NORTHWEST FISHERIES CENTER
PROCESSED REPORT
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The Snake River Salmon and Steelhead CRISIS

Its Relation to Dams and the National Energy Crisis

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

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by

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INTRODUCTION

Dams constructed on the Columbia and Snake Rivers in the past decade to provide hydroelectric energy have impounded most of the free flowing sections of these rivers and created water conditions that in both high and low flow years are deadly to migrating salmon, Oncorhynchus spp., and steelhead trout, Salmo gairdneri. With high spills, the water becomes supersaturated with atmospheric gases to levels that are lethal to fish. In low flow years, with no spill, an even more destructive situation develops in which all downstream migrants must pass through turbines where many are killed outright and others are injured or stunned and left vulnerable to intensive predation. Young migrants from the Salmon River (a tributary of the Snake River) must pass through eight large impoundments and over eight major dams to reach the sea (Figure 1). Even small losses or delays at each dam become serious because of the large number of dams.

The rapid acceleration of powerhouse construction in the Columbia Basin in response to the national energy crisis means that very soon the disastrous "no spill" condition will occur with greater frequency and an even greater percentage of young migrants will pass through turbines. The time available to develop and refine solutions to fish passage problems has been severely shortened. Fortunately, our research has already pointed the way to several important practical steps to minimize salmon and steelhead losses due to dams.

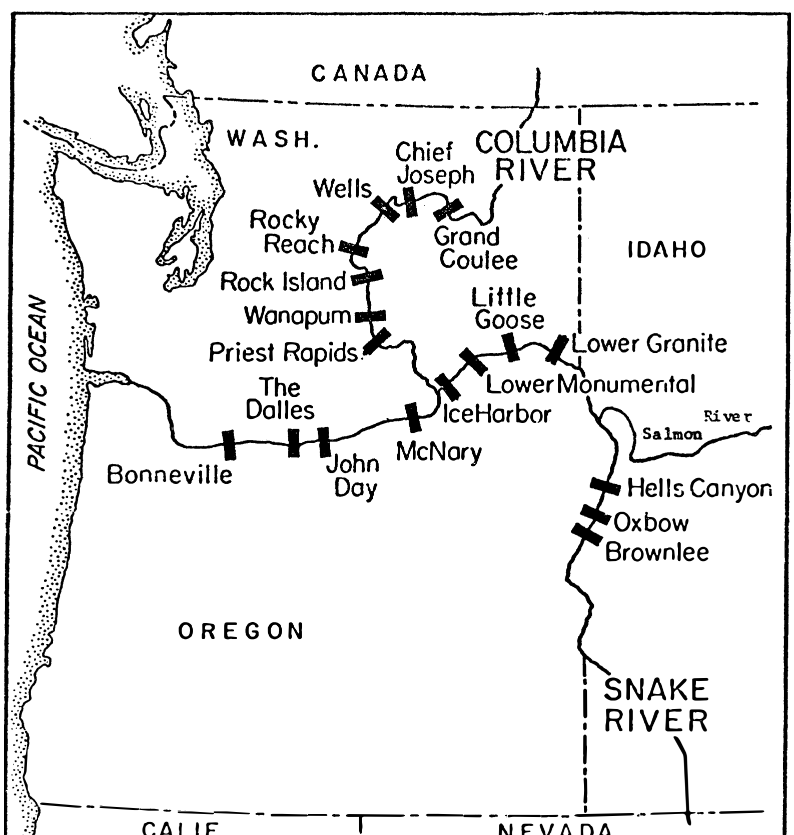


Figure 1.-Main stem dams in the Columbia River Basin

TRENDS IN THE SNAKE RIVER SALMON AND STEELHEAD TROUT POPULATIONS

A superficial examination of available data (Top panels–Figures 2 and 3) indicates there was no serious decline in chinook salmon, O. tshawytscha, 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 salmon 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 salmon and steelhead migrating up the Columbia River each year consists of survivors 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 salmon 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 1968), 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.

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.

If the declines in fish populations since 1969 were due to increased fishing pressure in the ocean, then chinook salmon 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 adult salmon and steelhead in recent years (1970 to 1973) were no higher than losses in 1968 or 1969.

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

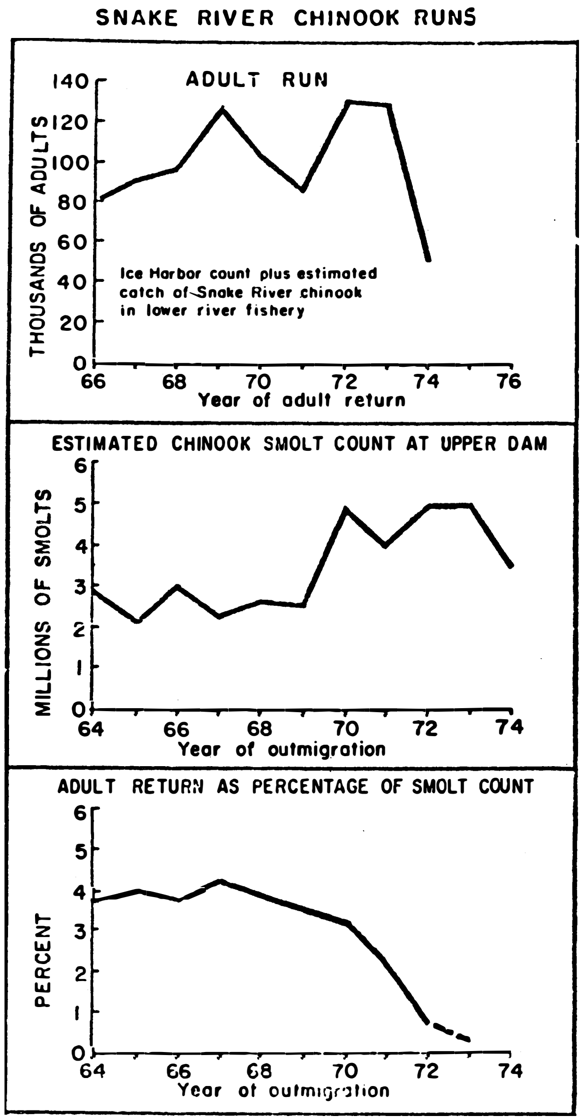


Figure 2

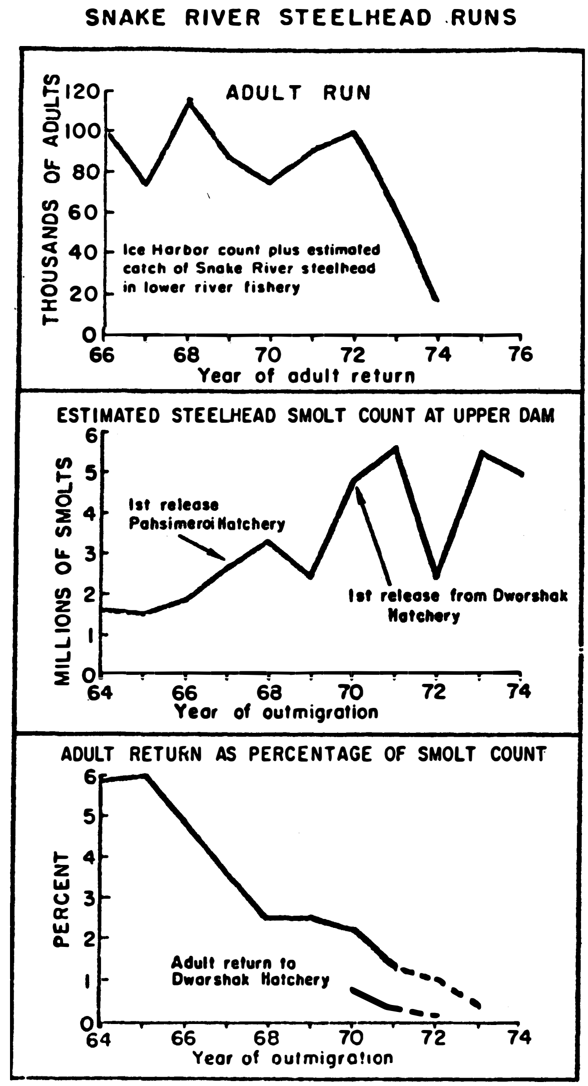


Figure 3

(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)

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 salmon 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 salmon 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.

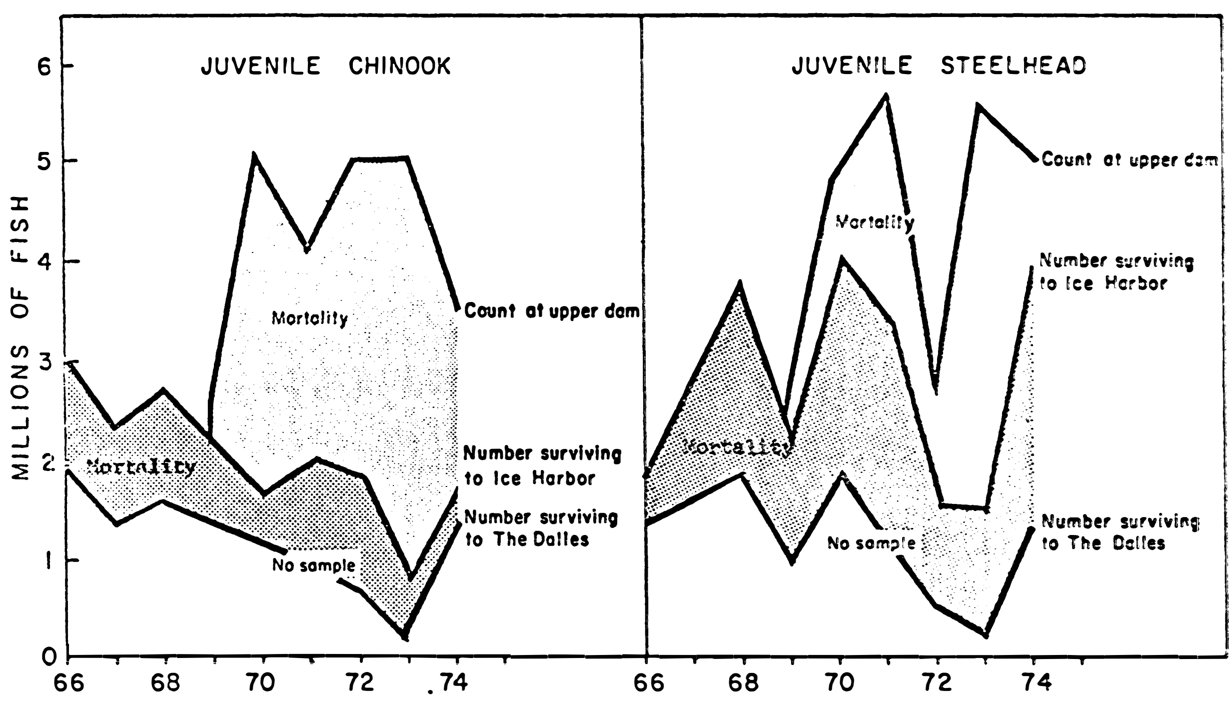


Figure 4.--Estimated number of juvenile chinook salmon and steelhead surviving to Ice Harbor and The Dalles Dams. (Source: Raymond, 1974).

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	Return (%)
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).

CAUSES OF THE DECLINE

Turbines

Numerous experiments have been conducted to measure survival of salmonids passing through turbines. Bell, et al. (1967) summarized these experiments and analyzed the effect of numerous variables such as wicket gate opening, water head, size of fish, etc., on fish survival. Tests pertinent to the Kaplan turbines of the Columbia River indicated a mean loss of 7%. However, these data frequently included only direct mortality. Indirect mortality, such as increased predation on temporarily debilitated fish slightly injured or stunned by passing through the turbines can be substantial. More recent studies by Long et al. (1968, 1975) showed that mortality of juvenile coho salmon, *O. kisutch*, passing through turbines at Ice Harbor and Lower Monumental Dams was as high as 30% when indirect mortality from predation was included. Losses from predation will vary from dam to dam and year to year depending on the fluctuating populations of predators. However, when the predation loss at dams is combined with the direct loss in turbines, it becomes apparent that the turbine-related mortality occuring to a population of downstream migrants passing over a long series of dams can be enormous. In 1973, a low flow year in which almost all of the young migrants had to pass through turbines, a 95% loss of both chinook salmon and steelhead populations was measured from the Salmon River to The Dalles Dam (Raymond, 1974).

Supersaturation

Supersaturation of nitrogen was recognized as a 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 River from Grand Coulee Dam to the estuary at Astoria, Oregon substantiated that high levels of dissolved gases occurred throughout the study area. The study also showed that water plunging over spillways is the main cause of supersaturation and that little equilibration occurs in the reservoirs associated with the dams.

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 (Ebel et al., 1975). The severity of the disease and its consequences depend on the level of supersaturation, 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 (135 to 140%) are well above critical levels. Unfortunately, even with maximum utilization of turbine capacities, the dissolved gas levels during the 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 and Smith, 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% when levels as low as 115% can cause substantial mortality.

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. During the time the fish are in the fishways, they are restricted to a maximum depth of about 7 feet. Observations at various dams (Monan and Liscom, 1973) 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 by Ebel *et al.* (1975). The main conclusions reached are:

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

2. Juvenile and adult salmonids confined to shallow water (1 m) suffer substantial mortality at 115% total dissolved gas (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 after more than 20 days exposure when saturation levels (TDG) exceed 120%.

4. On the basis of survival estimates made in the Snake and Columbia Rivers from 1966 to the present, 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.

Delays in Migration

Data from migration rate and timing studies (Raymond 1968a, 1968b, 1969) indicate that juvenile chinook salmon move about one-third as fast through impounded areas of the river as through free-flowing areas. During low-flow years, we estimate (Table 2) that juvenile chinook and steelhead migrating from the Salmon River will take 78 days to reach the estuary; arriving there about 40 days later than they did before the dams were constructed. The total effect of this drastic change in the timing of anadromous fish with a life cycle precisely tuned to specific environmental patterns is not yet completely known. One immediate effect in low flow years is a tendency for some fish to residualize and spend their entire life cycle in fresh water. Of even greater consequence are the effects of prolonged exposure to intensive predation, exposure to disease organisms, and exposure to stresses imposed by pollution. The impoundment of river flows by dams has more than doubled the time required for the hazardous migration of juvenile salmon and steelhead to the sea.

Adult migrants are delayed at dams during high flow years. This results in increased exposure to high nitrogen supersaturation which has caused direct mortality to substantial numbers (Beiningen and Ebel, 1970). Delayed indirect mortality from increased disease incidence caused by prior exposure to high nitrogen supersaturation has also been measured (Ebel *et al.*, 1975).

Table 2. 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

(Estimated from the data of Raymond, 1968b, 1969; Bentley and Raymond, 1975)

RECOMMENDED MEASURES FOR REDUCING LOSSES

Collect and Transport

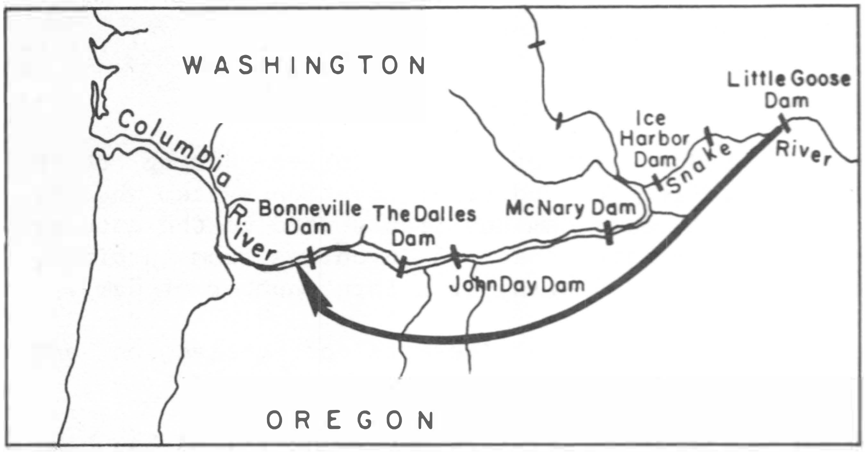
One practical way to reduce losses of juveniles during their downstream migration is by a collection and transportation system whereby fish are collected at an upstream dam and transported to the estuary around many dams. This would eliminate losses of juveniles from turbines, nitrogen supersaturation,pollution, and delay at a large number of dams.

A summary, therefore of the recent results of collection and transportation experiments follows:

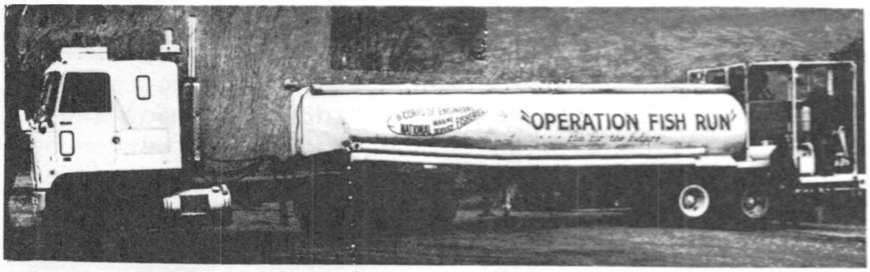
Since 1970, the National Marine Fisheries Service (NMFS) has been concentrating on an experiment where migrating juvenile salmon and steelhead trout are collected at Little Goose Dam and transported to two locations downstream from Bonneville Dam (Figure 5). The experiment is designed to determine the effect of transportation on homing and survival. The data, summarized in Figures 6 (chinook salmon) and 7 (steelhead) indicate that survival of both chinook and steelhead can be increased by collection and transportation. The percentage increase in survival varies from year to year depending on river conditions. During years when survival of natural migrants was very low survival of control releases was also low and the percentage benefit from transport was greatest. For example, in 1973 survival estimates (see Figure 4) indicated an all time low survival rate for both juvenile chinook salmon and steelhead migrants; transport/control ratios obtained from adults returning after 1 year in the ocean were the highest (22:1 for chinook--Figure 6; 23:1 for steelhead--Figure 7) recorded to date (October 20).

Analysis of the test-to-control ratios provides the best insight to the benefit possible from the transportation system, but total percentage return obtained from the groups transported must also be examined to accurately assess the effectiveness of the system as it now operates. If both test and control groups are excessively stressed during the diversion, collection, marking, and transport operation, then percentage return will be abnormally low even though test-to-control ratios are favorable. We therefore have been comparing percentage return of the transport groups with percentage returns achieved at Dworshak and Rapid River Hatcheries and with estimated percentage return of steelhead and chinook salmon to Little Goose Dam.

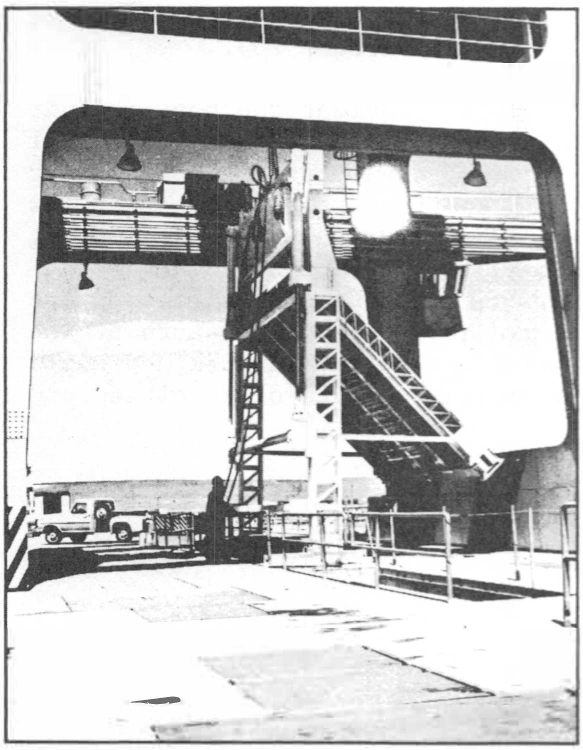
Figure 5.--Collection and transportation of juvenile chinook salmon and steelhead.



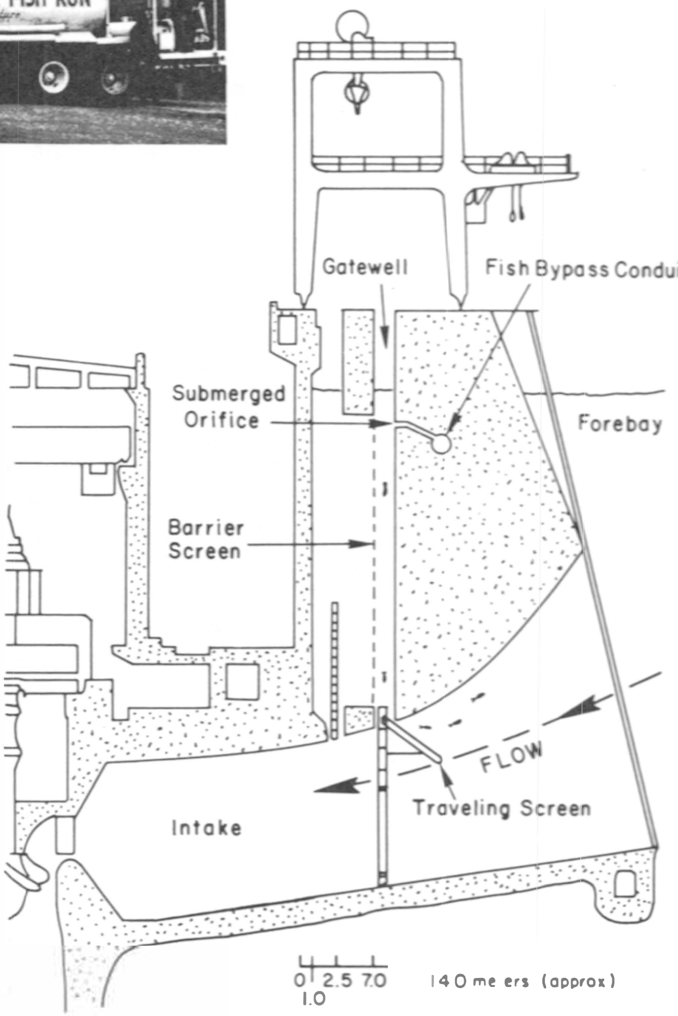
·Transportation route (heavy black arrow) from Little Goose Dam to Bonneville tailrace.



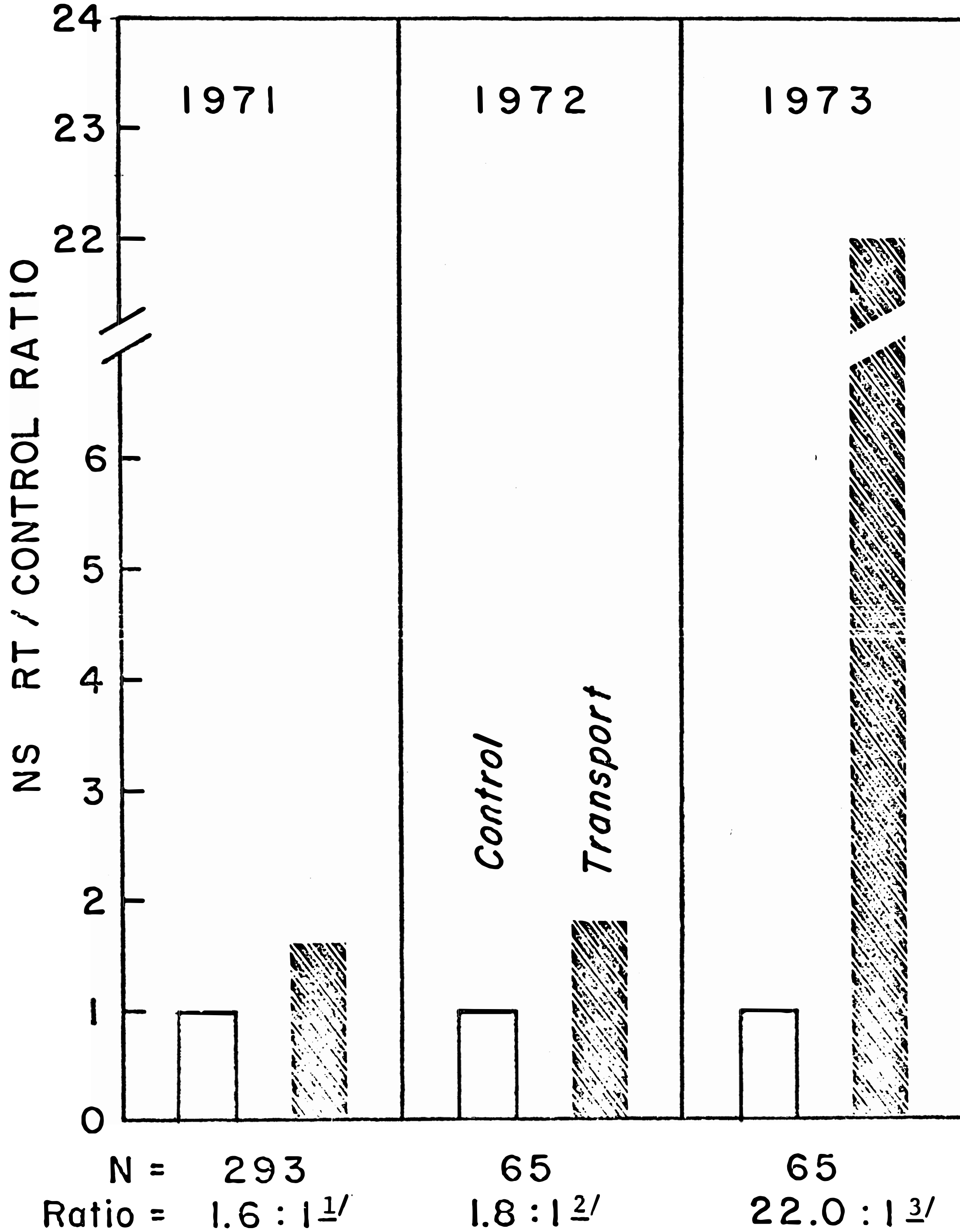
Inclined traveling screen shown in operating position on deck of dam. Hydraulically operated arm is withdrawn to permit lowering of screen through gatewell slot.



Sectional view of power ouse showing traveling screen in operating position within turbine inta e.



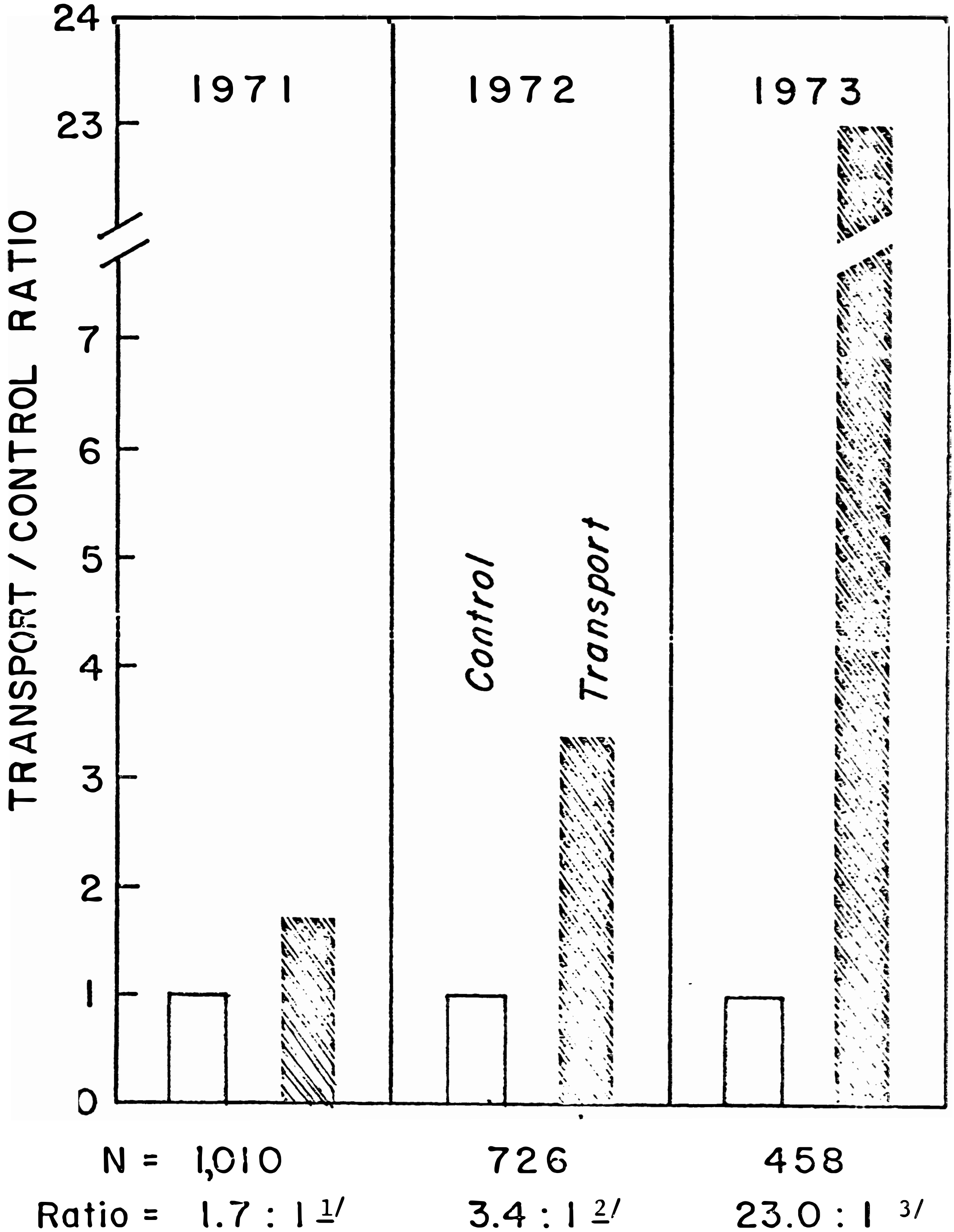
COMPARISONS OF ADULT RETURNS FROM CONTROL & TRANSPORT RELEASES OF JUVENILE CHINOOK SALMON FROM LITTLE GOOSE DAM



1/ Based on 1, 2, and 3 ocean returns,
2/ Based on 1 and 2 ocean returns.
3/ Based on 1 ocean returns only.

Figure 6 (Source: Ebel, 1974)

COMPARISONS OF ADULT RETURNS FROM CONTROL & TRANSPORT RELEASES OF JUVENILE STEELHEAD FROM LITTLE GOOSE DAM



1/ Based on 1, 2, and 3 ocean returns.
2/ Based on 1 and 2 ocean returns.
3/ Based on 1 ocean returns only.

Figure 7 (Source: Ebel, 1974)

Percentage returns of steelhead from those transports from Little Goose Dam in 1971 and 1972 were 1.7 and 2.1% (Table 3). Corresponding percentage returns from release of steelhead at Dworshak Hatchery were 0.25% in 1971 and 0.12% in 1972 (Table 3). Estimated percentage returns from a mixture of wild and hatchery populations of juvenile steelhead passing Little Goose Dam in 1971 and 1972 were 0.70 and 0.50%, respectively (Raymond, 1974).

An obvious substantial increase in survival of steelhead is indicated by either test/control type analysis or percentage return comparisons.

Percentage returns of chinook salmon from those transport from Little Goose Dam in 1971 and 1972 were 0.61 and 0.05% (Table 4). Corresponding percentage returns from release of chinook salmon at Rapid River Hatchery were 0.57% in 1971 and 0.08% in 1972 (Table 4). Estimated percentage returns from a mixture of wild and hatchery populations of juvenile chinook salmon passing Little Goose Dam in 1971 and 1972 were 1.1 and 0.8%, respectively (Raymond, 1974).

A definite benefit is shown by test/control type analysis and some benefit can be shown when percentage return data from transported groups are compared with only the Rapid River Hatchery returns for 1971, but no benefit is shown when transport returns are compared with estimated percentage returns to Little Goose Dam.

In summary, we believe sufficient data exist to recommend mass transport of steelhead from Little Goose Dam as soon as possible. However, we would reserve judgement on mass transport of chinook until the collection system at Lower Granite Dam, which we believe is an improvement over the system at Little Goose Dam, is tested.

Juvenile loss data and adult return data (Raymond, 1974) indicate that decisions regarding mass transportation of juvenile chinook salmon and steelhead in the years 1975 to 1978 may be critical in determining the ultimate survival of the Snake River populations. Careful examination of the predicted river flows and the results of ongoing transportation studies will provide the necessary data to determine the degree to which mass transport should be implemented during a given year. Adequate return data will not be available from groups transported from Lower Granite Dam until 1976 and 1977. However, as indicated earlier, sufficient data regarding effects of collection and transportation of steelhead from Little Goose Dam is available now and decisions can be made <u>now</u>.

Table 3.

Returns to Little Goose Dam of steelhead from control and transport releases of smolts, 1971-73. (Source: Ebel, 1974).

Release site and year (experimental group)	Number released	Number adults recaptured	Adult return in % of juveniles released: Obsv ret	Est ret	(Dw) 3/	Transport benefit (year)
Little Goose (control) (1971)	33,243	196	0.59	0.99	(0.25)	
Bonneville (transport) (1971)	80,906	814	1.01	1.70	(0.25)	(1971) 1.7:1
Little Goose (control) (1972)	46,071	159 1/	0.34	0.61	(0.12)	
Bonneville (transport) (1972)	50,157	571 1/	1.14	2.05	(0.12)	(1972) 3.4:1
Little Goose (control) (1973)	42,461	13 1/	0.03	2/		
Bonneville (transport) (1973)	63,452	445 1/	0.70	2/		(1973) 23:1

1/ Returns through October 15, 1974

2/ Only partial returns of 1-ocean fish are in at this time

3/ Percentage return of adults observed at Dworshak Hatchery, Idaho

Table 4.

Returns to Little Goose Dam of spring and summer chinook from control and transport releases of smolts, 1971-73. (Source: Ebel, 1974).

Release site and year (experimental group)	Number released	Number adults recaptured	Adult return in % of juveniles released: Obsv ret	Est Ret	(RR) 3/	Transport benefit (year)
Little Goose (control) (1971)	20,674	47	0.23	0.37	(0.57)	
Bonneville (transport) (1971)	65,889	246	0.37	0.61	(0.57)	(1971) 1.6:1
Little Goose (control) (1972)	57,213	15	0.03 1/		(0.08)	
Bonneville (transport) (1972)	106,405	48	0.05 1/		(0.08)	(1972) 1.73:1
Little Goose (control) (1973)	88,170	2	0.00 2/			
Bonneville (transport) (1973)	141,364	63	0.04 2/			(1973) 22.0:1

1/ Incomplete data based on 2-ocean fish only.

2/ Incomplete data based on 1-ocean (jacks) only.

3/ Percentage return of adults observed at Rapid River Hatchery, Idaho

Screen and Bypass

Collection and transportation can provide one practical solution to turbine mortality. Another solution would be to install traveling screens in every turbine intake and bypass the fish around the turbines. However, the cost would be very high and at some dams, such as John Day, where the juvenile fish bypass system functions poorly, the losses might be greater from screening and bypass than from turbines. In addition, the problems of migration delay and predation at many dams would still exist.

Additional studies are needed to determine how screening and bypass systems can be made more effective at dams like John Day. The intake traveling screen system currently in use at Little Goose Dam, for example, is adequate for collection and bypass of steelhead, but could be improved for collection and bypass of chinook salmon. We anticipate the collection and bypass system at Lower Granite Dam will be an improvement over that operating at Little Goose Dam, but this has not been evaluated at this time. Of great concern at all existing dams is the potential for predation where young fish are concentrated at a bypass exit. Bypass systems must be carefully evaluated on a dam by dam basis before the use of screens is recommended. Bonneville Dam, which will soon have a second powerhouse, should receive a high priority for consideration of a screening and bypass system. Several million juvenile salmonid migrants will have to pass through the turbines of this dam in the near future. However, even at the new Bonneville installation, the bypass system should be evaluated before the screens are installed.

Reduce Supersaturation

Spillway deflectors (concrete sills placed near the base of the spillway (Figure 8) 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 (1974), and Monan and Liscom (1974, 1975) show that supersaturation of the water with air (primarily nitrogen) is substantially reduced and no injury or adverse effect on either adults or juveniles could be measured.

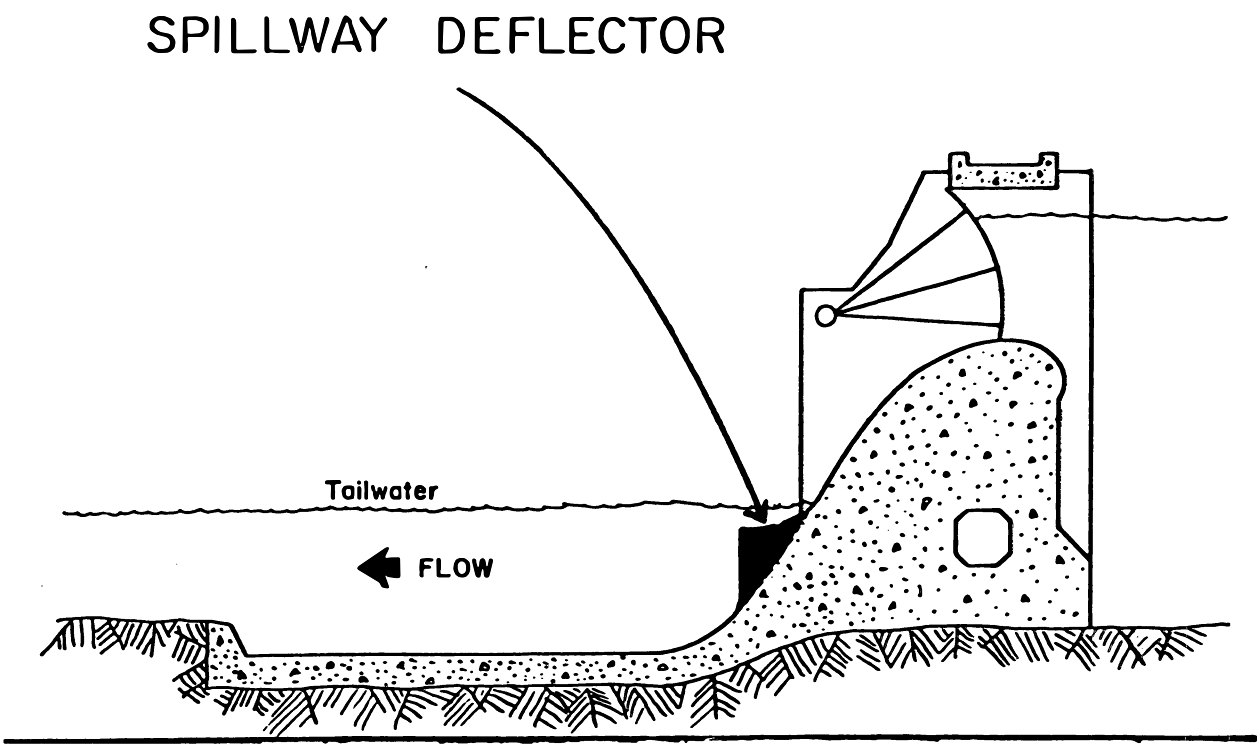


Figure 8.--Sketch of spillway deflector. A structural design used to reduce gas supersaturation.

Spillway deflectors have already been installed at Lower Monumental and Lower Granite Dams, and we have recommended that spillway deflectors be installed at Little Goose, Ice Harbor, McNary, and Bonneville Dams as soon as possible. Spillway deflector installations are also being considered for The Dalles and John Day Dams.

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.

Minimize Delay in Migration

There are two possible ways to reduce delay of migrating juveniles: flow control (utilization of upstream storage), and collection and transportation.

A committee was established recently to recommend minimum flows in the Snake and Columbia Rivers, and it was suggested that dams may be operated sequentially during the juvenile migration to provide more favorable flows to speed up downstream migration during low flow years. Power producers indicate this may be possible if energy demands can be met. However, the concept has not been tested, and the benefit that might be achieved is unknown at this time.

Collection and transportation systems provide, in our opinion, the best opportunity for overcoming the hazards of delayed migration. Transported fish would arrive at the estuary 16 days early (rather than 40 days late) having avoided a prolonged exposure to predation, pollution, and disease in many impoundments as well as avoiding the effects of turbines at many dams. Information obtained from migration rates, timing, and survival studies indicates that delays in migration of juveniles during high flow years will not be a serious problem when nitrogen supersaturation is reduced by the spillway deflectors.

Effects of delay on adults during low flow periods are not critical, but recent information indicates that optimum spill patterns and attraction flows can be sought out to improve upstream passage even during moderately low flows (Junge and Carnegie,1974). This work is currently being pursued.

Delays to adult migrants during high flow periods can be serious. However, these delays can be reduced by perfecting operation of spillways and turbines at the dams to provide the best possible attraction flows for entrance of adults to the fishways.

PREDICTED BENEFITS OF REMEDIAL ACTION

Preliminary steps have been taken on two major actions to minimize the losses caused by dams--(1) reduction of supersaturation by installation of spillway deflectors at Bonneville, McNary, Ice Harbor, and Little Goose Dams; and, (2) the initiation of a full-scale test of the collection of juvenile steelhead and chinook migrants from the two uppermost dams (Lower Granite and Little Goose) and transportation to below Bonneville Dam. In Figures 9 and 10, we have attempted to predict the benefits that can be realized from these actions. The method of calculating levels of benefit is outlined in Table 5.

Steelhead are used to illustrate the scale of benefit anticipated because we now have enough survival information on steelhead for a reasonable projection. We expect to have sufficient information on survival of juvenile chinook salmon to make similar estimates on the benefits to chinook salmon next year. The authors anticipate that the benefit to chinook salmon will be of the same order of magnitude as the benefit to steelhead.

All predictions require assumptions about future events. The major assumptions upon which our predictions are based are listed in Table 6.

Adult returns from smolt outmigrations are predicted to increase from the low return of 0.5% (1973 outmigration) to an average of 3.4% as a result of the installation of spillway deflectors and initiation of a collection and transportation system (Lower panel , Figure 9). This, we believe is a conservative estimate. The maximum benefit occurs after the two collector dams, Lower Granite and Little Goose, each has installed six screened turbines, permitting maximum collection of downstream migrants. Note that the percent of adult return per smolt-migration does not reach the level that existed in 1965 (6.0%), indicating that all of the losses caused by dams will not be eliminated by the proposed actions.

Increased hatchery production has been recommended to compensate for the remaining losses. The importance of the proposed actions in obtaining the maximum benefit from additional hatchery production is illustrated in the lower panel of Figure 10. With the remedial actions, an additional production of 2 million smolts would produce 55,200 adults; without the proposed measures, we estimate 12,000 adults would be produced.

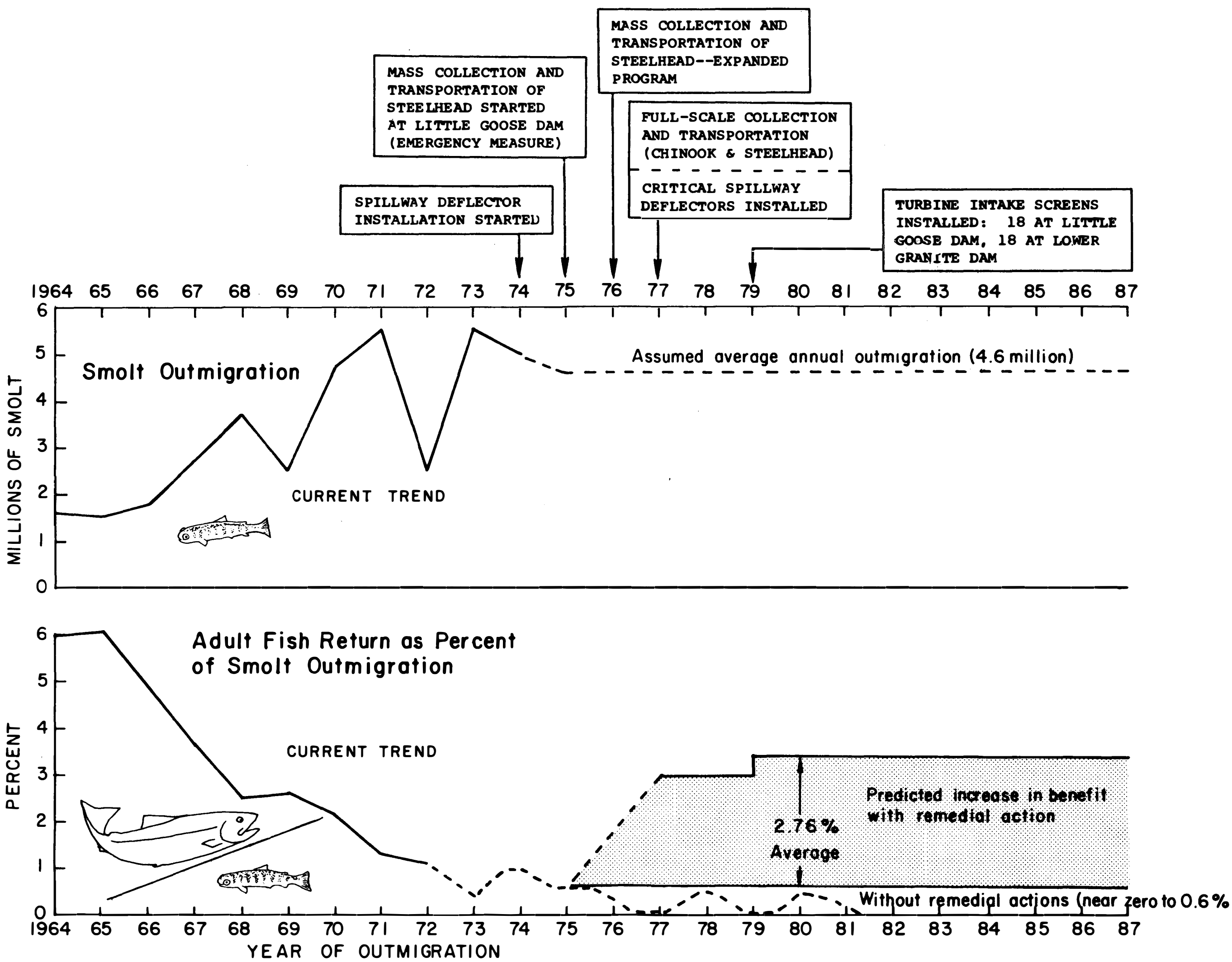


Figure 9.--Predicted benefits -- adult returns as percent of smolt outmigration (steelhead).

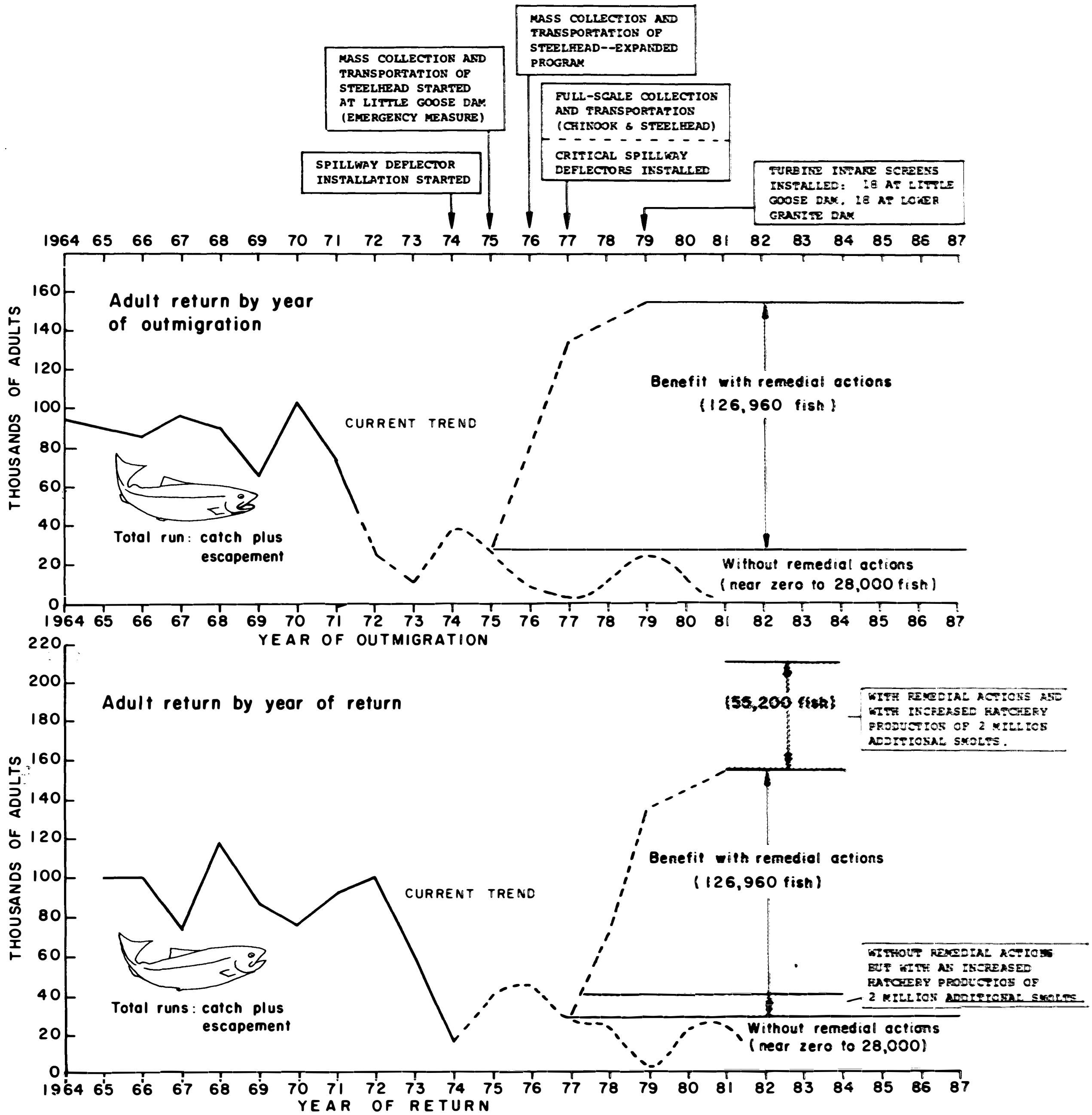


Figure 10.--Predicted benefits -- numbers of adults returning (steelhead).

Table 5.--Derivation of estimates on predicted benefits of proposed remedial actions. Example is on Snake River steelhead.

Remedial action and event	River flow at time of juvenile outmigration		
	Low	Average	High
Spillway deflectors (reduce nitrogen supersaturation)			
Net increase in percent of adult steelhead per smolt outmigration 1/	0	0	1.40%
Collect and transport			
Net benefit of action	(2.23%) 3/	1.57% 2/	0.72% 2/
Adjusted for contribution to lower river fisheries 4/	3.57%	2.51%	1.15%
Collection and transport capability (percent of outmigrations)	90%	70%	40%
Net increase in percent of adult steelhead per smolt outmigration 5/	3.21%	1.76%	0.46%
Total net increase in percent of adult steelhead per smolt outmigration attributable to remedial actions . .	3.21%	1.76%	1.86%
Event A (1977-1978)			
Average annual net increase in percent of adult steelhead per smolt outmigration during 1977-1978 6/	(3.21%)+(1.76%)+(1.86%)/3= 2.28%		
Event B (1979 and thereafter)			
Total net increase in percent of adult steelhead per smolt outmigration adjusted to reflect conditions from 1979 7/ . . .	3.21%	3.21%	1.86%
Average annual net increase in percent of adult steelhead per smolt outmigration from 1979 on 8/	(3.21%)+(3.21%)+(1.86%)/3= 2.76%		

Table 5.--(Cont'd)

Adult steelhead calculations (Figure 10)

Without remedial actions (total run)....	(.006)(4,600,000) =	27,600 adults
Without remedial actions and with additional hatchery output of 2 million smolts (total run).........	(.006)(6,600,000) =	39,600 adults
With remedial actions (net increase in run)............................	(.0276)(4,600,000) =	126,960 adults
With remedial actions and with additional hatchery output of 2 million smolts (net increase in run)............................	(.0276)(6,600,000) =	182,160 adults

1/ Source: Ebel et al (1975). The 1.40% net benefit estimate was derived from Table 19 of the source document.

2/ Net benefit estimates for high and average flow conditions were derived from Tables 10 and 11 respectively of Ebel et al (1974). [e.g., 1971 average transport return percentage of 1.714 minus the control return percentage of 0.999 = 0.72; the 1972 experiment is 2.229 minus 0.658 = 1.57%].

3/ A preliminary and conservative estimate based on the judgement of the investigators. Estimated as equalling the average transport return percentage of 2.23% of the 1972 (average flow year) experiment (Table 11, Ebel et al, 1974). Since returns to date from the 1973 (low flow year) experiment show survival of the control group at an extremely low 0.03%, we have assumed that the final percent net increase in benefit at low flow conditions will be about 2.23% or greater.

4/ Adjusted to account for the catch of adult steelhead by lower river commercial and sport fisheries that were not included in the adult return counts of the transport experiments. The median of 37.5% from the range 25% to 50% (Footnote 1, Raymond, 1974) was selected as the adjustment factor (e.g., 2.23/(1.00-.375) = 3.57).

5/ Adjusted to reflect the different capabilities in collecting and transporting juvenile outmigrants as related to river flow conditions. [e.g., (3.57)(.90) = 3.21].

6/ Since the occurrence of a particular flow condition (e.g., low flow) could not be predicted for the calendar years 1977 and 1978, the unweighted average (2.28%) of the three flow conditions was used to represent net benefits for those years.

7/ We estimate that mortality of juvenile steelhead to turbines during average flow conditions will be the same as mortality during low flow conditions when all turbines are operating in 1979 (see Figure 11 and Table 7). Therefore, the benefit from collection and transportation of fish during average flow conditions will equal the 3.21% under low flow conditions.

8/ Since the occurrence of a particular flow condition (e.g., low flow) could not be predicted by calendar year, the unweighted average (2.76%) of the three flow conditions was used to pepresent net benefits for year 1979 and thereafter.

Table 6.--Assumptions on which "Predicted Benefits" are based.

1. Production of steelhead and chinook smolts will remain equal to the level of 4.6 million steelhead smolts annually (Figure 9) and 4.5 million chinook smolts annually.

2. Construction of structures affecting supersaturation such as spillway deflectors and additional turbines will proceed as presently scheduled by the U.S. Army Corps of Engineers.

3. Turbine intake traveling screens for the collection of downstream migrants will be installed with the new turbines at Little Goose Dam and Lower Granite Dam.

4. Collection and handling procedures for chinook fingerlings are successfully developed and evaluated by the end of 1976 migration season. At this stage of our research this appears to be a safe assumption.

5. Full-scale test of collection and transportation of both chinook and steelhead fingerlings will be approved by the U.S. Army Corps of Engineers and state and federal fishery agencies for the 1977 migration.

6. Attritional losses due to water diversion and pollution will be kept at the present level. This requires screening of water intakes; and control of thermal pollution, industrial pollution, and agricultural pollution by enforcement of water quality standards.

HAZARDS OF INACTION

The predicted benefits from taking two specific remedial actions indicate that Snake River chinook salmon and steelhead runs could be restored to levels higher than the levels of 1965 (Figure 10). The hazards to taking no remedial action should also be considered. Of major concern is the impact of the national energy crisis on the existing low level runs. Power development once visualized as needed by the year 2000 is urgently demanded today. Many additional turbines are being installed to provide the "peaking" capacity needed to meet short periods of maximum power demand. This is a necessary complement to the base power to be provided by expanded thermal power production. However, with the additional turbines come additional hazards to migrant fish.

The gravity of the situation in the Snake River for chinook salmon and steelhead can be appreciated by noting the rapid decline in the runs in recent years and realizing that this happened largely because of the addition of Lower Monumental and Little Goose Dams which have a total of only 6 turbines. There are now 4 dams affecting fish passage in the Snake River (Lower Granite was put into operation this year); and, by the end of 1978, 15 more turbines will have been installed, making a total of 24 turbines in the lower Snake River (Table 7).

It is obvious that turbine-related mortalities will occur with greater frequency as a greater percentage of the juveniles are exposed to turbines. The diagrams in Figure 11 illustrate the situation for Snake River salmon and steelhead in 1974 in contrast to their situation in 1979. Critical losses that in the past occurred only during low-flow years will also be expected during average-flow years after 1979. The survival shown in Figure 11 is actually conservative. For example, in 1973,--a low flow year, steelhead survival from above Little Goose Dam to The Dalles Dam was measured at 5% (Raymond, 1974). With the Snake River steelhead population fluctuating at a very low level, near zero to 28,000 (Figure 10), two successive bad years could destroy the run. A similar situation exists for chinook.

In the opinion of the authors, the salmon and steelhead runs of the Snake River will be unable to survive long after 1979 unless corrective action already initiated is carried out without delay.

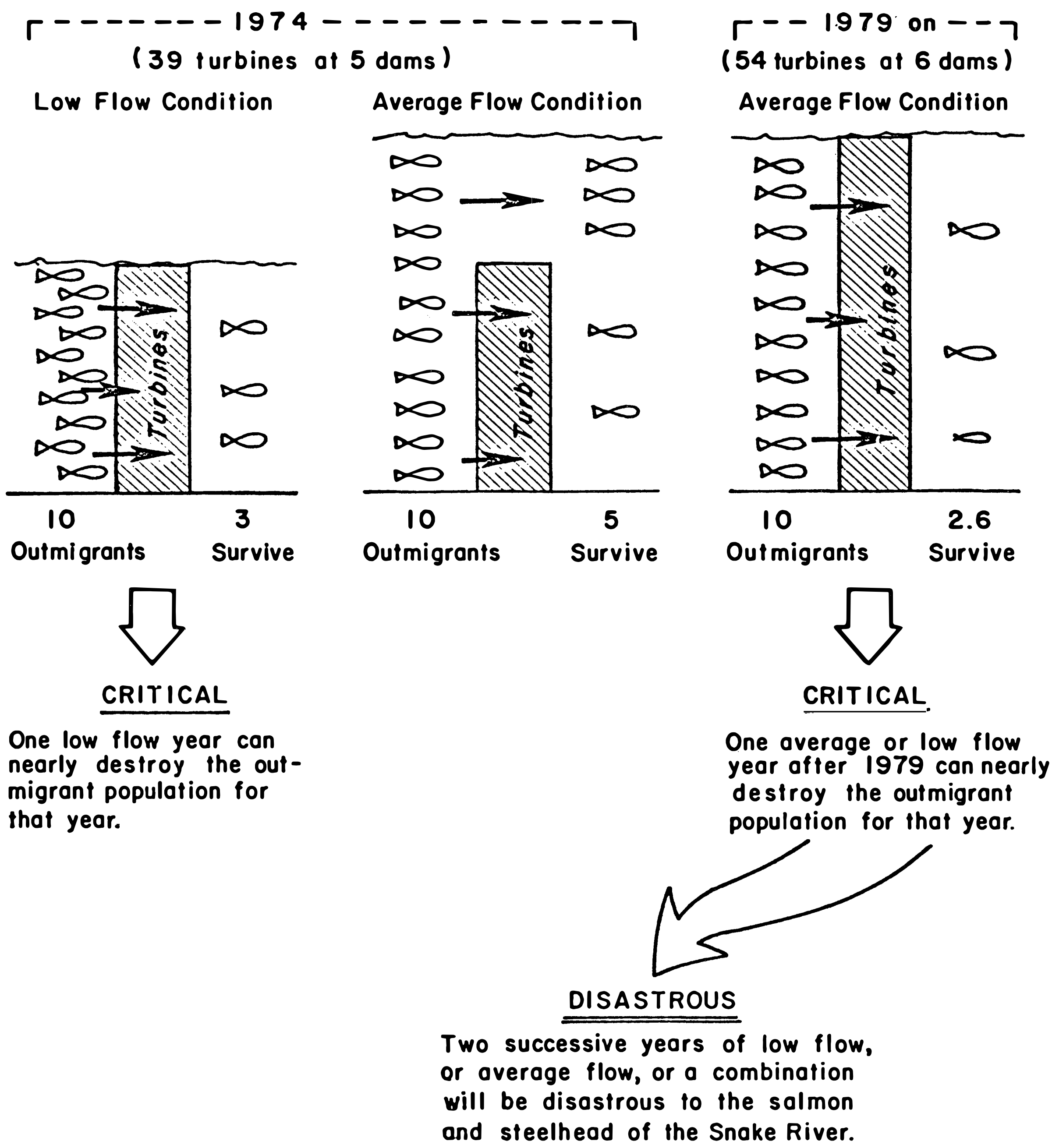


Figure 11.--Reduced juvenile fish survival to be caused by additional turbines if no action is taken -- Lower Granite Dam through John Day Dam.

Table 7.--Survival of juvenile salmon and steelhead through turbines at dams from Lower Granite down through John Day Dams.[1/]

Dam and construction date	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
	Year																										
	(Cumulative number of turbines)																										
McNary (1953)	0	3	8	12	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Ice Harbor (1962)	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6
John Day (1968)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	11	14	16	16	16	16	16	16	16	16
Lower Monumental (1969)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	6
Little Goose (1970)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	6	6
Lower Granite (1975)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	6	6
Total =	0	3	8	12	14	14	14	14	14	14	17	17	17	17	17	17	23	31	37	39	39	39	45	45	45	51	54
	Low Flow Condition (percent survival)[2/]																										
McNary	100	96	89	83	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
Ice Harbor											80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
John Day																	80	80	80	80	80	80	80	80	80	80	80
Lower Monumental																		80	80	80	80	80	80	80	80	80	80
Little Goose																			80	80	80	80	80	80	80	80	80
Lower Granite																							80	80	80	80	80
Final survival(%)	100	95	90	85	80	80	80	80	80	80	64	64	64	64	64	64	51	41	33	33	33	33	26	26	26	26	26
	Average Flow Condition (percent survival)[3/]																										
McNary	100	98	95	92	85	85	85	85	85	85	85	85	85	85	85	85	80	80	80	80	80	80	80	80	80	80	80
Ice Harbor											90	90	90	90	90	90	90	90	90	90	90	90	80	80	80	80	80
John Day																	92	86	82	80	80	80	80	80	80	80	80
Lower Monumental																		90	90	90	90	90	90	90	90	90	90
Little Goose																			90	90	90	90	90	90	90	80	80
Lower Granite																							90	90	90	80	80
Final survival(%)	100	98	95	92	85	85	85	85	85	85	77	77	77	77	77	77	66	56	48	47	47	47	42	42	42	29	26

1/ Analysis is based on the unit survival rate of 80% which is the high estimate in the range 70-80% reported in Long et al., 1968).

2/ Assumption: During low flow conditions all of the water (and, therefore, juvenile fish) pass through the turbines at each dam. Survival, therefore, is 80% at each dam with the exception of the prorated survival estimates shown for McNary Dam during 1954-1956.

3/ Assumptions: Survival of fish through turbines during average flow conditions depends on volume of water passing through existing turbines and over the spillway. Examples of our calculations: (1) if all turbines are in and operating at a dam, then all of the water (and fish) will pass through the turbines as in low flow situations and survival, therefore, is 80%, and (2) if half of the number of turbines are in at a dam, then half of the water (and fish) will pass through the turbines resulting in a 90% survival. (Exception is the 85% (rather than 80%) survival through turbines at McNary Dam during 1957 to 1968 even though all turbines were in and operating during that period. Based on the judgement of the investigators).

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