam have ranged from about 40 to 95% since 1968. The proportion of this loss that can be attributed to exposure of fish to supersaturation of nitrogen varies from zero in low-flow years as in 1973 to 80% in high-flow years as in 1971.

Effect of Supersaturation on Adult Fish

Spawning migrations of steelhead trout and chinook and sockeye salmon take place in the Columbia River Basin when levels of dissolved gases are at critically high levels. Evidence of detrimental consequences are found in both laboratory experiments and field observations.

Laboratory Studies

The most comprehensive laboratory study conducted to date was by Nebeker (1973). In this study, groups of adult salmon and steelhead trout were held at various levels of supersaturation while the water temperature was maintained at 10°C. The fish were observed and the resistance times until 50% mortality were determined.

Coho salmon were the most susceptible of the adults tested (Table 7), with 50% mortality occurring after slightly less than 7 days exposure at 115% saturation. Spring chinook were the most tolerant requiring about 22 days exposure at 115% to reach the 50% level of mortality.

Coutant and Genoway (1968) held groups of fish at one of two levels of nitrogen supersaturation (low 110%, high 118%) for 5 days and then transferred them into either high or low level nitrogen conditions with the water elevated 5°C (from approximately 17° to 22°C). The objective was to determine if a 5°C raise in temperature (that was not in itself lethal) would result in mortality when combined with effects of supersaturated gases.

***** Verbal communication Kirk Beiningen, Fish Commission of Oregon, 17330 SE Evelyn St., Clackamas, OR 97015

Table 7. Hours to median mortality (50% dead) of various adult salmonids at various levels of supersaturation. (Nebeker, 1973).

Species	Sex	Level of Supersaturation			
		115% hrs	120% hrs	125% hrs	130% hrs
Spring chinook	Female	526	46;80	17.5	7.8
Spring chinook	Male	526	40;68.5	16.3	8.8
Sockeye	Not specified	30% in 192	82	18	-
Coho	Female	166	45;51	21	-
Coho	Male	264	74;86	20	-
Winter steelhead	Female	10% in 350	92	-	-
Winter steelhead	Male	30% in 350	76	-	-
Summer steelhead	Not specified	-	118	31	-

In this study, they found that fish held for the 5 day period in the high nitrogen level water at control temperatures showed visible symptoms of gas bubble disease (bubbles in the dorsal fin) within 24 hours. Coloration and alertness were affected after 4 days. Fish held at the low nitrogen level water at control temperatures showed no gas bubble disease symptoms and retained good coloration, skin texture, and alertness throughout the 27 day test period. All fish, regardless of nitrogen acclimation level, died within 24 hours when placed into high nitrogen water with the water temperature elevated 5°C. Regardless of nitrogen acclimation level, all fish died within 10 days when placed into low nitrogen water with the water temperature elevated 5°C. Those fish stressed at the high nitrogen level died sooner. External symptoms of gas bubble disease that were evident on fish disappeared rapidly after death; nearly all symptoms were lost within 24 hours.

Bouck et al. (1970) confirmed gas bubble disease among wild adult sockeye salmon migrating upstream through the Columbia River in 1968 and 1969. Adult sockeye salmon were taken from the river and examined in July 1968 and July 1969 when dissolved nitrogen levels were in excess of 120% throughout the lower 600 kilometers of the Columbia River.

In July 1968, seven live sockeye salmon were collected near the south entrance to the Oregon shore fishway at John Day Dam (river kilometer 345). These fish were examined for external symptoms of gas bubble disease and then immediately killed so histological and other internal examinations could be carried out. Three of the seven fish had external symptoms of gas bubble disease (gas bubbles in skin and on fins and eye damage). Histological studies revealed microscopic sized vesicles in the extravascular spaces of the spleen and other tissues, but it was not possible to state whether the vesicles existed during life or evolved during fixation. Aneurysms filled with blood were found in the gill lamellae of all fish that had macroscopic gas bubbles in the skin or fins.

In July 1969, 123 adult sockeye salmon collected from the Washington shore fishway at Bonneville Dam (river kilometer 235) were held at the Oregon Fish Commission's hatchery at Bonneville Dam. A cursory external examination of these fish revealed gas bubble disease symptoms in 13 fish. The 123 fish were divided into four groups, and each group was held in water of a different temperature but with the nitrogen level maintained at approximately 100%. Visible symptoms of eye damage developed that were compatible with the eye damage observed in the sockeye salmon at John Day Dam in 1968. The results of the study are summarized in Table 7a taken directly from the manuscript of Bouck et al. (1970). As a result of their work in 1968 and 1969, the authors concluded that dissolved nitrogen gas causes significant damage to salmon in the Columbia River.

Table 7a.--Incidence of eye damage and mortality among adult Columbia River sockeye salmon, Onchorhynchus nerka, during a post-capture holding period at various temperatures (From Bouck et al., 1970).

	Tank #1	Tank #2	Tank #3	Tank #4
Test Temperature (C°)	10	16 (ambient)	20	22.5
Number of Specimens	31	31	30	31
Incidence of Eye Damage				
Left Eye Only	19%	10%	33%	35%
Right Eye Only	3%	0%	7%	10%
Both Eyes	13%	19%	13%	19%
Blindness in at Least				
One Eye	35%	29%	53%	65%
Total Mortality	19% in 44 days 1/	32% in 44 days 1/	100% in 31 days	100% 12 days

1/ Experiment terminated on the 44th day.

Field Studies

In 1962, during an investigation of a high rate of prespawning mortality among chinook salmon at the McNary spawning channel, it was noted that a high percentage of the dead fish were blind. Subsequent investigation (Westgard, 1964) revealed that the problem was a result of gas bubble disease caused by high levels (up to 130%) of dissolved gases in the water. In addition, test lots of chinook salmon were placed in live boxes located in water having one of two levels of nitrogen supersaturation: (1) low-104 to 107% and (2) high-116 to 130%. Thirty-four percent of the fish held in the high nitrogen level water were blind within 10 days. Eighty-eight percent of the blinded fish died before spawning (only 6% of the non-blind died before spawning). In addition, blinded females did not dig redds and blinded males were unable to successfully cover eggs with milt.

Surveys were conducted during 1967 to determine the levels of supersaturation of dissolved nitrogen in the Columbia River and its effect on salmon and steelhead (Ebel, 1969). During periods of high nitrogen, adult salmon and steelhead were examined for symptoms of gas bubble disease. Saturation levels of dissolved nitrogen gas were found to be high enough and persisted for a long enough period in a large enough area to be potentially dangerous to adult salmon and steelhead trout. In July, symptoms of gas bubble disease were observed in 10 out of 1,000 sockeye salmon examined at McNary Dam. No symptoms were noted in 1,762 chinook salmon and 1,461 steelhead trout. Field evidence did not positively indicate that high nitrogen in the Columbia River in 1967 caused substantial mortality of adult salmon but the possibility cannot be discounted.

The first substantial loss of adult salmon and steelhead was documented in 1968 by Beiningen and Ebel (1970). Concentrations of dissolved nitrogen gas were measured in the Columbia River from April to September 1968 to determine the effect of newly constructed John Day Dam on nitrogen saturation. Adult salmon were also observed for symptoms of gas bubble disease and mortality. Nitrogen levels of 123 to 143% saturation were measured below the dam. These concentrations were considerably higher than measured previously, and they persisted throughout the salmon migration. During the period of high nitrogen levels, a high incidence of injury and death to adult fish from gas bubble disease was observed near John Day Dam. As many as 13 sockeye and 365 chinook salmon were recovered in 1 day below John Day Dam. Fish captured at the entrance to the ladder at John Day Dam exhibited obvious symptoms of gas bubble disease; eyes distended and hemorrhaged; bubbles in the subcutaneous layers surrounding the eyeball (Figure 16) and large vesicles in the roof of the mouth and on the outside of the opercula. Reports from fish counters observing fish at the underwater viewing chamber in the south fishway at John Day Dam are replete with observations of typical gas bubble disease symptoms. Tissue specimens of salmon and steelhead trout collected by Dr. Gerald R. Bouck, EPA, indicated definite tissue damage from gas bubble disease in spleen and gill lamellae of sockeye salmon as well as tentative indications of gas emboli in gill filaments of chinook salmon.

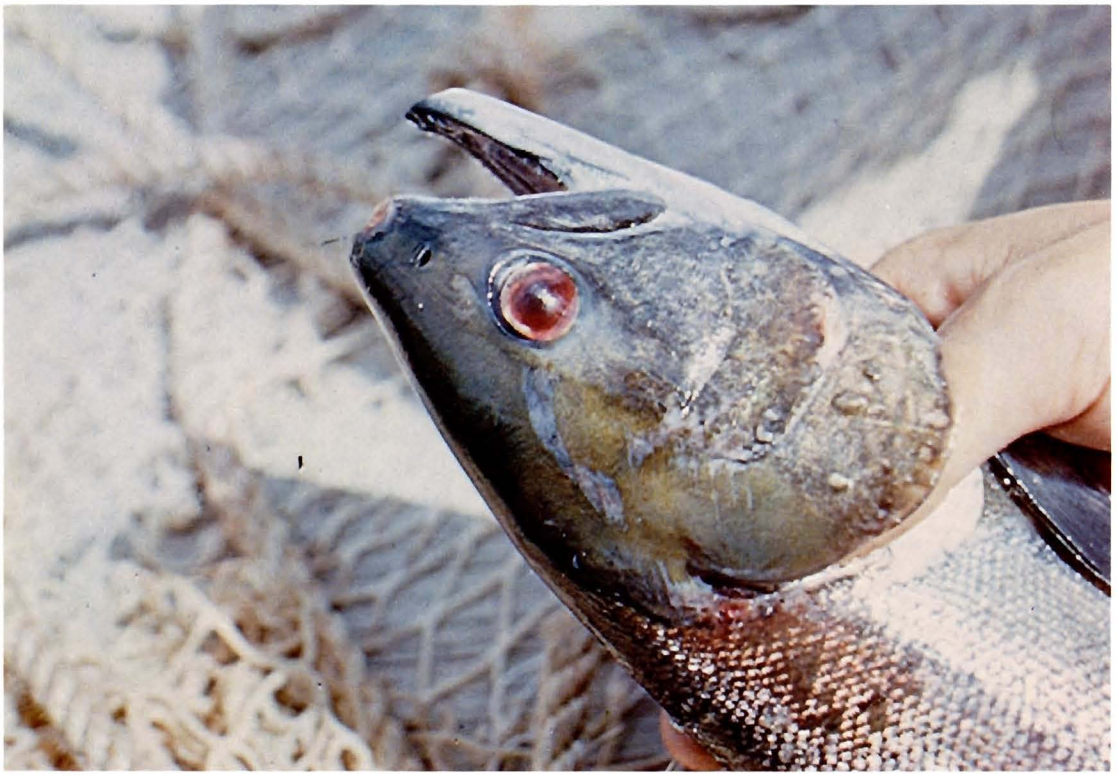
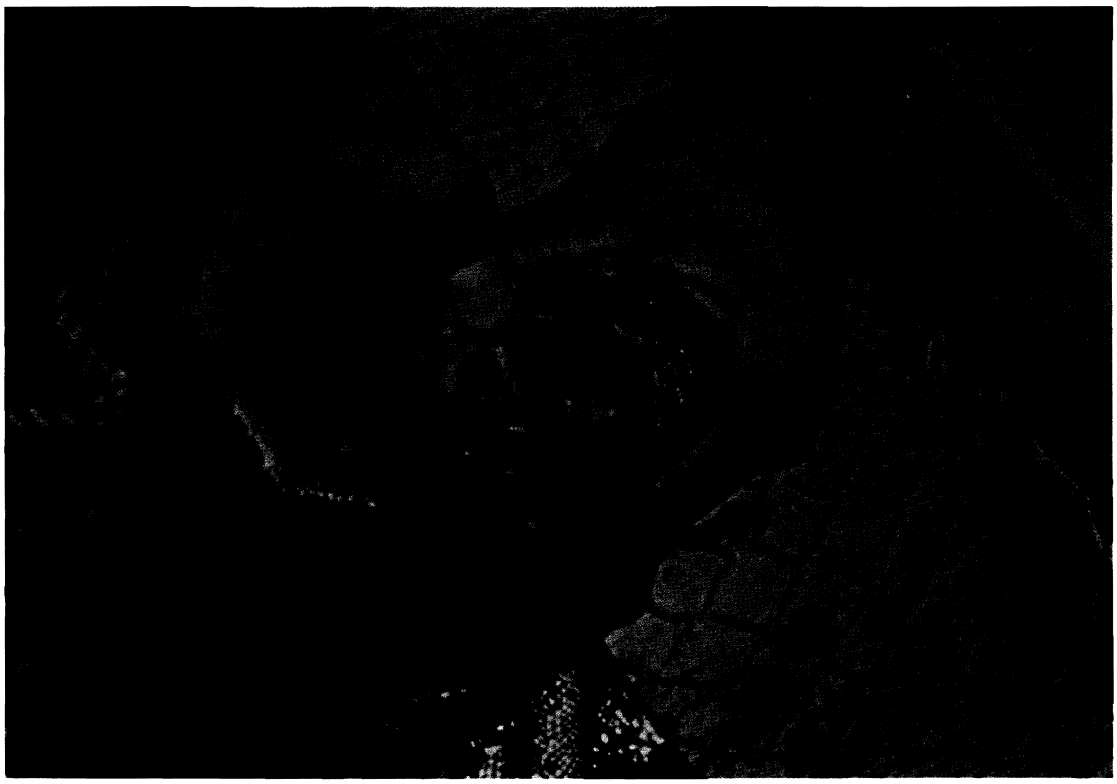


Figure 16.--(Upper) Vesicles in roof of mouth and distended eyes of adult sockeye salmon captured at entrance to south ladder at John Day Dam, 20 July 1968. (Lower) Large gas bubble in eye tissue and numerous gas bubbles on operculum of adult sockeye salmon



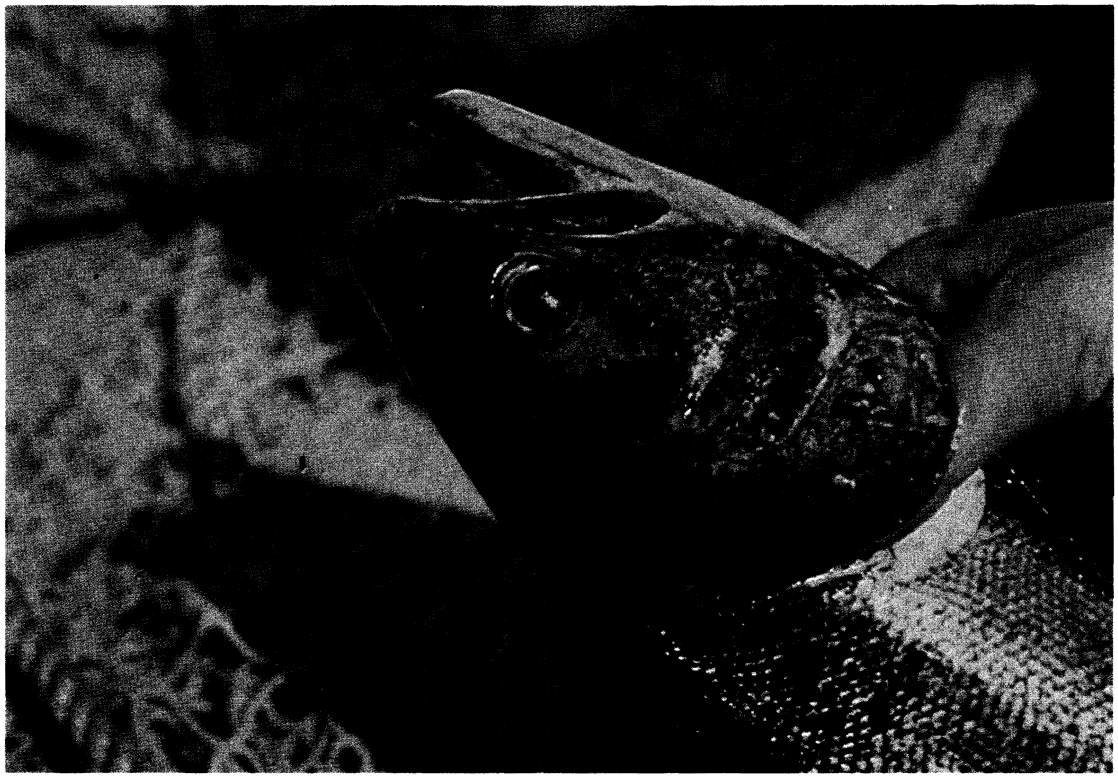


Figure 16.--(Upper) Vesicles in roof of mouth and distended eyes of adult sockeye salmon captured at entrance to south ladder at John Day Dam, 20 July 1968. (Lower) Large gas bubble in eye tissue and numerous gas bubbles on operculum of adult sockeye salmon captured at entrance to south ladder at John Day Dam, 20 July 1968. (Photo source: Beiningen and Ebel, 1970).

Based on the recovery of dead salmon, the Fish Commission of Oregon estimated that over 20,000 summer chinook were missing in the area of concern.

Investigations were carried out in the upper Columbia River from 1965 to 1969 by Meekin and Allen (1974) to determine the effect of Grand Coulee and Chief Joseph Dams on dissolved nitrogen gas levels and their effect on spawning salmon. They found that nitrogen levels of from 125 to 135% occurred each year as a result of spilling at Grand Coulee Dam. The supersaturated water did not equilibrate while passing through Chief Joseph Reservoir and subsequent spilling at the dam maintained or increased the high levels. Boat searches and aerial surveys from 1967 between Chief Joseph and Wells Dams revealed that mortalities of unspawned summer chinook and sockeye salmon occurred during the spill season and terminated after spilling stopped.

In 1970, spilling was greatly reduced and nitrogen levels were considerably lower than 1967 to 69 (generally less than 118%). Field surveys during this time showed that both adult chinook and sockeye salmon mortalities were substantially reduced from previous years.

Estimated Losses of Adult Sockeye and Summer Chinook Below Chief Joseph Dam, 1967-70.

Year	Loss		Nitrogen Level
	Chinook	Sockeye	
1967	68%	46%	High
1968	44%	-	High
1969	56%	-	High
1970	5%	30%	Low

We have examined the relationship between dissolved gas supersaturation in the Snake River and the number of spring and summer chinook redds on the spawning grounds in the Salmon River system. Redd count index number was calculated by dividing the number of redds counted during spawning ground surveys (Idaho Fish and Game Department) by the number of spring and summer chinook salmon counted over Ice Harbor Dam minus the subsequent sports catch and hatchery returns. In general, we found a sharp reduction in the redd count index number after 1968 when nitrogen levels sharply increased. However, in 1972 when the nitrogen levels were reduced through the use of slotted bulkheads and in 1973 when very low flows eliminated spilling, there was a return to the higher redd count index numbers.

Relation of Nitrogen Supersaturation in the Snake River to Spring and Summer Chinook Redd Counts in the Salmon River System

Period	N_2 Level (Mid April through May)	Redd Count Index No. (Range) 1/
1963-1968	Low (100-110%)	11-19
1969-1971	High (125-135%)	6-8
1972-1973	Low (100-110%)	10-13

1/ Index No. = $\frac{\text{Redd counts (spring and summer chinook) in Salmon River System}}{\text{No. of Spring \& Summer chinook over Ice Harbor Dam minus sports catch \& hatchery return.}}$

Summary and Conclusions

In summation, there is ample evidence, both in laboratory and field studies, that adult and juvenile salmon and steelhead are jeopardized by gas bubble disease in the Columbia River Basin. The severity of the disease and its consequences depend on the level of supersaturation, the duration of exposure, water temperature, general physical condition of the fish, and the swimming depth maintained by the fish.

During spill, levels of dissolved gases measured at and between major dams are well above critical levels. Unfortunately, even with maximum utilization of turbine capacities, the dissolved gas levels during average and high flow years will continue to be high enough to cause problems for upstream and downstream migrants. Because all reaches of the Columbia and Snake Rivers through which adult and juvenile salmon and steelhead must migrate are significantly supersaturated, the total time of exposure is serious, and any undue delays that fish may encounter could prove disastrous.

Information currently available on depth distribution of juveniles (Mains et al., 1964; Smith et al., 1968; Monan et al., 1969; Smith, 1974) all indicate that the largest percentage of downstream migrants are found in the top 5 feet of water. This means that the average hydrostatic compensation achieved is about 7.5% of saturation--insufficient to compensate for levels as high as 135 to 140% which occur over wide areas during high flow years.

Even if migrants are able to gain relief by traveling deep in the river, adults are forced to utilize restricted depths when entering and negotiating fishways at dams. Radio tracking studies (Monan and Liscom, 1973) have shown that the amount of time adult salmon spend negotiating fishways can be a substantial period that varies from dam to dam. For example, a group of spring chinook salmon tracked through the fishways at Bonneville Dam took from 4 to 57 hours each (avg. 22 hr), while the same fish tracked through the fishways at The Dalles Dam took 3 to 23 hrs (avg. 7 hr). During the time the fish are in the fishways, they are restricted to a maximum depth of about 7 feet. Observations at various dams indicate the fish are frequently near the surface in the fishways. Even though there is some reduction in the dissolved gas levels in the ladder, the restricted depth places an additional stress on fish previously equilibrated to high levels of gas supersaturation.

Several conclusions regarding the effect of supersaturation of atmospheric gas on fish in the Columbia River can be made from the laboratory and field data presented. The main conclusions we reached are:

1. Supersaturation of atmospheric gas has exceeded 130% over long stretches of the Columbia and Snake Rivers during several years since 1968.

2. Juvenile and adult salmonids confined to shallow water (1 m) suffer substantial mortality at 115% (TDG) saturation after 25 days of exposure.

3. Juvenile or adult salmonids allowed the option to sound and obtain hydrostatic compensation either in the laboratory or in the field, still suffer substantial mortality when saturation levels (TDG) exceed 120% saturation after more than 20 days exposure.

4. On the basis of survival estimates made in the Snake and Columbia Rivers from 1966 to the present, we conclude that juvenile fish losses ranging from 40 to 95% do occur and a major portion of this mortality can be attributed to fish exposure to supersaturation of atmospheric gases during years of high flow.

5. 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 to supersaturation.

REMEDIAL MEASURES

When it became apparent in 1970 that supersaturation of river waters with atmospheric gas due to spilling at dams was a substantial problem to both adult and juvenile stocks of fish in the Columbia and Snake Rivers, the U.S. Army Corps of Engineers took the lead role in devising methods to reduce supersaturation. Systems investigated were: use of head water storage to control flow during spring freshet season; installation of additional turbines to reduce spilling; use of slotted bulkheads in skeleton bays and turbine intakes to reduce spilling; and installation of spillway flow deflectors to reduce air entrainment during spilling.

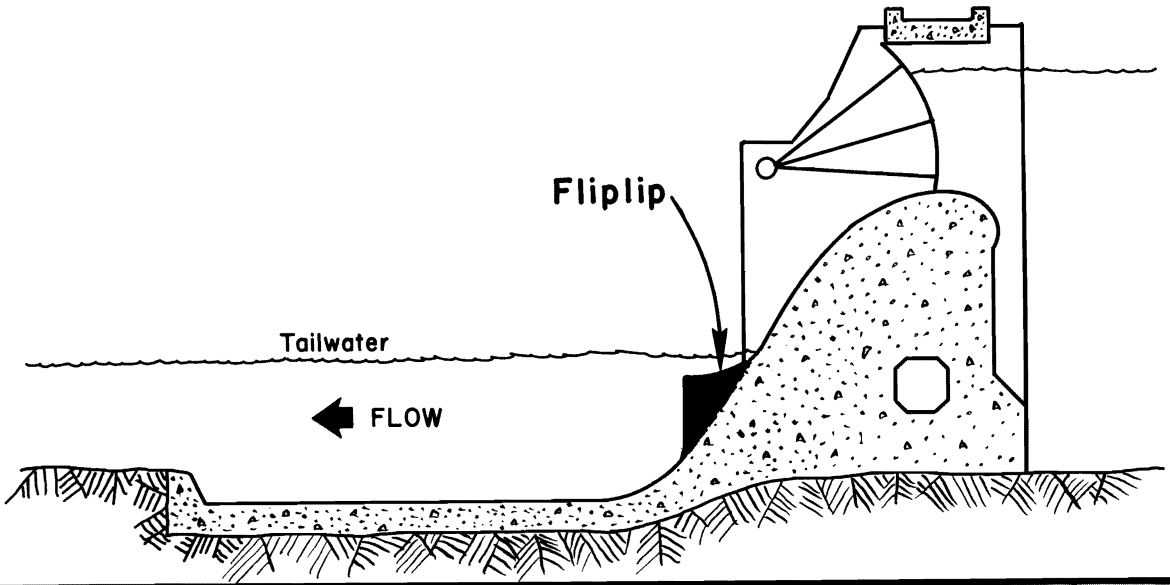
The use of headwater storage provides some relief during low and moderate flow years, but at this time the storage capacity is entirely inadequate, particularly in the Snake River, to reduce the levels of supersaturation sufficiently to significantly improve survival during average to high-flow years.

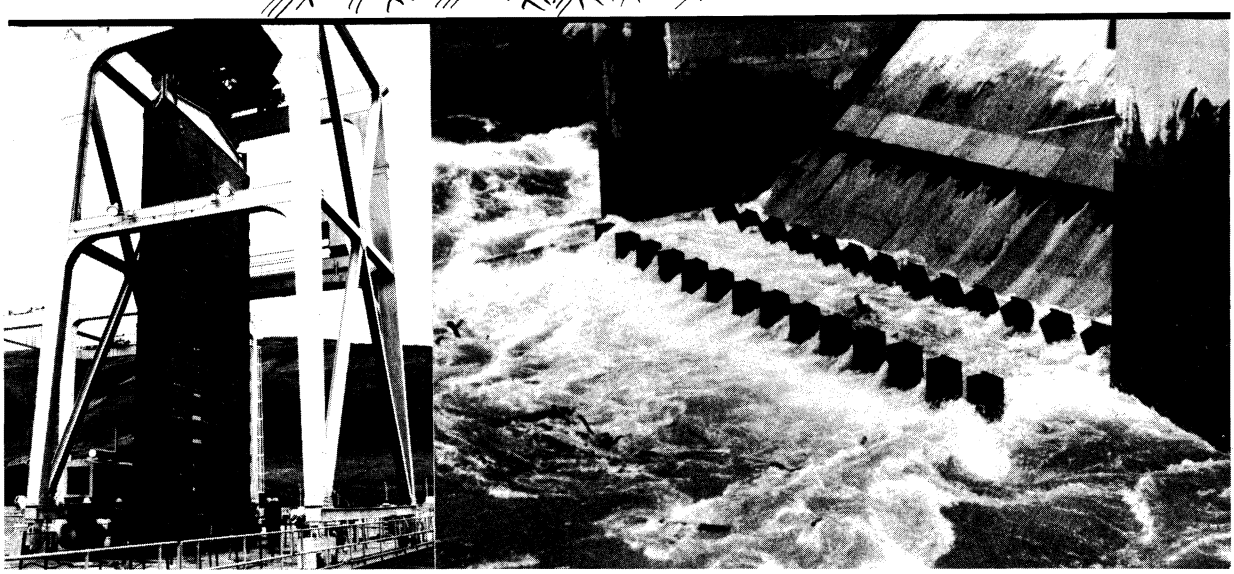
Addition of turbine units at dams (particularly those creating the highest levels of supersaturation) would substantially reduce spilling and hence, supersaturation. However, the current schedule of turbine installation (if followed) would not provide a sufficient reduction of supersaturation until sometime after 1985; by this time upper river stocks of salmonids could be lost.

The use of slotted bulkheads in turbine skeleton bays (Figure 17) proved effective for reduction of supersaturation, but studies conducted by Long and Ossiander (1974) showed that mortality of juvenile chinook and coho passing through the slotted bulkheads was 50 and 44%, respectively--too high for use during the spring juvenile fish migration. Subsequent studies (Long, et al., 1975) have shown that these bulkheads can be installed upstream from an operating turbine. Survival of fish passing through the bulkhead placed in front of a turbine unit (Figure 18) was the same as survival without the bulkhead. Placement of slotted bulkheads in front of an operating unit would allow dam projects to pass extra water through unloaded turbine units during the spring freshet season when power demand may not be sufficient to fully load all turbines.

Spillway deflectors (concrete sills placed near the base of the spillway (Figure 17) to direct flow horizontally into the stilling basin) are the most promising way to reduce gas supersaturation at this time. The lateral deflection of the water prevents deep plunging action where air entrainment (the primary source of supersaturation) takes place. Studies by Ebel, Krcma, and Raymond (1973), Long and Ossiander (1974), Johnsen and Dawley (1975), and Monan and Liscom (1974 and 1975) show that supersaturation of the water with air (primarily nitrogen) is substantially reduced (Figure 19) and no injury or adverse effect on either adults or juveniles could be measured.

SPILLWAY DEFLECTOR (FLIPLIP)





SLOTTED BULKHEAD GATES

FLIPLIP WITH DENTATES

Figure 17.--Three structual designs used to reduce gas supersaturation. (Top) Sketch of spillway deflector (fliplip) without dentates. (Lower left) Slotted bulkhead for placement in skeleton bays at dams. (Lower right) Spillway deflector with dentates.

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Test no.	Blade angle	Wicket gate	Water discharge cfs	Water velocity thru bulkhead fps	Electrical output megawatts
1	4.6°	66%	13,500	46	60
2	4.6°	83%	14,500	51	60
3	13.5°	66%	14,500	51	27.5
4	13.5°	82%	16,500	58	29

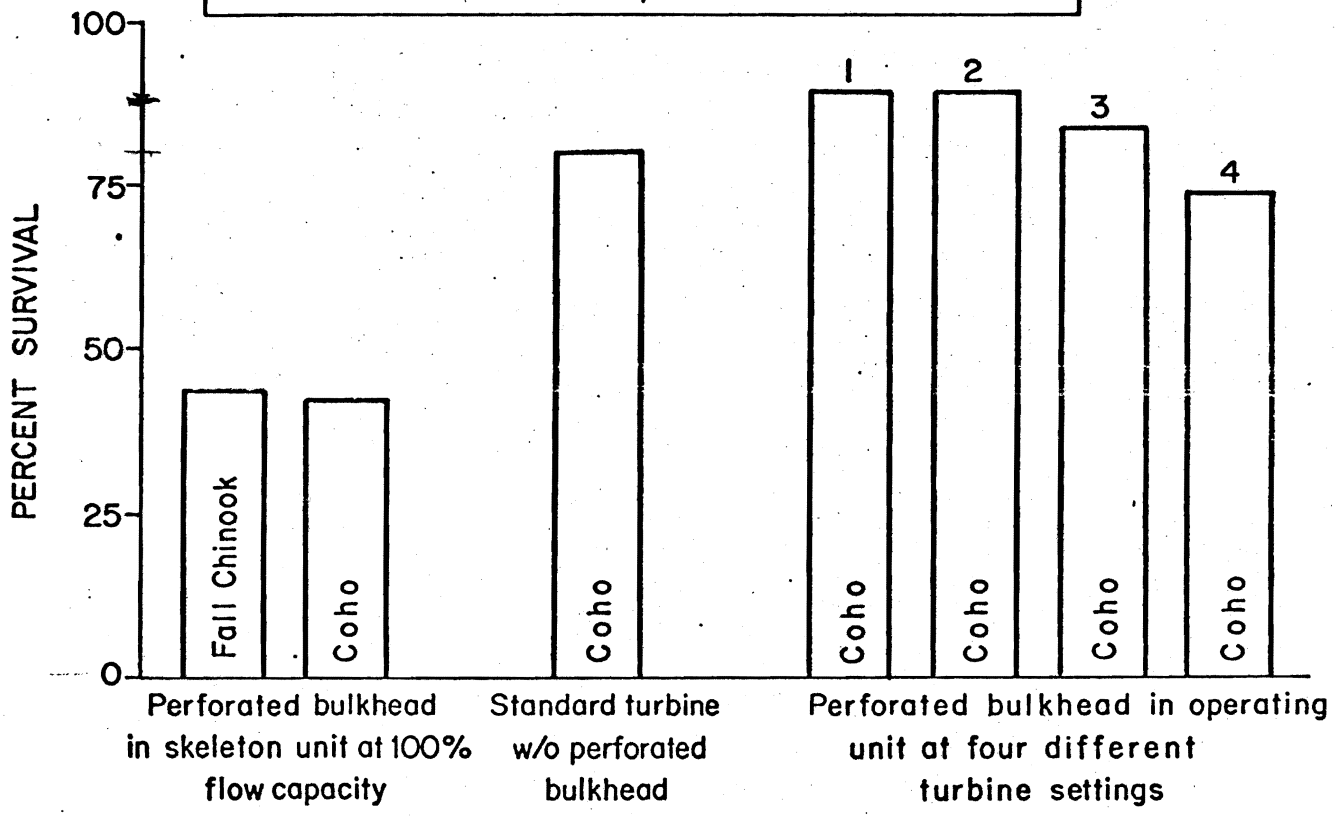


Figure 18.--Survival of fingerling salmon through perforated bulkheads in an operating turbine.

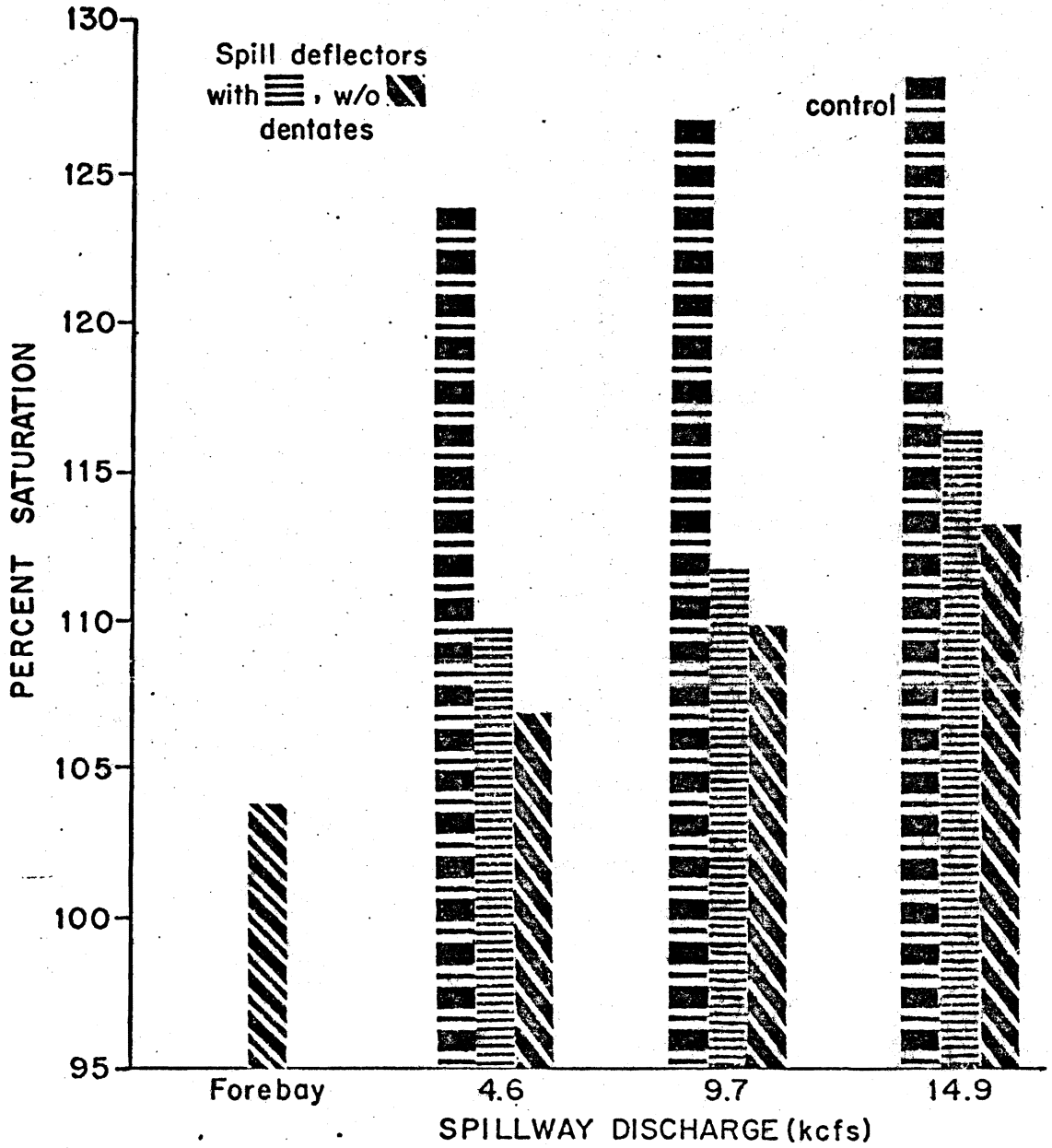


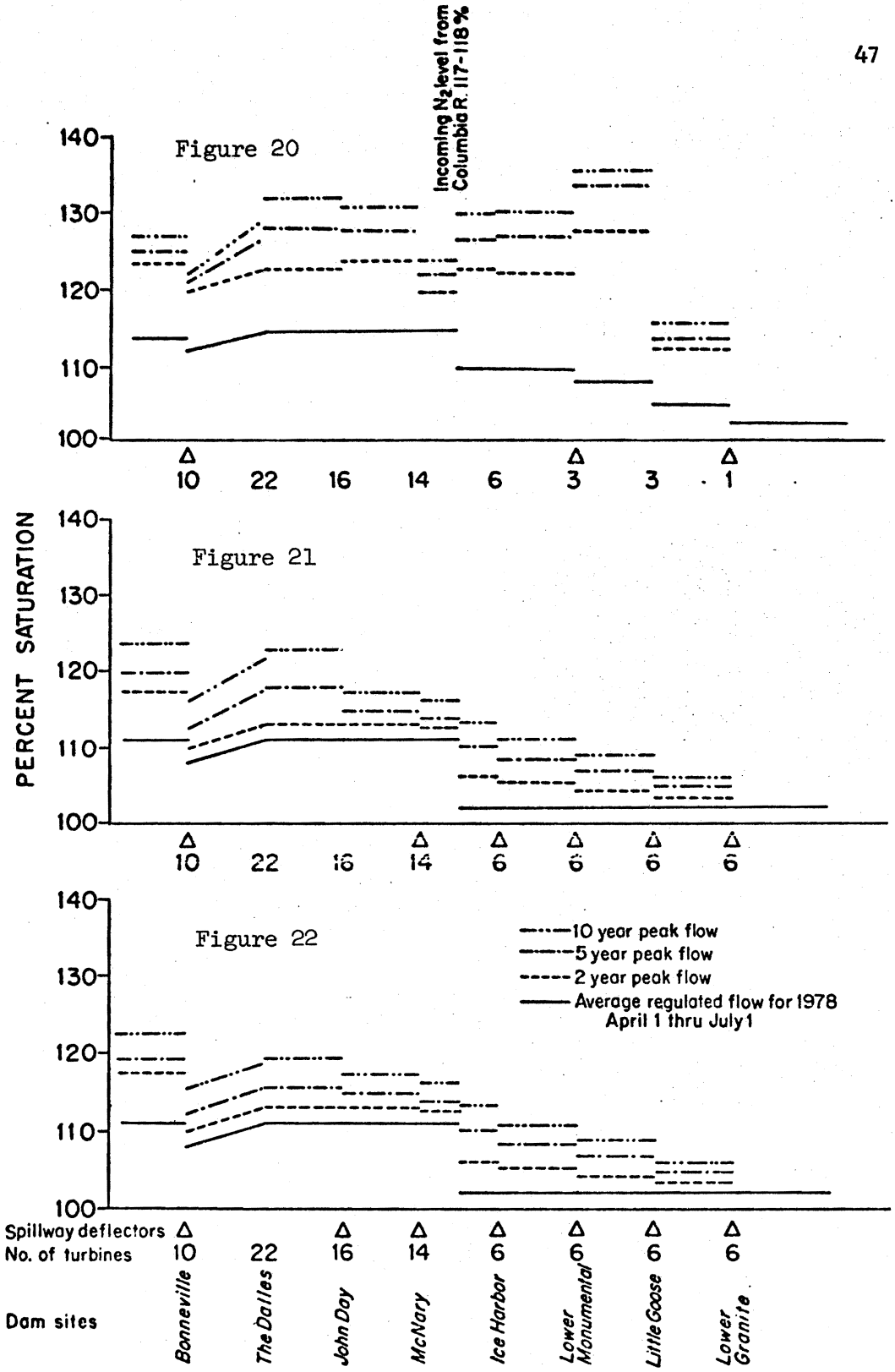
Figure 19.--Average nitrogen concentrations of forebay, control spillway, and two prototype spillway deflectors at three separate flows, March 29, 1973, Lower Monumental Dam. (Ebel et al., 1973).

A system of collecting juvenile fish and transporting them around a series of dams is under study. The system bypasses, not only the problem of supersaturation, but turbine losses, predation, and delays in migration. Data obtained to date (Ebel, Krcma, and Raymond, 1973; Ebel, Raymond et al., 1973; Ebel, Krcma, Park et al., 1974) indicate that both juvenile steelhead and chinook migrants can be collected at an upstream dam such as Little Goose Dam and transported 300 miles downstream and released below Bonneville Dam without seriously affecting their ability to home or return to their parent stream as adults. Data on returning adults (from juvenile fish transported during 1971 to 1973 from Little Goose Dam to Bonneville Dam) indicate that survival can be increased from 50 to more than 2,000 percent depending on river conditions during the transport operation and the species transported. Transportation of juveniles, however does not solve the problem of exposure of adult migrants to supersaturation. Resident species and other anadromous juvenile populations entering the Columbia at downstream locations also would not be protected.

Estimated Benefit From Installation of Spillway Deflectors

To determine the benefit that will be achieved by installing spillway deflectors, the dissolved gas (primarily nitrogen) concentrations that will occur with and without additional spillway deflectors must be estimated for various flows. It is then possible to estimate the reduction in loss of juveniles that can be expected at the reduced dissolved gas concentrations. The year 1975 was used as the base year, and estimates of gas concentrations and losses for that year were--done assuming installation of spillway deflectors and turbines indicated in Figure 20 would be completed by April.

The estimates of the dissolved nitrogen levels (Figures 20, 21, and 22) in the Snake and Lower Columbia Rivers were prepared from information obtained by several agencies and compiled by Boyer (1974). Estimates of dissolved gas levels for 1980 (Figure 21 - Project A) consider all of the scheduled turbines and spillway deflectors in the Snake River system and the spillway deflectors at Bonneville and McNary Dams in the Columbia River. Estimates for 1980 (Figure 22 - Project B) consider all of the turbines and deflectors for Project A plus deflectors at John Day Dam. Spillway deflectors for The Dalles Dam were not considered in Project B because the calculated reductions in gas supersaturations (below The Dalles Dam) amounted to only 2% during the projected 5-year peak flows and 2½% during the projected 10-year peak flows.



Figures 20, 21, 22.--Estimated dissolved gas levels with spillway deflectors and turbines installed as indicated. All turbines are assumed to be operating. Figure 20, gas levels for 1975. Figure 21, gas levels for 1980 (Project A). Figure 22, gas levels for 1980 (Project B).

The calculations for the N_2 saturation below each dam were done assuming that all of the installed turbines were operating and that the spillway flow was divided equally over each spill bay. The saturation level of water going through the turbines was assumed to remain the same. This flow, when combined with the spillway flow, produced the gas level in the downstream forebay. Equilibration was virtually nil between the tailrace of most dams and the forebay of the next dam downstream. The exceptions to this were the McNary and Bonneville Dam forebay as shown in appendix Figures C-1 through C-7. Equilibration in the Bonneville Dam forebay was taken into consideration and the impact of the middle Columbia River flow when combined with the Snake River flow, was considered in computing gas values for the McNary Dam forebay.

The nitrogen saturation below the spillways without flow deflectors was estimated using the spillway rating curves, (appendix Figures C-8 and C-9). The nitrogen saturation below the spillways with flow deflectors was estimated from Appendix Figures C-10 and C-11 which indicate the effect of flow deflectors at Lower Monumental and Bonneville Dams. An attempt was made to adjust the estimates to compensate for the different forebay saturation levels. Sample calculations are shown in appendix Tables C-1 and C-2. The dissolved gas saturation level above Lower Granite Dam was assumed to be 102%.

The saturation shown for the combined flows downstream from any dam will probably be higher than that calculated because the calculations assume that all turbines are operating and the rating curves were prepared from samples obtained in areas where some of the turbine flow mixed with the spillway flow. Estimates (Figure 20) of nitrogen levels for 1975 were derived by including the effect of all installed turbines operating together with the spillway deflectors installed prior to 1975. Therefore, the saturation shown for 1975 (for the flows considered) is below the levels recorded for the same flows prior to the construction of spillway deflectors at Lower Monumental and Bonneville Dams.

The flows used in this study were the average regulated flow of 80,000 cfs in the Snake River and 220,000 cfs in the Lower Columbia River for April 1 to July 1, 1978. The 2-, 5-, and 10-year peak flows were obtained from Table 8 for the Lower Columbia, middle Columbia, and Lower Snake Rivers.

Table 8.--Average and 2-, 5-, and 10-year peak flows for the Columbia and Snake Rivers. (Source: Smith, 1973).

HYDROLOGIC DATA - COLUMBIA AND SNAKE RIVERS

RIVER REACH	DRAINAGE AREA	AVERAGE YEARLY RUNOFF		PEAK FLOWS HAVING AN AVERAGE [1] RECURRENCE INTERVAL OF --		
		VOLUME	AVERAGE FLOW	2 YEARS	5 YEARS	10 YEARS
LOWER COLUMBIA RIVER [2] (BONNEVILLE, THE DALLES, JOHN DAY & McNARY DAMS)	240,000 sq mi (622,000 sq km)	142 x 10^6 ac ft (175 x $10^9 m^3$)	195,000 cfs (5,520 m^3/s)	360,000 cfs (10,200 m^3/s)	450,000 cfs (12,740 m^3/s)	510,000 cfs (14,440 m^3/s)
MID - COLUMBIA RIVER [2] (PREIST RAPIDS WANAPUM, ROCK ISLAND, ROCKY REACH, WELLS, CHIEF JOSEPH & GRAND COULEE DAMS)	90,000 sq mi (233,000 sq km)	86 x 10^6 ac ft (106 x $10^9 m^3$)	120,000 cfs (3,400 m^3/s	210,000 cfs (5,950 m^3/s)	280,000 cfs (7,930 m^3/s	320,000cfs (9,060 m^3/s)
LOWER SNAKE RIVER [2] (ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE & LOWER GRANITE DAMS)	109,000 sq mi (282,000 sq km)	36 x 10^6 ac ft (44.4 x $10^9 m^3$)	49,800cfs (1,410 m^3/s)	160,000 cfs (4,530 m^3/s)	210,000 cfs (5,950 m^3/s)	250,000 cfs (7,080 m^3/s)

NOTES:

1. Based on regulation expected with headwater storage to be available after 1973
2. Although the data is actually for the lowermost project in each reach of the river the runoff is essentially the same for the affected hydro projects

Records of dissolved gas concentrations in the Columbia River between Priest Rapids and Grand Coulee Dams indicate that levels often exceed 130% saturation, particularly in the river stretch between Wanapum and Priest Rapids Dams. However, considerable equilibration occurs between Priest Rapids and McNary Dams, and it is estimated that the average level of saturation of this water entering McNary Dam forebay will not exceed 118% (Appendix Figures C-1 through C-7) at the flow levels considered in this report.

Table 9 gives a tentative installation schedule for additional turbine units for the Columbia and Snake River Dams. Table 10 gives the schedule and projected cost of flow deflectors for Corps Dams. Installation of flow deflectors at Chief Joseph Dam will reduce supersaturation in the Wells Dam forebay, but current dissolved gas data indicate that the levels between the Wells Dam and the tailrace of the Priest Rapids Dam will continue to be high. Estimates of dissolved gas concentrations and corresponding fish survival for the Columbia River above the McNary Dam forebay were not attempted because rating curves for Grand Coulee, Chief Joseph, and the Public Utility District (P.U.D.) Dams are not available, and data on current magnitude of spring migrating juvenile salmonid populations in the area are inadequate.

Estimates of mortality attributable to exposure of juvenile chinook and steelhead to supersaturation of nitrogen can be made from the estimates of dissolved nitrogen levels (Figures 20, 21, and 22) that will occur with spillway deflectors installed as scheduled for 1975 and as indicated for 1980 (Projects A and B). The rationale used in calculating these estimates and the total loss predicted with and without Projects A and B are shown in Tables 11 through 14. Information on vertical distribution of juvenile salmonids was used to calculate the percentage of steelhead and chinook that are at a specific depth. The initial level of saturation was taken from Figures 20, 21, and 22 and the corresponding hydrostatic compensation was based on the average depth of groups between 0 to 5 and 5 to 7 feet of depth. Exposure time was based on migration rate and timing data. Percentage mortality was based on bioassay data.

The estimated economic and biological benefits that will be achieved by completing Project A and B are based on these loss estimates and are described in the following section.

Table 9.--Tentative hydroelectric installations, Columbia and Snake Rivers.*

HYDRO PROJECT DATA

PROJECT	1/ Owner	Date Completed	Pool Elevation (ft)	HYDROELECTRIC INSTALLATION Year: 1975-1980 No. of Powerhouse Units	CAPACITY MW	CAPACITY FLOW cfs	Year: 1980-1985 Powerhouse Units	CAPACITY MW	CAPACITY FLOW cfs
LOWER COLUMBIA RIVER PROJECTS									
1. Bonneville Dam	C	1938	72	10	570	140,000	18		300,000
2. The Dalles Dam	C	1957	160	22	2070	375,000	22	2070	375,000
3. John Day Dam	C	1968	265	16	2480	350,000	20		437,500
4. McNary Dam	C	1953	340	14	1130	240,000	20		350,000
MID-COLUMBIA RIVER PROJECTS									
5. Priest Rapids Dam	G	1959	488	10	910	180,000	12		210,000
6. Wanapum Dam	G	1963	571.5	10	980	180,000	14		257,000
7. Rock Island Dam	CH	1932	606.5	10	270	85,000	18		214,000
8. Rocky Reach Dam	CH	1961	707	11	1320	210,000	11		210,000
9. Wells Dam	D	1967	779	10	890	200,000	10		220,000
10. Chief Joseph Dam	C	1955	946	16	1280	110,000	27		220,000
11. Grand Coulee Dam	B	1941	1290	18	2300	90,000	24		290,000
LOWER SNAKE RIVER PROJECTS									
12. Ice Harbor Dam	C	1962	440	6	775	45,000	6	775	110,000
13. Lower Monumental Dam	C	1969	540	6	930	65,000	6	930	110,000
14. Little Goose Dam	C	1970	638	6	930	65,000	6	930	130,000
15. Lower Granite Dam	C	1975	738	6	930	65,000	6	930	130,000

Notes: 1. C - U.S. Army Corps of Engineers; G - Grant County Public Utility District; CH - Chelan County Public Utility District; D - Douglas County Public Uility District; B - U.S. Bureau of Reclamation

* Verbal communication, Hugh Smith, U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Table 10.--Projected construction schedule and costs for spillway deflectors on the Corps of Engineers Dams in the Columbia and Snake Rivers.[1/]

SPILLWAY DEFLECTORS

DAM	Installation schedule and costs ($ thousands) *					
	FY					
	75	76	77	78	79	80
Little Goose		200	1,200			
Ice Harbor			600	1,400		
Chief Joseph		900	1,600	1,200		
McNary		600	1,900	2,500		
John Day			600	2,000	1,400	800
The Dalles				2,600	2,000	300
Bonneville	700					

*Includes caissons.

Total for above:	$22.5 million
Delete John Day & The Dalles	9.7 "
Sub Total	12.8 "
Delete Chief Joseph	3.7 "
Sub Total	9.1 "

1/ Verbal communication, Hugh Smith, U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Table 11.-Calculation of estimated mortality of migrating juvenile chinook salmon from exposure to water supersaturated with atmospheric gas considering spillway deflectors installed at Lower Granite, Lower Monumental, and Bonneville Dam as scheduled for 1975

River flow levels	Depth distribution (feet)	Percentage 1/ migration	Gas 2/ level (% sat.)	Depth 3/ Compensated level (% sat.)	Exposure 4/ time (days)	Percentage 5/ mortality	Total estimated mortality (%)
Controlled medium flow	0-5 (ave.2.5)	34	115	107.5	26	0	0.0
	5-7 (ave.6)	11	115	97.0	26	0	0.0
						Sub. T	0.0
2 year peak flow	0-5 (ave.2.5)	34	124	116.5	39	30	10.2 (.30x.34)
	5-7 (ave.6)	11	124	106.0	39	0	0.0
						Sub. T	10.2
5 year peak flow	0-5 (ave.2.5)	34	130	122.5	30	100	34.0
	5-7 (ave.6)	11	130	112.0	30	1	0.0
						Sub.T	34.0
10 year peak flow	0-5 (ave.2.5)	34	133	125.5	23	100	34.0
	5-7 (ave.6)	11	133	115.0	23	30	3.3
						Sub. T	37.3

Table 12. -- Calculation of estimated mortality of juvenile chinook from exposure to water supersaturated with atmospheric gas considering spillway deflectors installed at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary and Bonneville Dams.

Controlled medium flow	0-5 (ave.2.5)	34	111	102.5	26	0	0
	5-7 (ave.6)	11	111	93.0	26	0	0
						Sub.T	0
2 years peak flow	0-5 (ave.2.5)	34	113	105.5	39	0	0
	5-7 (ave.6)	11	113	95.0	39	0	0
						Sub.T	0
5 year peak flow	0-5 (ave.2.5)	34	117	109.5	30	0	0
	5-7 (ave.6)	11	117	99.0	30	0	0
						Sub.T	0
10 year peak flow	0-5 (ave.2.5)	34	120	112.5	23	5	1.7
	5-7 (ave.6)	11	120	102.0	23	0	0
						Sub.T	1.7

Table 13.-Calculation of estimated mortality of juvenile steelhead migrants from exposure to water supersaturated with atmospheric gas considering spillway deflectors installed at Lower Granite, Lower Monumental and Bonneville Dams as scheduled for 1975.

River flow levels	Depth distribution (feet)	Percentage 1/ migration	Gas 2/ level (% sat.)	Depth 3/ compensated lev level (% sat.)	Exposure 4/ time (days)	Percentage 5/ mortality	Total estimated mortality (%)
Controlled medium flow	0-5 (ave.2.5)	24	115	107.5	26	0	0.0
	5-7 (ave.6)	5	115	97.0	26	0	0.0
						Sub.T	0.0
2 year peak flow	0-5 (ave.2.5)	24	124	116.5	39	100	24.0
	5-7 (ave.6)	5	124	106.0	39	0	0.0
						Sub.T	24.0
5 year peak flow	0-5 (ave.2.5)	24	130	~~112.5~~ 122.5	30	~~10.0~~ 100	~~20.0~~ 24.0
	5-7 (ave.6)	5	130	112.0	30	0	0.0
							24.0
10 year p peak flow	0-5 (ave.2.5)	24	133	125.5	23	100	24.0
	5-7 (ave.6)	5	133	115.0	23	60	3.0
						Sub.T	27.0

Table 14. --Calculation of estimated mortality of juvenile steelhead migrants from exposure to water supersaturated with atmospheric gas considering spillway deflectors inscalled at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary and Bonneville Dams to be completed by 1980.

Controlled medium flow	0-5 (ave.2.5)	24	111	102.5	26	0	0.0
	5-7 (ave.6)	5	111	93.0	26	0	0.0
						Sub.T.	0.0
2 year peak flow	0-5 (ave.215)	24	113	105.5	39	0	0.0
	5-7 (ave.6)	5	113	95.0	39	0	0.0
						Sub.T	0.0
5 year peak flow	0-5 (ave.2.5)	24	117	109.5	30	0	0.0
	5-7 (ave.6)	5	117	99.0	30	0	0.0
						Sub.T	0.0
10 year peak flow	0-5 (ave.2.5)	24	120	112.5	23	10	2.4
	5-7 (ave.6)	5	120	102.0	23	0	0.0
						Sub. T	2.4

1/ Determined from depth distribution study by Smith (1973)

2/ The average gas concentration that will occur during the spring migration of juvenile salmonids. (See Figures 20 to 22)

3/ Computed from prevailing gas concentrations minus hydrostatic pressure compensation as determined by average depth of migrants

4/ Determined from migration rate and timing data (Raymond 1968b, 1974).

5/ Percentage mortality as determined from exposure time and bioassay data.

ALTERNATIVES, COSTS AND BENEFITS

The analysis and evaluation described in this section is based solely on the effects of various levels of gas supersaturation on downstream migrating juvenile chinook salmon and steelhead of the Snake River and does not include the effects on migrating adult salmon and steelhead, on other anadromous fish, or on resident fish populations. Furthermore, there was no attempt to relate the projects, and their costs and benefits, to the provisional gas saturation standard of 110% (EPA).

Evaluation is made of two spillway deflector construction projects tentatively scheduled for the period 1975 through 1980. These are:

(1) Project A (1975-78). This project consists of spillway deflector construction at Bonneville, McNary, Ice Harbor, and Little Goose Dams (Table 15). Spillway deflectors at these dams have been determined as the fundamental grouping necessary for overall reduction in gas saturation levels in the Snake and middle Columbia Rivers.

(2) Project B (1977-80). This project consists of spillway deflector construction at John Day Dam as an addition to the deflectors constructed under Project A above (Table 15). This project, therefore, is not an independent alternative but represents an undertaking which is incremental to Project A. Analysis of the costs and benefits from this project will be treated in this incremental fashion.

A third project -- Project C (1976-78)--consisting of spillway deflector construction at Chief Joseph Dam in the upper Columbia River will not be considered for analysis at this time because of the lack of information such as: (1) its contribution to reduction in gas saturation levels in the middle and lower Columbia River and (2) its contribution to survival of upper Columbia River stocks of fish.

Prior to evaluating Projects A and B, an evaluation will be made of the conditions (losses) expected without any of the remedial projects.

Table 15.--Construction schedule and costs of spillway deflector projects, 1975-80.[1/]

Year \ Dam	Project A					Project B	Project C
	Bonneville	McNary	Ice Harbor	Little Goose	Total	John Day	Chief Joseph
	($ thousand)						
1975	700	-	-	-	700	-	-
1976	-	600	-	200	800	-	900
1977	-	1,900	600	1,200	3,700	600	1,600
1978	-	2,500	1,400	-	3,900	2,000	1,200
1979	-	-	-	-	-	1,400	-
1980	-	-	-	-	-	800	-
Total	700	5,000	2,000	1,400	9,100	4,800	3,700

1/ Data source: Table 10 of this document. Spillway deflectors have an estimated life of 50 years. Capital construction cost only. Operation and maintenance cost will be nil.

Evaluation of Fish Losses Without the Remedial Projects

Considering only the Snake River chinook salmon and steelhead stocks, we estimate a total loss of 2 million adult fish during the period 1976 to 2000 if no remedial actions are taken. In economic terms, and in terms of 1974 dollars, this represents a loss in the range of $47.2 million to $126.9 million in net economic yield to our society. The number of adult fish lost as well as economic losses are considered to be conservative because not included are the loss of upriver migrants (the spawning adults) to gas disease, and the loss of other salmon species (e.g., sockeye and coho).

Since nitrogen saturation levels for the average flow years are not excessive, the higher flow conditions of 2-year, 5-year, and 10-year peaks form the basic physical parameters. The relationship of these flow peaks to gas saturation levels and to juvenile fish mortality rates was covered earlier in this document. The expected unit loss of adult chinook salmon and steelhead as a result of losses to juveniles from gas disease during their downstream migrant stage is presented in Table 16. Losses vary with flow conditions; generally, greater fish losses are associated with the higher flow conditions.

The magnitude of these unit losses in terms of a selected time period is presented in Table 17. During the 25-year period from 1976 to 2000 alone, a total loss of 2 million adult chinook salmon and steelhead is expected. This loss is based on the assumption that during the time period (1976-2000): (1) the expected occurrence of a 2-year type peak flow is 9 times, a 5-year type peak flow is 5 times, a 10-year type peak flow is 2 times, and average to below-average type flow is 9 times and (2) the annual juvenile migrant population size average is 4.5 million fish for chinook and 4.6 million for steelhead.

The economic implication of the adult fish losses is developed in Table 18. The total loss in net economic value of $47.2 million to $126.9 million is a conservative estimate because of the assumption that losses are experienced only by the commercial and sport fisheries in the Columbia River proper. The losses to our coastal commercial and sport fisheries could not be determined at this time. Furthermore, the greater value of an adult fish as a spawner was not considered (see footnote 1 in Table 21).

Table 16.--Expected unit loss in adult chinook salmon and steelhead as a result of losses to gas bubble disease during their juvenile downstream migrant stage.

Species	Loss Factor	Expected unit losses per 1 million downstream juvenile migrants at flow condition of		
		2-year Peak	5-year Peak	10-year Peak
Chinook	Mortality rate 1/ (percent)	10.2%	34.7%	37.3%
	Juvenile losses 2/ (number)	102,000	347,000	373,000
	Resulting adult losses 3/ (number)	6,426	21,861	23,499
Steelhead	Mortality rate 1/ (percent)	24.0%	24.0%	27.0%
	Juvenile losses 2/ (number)	240,000	240,000	270,000
	Resulting adult losses 3/ (number)	13,920	13,920	15,660

1/ Source: Table 11 (chinook data) and Table 13 (steelhead data).

2/ Mortality rate applied to downstream juvenile population size of 1 million fish.

3/ Adult losses here represent the adult fish which would have returned if the indicated juvenile fish losses did not take place. Based on the average return (or survival) rate of 5.3 percent for chinook and 5.8 percent for steelhead estimated from the data in Table 1 of Raymond (1974) on juvenile and adult return counts at The Dalles Dam.

Table 17.--Expected total loss in adult chinook salmon and steelhead during the 25 year period, 1976-2000.

Species	River flow condition		Unit adult loss per million juvenile migrants 2/	Annual juvenile migrant population (million) 3/	Total adult fish losses expected during 1976-2000 4/
	Type	Expected occurrence during 1976-2000 1/			
		(A)	(B)	(C)	(D)
Chinook	2-year peak	9 times	6,426	4.5	260,253
	5-year peak	5 times	21,861	4.5	491,872
	10-year peak	2 times	23,499	4.5	211,491
				Chinook total =	963,616
Steelhead	2-year peak	9 times	13,920	4.6	576,288
	5-year peak	5 times	13,920	4.6	320,160
	10-year peak	2 times	15,660	4.6	144,072
				Steelhead total =	1,040,520
Species combined -				Grand total =	2,004,136

1/ Selection of frequency was based on the judgement of the investigators.

2/ Adult loss estimates from Table 16.

3/ Average annual population size as estimated from the 1970-74 data in Table 4 of Raymond (1974).

4/ Total adult losses (D) is calculated as: (A) x (B) x (C) = (D).

Table 18.--Economic implication of the adult chinook and steelhead losses occurring during 1976-2000.

Species	Total adult loss during 1976-2000 1/	Allocation of loss by fishery 2/		Net value per fish 3/		Total net value by fishery 4/		Total loss in terms of net value
		Commercial	Sport	Commercial	Sport	Commercial	Sport	
	(number)	(percent)		(dollar)		($ thousand)		($ million)
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(F) + (G)
Chinook	963,616	45	55	20.07	14.52-56.68	8,703	7,695-30,040	16.4 - 38.7
Steelhead	1,040,520	26	74	6.53	37.73-112.18	1,767	29,052-86,377	30.8 - 88.2
Total	2,004,136	- - -	- - -	- - -	- - -	- - -	- - -	$47.2 - $126.9

1/ Total adult loss data from Table 17.

2/ Average of 1967-71 data in Oregon Wildlife Commission (1974); Table 6 (chinook) and Table 8 (steelhead).

3/ Data source: Commercial fishery net value per fish, Appendix Table B-5; sport fishery net value per fish, Appendix Table B-8.

4/ Calculation for commercial fishery net value (F) is: (A) x (B) x (D) = (F). Calculation for sport fishery net value (G) is: (A) x (C) x (E_n) = (G_n).

Finally, viewed in another way the $47.2 million to $126.9 million net economic loss represents an average loss annually of $1.9 million to $5.1 million to our society. At 6% interest the capitalized value of these annual losses is $31.7 million to $85.0 million.

Project Evaluation

In evaluating the capital projects directed to increasing the survival of anadromous fish in the Columbia River Basin through reduction in gas supersaturation levels, a minimum criterion to be considered is that of economic efficiency, represented as the ratio of net benefits to costs (B/C) being greater than unity (1.0). Each remedial project will be evaluated on the basis of this criterion.

Evaluation of Project A

As shown in Figure 21 the construction of spillway deflectors at the Bonneville, McNary, Ice Harbor, and Little Goose Dams coupled with the installation of additional turbines will effectively reduce the gas saturation levels. It is estimated that the maximum levels will be reduced to about 113% in the Snake River and to about 123% in the Columbia River below John Day Dam. These reduced saturation levels are expected to lead to a net reduction of 10.2 to 35.6% in juvenile fish mortality, with a resulting increased availability of adult fish.

In terms of the economic efficiency criterion, the ratio of net benefits****** to project costs range from 2.28 to 6.15 at a discount rate of 5-7/8%. This represents expected returns of $2.28 to $6.15 from each $1.00 invested in Project A. Project A, therefore, exceeds the minimum criterion of unity in benefit to cost. The derivation of benefits and costs of Project A follow.

****** Net benefit here is the net value at the fishermen level of the commercial fishery and the sportsmen level of the sport fishery. See Appendix B for details on net benefit concept, methods, rationale, and estimates used in this document.

The unit net gain in adult fish resulting from Project A is presented in Table 19. Only Snake River chinook salmon and steelhead are considered and, therefore, the benefit estimates to follow is extremely conservative. River flow conditions of 2-year, 5-year, and 10-year peaks form the basic physical parameters. Generally, the number of adult fish gained (as a result of juveniles saved during their downstream migration) varies depending on flow conditions.

As a result of Project A, a total gain in 1.7 million adult chinook salmon and steelhead is expected during the 21 years from 1980 to 2000 (Table 20). Assumptions are (1) the expected occurrence of a 2-year type peak flow is 8 times during that period, a 5-year type peak flow is 4 times, and a 10-year type peak flow is 2 times and (2) the annual juvenile migrant population size average is 4.5 million fish for chinook and 4.6 million fish for steelhead.

The 1.7 million adult fish represent a total net benefit, in 1974 dollars, of $40.7 million to $109.7 million (Table 21). This is considered to be conservative in that:

1. The nitrogen saturation estimates used in calculating the levels in the river system were based on the assumption that all turbines installed would be operating throughout the period.

2. The survival rate of adults used in the calculations would be higher if there were no adult migrant loss at Bonneville Dam.

3. The gains in adult fish are valued only to the commercial and sport fisheries with none allocated to the higher valued spawning type fish.

4. The limiting of benefits only to a 21-year span from 1980 to 2000. This 21-year period is far less than the expected life of the project of 50 years.

5. The unit gain in adult chinook (Table 19) is a low estimate because it accounts only for adult returns to the river and none to the coastal commercial and sport fisheries. (Data were not available for estimating the coastal catches).

Table 19.--Expected unit net gain in adult chinook salmon and steelhead from gas saturation reduction Projects A and B.[1/]

Species	Production factor	Project A			Project B		
		Flow conditon			Flow condition		
		2-yr peak	5-yr peak	10-yr peak	2-yr peak	5-yr peak	10-yr peak
Chinook	Mortality rate without the project (percent)[2/]	10.2	34.7	37.3	0	0	1.7
	Mortality rate with the project (percent)[2/]	0	0	1.7	0	0	0
	Net reduction in mortality (percent)	10.2	34.7	35.6	0	0	1.7
	Number of juveniles saved per 1 million downstream population	102,000	347,000	356,000	0	0	17,000
	Number of adult fish saved[3/]	6,426	21,861	22,428	0	0	1,071
Steelhead	Mortality rate without the project (percent)[2/]	24.0	24.0	27.0	0	0	2.4
	Mortality rate with the project (percent)[2/]	0	0	2.4	0	0	0
	Net reduction in mortality (percent)	24.0	24.0	24.6	0	0	2.4
	Number of juveniles saved per 1 million downstream population	240,000	240,000	246,000	0	0	24,000
	Number of adult fish saved[3/]	13,920	13,920	14,268	0	0	1,392

1/ Remedial Project A: Consists of spillway deflector construction and turbine installation, as per scheduled completion by 1978, at Bonneville, McNary, Ice Harbor and Little Goose Dams (see construction schedule, Table 15).

Remedial Project B: Consists of spillway deflector construction and turbine installation, as per scheduled completion by 1980, at John Day Dam (see construction schedule, Table 15).

2/ Source: Table 12 (chinook data) and Table 14 (steelhead data) of this document.

3/ Estimated on the basis of an average return (or survival) rate of 6.3 percent for chinook and 5.8 percent for steelhead as derived from the data in Table 1 of Raymond (1974) on juvenile and adult return counts at The Dalles Dam.

Table 20.--Total gain in adult chinook salmon and steelhead from Project A and Project B during the 21-year period from 1980-2000.[1]

Project and Species	River flow condition: Type	River flow condition: Expected Occurrence during 1980-2000[2] (A)	Unit net gain in adults per million juvenile migrants[3] (B)	Annual juvenile migrant population[4] (million) (C)	Total gain in adult fish during 1980-2000[5] (D)
Project A					
Chinook	2-year peak	8 times	6,426	4.5	231,336
	5-year peak	4 times	21,861	4.5	393,498
	10-year peak	2 times	22,428	4.5	201,852
				Chinook total =	826,686
Steelhead	2-year peak	8 times	13,920	4.6	512,256
	5-year peak	4 times	13,920	4.6	256,128
	10-year peak	2 times	14,268	4.6	131,266
				Steelhead total =	899,650
				Combined total =	1,726,336
Project B					
Chinook	2-year peak	8 times	0	4.5	0
	5-year peak	4 times	0	4.5	0
	10-year peak	2 times	1,071	4.5	9,639
				Chinook total =	9,639
Steelhead	2-year peak	8 times	0	4.6	0
	5-year peak	4 times	0	4.6	0
	10-year peak	2 times	1,392	4.6	0
				Steelhead total =	12,806
				Combined total =	22,445

1/ The planning period here of 21 years (1980-2000) differs from the planning period of 25 years (1976-2000) used in estimating the expected losses without the remedial projects (see Table 16, 17, and 18). It is assumed that full benefits from Project A and Project B (in terms of reducing the mortality of juvenile fish) will take place starting in 1980 when spillway deflectors are in place at the indicated dams. However, partial benefits (in terms of the juveniles) will also be taking place between 1976-1980 based on the assumption that some peak flows will be occurring during that period. Furthermore, the real benefits to be derived are in terms of adult fish which become available to the fisheries (and for spawning escapement) 1 to 3 years after the year in which savings in juveniles took place. Therefore, because of these conditions and resulting complexities, the planning period of 1980-2000, with full benefits starting in 1980, was selected to permit ease in benefit calculations.

2/ Selection of frequency was based on the judgement of the investigators.

3/ Unit net gain estimates from Table 19.

4/ Average annual population size as estimated from the 1970-74 data in Table 4 of Raymond (1974).

5/ Total adult losses (D) is calculated as: (A) x (B) x (C) = (D).

Table 21.--Economic benefits from the gain in adult chinook salmon and steelhead--Project A and Project B, 1980-2000.[1]

Project / Species	Total net gain in adult during 1980-2000[2]	Allocation of adults by fishery[3] Commercial	Sport	Net value per fish[4] Commercial	Sport	Total net value by fishery[5] Commercial	Sport	Total net benefit
	(number)	(percent)		(dollar)		($ thousand)		($ million)
Project A	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(F) + (G)
Chinook	826,686	45	55	20.07	14.52-56.68	7,466	6,602-25,771	14.1 - 33.2
Steelhead	899,650	26	74	6.53	37.73-112.68	1,527	25,118-75,016	26.6 - 76.5
Combined	1,726,336	- - -	- - -	- - -	- - -	- - -	- - -	$40.7 - $109.7
Project B								
Chinook	9,639	45	55	20.07	14.52-56.68	87	77-300	0.2 - 0.4
Steelhead	12,806	26	74	6.53	37.73-112.68	22	358-1,068	0.4 - 1.1
Combined	22,445	- - -	- - -	- - -	- - -	- - -	- - -	$0.6 - $1.5

1/ To permit ease in calculations, it will be assumed that all of the net gain in adult fish will be taken by the commercial and sport fisheries and none for spawning escapement. This makes the value estimates on a conservative side since a spawner leads eventually to 1.5 to 4.0 adults (see Table 1 of Tuttle et al., 1973).

2/ Adult fish gain data from Table 20.

3/ Average of 1967-71 data in Oregon Wildlife Commission (1974); Table 6 (chinook) and Table 8 (steelhead).

4/ Data source: Commercial fishery net value per fish, Appendix Table B-5; sport fishery net value per fish, Appendix Table B-8.

5/ Calculation for commercial fishery net value (F) is: (A) x (B) x (D) = (F). Calculation for sport fishery net value (G) is: (A) x (C) x (E_n) = (G_n).

To perform project efficiency calculations, the total net benefit up to now of $40.7 million to $109.7 million must be appropriately identified along a time span. However, this was not feasible because the occurrence of a type of peak flow (e.g., a 5-year peak) could not be predicted for any particular calendar year, nor could the multitude of combinations of flow conditions be similarly predicted by calendar years. Therefore, for purposes of simplicity and ease in calculations, the total net benefit was simply divided by the number of years involved (21 years in this case) and the resulting average annual net benefit was assigned to each year from 1980 through 2000.

The planning periods, time stream in benefits and costs, and investment analysis of Project A are presented in Table 22. Base year for analysis is 1975. The discount rate is 5-7/8%. This is the rate determined for application to federal water resource projects during Fiscal Year 1975. As shown, benefit to cost ratios ranging from 2.28 to 6.15 are estimated for Project A. The efficiency criterion is more than met by Project A.

Evaluation of Project B

As shown earlier (Figure 22), the construction of spillway deflectors at John Day Dam (in addition to the deflectors constructed and turbines installed under Project A) will lead to further reduction in gas saturation levels. Under Project B the maximum level below John Day Dam will be about 119% and about 122% below Bonneville Dam. The gas saturation level below Bonneville Dam can only be substantially reduced by the installation of additional turbines at the dam. Construction of spillway deflectors at The Dalles Dam was not considered because of the lower spillway gas supersaturation levels (Appendix Figure C-9) and the gas equilibration that takes place in the Bonneville Dam forebay. The indicated reduction in gas supersaturation is expected to lead to a net reduction in juvenile fish mortality of 1.7%.

In terms of the economic efficiency criterion, the ratios of net benefits to project costs range from 0.07 to 0.17 at a discount rate of 5-7/8%. That is, a return of 7 cents to 17 cents is expected from each $1.00 invested in Project B. Since these ratios are less than unity, Project B does not meet the efficiency criterion. (The derivation of net benefits, costs, and B-C ratios of Project B follow.)

Table 22.--Analysis of investment in Project A--Construction of spillway deflectors at Bonneville, McNary, Ice Harbor, and Little Goose dams to reduce gas supersaturation.

Project Analysis

Overall planning period = 1975-2000
Total project cost (1975-78) - - - - - - - - - - - - - - - - $9,100,000
Total net benefit (1980-2000) - - - - - $40,700,000 to $109,700,000
Base year is 1975

Year	Cost 1/	Net Benefit 2/ Lower	Net Benefit 2/ Higher
	($ thousand)		
1975	700	-	-
76	800	-	-
77	3,700	-	-
78	3,900	-	-
79	-	-	-
1980	-	1,939	5,226
81	-	1,939	5,226
82	-	1,939	5,226
83	-	1,939	5,226
⋮	⋮	⋮	⋮
2000	-	1,939	5,226
Total	$9,100	$40,719	$109,746

Investment Analysis

Discount rate(%) 3/	Present value (year 1975) Cost	Net benefit Lower	Net benefit Higher	Benefit-Cost ratio Lower	Benefit-Cost ratio Higher
	($ thousand)				
5-7/8	8,043	18,346	49,446	2.28	6.15

1/ Cost and schedule from Table 15. Operation and maintenance cost is nil.

2/ Net benefits on an annual average basis. Calculated as the total net benefit divided by the number of years of benefits (21 years) during 1980-2000.

3/ The discount rate to be used in federal water resource project analysis during Fiscal Year 1975 (Water Resources Council, 1974).

The unit net gain in adult fish as a result of Project B was presented earlier in Table 19. Only Snake River chinook salmon and steelhead are considered and therefore, the benefit estimates are extremely conservative. River flow conditions of a 2-year, 5-year, and 10-year peaks form the basic physical parameters. A net gain in adult fish is expected only at the 10-year peak flow condition.

Project B will lead to a total net gain of 22,445 adult chinook salmon and steelhead (of Snake River origin) during the period 1980 to 2000 (Table 20). These adult fish represent a total net benefit, in 1974 dollars, of $0.6 to $1.5 million (Table 21). These net benefit estimates are conservative for the same reasons stated under Project A.

The planning periods, time span in net benefits and costs, and investment analysis of Project B are presented in Table 23. Base year for analysis is 1975. The discount rate is 5-7/8%. Furthermore, to permit ease in project efficiency calculations, the total net benefits of $0.6 to $1.5 million were divided by the 21 years involved in the benefit time span to arrive at the average annual net benefit estimates shown in Table 23. As shown, benefit to cost ratios ranging from 0.07 to 0.17 are estimated for Project B and, therefore, Project B does not meet the economic efficiency criterion.

Table 23.--Analysis of investment in Project B -- Construction of spillway deflectors at John Day Dam to reduce gas supersaturation.

Project Analysis

Overall planning period = 1977 - 2000

Total project cost (1977 - 80) - - - - - - - - - - - - - - - - - - - $4,800,000

Total net benefit (1980 - 2000) - - - - - - - - - - $600,000 to $1,500,000

Base year is 1975

Year	Cost[1/]	Net benefit[2/] Lower	Net benefit[2/] Higher
	- - - - - - ($ thousand)	- - - - - -	
1975	-	-	-
76	-	-	-
77	600	-	-
78	2,000	-	-
79	1,400	-	-
1980	800	29	72
81	-	29	72
82	-	29	72
83	-	29	72
⋮	⋮	⋮	⋮
2000	-	29	72
Total	$4,800	$609	$1,512

Investment Analysis

Discount rate (%)[3/]	Present Value (Year 1975) Cost	Net benefit Lower	Net benefit Higher	Benefit-Cost ratio Lower	Benefit-Cost ratio Higher
	- - - - - - - ($ thousand)	- - - - -			
5-7/8	3,972	274	681	0.07	0.17

1/ Cost and schedule from Table 15. Operation and maintenance cost is nil.

2/ Net benefits on an annual average basis. Calculated as the total net benefit divided by the number of years of benefits (21 years) during 1980-2000.

3/ The discount rate to be used in Federal water resource project analysis during Fiscal Year 1975 (Water Resources Council, 1974).

RECOMMENDATIONS

The two main factors considered in formulating recommendations from the information contained in this report were: (A) the impact of the recommendation on survival of fish and (B) the relation of costs associated with the recommendations to the economic benefits to be derived.

On this basis we recommend:

1. Spillway deflectors be installed at Little Goose, Ice Harbor, McNary, and Bonneville Dams (Project A) as soon as possible.

2. Spillway deflector installations be deferred at The Dalles and John Day Dams at this time subject to review if conditions at a later date indicate reasonable benefits can be obtained.

These recommendations assume that maximum power load will be programmed during the spring run-off period for the turbines at John Day Dam. Less than 85% of full operation would result in unacceptable levels of supersaturation downstream from John Day Dam. If so, this would change our current evaluation of Project B.

In our opinion, if the recommended spillway deflectors are installed and if the turbines scheduled for installation by 1980 are actually in and programmed to their capacity, the problem of supersaturation in high flow years will be for all practical purposes under control for anadromous migrants in the Snake River.

We feel obligated to point out again, however, that the supersaturation problem is associated with high flow years, but substantial mortality also occurs during low flow years from turbine-predator related problems. Current data indicate that two low-flow years in succession could eliminate upper river stocks of salmonids. To insure survival of these stocks so that maximum benefit from spillway deflectors can be achieved, the young migrants must be protected in low flow years. We, therefore, further recommend that the U.S. Army Corps of Engineers provide and maintain the capability to collect and transport juvenile salmonids from Little Goose and Lower Granite Dams for release below Bonneville Dam and, that the development and refinement of turbine intake screening systems be continued.

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APPENDIX A

CONTRIBUTION OF COLUMBIA RIVER SALMON AND STEELHEAD RESOURCES TO OUR COMMERCIAL AND SPORT FISHERIES, AND AESTHETIC EXPERIENCES

APPENDIX A

Table A-1.--Commercial catch of Pacific salmon and steelhead, 1965-69.

Year	Pacific Salmon					Steelhead
	Chinook	Coho	Sockeye	Pink	Chum	
	(thousand pounds)					
	World Catch[1/]					
1965	48,281	96,782	228,838	355,822	215,610	na
1966	44,974	97,664	172,620	385,144	264,993	na
1967	46,297	76,720	154,983	373,239	212,082	na
1968	46,517	90,830	138,008	345,020	224,869	na
1969	48,942	67,681	135,803	430,117	144,401	na
Average	47,002	85,935	166,050	377,868	212,391	na
	United States Catch[2/]					
1965	29,316	38,515	148,054	79,655	31,266	508
1966	27,223	38,755	102,012	163,016	56,506	580
1967	26,181	38,290	66,013	51,721	34,459	644
1968	25,838	37,786	54,047	148,472	61,466	678
1969	28,028	21,326	81,444	112,214	24,816	680
Average	27,317	34,934	90,314	111,016	41,703	618
U.S. as percent of world	58.1%	40.6%	54.4%	29.4%	19.6%	na
	Columbia River Origin[3/]					
1965	12,514	7,756	25	0	7	485
1966	10,396	9,006	19	0	11	396
1967	11,408	11,357	195	0	10	445
1968	10,914	5,620	90	0	3	428
1969	12,627	5,017	104	0	4	490
Average	11,572	7,751	87	0	7	449
Columbia River as percent of U.S.	42.4	22.2%	0.1%	0	0	72.6%

1/ Source: International North Pacific Fisheries Commission (1974, Table 1).

2/ Source: Fishery Statistics of the United States. National Marine Fisheries Service (1967-1969, 1971a, 1972);

3/ 1965-66 data are from Table 9, Richards (1969). 1967-69 data were estimated by applying the Columbia River percentage factors in Table 8 of Richards (1969) to the detailed catch statistics by fishery districts of the National Marine Fisheries Service (1969, 1971a, 1972), Department of Fisheries of Canada (1968-70).

Appendix A

Table A-2.--Sports catch of Pacific salmon and steelhead, 1965-69.

Year	Pacific Salmon				Steelhead
	Chinook	Coho	Pink	Chum	
	(thousands of fish)				
	U.S. Pacific Coast[1/]				
1965	369.9	1,084.0	68.9	na	369.2
1966	431.4	685.9	9.7	21.8	656.7
1967	408.2	974.9	106.7	21.6	463.1
1968	463.2	880.5	12.1	22.5	496.8
1969	480.0	776.2	46.8	22.6	381.3
Average	430.5	880.3	48.8	22.1	473.4
	Columbia River Origin[2/]				
1965	223.6	469.7	0	na	147.8
1966	246.2	396.2	0	na	146.5
1967	260.5	463.7	0	na	165.1
1968	196.1	369.6	0	na	184.4
1969	238.2	336.2	0	na	141.0
Average	232.9	407.1	0	na	157.0
Columbia River as percent of Pacific Coast----	54.1%	46.2%	0	na	33.2%

1/ Sport catches of Alaska, California, Idaho, Oregon and Washington. Data do not include sport catch of kokanee salmon (land locked sockeye). Data source: Tanonaka (1972a),

2/ 1965-66 data are from Appendix Tables 17, 18 and 19, Richards (1969). 1967-69 data were estimated by applying the Columbia River percentage factors in Table 16 of Richards (1969) to the catch statistics of California, Idaho, Oregon, and Washington; the data and sources for which are reported in Tanonaka (1972a).

APPENDIX A

Table A-3. -- Estimated visitor days at anadromous fish facilities (adult fishways and hatcheries) in the Columbia River Basin.

Adult Fish Passage facility	Year	Estimated Visitors Days
Bonneville	1974	1,986,000 1/
The Dalles	1974	829,000 2/
McNary	1965	55,000 3/
Ice Harbor	1965	85,000 3/
Rocky Reach	1971	350,000 4/
John Day	n/a	n/a
Lower Monumental	n/a	n/a
Little Goose	n/a	n/a
Wells	n/a	n/a
Wanapum	n/a	n/a
Priest Rapids	n/a	n/a
Rock Island	n/a	n/a
Partial total		3,305,000

Hatchery	Year	Estimated Visitors Days
Nine Federal Hatcheries	1972	78,000 5/
Bonneville	1971	1,000,000 5/
Other	1971	336,000 6/
Partial total		1,414,000
Grand total (fishway and hatchery)		4,719,000

n/a = not available

1/ Estimated by applying the average annual increase in visitor days during 1955-69 of 8.1 percent to the latest count of 1,345,069 visitor days in 1969 and thereafter to 1974. Data source: U.S. Army Corps of Engineers (1955-69).

2/ Estimated by applying the average annual increase in visitor days during 1957-69 of 11.4 percent to the latest count of 483,400 visitor days in 1969 and thereafter to 1974. Data source: U.S. Army Corps of Engineers (1957-69).

3/ Last available count reported by the U.S. Army Corps of Engineers (1965).

4/ Personal communication, Chelan County Public Utility District, 1971.

5/ Total visitor count at nine federal hatcheries and estimated visitor days at the Bonneville hatchery. Personal communication, Columbia Fisheries Program Office, National Marine Fisheries Service, 1973.

6/ Estimate for the 39 other hatcheries in the Columbia River Basin. Estimated simply from the proportion of 78,000 visitor days at the nine federal hatcheries to the 39 other hatcheries.

APPENDIX A

Table A-4.--Catch estimates on Columbia River Salmon and Steelhead.

HISTORICAL HIGH

Year	Catch (million pounds)	Source
1911	49.5	Figure 17, Richards (1969)

1965-1969 Average

Year	Commercial 1/	Sport 2/	Total
	(million pounds)		
1965-69	19.9	5.6	25.5

1/ Source: Table A-1.

2/ Derived by applying the average weight per fish data of Gebhards (1969) to the average catch in numbers of fish of Table A-2.

Chinook (232,900 fish)	x 10.0 lbs	=	2,329,000 lbs
Coho (407,100 fish)	x 6.0 lbs	=	2,442,600 lbs
Steelhead (157,000 fish)	x 5.0 lbs	=	785,000 lbs
	Total	=	5,556,000 lbs

APPENDIX B

DERIVATION AND ESTIMATES OF ECONOMIC VALUES FOR COLUMBIA RIVER SALMON AND STEELHEAD

The various economic values reported in this document such as,

-- Current ex-vessel and retail values (commercial fishery)
-- Current net value and gross expenditure value (sports fishery)
-- Net values (or benefits) for project efficiency calculations,

were based on the estimates developed in this appendix.

CURRENT VALUE OF COLUMBIA RIVER SALMON AND STEELHEAD RESOURCES

Commercial Fishery Value (1974)

Ex-vessel (Landed) Value

Table B-1 gives the estimated value per pound, in 1974 terms, for salmon and steelhead of Columbia River origin taken by the commercial fisheries.

Table B-1.--Value per pound estimates; commercial fishery.

Species	Coastal fishery	Columbia River fishery
	- - - - - (value per pound)	- - - - - - -
Chinook 1/	$1.37	$1.16
Coho 1/	1.00	0.99
Sockeye 2/	--	0.79
Chum 2/	--	0.59
Steelhead 1/	--	0.64

1/ The 1973 value per pound estimates from Table 1, Tuttle, Richards, and Wahle (1973) were adjusted by the Wholesale Price Index (all items) to reflect 1974 values. Furthermore, the coastal fishery value of chinook and coho salmon were on a dressed fish basis. Therefore, these were further adjusted to reflect a value per pound on a whole fish basis.

2/ The 1972 average value per pound, estimated from the data of Shea (1972), was adjusted by the Wholesale Price Index (all items) to reflect these 1974 values.

The annual ex-vessel value (at 1974 prices) of salmon and steelhead of Columbia River origin taken in the commercial fisheries is estimated at $22.5 million (Table B-2).

Table B-2.--Annual ex-vessel value of Columbia River salmon and steelhead

Species	Average annual catch 1/ (pounds)	Catch allocation 2/ Coastal (percent)	Catch allocation 2/ Columbia River (percent)	Unit value 3/ Coastal (dollar/pound)	Unit value 3/ Columbia River (dollar/pound)	Total Value ($thousands)
Chinook	11,572,000	40	60	$1.37	$1.16	$14,396
Coho	7,751,000	85	15	1.00	0.99	7,739
Sockeye	87,000	0	100	--	0.79	69
Chum	7,000	0	100	--	0.59	4
Steelhead	449,000	0	100	--	0.64	287
Total:	20,046,000					$22,495

1/ In the absence of information on more current detailed catch statistics needed to arrive at estimating the contribution of Columbia River salmon and steelhead to the commercial fisheries, the average annual catch of 20,046,000 pounds estimated from the 1965-69 data (Appendix Table A-1) was used in this valuation.

2/ Data source: Table 9, National Marine Fisheries Service (1971b).

3/ Source: The value per pound estimates in Appendix Table B-1 .

Retail Value

The average annual retail value, in terms of 1974 values, of the commercially taken salmon and steelhead of Columbia River origin is estimated at $77.2 million. This retail value was obtained by applying the average spread of 243 precent (found between ex-vessel and retail values for salmon (1965-70 data) in Table II-7, National Marine Fisheries Service (1973) to our ex-vessel value of $22.5 million.

$22.5 million (annual ex-vessel value) x (1+2.43) = $77.2 million (annual retail value)

Sports Fishery Value (1974)

Net Economic Value

The annual net sports fishery value, in terms of 1974 values, of Columbia River salmon and steelhead is estimated at $15.2 to $53.9 million (Table B-3). (The concept of "net economic value," analytical methods, the derivation of unit value estimates, etc. are treated in detail later on in this appendix).

Table B-3.--Annual net sports fishery value of Columbia River salmon and steelhead

Resource	Average annual catch 1/ (number of fish)	Net value per fish 2/ (dollar)	Total net value ($million)
Salmon	640,000	$14.52 to $56.68	$9.3 to $6.3
Steelhead	157,000	$37.73 to $112.18	$5.9 to $17.6
Total	797,000		$15.2 to $53.9 million

1/ Data source: Appendix Table A-2.

2/ Data source: Appendix Table B-8.

Gross Expenditure Value

Columbia River salmon and steelhead resources account for annual expenditures (in terms of 1974 dollars) of $34.1 to $72.7 million by sports fishermen (Table B-4).

Table B-4.--Annual gross expenditure value of Columbia River salmon and steelhead sports fisheries

Resources	Average annual catch 1/ (number of fish)	Gross expenditures per fish 2/ (dollar)	Total gross expenditure ($million)
Salmon	640,000	$37.08 to $90.74	$23.7 to $58.1
Steelhead	157,000	$66.15 to $93.10	$10.4 to $14.6
Total	797,000		$34.1 to $72.7 million

1/ Data source: Appendix Table A-2.

2/ Data source: Appendix Table B-8.

NET VALUES IN PROJECT EFFICIENCY CALCULATIONS

Standard project efficiency calculations (or benefit-cost analysis) call for comparison of net values (or net benefits) to project costs on a present value basis. Unit net values (on a per-fish basis) used in determining commercial and sports fisheries net benefits, and the methods underlying them, are covered in this section. The primary guide was "Principles and Standards" of the Water Resources Council (1973). However, many variations from the guide were necessary because of institutional factors affecting fisheries, the limitation in data, and the incomplete state of art and knowledge in the area of fishery economics (for example, see the results from the workshops in fishery economics; Idaho Cooperative Fishery Unit (1973)).

The net value at the harvesting level (fishermen) of the commercial fishery and the net value at the user level (sports fishermen) of the sport fishery were used for purposes of project efficiency calculations in this document. The rationale, methods, and justification of net value estimates follow.

Commercial Fishery Net Values

The Water Resources Council's guideline calls for the evaluation of benefits in terms of National Economic Development (NED). Comprehensive evaluation was not possible here because of limitations in data and analyses. As an alternative, we have selected net values at the harvesting level of the commercial fishery. Furthermore, our unit values will be based on the gear overcapacity rationale and approach--which is one of three approaches found in fishery economics literature.

Conventional Net Valuation

Net benefit is total benefit less associated costs or price received by a fisherman for his catch less his harvesting costs. Underlying most of our fisheries, however, is the characteristic of common property or "open access" resources. This has caused difficulties in that it creates a pattern of behavior where,

> "The individual user of a common property resource is usually in physical competition with all others in his attempt to get a large share of the product for himself. It is unreasonable to expect an individual producer to willingly and one-sidedly restrain his effort; anything that he leaves will be taken by other producers. Furthermore, in the fishery there is no limit on the number that can participate so that as long as there is any profit to be gained, additional producers will enter the industry until all true profit (or rent) is dissipated." (Christy and Scott, 1965).

As put by Crutchfield and Pontecorvo (1969),

> "In these cases, exploitation is pushed to the point where average unit costs are equal to price exclusive of rent. In these circumstances, the economic rent inherent in 'superior situations' is dissipated to pay the opportunity incomes of the additional entrants."

In view of this situation, economists and fishery researchers have arrived at alternative methods in measuring net value for commercial fisheries: (1) efficiency approach and (2) gear overcapacity approach.

Efficiency Approach

In context of benefit-cost analysis, one of the earliest approaches to measurement of net economic yield for commercial fisheries is that of Crutchfield (1962). His argument is that since, in benefit-cost analysis in the water resources area, net yield from power, irrigation, and other water uses is calculated on the assumption of sensible management to maximize income from a valuable property right--then to make valid comparison, the net yield from a fishery should be estimated on the assumption that the fishery is managed with that objective. On this assumption, net economic yield is estimated as the difference in gross receipt from the sale of the catch and the potential fishing costs (including opportunity costs for capital and labor) of either: (1) the cost associated with that minimum number of productive units needed to harvest the current levels of fish or (2) the most efficient harvesting method (lowest cost) based on current technology.

In Pacific salmon fisheries, Fry (1962) applied the above criteria to arrive at a potential net economic yield for the chinook salmon fishery of the Sacramento River which was nearly equal to 90% of the gross value to fishermen.

In a benefit-cost analysis of the Columbia River anadromous fish programs, Richards (1969) used the latter criterion (most efficient harvesting method) to arrive at net economic yield, which was equal to 90% of the gross value to fishermen.

Based on the limited entry or reduced gear criterion, Crutchfield and Pontecorvo (1969) report (1) potential net economic yield of 64 to 81% of gross value in the Bristol Bay salmon fishery for 1955-59, (2) net yield (expressed as savings) of $1 to $4 million annually with 50% reduction in gear for the Puget Sound salmon fishery during 1955-56 and 1958-59, and (3) potential net economic yield of 75% of the gross value to fishermen for Columbia River chinook and coho salmon.

Mathews and Wendler (1968) computed potential net yields to the Columbia River gillnet fishery from the 1965 spring and fall chinook runs. Converted to basis of gross value, their estimate represents 39% potential (with 50% reduction in gear) of gross value for the two runs combined.

Under this approach the potential net value for Columbia River salmon and steelhead ranged from 39% to 90% of gross value, depending upon the efficiency measure or the amount of gear reduced.

Gear Overcapacity Approach

In assessing the contribution of salmon culture and resource enhancement activities, estimates of incremental gain in net value have been expressed as 100% of the gross value (Crutchfield, Phinney, and Kral, 1967; Senn and Noble, 1968; Worlund, Wahle, and Zimmer, 1969; National Marine Fisheries Service, 1971b). The underlying rationale is that their studies, the studies reported in the previous section on efficiency approach, and studies on the extent of capitalization in United States fisheries (Bell et al., 1972) have shown that there is fleet, or gear, overcapacity in the commercial salmon fishery and that any incremental contribution to the fishery could be harvested with little or no additional associated costs.

This approach generally assumes a continuation of excess harvesting capacity which is in contrast to the previous approach which assumes a reduction in these excesses. Since excess capacity is here today, we have selected this approach and a unit net value which is equal to the gross value to fishermen for purposes of analyses.

Net Value (or Benefit)

A summary of commercial fishery unit net values used in this document is presented in Table B-5. They are expressed in terms of net value per-fish to permit ease in computing benefits from nitrogen supersaturation reduction projects.

Table B-5.--Unit net value estimates (commercial fishery) for project efficiency calculation

Species	Average weight per fish 1/		1974 price per pound 2/		Gross value per fish		Net value per fish	
	Ocean	River	Ocean	River	Ocean	River	Ocean	River
	- - (pound) - -		- - - - - - - - -		(dollar) - - -		- - - - - - - - - -	
Chinook	10.9	17.3	$1.37	$1.16	$14.93	$20.07	$14.93	$20.07
Coho	6.1	7.6	1.00	.99	6.10	7.52	6.10	7.52
Sockeye	--	3.8	--	.79	--	3.00	--	3.00
Chum	--	10.7	--	.59	--	6.31	--	6.31
Steelhead	--	10.2	--	.64	--	6.53	--	6.53

1/ Source: Average weight for salmon is from Table 24, International North Pacific Fisheries Commission (1973). Average weight for steelhead is from Table 1, Tuttle, Richards, and Wahle (1973).

2/ Source: 1974 value per pound data reported in Appendix Table B-1.

Sports Fishery Net Values

Sport salmon or steelhead fishery is essentially a non-marketed outdoor recreational activity. As such, market prices for the final product are absent. In its place, economists have introduced the term "net economic value." For recreational fishing according to Brown, Singh, and Castle (1964),

> "'Net economic value' will be our best estimate of the monetary value of the sport fishery resource which might exist if the resource were owned by a single individual, and a market existed for the opportunity to fish for salmon and steelhead. This net economic value would approximate the value of the resource to a single owner who could charge sport anglers for his permission to fish for salmon and steelhead."
>
> "The advantage of the above definition of net economic value is that it comes closest to imputing a value to the fishery resource comparable to what its value might be if it were privately owned."

The final product of a sport fishing activity is fishing. More appropriately, a day, or half-a-day, or hours of fishing (or trip). It is non-marketed in contrast to outdoor or indoor recreational activities such as professional football or basketball games, a stage play, skiing, etc. (Tanonaka, 1972b). Sport fishing satisfies the social-psychological experience of the consumer through the action of participation. If a salmon or steelhead landed is also consumed by the sportsman, then his gastronomic experience would also satisfy him.

Currently, the net value of sports fishing is this "net economic value" expressed on a per-day or per-trip basis. The general approach used to measure this value is the simulation of a demand curve for the experience by the travel cost-user intensity method on a resource under an assumed single ownership with capabilities of charging for the opportunity to fish. As summarized by Mathews and Wendler (1968):

> "This method was first suggested by Hotelling (1949), refined by Clawson (1959) and applied recently by Brown, Singh, and Castle (1964) to measure the net value of recreational salmon and steelhead fishery in Oregon."

and in general, demand for a salmon sport fishery can be expressed as:

$$"D = f(P, C, Z, T)$$

where:

D = Fishing days demanded per unit of population.

P = Price per day charged for fishing (at present zero for salmon fishing in Washington and nominal in Oregon).

C = Average cost per trip of gaining access to the fishery.

Z = Average catch-per-angler day.

T = An index reflecting income and leisure."

Generally, D should increase with increases in either Z or T and decrease with increases in either P or C.

A second approach to evaluation of net economic value of salmon sport fishery is found in the study by Mathews and Brown (1970). Here the technique was one of asking hypothetical evaluation questions, through questionnaires mailed to salmon sport fishermen in the state of Washington, to determine how much the "sport" was worth to them over and above their actual fishing expenditures. Two major questions were asked, (1) the price associated with willingness to <u>pay</u> (for the right to fish) and (2) the minimum price associated with willingness to <u>sell</u> (their assumed possession of a right to fish). The response based on the latter question (sell) was used to arrive at net value estimates of the Washington salmon sport fishery.

A third approach to estimating recreational benefits is through simulated market prices. This approach, with estimates, is found in the guidelines of the Water Resources Council (1971, 1973). However, strong objections to this approach, as well as the estimates, have been made by economists (Idaho Cooperative Fishery Unit, 1973).

A summary of net values estimated for salmon and steelhead sports fisheries in the United States and Canada is presented in Table B-6. Expenditure values are also included in the table.

Table B-6 -- Economic values reported for salmon and steelhead sport fisheries 1/

			Gross expenditure or value			Net economic value			
Area	Species	Year	Total ($ million)	Per day (dollar)	Per fish (dollar	Total ($million)	Per day (dollar)	Per fish (dollar	Source
Oregon	Salmon Steelhead	1962	15.0-21.0	(16.60)	51.14 (23.17)*	2.5-3.1	8.00	24.64 2/	Brown et al. (1964)
Oregon	Salmon Steelhead	1962		(16.60)			20.00		Brown et al.(1972)
Columbia River	Salmon - Steelhead	1965	(33.4)	(16.60)	(36.00)	5.8	8.00	17.35	Richards (1969)
Washington	Salmon	1966	50.0	(43.57)	(71.03)	5.0-8.0	(6.97)	11.09	Crutchfield and MacFarlane(1968)
Washington	Salmon	1967	24.5*	(14.44)*	(22.96)*	65.6	28.00	(51.24)	Mathews and Brown (1970)
Idaho	Salmon	1968	.376*	(5.78)*	(32.70)*	.217	8.00	(18.86	Gordon (no date)
	Steelhead	"	1.752*	(9.12)*	(71.51)*	.649	15.00	(26.49)	
British Columbia 3/	Steelhead	1968	.787	(73.57)	(255.93)	.130	11.50	(41.94)	Pearse-Bowden (1970)
British Columbia	Steelhead	1969							
	B.C. Resident:		(3.168)	10.80	(94.70)	-	-	-	Pearse-Bowden (1971)
	Non Canadian:		(.570)	42.50	(167.50)	-	-	-	
Washington	Steelhead	1968	(16.8)	(13.56)	(53.13)	-	-	-	Wn. St. Game Dept (1969)
	Steelhead	1969	-	-	60.00	-	-	-	" " " " (1971
Michagan (Great Lakes)	Salmon- Steelhead	1970	15.5*	8.77*	(13.22)*	8.3	4.75	(7.12)	Ellefson (1973)
United States	Salmon-Steelhead	1971	-	-	-	-	9.00 4/		Water Resources Council (1971)

* = Current (or variable, or direct) expenditures only.

1/ Values in parentheses were estimated from data in the source article or in combination with other catch and effort statistics.

2/ Estimate by Richards (1969).

3/ Values to British Columbia from expenditures by non-Canadian sport fishermen.

4/ The upper value in the $3.00 to$9.00 range in simulated market price for specialized recreation day such as salmon fishing (p. 24157, Water Resources Council, 1971).

The economic values most relevant to this document are the per-day estimates in the "expenditure" and "net value" categories for the Pacific Northwest area and the Water Resources Council's net value estimate. These are summarized in Table B-7. Furthermore, these estimates have been adjusted to reflect 1974 prices (or values) because of the variations in sampling year.

Quite evident is the wide variations in adjusted values. For this document we will be using both the low and high estimates of each species-value category rather than a median from the range in values.

Table B-7 -- Current (1974) unit values for Pacific Northwest salmon and steelhead sport fisheries

Data source	Area	Species	Sample Year	Expenditure per day		Net value per day	
				Sample Year	Adjusted to 1974	Sample Year	Adjusted to 1974
Brown et al.(1964)	Oregon	Salmon & steelhead	1962	$16.60	$26.60	$8.00	$12.82
Brown et al.(ms 1972)	Oregon	Salmon & steelhead	1962	$16.60	$26.60	$20.00	$32.05
Crutchfield & MacFarlane (1968)	Washington	Salmon	1966	$43.57	$65.09	$6.97	$10.42
Mathews & Brown (1970)	Washington	Salmon	1967	$14.44*	$20.96*	$28.00	$40.66
Gordon (no date)	Idaho	Salmon Steelhead	1968 1968	$5.78* $9.12*	$8.06* $12.71*	$8.00 $15.00	$11.15 $20.91
Wash. St. Dept. Game (1969)	Washington	Steelhead	1968	$13.56	$18.90	-	-
Water Resources Council (1971)	U.S.	Salmon & Steelhead	1971	-	-	$9.00	$10.78

Value range (1974 level)

	Gross expenditure per day	Net value per day
Salmon:	$26.60 - $65.09	$10.42 - $40.66
Steelhead:	$18.90 - $26.60	$10.78 - $32.05

* Direct expenditure values. Other in the expenditure column are gross expenditure values.

1/ Data from Appendix Table B-6 were adjusted by the Consumer Price Index (all items) to reflect 1974 values.

Finally, the per-day estimates were converted to a per-fish basis (Table B-8) to permit ease in computing the current value of the Columbia River salmon and steelhead resources to our recreational fisheries and for project efficiency calculations.

Table B-8 -- Current (1974) per-fish values applicable to sport fisheries operating on Columbia River salmon and steelhead resources

	Net Value		
Species	Net value per-day 1/	Fishing days per fish 2/	Net value per-fish
Salmon	$10.42 - $40.66	1.394	$14.52 - $56.68
Steelhead	$10.78 - $32.05	3.5	$37.73 - $112.18

	Gross Expenditure Value		
Species	Gross expenditure per day 1/	Fishing days per fish 2/	Gross expenditure per-fish
Salmon	$26.60 - $65.09	1.394	$37.08 - $90.74
Steelhead	$18.90 - $26.60	3.5	$66.15 - $93.10

1/ Source: Appendix Table B-7

2/ Source: Table 1, Tuttle, Richards, and Wahle (1973)

SUPPLEMENTAL NOTE ON REGIONAL ECONOMIC DEVELOPMENT (BENEFIT)

As indicated earlier in this appendix, it was not possible to determine benefits in terms of National Economic Development (NED) because of the lack of data and pertinent analyses. Determination of benefits even at the regional level, as recommended by the Water Resources Council (1973), was not possible. To our knowledge, the only studies (and data) of general relevance here are the business multipliers developed on two local areas in Oregon.

Area	Activity	Business Multiplier	Source
Clatsop County, Oregon	Commercial fishing	1.3523	Table 8, Collin, Youmans, and Stoevener (no date)
"	Fish Processing	1.3198	"
Yaquina Bay, Oregon	Fisheries (sport)	1.88162	Table 3.3, Stoevener *et al.* (1972)

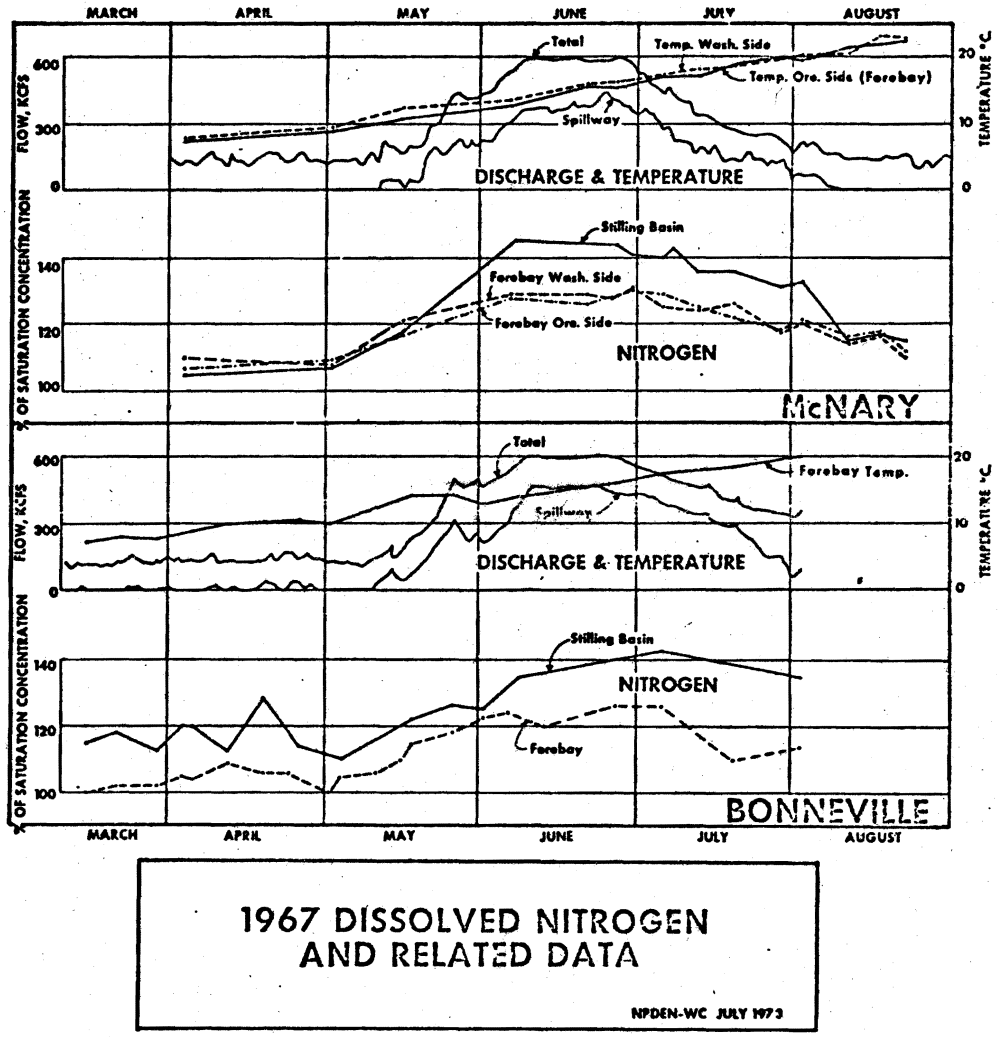
The general implication of the above multipliers to resource enhancement projects of this document is that for each one dollar ($1) increase in economic activity attributable to Columbia River salmon and steelhead resources, the following additional economic output may take place in the respective local areas:

1. Clatsop County (commercial fishing) - 35 cents ($0.35)
2. Clatsop County (fish processing) - 32 cents ($0.32)
3. Yaquina Bay (sport fishery) - 88 cents ($0.88)

APPENDIX C

DISSOLVED NITROGEN AND RELATED DATA

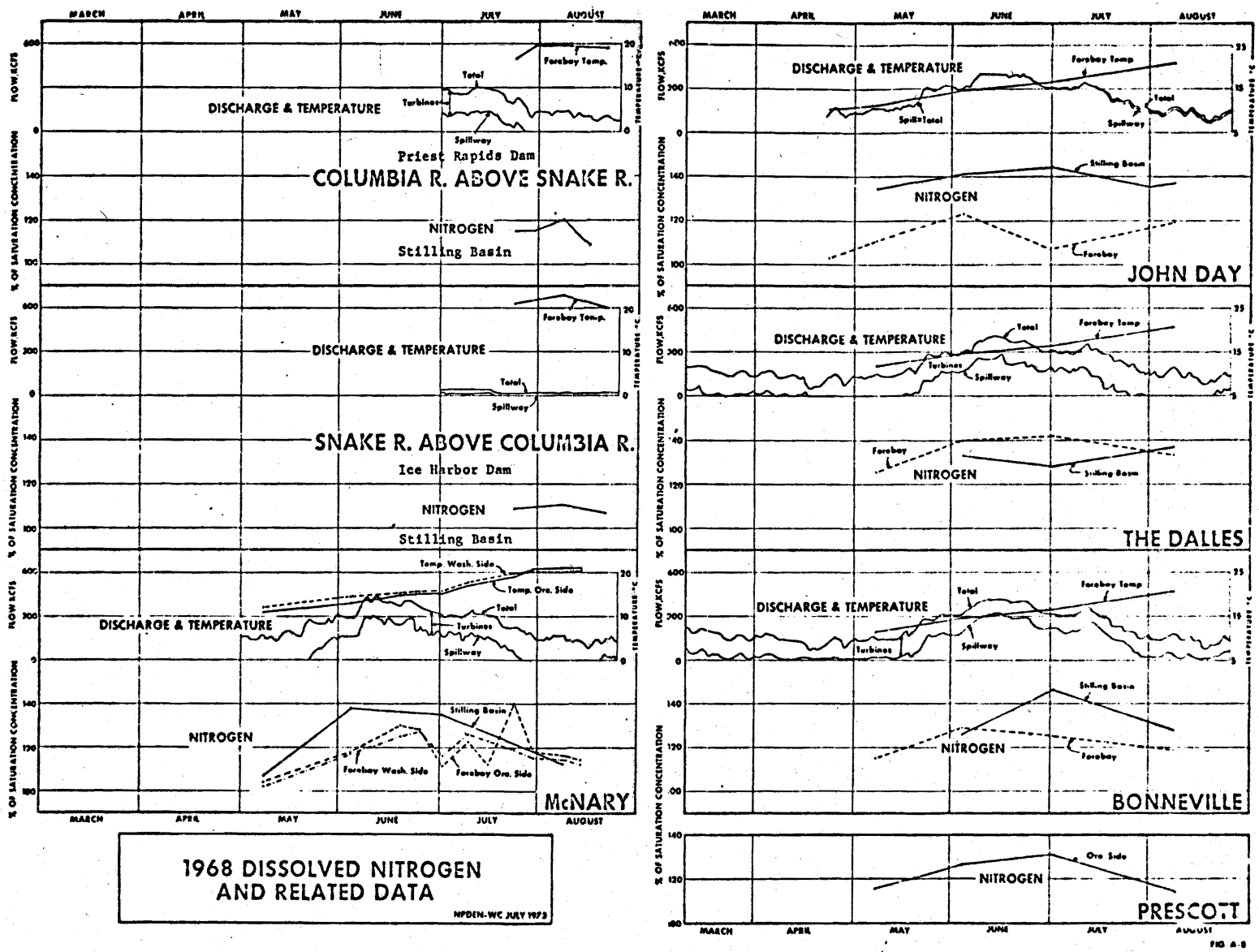
Appendix C



1967 DISSOLVED NITROGEN
AND RELATED DATA

NPDEN-WC JULY 1973

Figure C-1.--(Boyer, 1974).



1968 DISSOLVED NITROGEN AND RELATED DATA

NPDEN-WC JULY 1973

Figure C-2.--(Boyer, 1974).

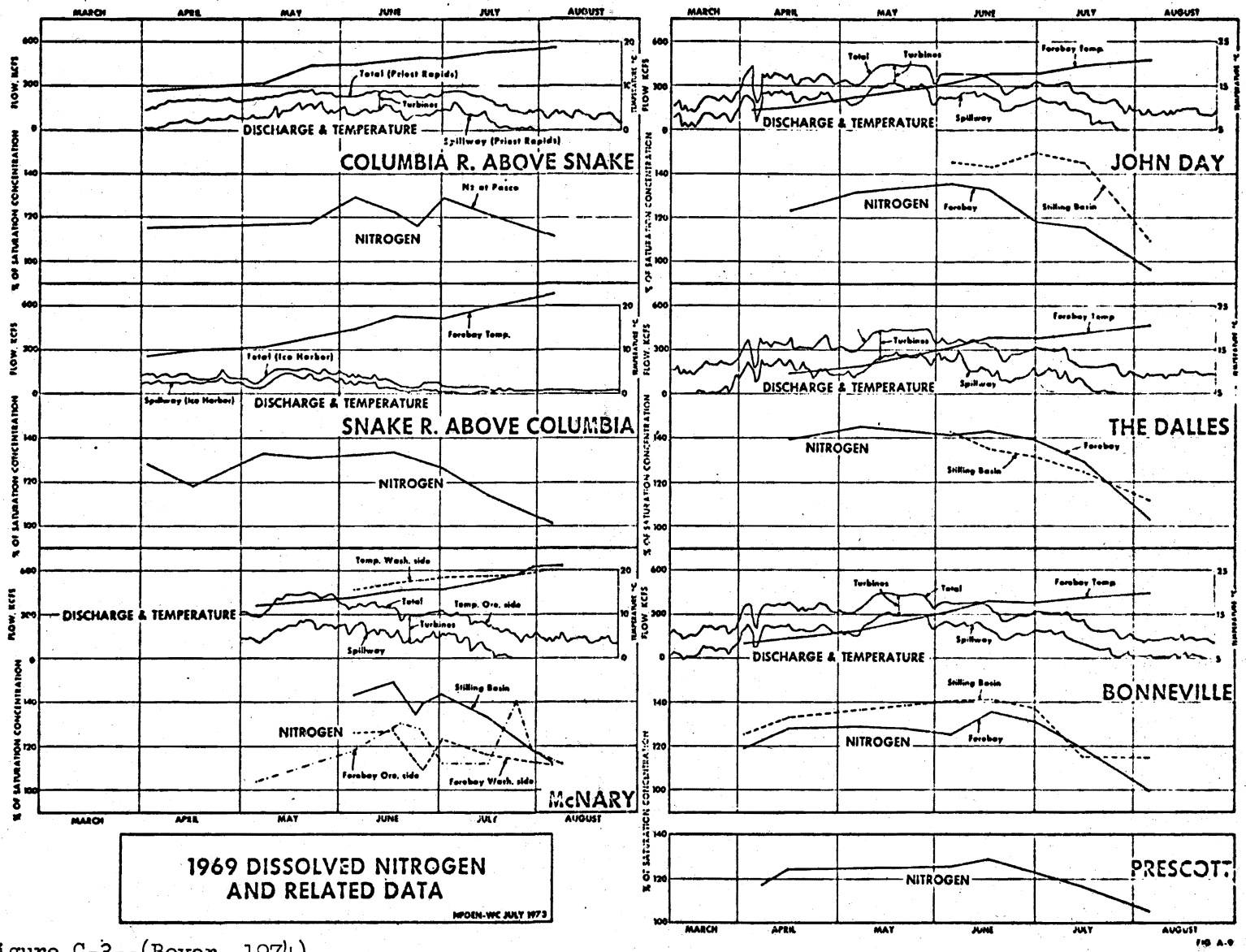


Figure C-3--(Boyer, 1974)

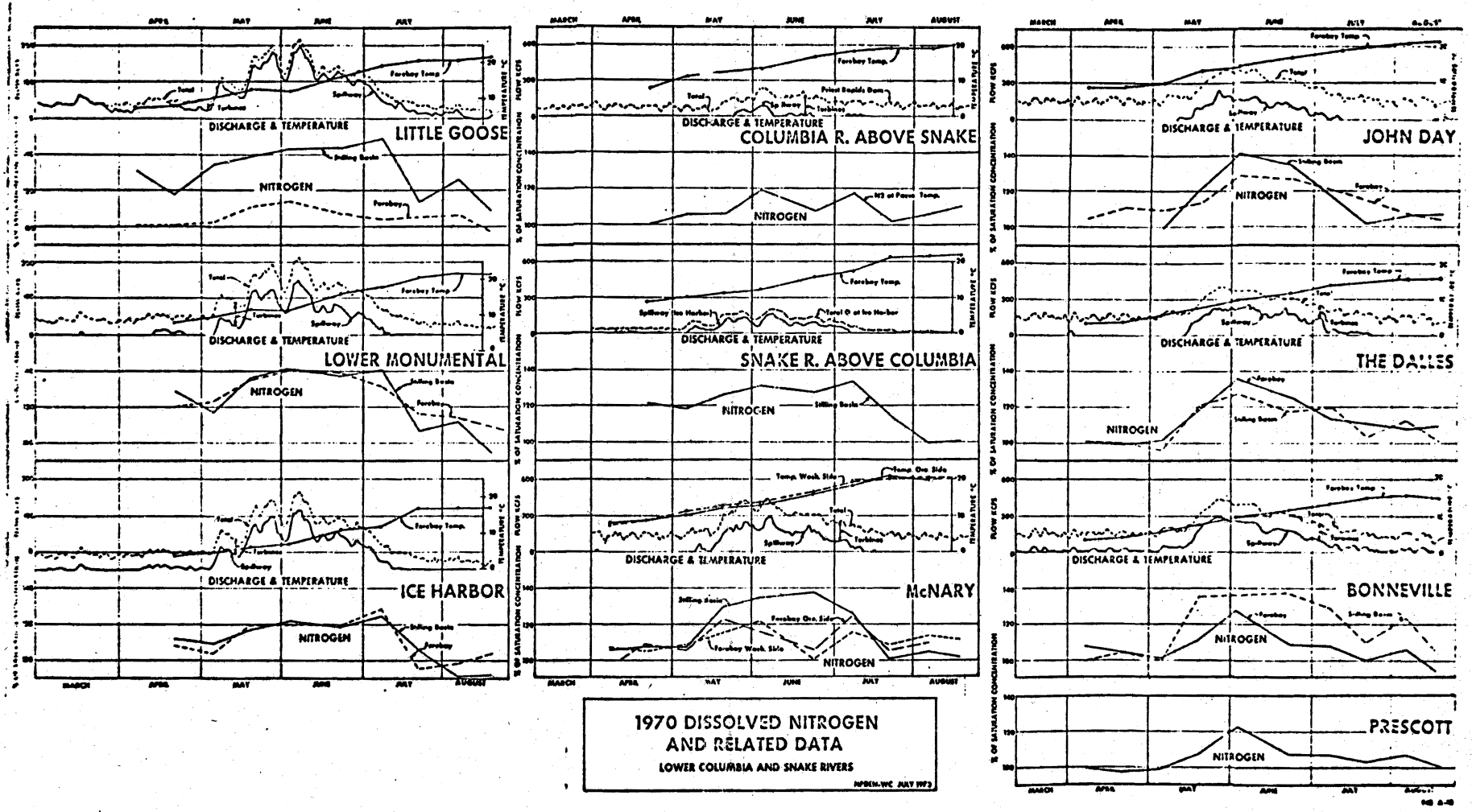


Figure C-4.--(Boyer, 1974)

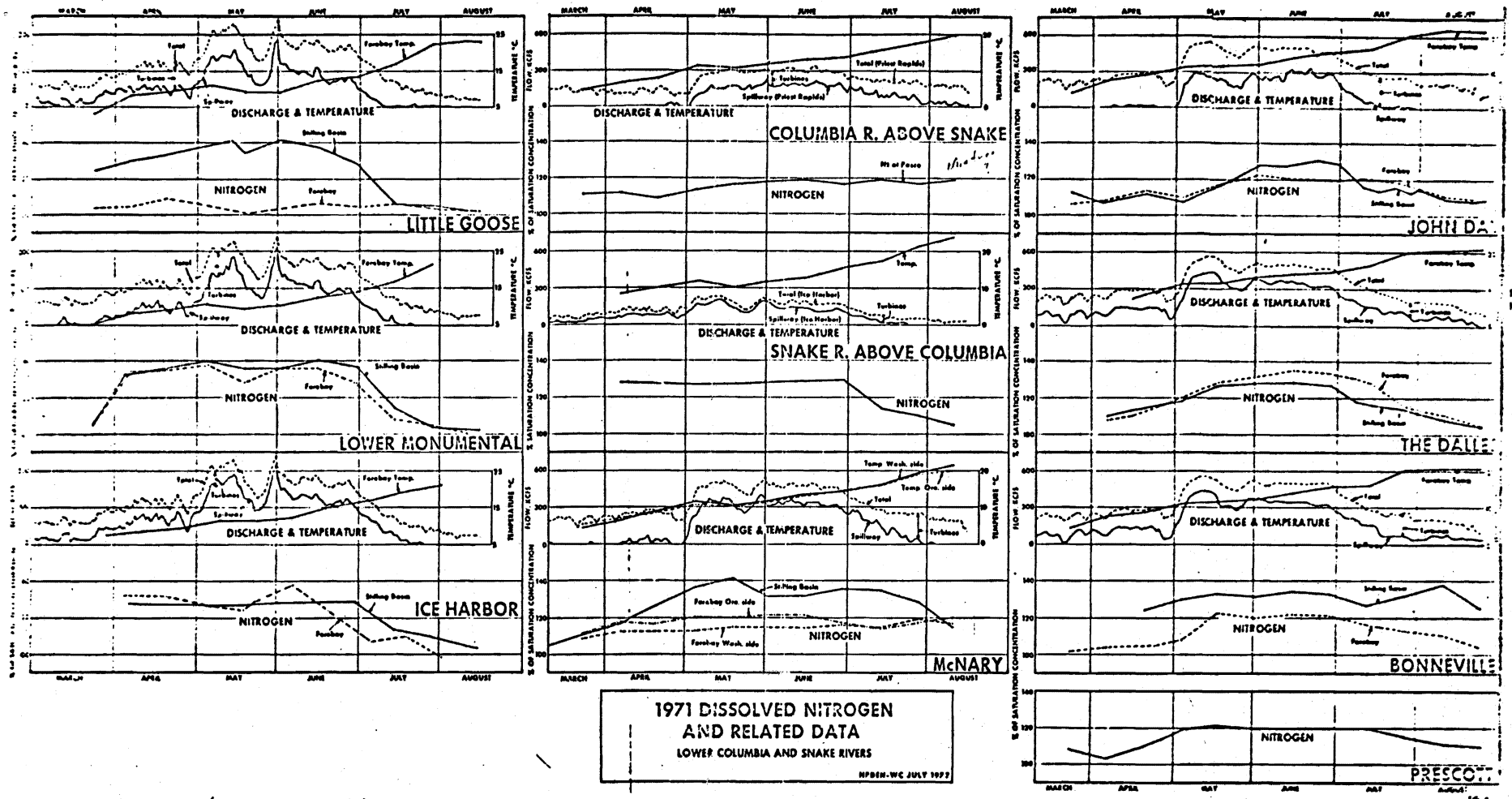
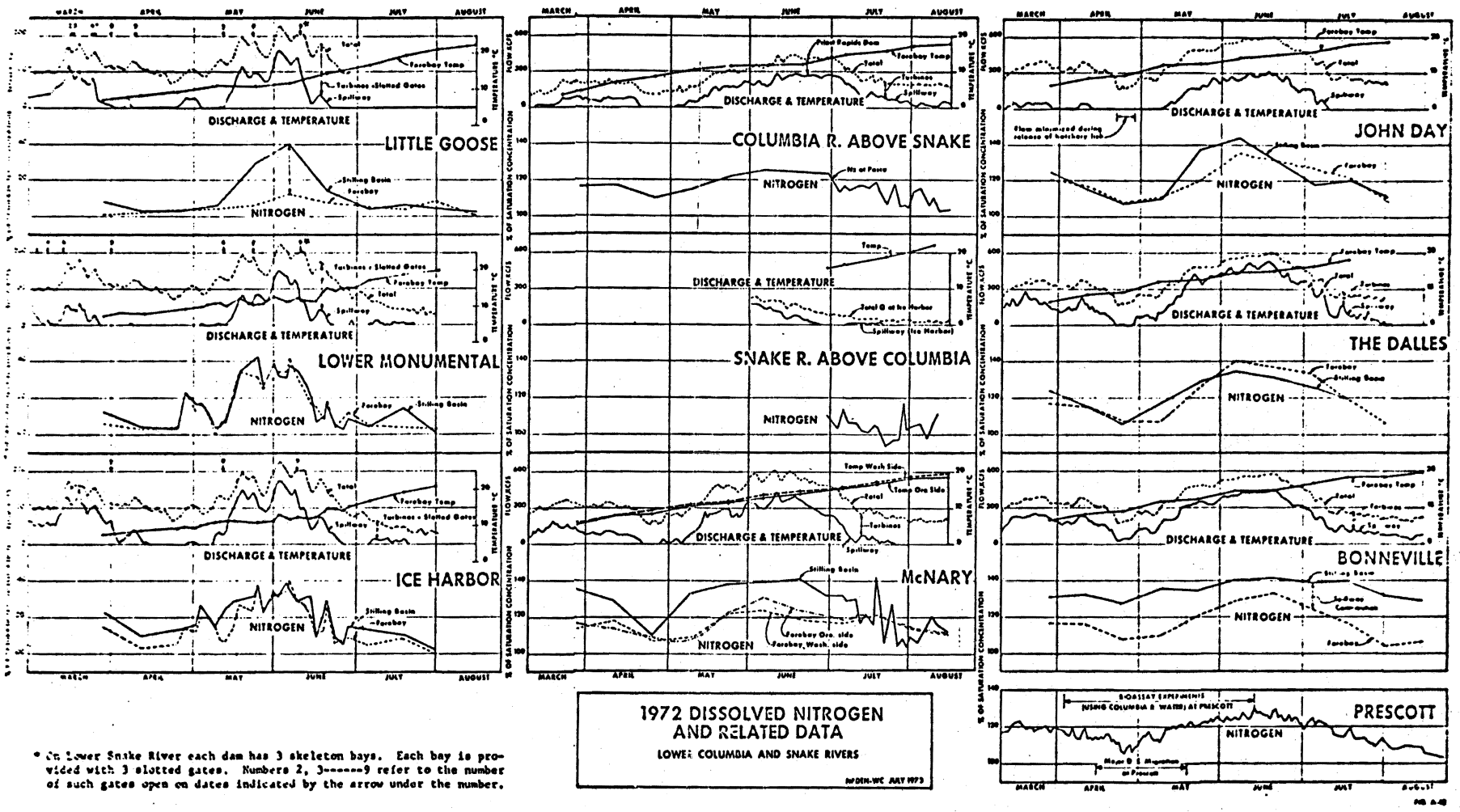


Figure C-5.--(Boyer, 1974)



* On Lower Snake River each dam has 3 skeleton bays. Each bay is provided with 3 slotted gates. Numbers 2, 3------9 refer to the number of such gates open on dates indicated by the arrow under the number.

Figure C-6.--(Boyer, 1974)

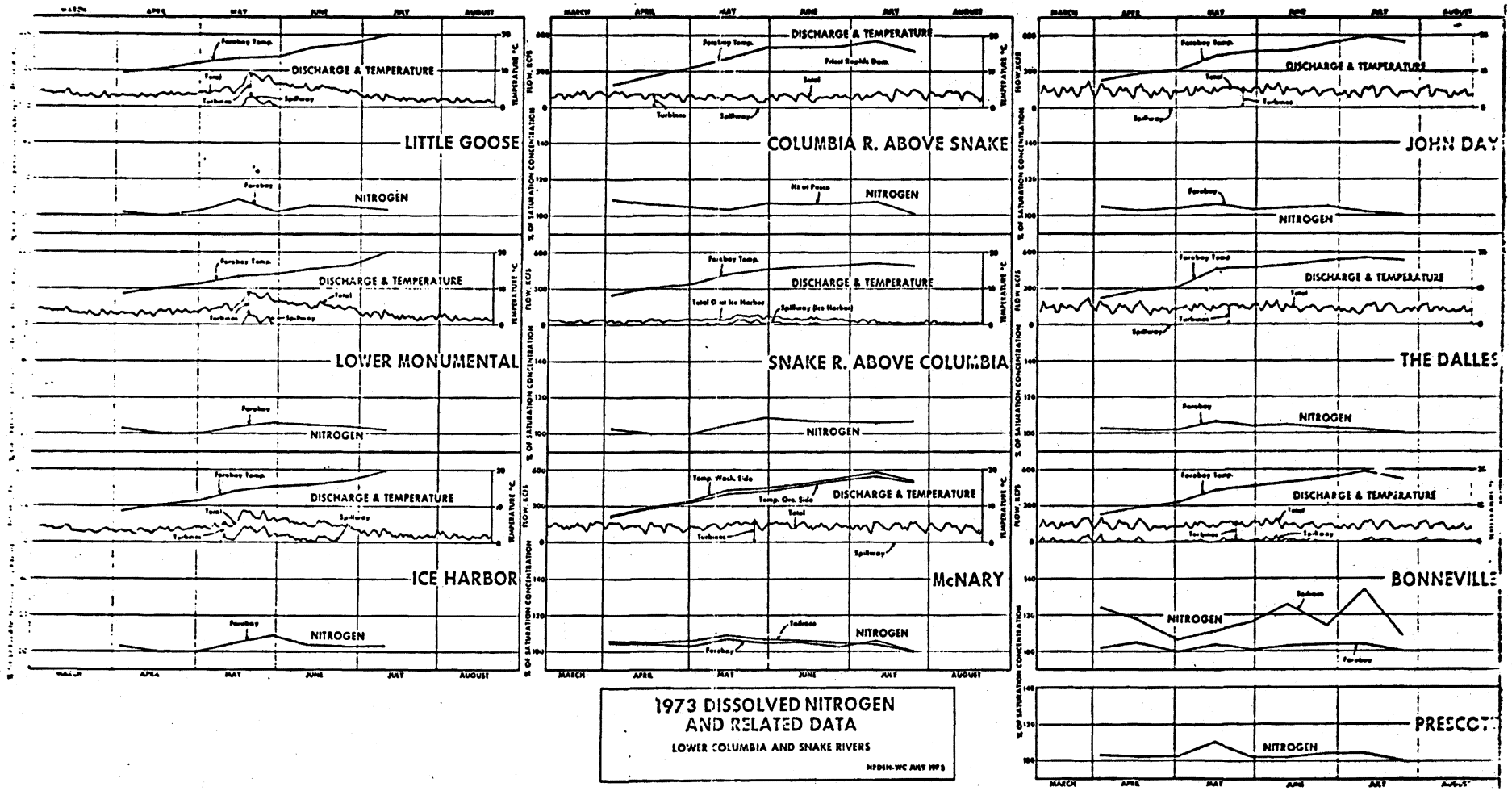


Figure C-7.--(Boyer, 1974)

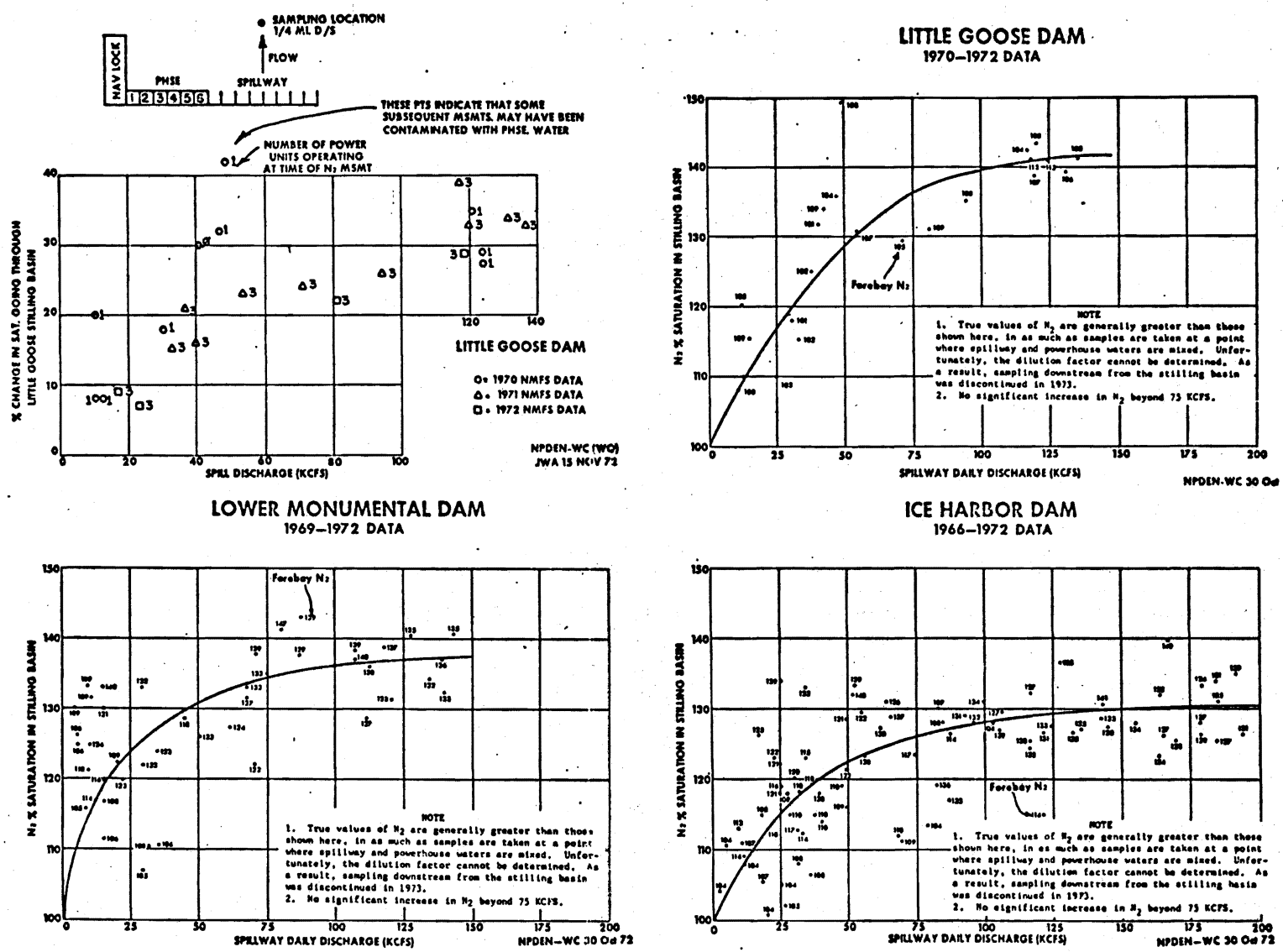


Figure C-8.--Spillway rating curves (Boyer, 1974).

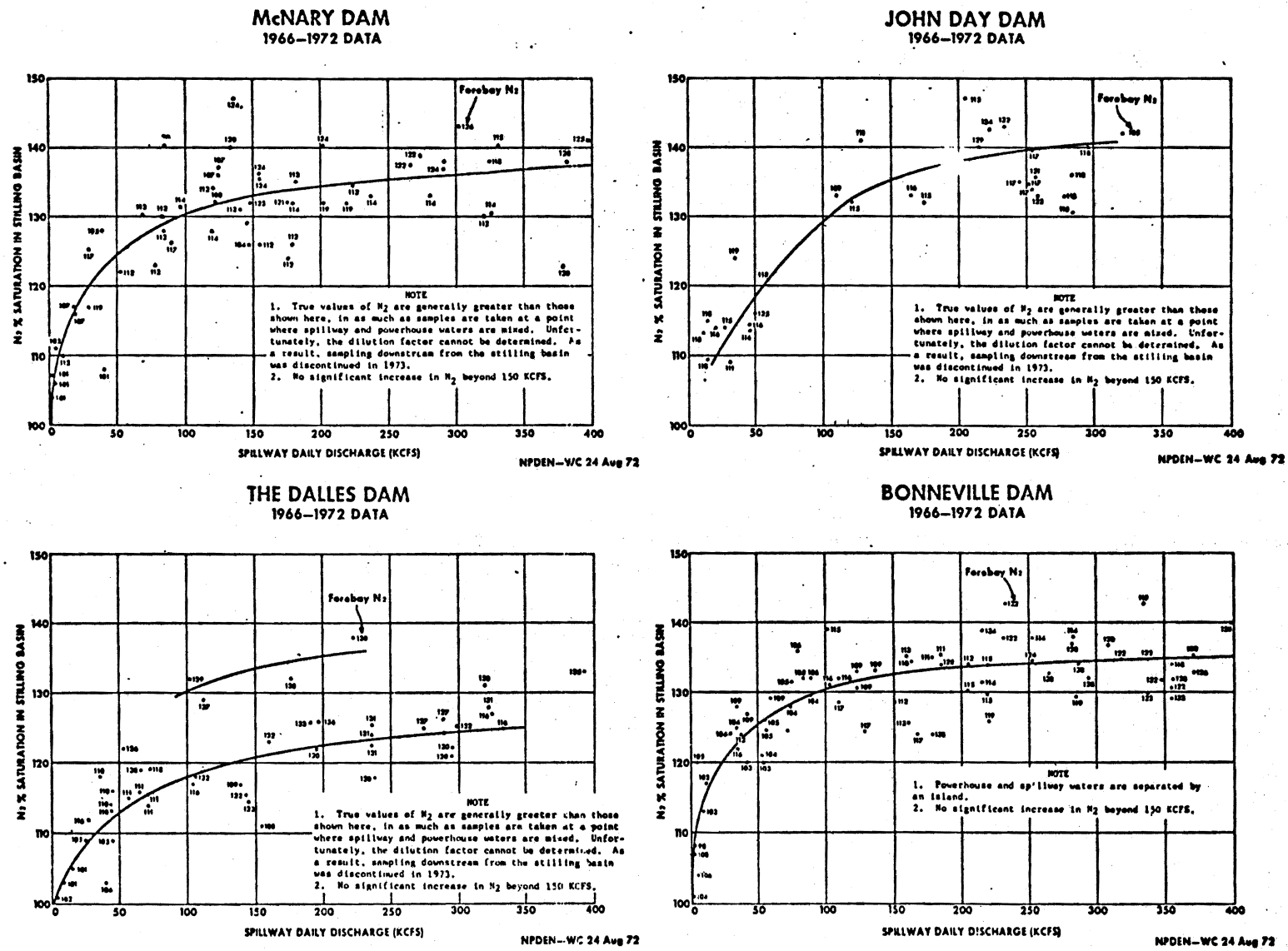


Figure C-9.--Spillway rating curves (Boyer, 1974).

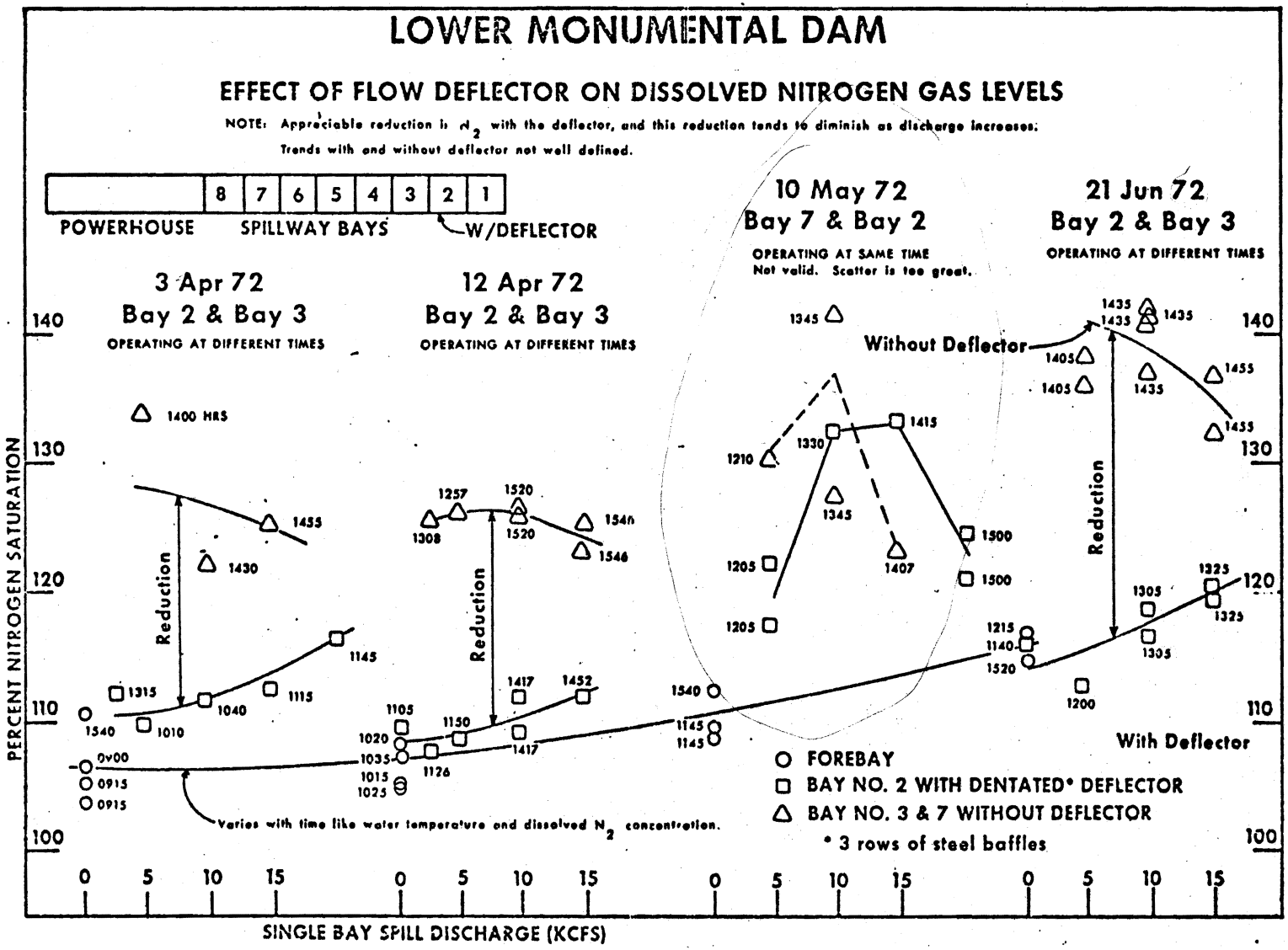


Figure C-10.--(Boyer, 1974)

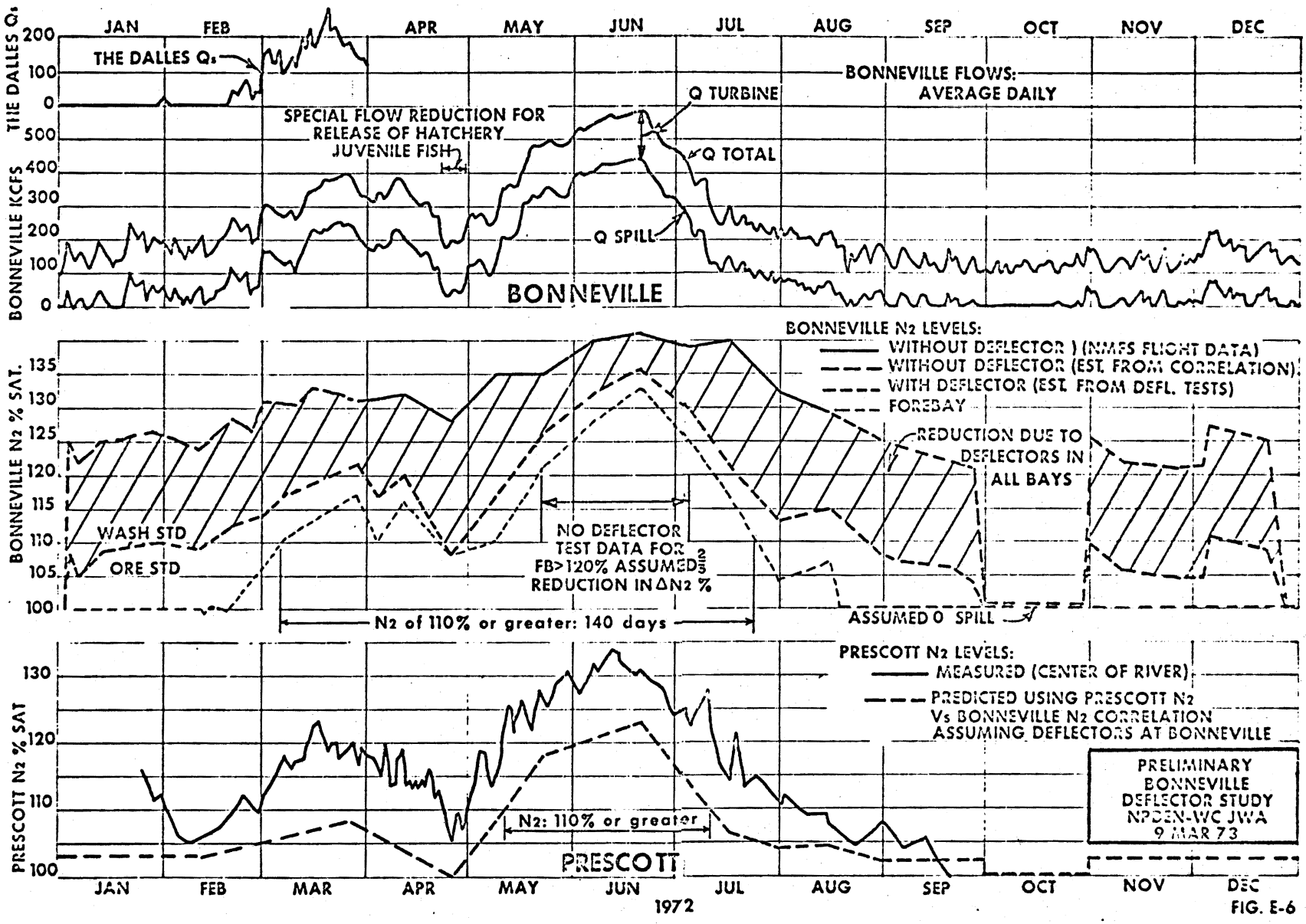


Figure C-11.--(Boyer, 1974)

APPENDIX C

TABLE C-1

SAMPLE CALCULATIONS

LOWER MONUMENTAL DAM

1975

Turbine Operating	3
Spillway Deflectors Installed	8
Average Flow (cfs)	89,100

a) Spillway - 24,100
b) Turbines - 65,000
I. N_2 Levels (%)
a) Forebay - 107.7
b) Spillway - 113.1
c) Average downstream - 109.2

Two Year Peak Flow (cfs)	160,000

a) Spillway - 95,000
b) Turbines - 65,000
I. N_2 levels (%)
a) Forebay - 127.3
b) Spillway - 118.0
c) Average Downstream - 121.8

Five Year Peak Flow (cfs)	210,000

a) Spillway - 145,000
b) Turbines - 65,000
I. N_2 Levels (%)
a) Forebay - 133.0
b) Spillway - 124.0
c) Average Downstream - 126.8

Ten Year Peak Flow (cfs)	250,000

a) Spillway - 185,000
b) Turbines - 65,000
I. N_2 Levels (%)
a) Forebay - 134.9
b) Spillway - 128.0
c) Average Downstream - 129.8

APPENDIX C

TABLE C-2

SAMPLE CALCULATIONS

ICE HARBOR DAM

1975

Turbines Operating	6
Spillway Deflectors Installed	0
Average Flow (cfs)	89,100

a) Spillway - 0
b) Turbine - 89,100
   I. N_2 Levels (%)
      a) Forebay - 109.2
      b) Spillway -
      c) Average Downstream - 109.2

Two Year Peak Flow (cfs)	160,000

a) Spillway - 50,000
b) Turbines - 110,000
   I. N_2 Levels (%)
      a) Forebay - 121.8
      b) Spillway - 123.0
      c) Average Downstream - 122.2

Five Year Peak Flow (cfs)	210,000

a) Spillway - 100,000
b) Turbines - 110,000
   I. N_2 Levels (%)
      a) Forebay - 126.8
      b) Spillway - 128.0
      c) Average Downstream - 127.4

Ten Year Peak Flow (cfs)	250,000

a) Spillway - 140,000
b) Turbines - 110,000
   I. N_2 Levels (%)
      a) Forebay - 129.8
      b) Spillway - 130.0
      c) Average Downstream - 129.4

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