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Migrations of Juvenile Chinook Salmon and Steelhead Trout in the Snake River from 1973 to 1979

A Research Summary

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INTRODUCTION

Even with the operation of fingerling collection and transportation systems at upstream collector dams on the Snake and Columbia Rivers, large numbers of fingerlings continue to migrate downstream on their own volition. Consequently, the U.S. Army Corps of Engineers (CofE) has pledged support in providing optimum fish passage conditions and fingerling bypass systems consistent with the multipurpose nature of the management plans for the river system. Both fishery and water management agencies agreed that research aimed at defining the effects of river flow and dam operations on migrating juvenile salmonids has high priority.

To provide such information, the National Marine Fisheries Service, under contract to the CofE, conducted a 5-year study (1973 to 1979) of the effects of river flow regulation and dam operations on juvenile salmonid migrations in the Snake and Columbia Rivers.

This report summarizes this research. Some data collected in 1973 and 1979 under other CofE contracts have been included in this summary to enhance analysis precision. Research objectives were to: (1) monitor and index the magnitude, timing, and survival of juvenile salmonids in the Snake and Columbia Rivers under various flow and operating conditions and (2) define the relation of flow and operating procedures at the dams on travel time, survival, and migrational and passage behavior of juvenile salmonids.

METHODS

Detailed descriptions of the methods used in many specific areas of this research can be found in Raymond et al. (1974); Raymond et al. (1975); Sims et al. (1976, 1977, 1978); Raymond (1979); and Raymond and Sims (1979).

Juvenile salmon and steelhead migrations were monitored on the Salmon, Snake, and Columbia Rivers from 1973 through 1978 and on the Snake and Columbia Rivers in 1979 (Figure 1). Self-cleaning scoop traps were used to sample juvenile outmigrations from the Salmon River at Riggins and Whitebird, Idaho. On the Snake River, juvenile salmonid migrations were monitored at Ice Harbor Dam by dipnetting turbine intake gatewells in the manner described by Bentley and Raymond (1968) and at Lower Granite and/or Little Goose Dams by sampling catches at the fingerling collection facilities. On the Columbia River, turbine intake gatewells were dipnetted at McNary, The Dalles, and/or John Day Dams.

Subsamples of smolts from the various sampling operations were marked by cold branding and released at various locations. Recoveries from these releases of marked fish were used to define magnitude, timing, travel time, and survival of the various outmigrations. Marked hatchery fish were released above and below John Day Dam in 1978 to measure the effects of spill and sequential turbine load dropping on smolt survival.

Timing and Travel Time

Migrational timing is based on the date the 50th percentile of a group of marked or unmarked fish passed a specified sampling site. During low flow years when little or no spill occurred at dams, calculations were

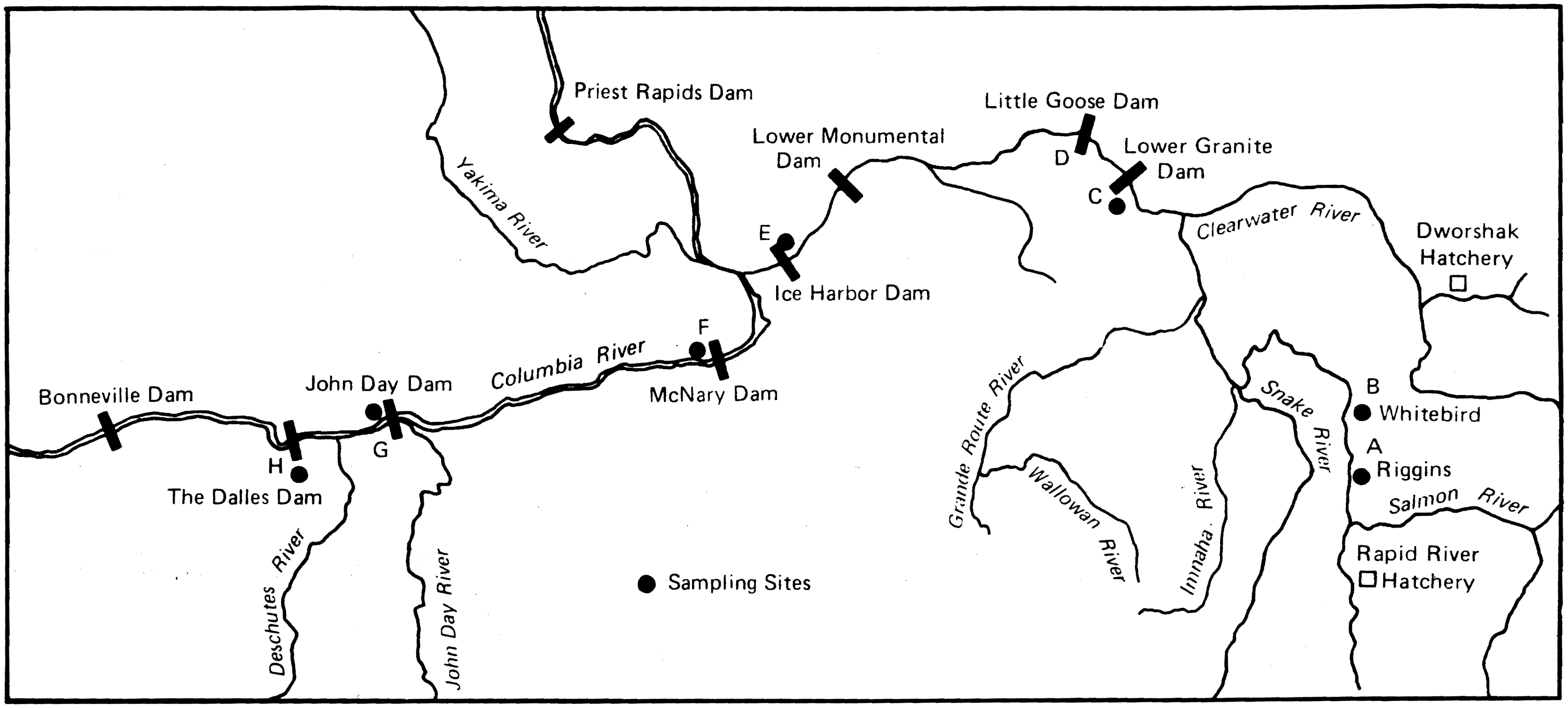

Figure 1.--Juvenile salmonid sampling sites in the Snake and Columbia River systems.

simplified (1973 and 1977). Nearly all migrants passed through the powerhouse at the various dams, and collection or sampling efficiency was relatively constant over the entire downstream migration. Migrational timing was calculated by determining the date that the cumulative total of yearling chinook salmon or steelhead at a given sampling site reached 50%.

Higher flows in the Snake River in 1974-76 and in 1978 resulted in spilling at the dams during the smolt outmigration. Since sampling efficiencies vary with the amount of spill, timing at the Snake River dams in these years was determined by adjusting sample catches according to prevailing efficiencies during the period of capture to calculate when the 50th percentile passed a specific dam.

Timing of Snake River migrations at the Columbia River dams cannot be determined by the above method because downstream migrants from the mid-Columbia River are entering the turbine intake gatewells at the same time. Timing of Snake River stocks at McNary, John Day, and The Dalles Dams was determined from the median recovery dates of marked fish released upriver during periods of peak migration at the Snake River dams.

Recoveries of marked fish at the various sampling sites were used to determine the average passage time through specific sections of the river; median recovery date is subtracted from the median date of release. The use of median release and recapture dates avoids some of the distortion inherent in all measurements of central tendency.

Survival Estimates

Estimates of survival were calculated for Snake River yearling chinook salmon and steelhead through three areas: (1) from the upper Snake River

Dam (Little Goose 1973-74 or Lower Granite 1975-78) to Ice Harbor Dam, (2) from Ice Harbor Dam to The Dalles Dam, and (3) from the upper Snake River Dam to The Dalles Dam. The estimates were calculated from differences in observed and expected recovery rates of upstream releases of marked fish. Expected recovery rate at a given dam (sampling efficiency) was determined from forebay releases of marked fish at that dam. For example, if the recovery rate of Ice Harbor Dam tailrace releases at The Dalles Dam was half that of The Dalles Dam forebay releases, survival from Ice Harbor Dam to the Dalles Dam would be calculated at 50%. Additional details on methods to determine survival and sampling efficiency are contained in Raymond (1979).

Population Estimates

Population estimates of salmonid smolts passing the upper Snake River dam in 1973-75 were calculated by applying survival rates between the upper dam and Ice harbor Dam to the population estimates at Ice Harbor Dam. Population estimates at Ice Harbor Dam in 1973 through 1975 were calculated from the gatewell catches and the flow-sampling efficiency curves derived by Raymond (1979). From 1976 to 1979, population estimates at Lower Granite Dam were derived from efficiency releases of marked fish into the forebay above the dam and samples from the fingerling collection system.

Population estimates of Snake River salmonid smolts at the lower sampling sites, (The Dalles Dam 1973-1975, John Day Dam 1976-79) were calculated by applying appropriate survival estimates based on upriver releases of marked fish to population estimates at Ice Harbor Dam (1973-78) or Lower Granite Dam (1979).

Diel Movement Patterns

Diel movement patterns of salmonid smolts entering the turbine intake gatewells at John Day and The Dalles Dams were defined by dipnetting specific turbine intake gatewells (Unit 3 at John Day Dam and Unit 1 at The Dalles Dam) at 2-hour intervals over 28- to 30-hour periods.

SMOLT MIGRATIONS 1973-1979

Magnitude of Smolt Migrations

The size of the spring and summer chinook salmon outmigration in the Snake River during the 1973-1979 period averaged 3.9 million fish and ranged from 2.0 million fish at Lower Granite Dam during the extreme drought in 1977 to 5.1 million fish at the same dam in 1976 (Table 1). During the preceding 7-year period (1966-1972), the chinook salmon migration in the Snake River averaged 3.2 million fish and ranged from 2.2 million in 1967 to 5.4 million in 1970 (Raymond 1979). The significant increase in hatchery production beginning in 1970 appears to be sustaining the size of the smolt outmigrations at a somewhat constant level, but the proportion of wild fish has continued to decline (Raymond 1979). In contrast to the fairly consistent numbers of Snake River chinook salmon arriving each year at the upper Snake River dam, the number arriving at The Dalles Dam has fluctuated considerably each year as a result of differences in migratory survival and the effect of mass collection and transportation operations. Since 1976, over 75% of the total number of Snake River chinook salmon smolts downstream from The Dalles Dam resulted from the collection and transportation operations at Little Goose and Lower Granite Dams.

Steelhead smolt migrations in the Snake River averaged 3.3 million fish from 1973 to 1979 and ranged from 1.4 million in 1977 to 5.5 million in 1973 (Table 2). As a result of increased hatchery production, steelhead

Table 1.--Estimated number of yearling chinook salmon smolts arriving at the upper Snake River dam and The Dalles Dam, 1973-79.

	Number of smolts (millions)			
Year	Upper Snake River dam[a/]	The Dalles Dam	Transported	Total below The Dalles Dam
1973	5.0	0.3	-	0.3
1974	3.5	1.4	-	1.4
1975	4.0	0.9	0.4	1.3
1976	5.1	1.3	0.8	2.1
1977	2.0	0.01	1.4	1.4
1978	3.2	0.6	1.6	2.0
1979	4.2	0.5	2.1	2.6

a/ Little Goose Dam 1973-74, Lower Granite Dam 1975-79.

Table 2.--Estimated number of steelhead smolts arriving at the upper Snake River dam and The Dalles Dam, 1973-79.

	Number of smolts (millions)			
Year	Upper Snake River dam[a]	The Dalles Dam	Transported	Total below The Dalles Dam
1973	5.5	0.2	0	0.2
1974	5.0	1.4	0	1.4
1975	3.2	1.1	0.6	1.7
1976	3.0	0.8	0.4	1.2
1977	1.4	0.01	0.9	0.9
1978	2.1	0.2	1.4	1.6
1979	2.6	0.15	1.7	1.8

[a] Little Goose Dam 1973-74, Lower Granite Dam 1975-79.

migrations in the Snake River are holding at about the same level as the 1966-72 period (also 3.3 million). The number of steelhead reaching The Dalles Dam each year, (or below) as with chinook salmon, fluctuated depending on inriver survival and numbers of fish transported. Since 1976, transportation has accounted for more than 87% of this number.

Timing and Travel Time

The dates of peak chinook salmon migration at the upper Snake River dam ranged from 21 April in 1976 to 17 May in 1975 (Table 3). Peak migration of Snake River chinook salmon smolts at The Dalles Dam ranged from 8 May in 1976 (a high flow year) to 16 June during the drought of 1977. Steelhead peaks at the upper Snake River dam were generally a few days to a week later, ranging from 29 April in 1978 to 20 May in 1973. Peaks of steelhead migrations at The Dalles Dam ranged from 11 May in 1978 to 21 June during the drought year 1977.

Travel times from the upper Snake River dam to The Dalles Dam ranged from 12 to 39 days for chinook salmon smolts and from 10 to 40 days for steelhead smolts. The travel times were related to river flow; i.e., faster migrations occurred in higher flow years. Travel time in the drought of 1977 was twice that of travel in the other years.

Previous studies of Snake River salmonid smolt migrations have related travel time and rates of movement to river velocities and flow (Bentley and Raymond 1968; Raymond and Sims 1979; and Raymond 1979). During the period of this study, the relationship between flow and travel time was defined by plotting the average travel time per project during each year against the average flows that occurred at Ice Harbor Dam during the peak of migration $\pm$ 7 days; results corroborate the previous studies (Figure 2). Although

Table 3.--Timing and travel time of Snake River yearling chinook salmon and steelhead migrations, 1973-1979.

Species and year	Timing			Travel time: Upper dam to Ice Harbor Dam		Travel time: Upper dam to The Dalles Dam	
	Upper dam[a]	Ice Harbor Dam	The Dalles Dam	Days	Days per project	Days	Days per project
Chinook							
1973	14 May	21 May	5 June	7	3.5	22	4.4
1974	1 May	6 May	13 May	5	2.5	12	2.4
1975	17 May	21 May	29 May	4	1.3	12	2.0
1976	21 Apr	28 Apr	8 May	7	2.3	17	2.8
1977	9 May	26 May	17 June	17	5.7	39	6.5
1978	29 Apr	5 May	12 May	6	2.0	13	2.2
1979	4 May	11 May	19 May	7	2.8	15	2.5
Steelhead							
1973	20 May	29 May	9 June	9	4.5	20	4.0
1974	1 May	6 May	15 May	5	2.5	14	2.8
1975	19 May	23 May	29 May	4	1.3	10	1.7
1976	10 May	17 May	29 May	7	2.3	19	3.2
1977	12 May	28 May	21 June	16	5.3	40	6.7
1978	29 Apr	5 May	11 May	6	2.0	12	2.0
1979	10 May	15 May	25 May	5	1.7	15	2.5

[a] Little Goose Dam 1973-74, Lower Granite Dam 1975-79.

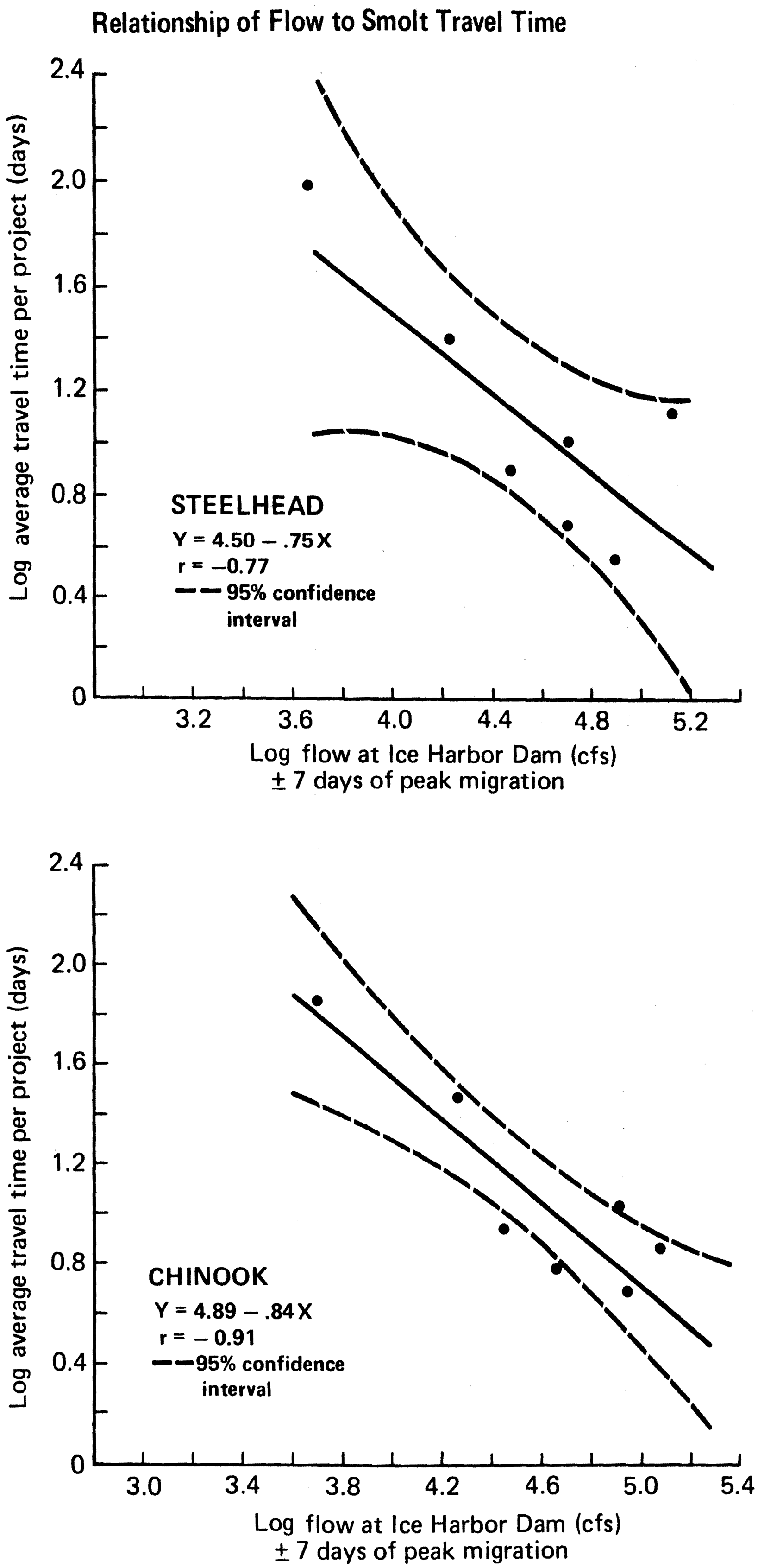

Figure 2.--Regression line for flow at Ice Harbor Dam1/ and travel time from the upper Snake River dam to The Dalles Dam for Snake River yearling chinook salmon and steelhead smolts, 1973-1979.

1/ At migration peak ± 7 days.

the precision of the regression lines is low, the r values are significant, and predictions of expected travel time from Lower Granite Dam to The Dalles Dam at various river flows were made (Table 4). For example, given average flows of 100,000 cfs at Ice Harbor Dam during the migration periods, we could expect both chinook salmon and steelhead smolts to reach The Dalles Dam in about 17 days. It should be pointed out, though, that the relations shown in Figure 2 are logrithmic, thus the relationship appears linear. However, travel time differences were more pronounced in lower flows than in higher flows. As indicated in Table 4, a 50,000 cfs drop in flow from 100,000 cfs adds 13 days travel, but a 50,000 cfs drop in flow from 150,000 cfs to 100,000 cfs adds only 5 days travel. Additional details on tests of significance, derivation of regression equations, and calculations of confidence limits are contained in Appendix Tables A1 and A2.

Raymond (1979) found that when travel time was in excess of 20 days, as in 1973, survival of smolts was adversely affected. Sims et al. (1978) found even lower survival in the record low flow of 1977. The fishery agencies have deemed 85,000 cfs as the minimum flows that can be tolerated in the Snake River. Data shown here and later in this paper (see flow/spill/travel time relationships) generally corroborate their position.

Smolt Survival

From 1973 to 1979, survival of yearling chinook salmon smolts from the upper dam on the Snake River to The Dalles Dam averaged 22% and ranged from 2% (in 1977) to 40% during 1974 (Figure 3). Steelhead survival during the same periods averaged 19% and ranged from 1% in 1977 to 42% in 1975.

When Snake River flows were in excess of 100,000 cfs, survival of yearling chinook salmon and steelhead remained somewhat constant--ranging

Table 4.--Predicted travel time for yearling chinook salmon and steelhead smolts from Lower Granite Dam to The Dalles Dam, given various flow levels.[a]

	Predicted travel time			
	Avg. per project (days)		Lower Granite to The Dalles Dam (days)	
Flow(cfs x 1000)	Chinook	Steelhead	Chinook	Steelhead
50	5.0	4.7	30	28
75	3.6	3.5	22	21
100	2.8	2.8	17	17
125	2.3	2.4	14	14
150	2.0	2.1	12	12
175	1.8	1.8	11	11

[a] Avg. flow at Ice Harbor Dam during migration peak (± 7 days).

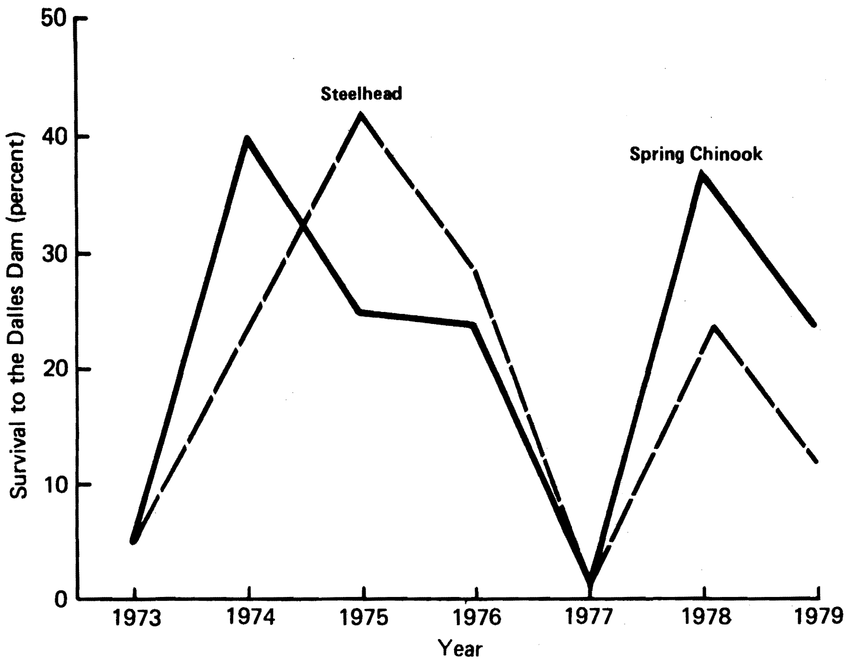

Figure 3.--Estimated survival of Snake River yearling chinook salmon and steelhead smolts from the upper Snake River dam[1/] to The Dalles Dam, 1973-1979.

1/ Little Goose Dam, 1973-74; Lower Granite Dam, 1975-79.

from 23 to 42% and averaging 30% (Table 5). In 1973 and 1977, the low smolt survival reflects the minimal amount of spilling and the low river velocities--increased smolt passage through the turbines increased direct mortality, and delayed reservoir passage probably subjected smolts to increased predation.

Diel Movement Patterns

Diel movement of juvenile salmonids into the turbine intake gatewells was examined at The Dalles Dam in 1976 and 1977 and at John Day Dam from 1975 to 1978. Tests conducted in 1976 (which accurately reflect all tests) indicated that 92% of yearling chinook salmon smolts, 77% of steelhead smolts, and 88% of fall chinook salmon smolts entered the turbine intake gatewells at John Day Dam during the 8.5-hour period between dusk and dawn (Figure 4). Turbine entry patterns at The Dalles Dam were very different (Figure 5); only 11% of the yearling chinook smolts and 29% of the steelhead smolts entered the turbine intake gatewell between dusk and dawn. This difference in entry behavior could reflect the difference in powerhouse orientation. At The Dalles Dam the powerhouse is parallel to the general river flow; whereas, at John Day the powerhouse is perpendicular to the general flow.

Flow/Spill and Smolt Survival Relationships

From 1973 to 1979, one additional dam was added to the Snake River system, and the number of operating turbines at Snake River Dam increased from 9 in 1973 to 24. Such variable conditions make a precise definition of the effects of flow and spill on smolt survival difficult. This is particularly true when attempting to define the effects of various levels of flow or spill on a project by project basis. However, an analysis of flow/spill survival relationships on a systems basis over the 1973-79

Table 5.--Survival of Snake River chinook salmon and steelhead smolts to The Dalles Dam and prevailing flow and spill, 1973-1979.

Species and year	Survival to The Dalles Dam(s) (%)	Survival per project $\sqrt[n]{s}$ (%)	Flow at Ice Harbor Dam (cfs x 1000)[a]	Avg. spill per dam (cfs x 1000)
Chinook				
1973	5	55	71	8.6
1974	40	86	158	102.8
1975	25	79	140	102.8
1976	24	79	110	67.0
1977	2	52	40	2.0
1978	37	85	106	34.7
1979	24	79	85	8.3
Steelhead				
1973	5	55	68	9.5
1974	23	75	103	80.8
1975	42	87	136	102.3
1976	29	81	167	122.5
1977	1	46	40	1.0
1978	24	79	106	34.7
1979	12	70	89	10.6

[a] Average flow at Ice Harbor Dam during the period ± 7 days from migration peak.

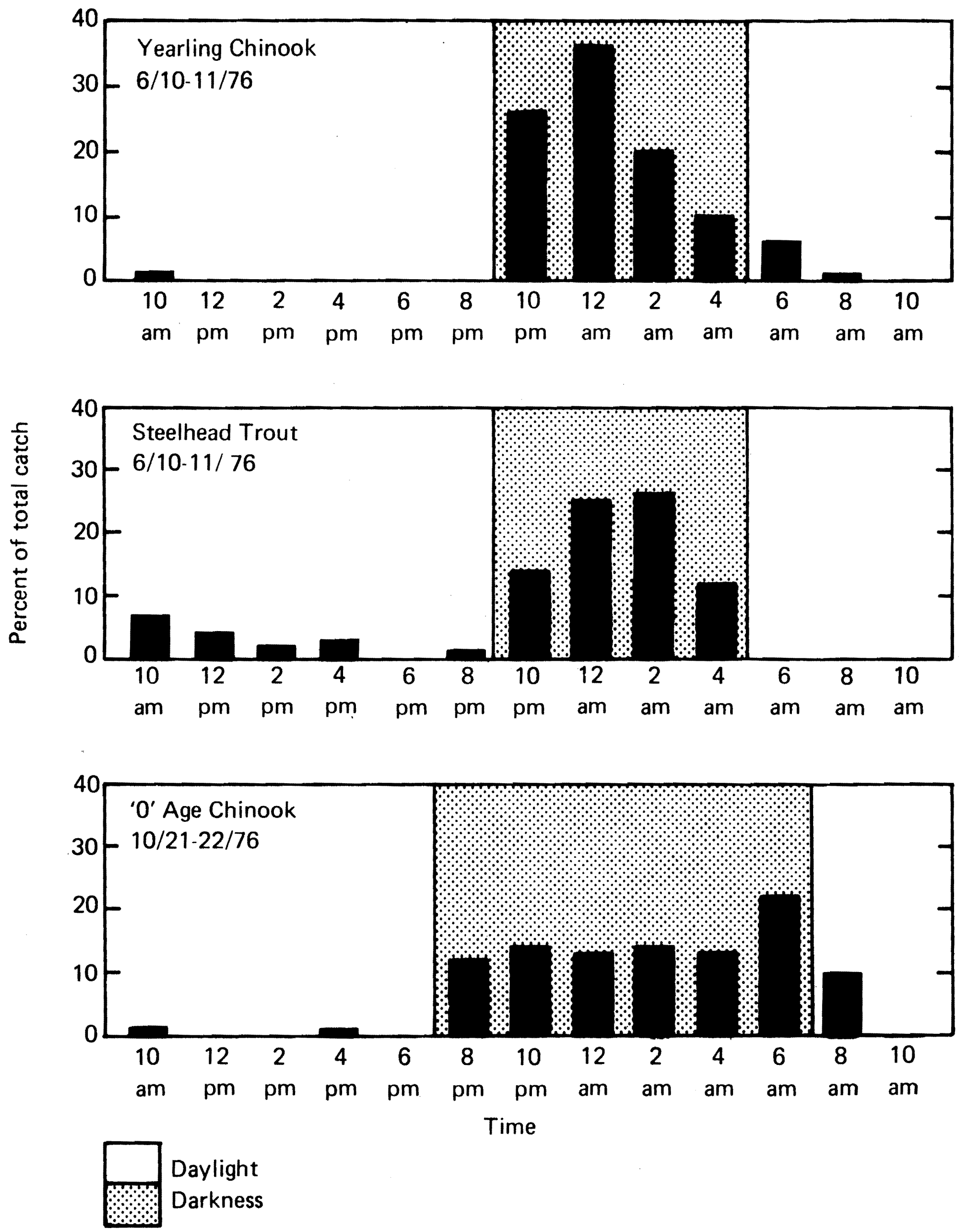

Figure 4.--Diel movement patterns of salmonid smolts entering turbine intake gatewells at John Day Dam.

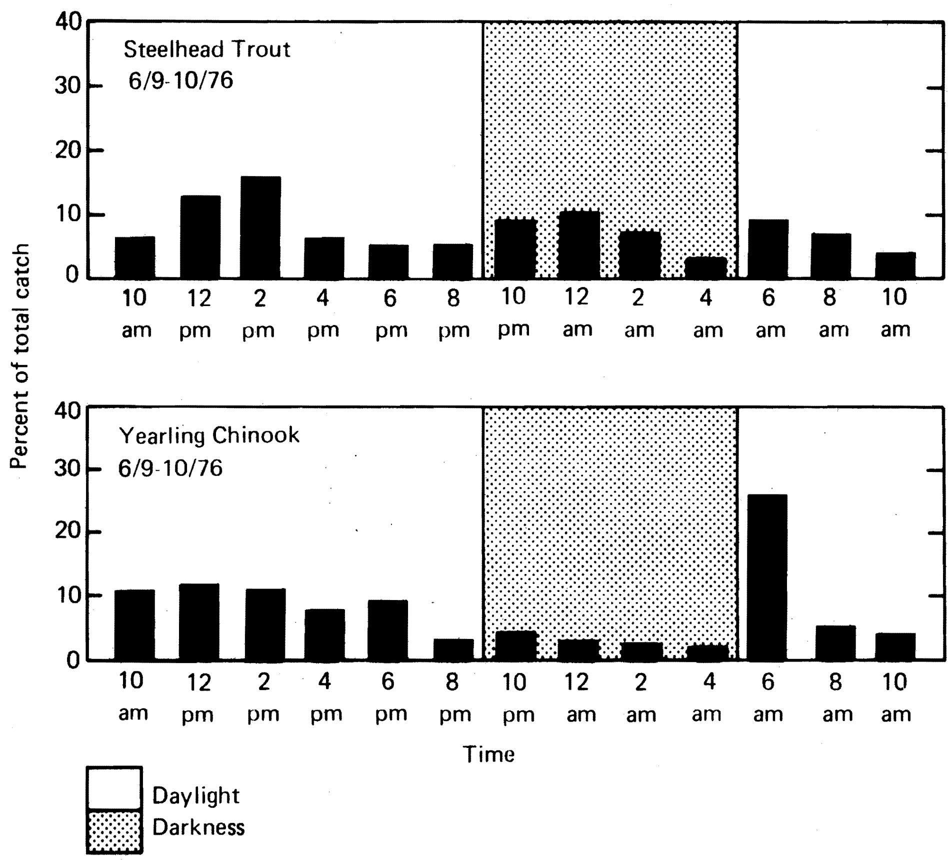

Figure 5.--Diel movement patterns of salmonid smolts entering turbine intake gatewells at The Dalles Dam.

period provided some insight as to the levels of flow and spill required to maintain smolt survival at the higher levels (Table 5).

Flow/Survival Relationships

If the correlation of river flow and rates of downstream movement described earlier are correct, and if the rate of smolt migration affects survival, there should be a positive correlation between river flow and smolt survival. When estimates of average smolt survival per project from 1973 to 1979 were plotted against flows at Ice Harbor Dam during the period of peak migration, a positive correlation was apparent (Figure 6). These flow/survival regressions had high correlation coefficients (r values of 0.87 and 0.95 for chinook salmon and steelhead, respectively--see Appendix Tables A3 and A4). The confidence band about these relationships is wide because of the small number of data points; as additional data become available, more precise estimates can be made.

The flow/spill regressions were used to predict expected smolt survival at given flow levels (Table 6). Survival rates to The Dalles Dam of 16% or greater can be expected only when river flows at Ice Harbor Dam during peak periods of migration are in excess of 100,000 cfs. Flows of less than 75,000 cfs can be expected to produce survival rates comparable with the drought years of 1973 and 1977.

Spill/Survival Relationships

Regression analysis of spill levels (average spill per dam during peak migration) and estimated smolt survival from 1973 to 1979 supports the contention that spill enhances smolt survival (Figure 7). Correlation coefficients (r values) for both chinook salmon and steelhead were high (0.81 and 0.92, respectively--see Appendix Tables A5 and A6). As in the

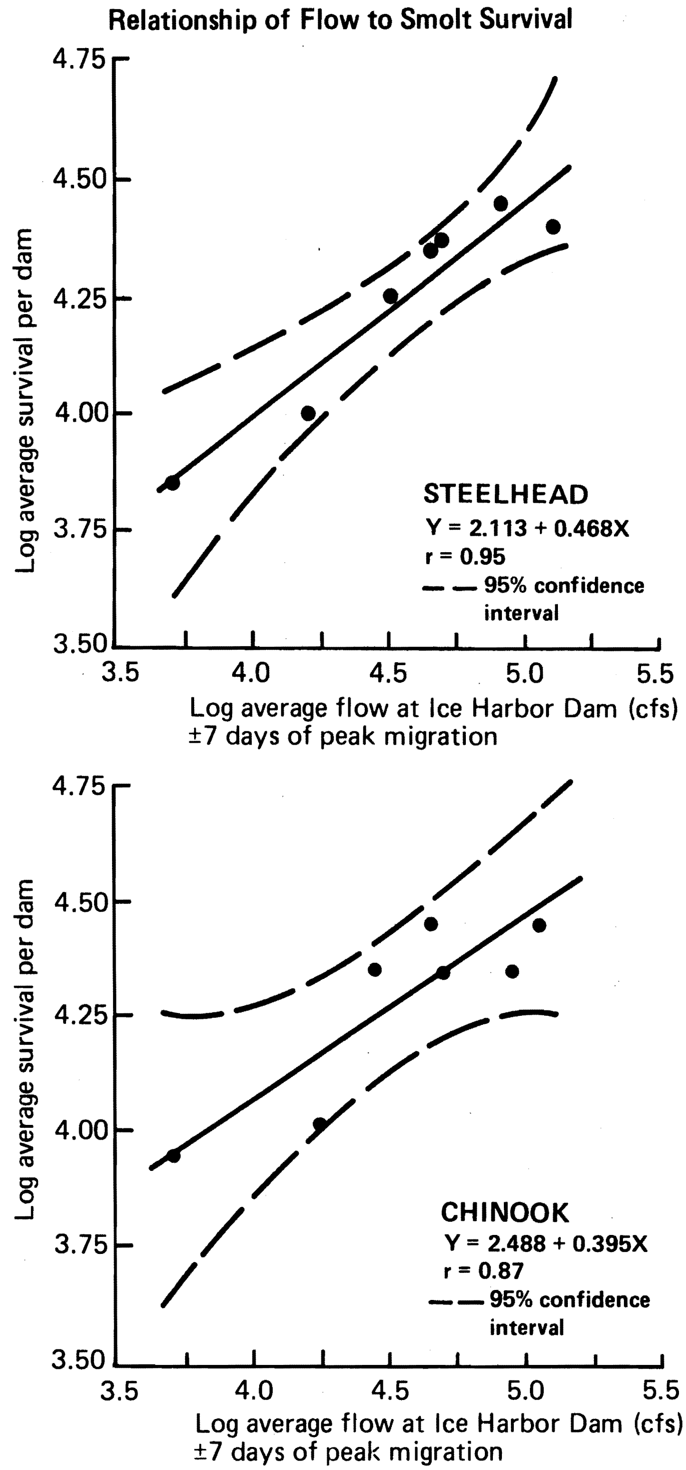

Figure 6.--Regression line for river flow at Ice Harbor Dam and survival of Snake River yearling chinook salmon and steelhead smolts, 1973-1979.

Table 6.--Predicted smolt survival at various levels of flow at Ice Harbor Dam at the time of peak migration.[a]

River flow[a] (cfs x 1000)	Predicted survival to The Dalles Dam: Chinook (%)	Steelhead (%)
40	2	1
60	5	3
80	10	7
100	16	13
120	26	23
140	38	33
160	50	50
180	69	69

a/ Average flow during the period ± 7 days from migration peak.

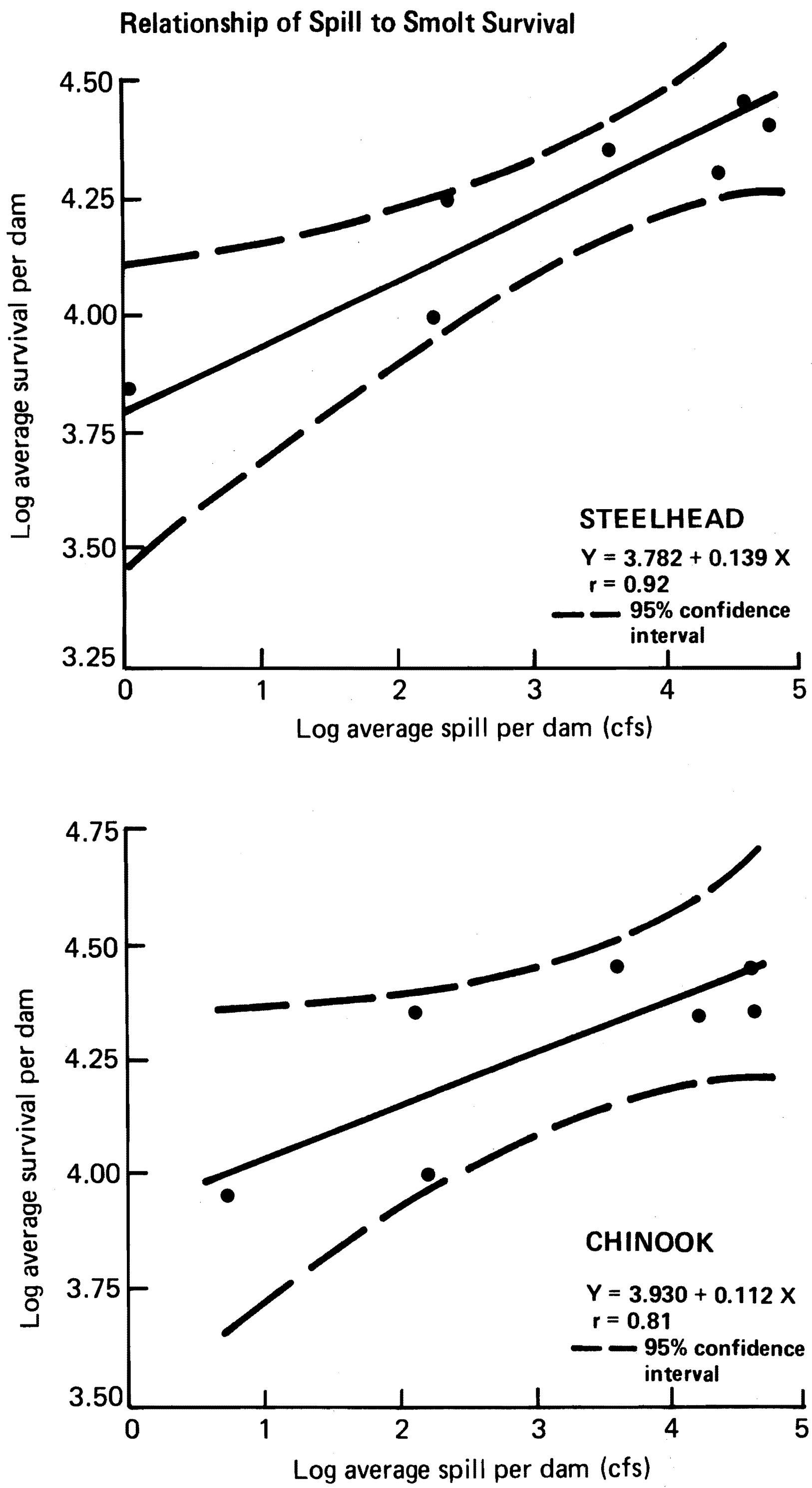

Figure 7.--Regression line for average daily spill per dam and survival of Snake River yearling chinook salmon and steelhead smolts, 1973-1979.

case of flow/survival relationship, precision was low because of the small number of data points.

Predictions of smolt survival to The Dalles Dam at various levels of spill were made, based on these regressions (Table 7). Results indicated that large amounts of spill were required to produce adequate survival levels. Survival levels greater than 20% can only be expected when the average spill per dam approaches 50,000 cfs. Although spills of this magnitude occurred regularly in the past, the increase in the number of turbines at the Snake River projects makes it unlikely that spills of this magnitude will occur very often in the future. This will require that available spill be used judiciously. Since these survival estimates were based on average daily spill, similar results could be expected by restricting daytime spill and using this water to provide larger spills (75,000 cfs or more) during the period of maximum smolt passage (2200 to 0200 hours).

The relationship between survival and spill has a much faster rate of change than the relationship between survival and flow. A proportionate increase in spill at low magnitudes will yield a greater increase in survival than the same proportionate increase in flow. For example, these data show that during the first 10% of possible spill, a 28% level of chinook salmon survival is attained; whereas, during the first 10% of flow only a 1% level of survival is attained. An increase to 30% for spill achieves a 60% level of survival; the comparable 30% increase in flow achieves only a 13% level of survival. The figures for steelhead are similar within a few percentage points. A moderate increase in spill, for spill in the lower range of values, will yield substantial improvement in survival.

Table 7.--Predicted smolt survival given various levels of spill at dams on the Snake and Columbia Rivers.[a]

Average spill per dam (cfs)	Predicted survival to The Dalles Dam Chinook (%)	Predicted survival to The Dalles Dam Steelhead (%)
5	5	3
10	8	5
20	13	9
70	24	19
80	30	24
100	33	28
	38	33

[a] Lower Granite to John Day.

EFFECT OF SPILL AND SEQUENTIAL TURBINE LOAD DROPPING ON SMOLT PASSAGE SURVIVAL

A special series of four tests was conducted at John Day Dam during the spring of 1978 (May and June) to determine the effect of spill and sequential turbine load dropping (SLD) on smolt passage survival. Test conditions involved concentrated spill (Spillbays 16-19) of approximately 40,000 cfs between 2200 and 2400 hours and SLD beginning with Turbine Units 1 and 2 at 2200 hours and progressing across the powerhouse two units at a time at 10-minute intervals. As the last two units were dropped, loading was resumed at the south end of the powerhouse. Each condition was maintained for a 10-day mark recovery period. Tests 1 and 2 (Table 8) utilized marked hatchery coho salmon (test fish) released at the mouth of the John Day River approximately 1.5 miles above the dam. Control releases were made into the tailrace below the dam. Test conditions were maintained between 2200 and 2400 hours for 10-day periods. Mark recovery data from the ice and trash sluiceway sampling program conducted at The Dalles Dam by the Oregon Department of Fish and Wildlife (ODFW) were used to make point estimates of survival using the method described by Schoeneman and Junge (1954).

Spill with SLD produced a passage survival of 85% (78-92%) compared to 65% (60-70%) during spill without SLD. Since the 95% confidence intervals of these point estimates do not overlap, this difference in the point estimates of survival is significant statistically. Details on calculations of point estimates and confidence limits are given in Appendix Tables A7 and A8.

Table 8.--Relative passage survival of marked coho salmon (hatchery origin) fingerlings passing John Day Dam during period of spilling with and without sequential turbine load dropping (SLD), 1978.

Test condition	No. released		No. recovered[a]		Estimated passage survival (%)[b]	95% confidence interval (%)[b]
	Test	Control	Test	Control		
Spill with SLD (Test 1)	98,138	48,510	1,494	866	85	78 - 92
Spill without SLD (Test 2)	94,325	47,791	1,380	1,077	65	60 - 70

[a] Recoveries by the Oregon Department of Fish and Wildlife from The Dalles Dam ice and trash sluiceways (adjusted for effort).

[b] See Appendix Tables A5 and A7 for details on calculations.

A similar experiment was conducted with marked 0-age chinook salmon fingerlings obtained from the gatewells at John Day Dam in July 1978 (Table 9). Two tests were conducted to measure passage survival of chinook salmon smolts during a period of no spilling or SLD. The marked fish were released at the same locations described above, and test conditions were also maintained between 2200 amd 2400 hours for 10-day periods. Recovery was also provided by ODFW at The Dalles Dam.

The difference in passage survival for chinook salmon during the two test conditions was significant. During spilling with SLD, survival was 87% compared to 35% when there was no spill or SLD. It was also interesting to note that chinook and coho salmon survival with spill and SLD were essentially the same (87 vs 85%). Details on calculations of point estimates and confidence limits are given in Appendix Tables A7 and A8.

SUMMARY

The National Marine Fisheries Service conducted a study of the effects of river flow regulation and dam operations on juvenile salmonid migrations in the Snake and Columbia Rivers from 1973 to 1979.

The outmigration of yearling chinook salmon from the Snake River averaged 3.9 million fish and ranged from 2.0 million fish in 1977 to 5.1 million fish in 1976. Snake River steelhead migrations averaged 3.3 million fish and ranged from 1.4 million fish in 1977 to 5.5 million fish in 1973.

Since 1970, increases in hatchery production have helped to maintain the size of the yearly salmonid migrations arriving at the upper Snake River dam at a somewhat constant level. However, the proportion of wild

Table 9.--Relative passage survival of marked chinook salmon fingerlings passing John Day Dam during periods of spilling and sequential turbine load dropping (SLD) and periods of no spilling or SLD, 1978.

Test condition	No. released		No. recovered[a]		Estimated passage survival (%)[b]	95% confidence interval (%)[b]
	Test	Control	Test	Control		
Spill with SLD (Test 3)	15,960	5,274	98	37	87	76 - 95
No spill or SLD (Test 4)	14,004	5,367	66	72	35	25 - 49

[a] Recoveries by the Oregon Department of Fish and Wildlife from The Dalles Dam ice and trash sluiceways (adjusted for effort).

[b] See Appendix Tables A7 and A8 for details on calculations.

fish has declined considerably and the number of smolts surviving to below the Dalles Dam has shown considerable fluctuation as a result of river mortality and the smolt transportation program.

The date of peak migration at the upper Snake River dam ranged from 21 April in 1976 to 17 May in 1975 for yearling chinook salmon and from 29 April in 1978 to 20 May in 1973 for steelhead. Peak migration of Snake River yearling chinook salmon at The Dalles Dam ranged from 8 May in 1976 to 17 June in 1977. Steelhead migration peaks at The Dalles Dam ranged from 11 May in 1978 to 21 June in 1977. Travel time from the upper Snake River dam to The Dalles Dam ranged from 12 to 39 days for yearling chinook salmon and from 10 to 40 days for steelhead.

Travel time and rates of movement are related to river flow. Both travel time and rates of downstream movement are more sensitive to changes in river flow during periods of low river flow than during periods of high river flow.

Survival of yearling chinook salmon from the upper Snake River dam to The Dalles Dam averaged 22% and ranged from 2% in 1977 to 40% in 1974. Steelhead survival averaged 19% and ranged from 1% in 1977 to 42% in 1975. When Snake River flows exceeded 100,000 cfs, smolt survival ranged from 23 to 42% and averaged 30%. The low smolt survivals in 1973 and 1977 reflected the low flows and minimal spilling.

Ninety-two percent of yearling chinook salmon, 77% of steelhead smolts, and 88% of fall chinook salmon smolts entered the turbine intake gatewells at John Day Dam between dusk and dawn. At The Dalles Dam, only 11% of the yearling chinook salmon smolts and 27% of the steelhead smolts entered the turbine intake gatewells during this time period.

The correlation of river flow at Ice Harbor Dam and smolt survival from the upper Snake River dam to The Dalles Dam was significant over the period of this study. The correlation coefficient was 0.87 and 0.95 for Snake River yearling chinook salmon and steelhead smolts, respectively. Regression analysis indicates that survival levels of greater than 20% can be expected only when river flows at Ice Harbor Dam during the peak migration period exceed 100,000 cfs.

Correlation coefficients for the regression analysis of smolt survival and spill were also significant; 0.81 for yearling chinook salmon and 0.92 for steelhead. Regression analysis indicates that survival levels greater than 20% can be expected only when the average spill at each dam from the upper Snake River to John Day Dam is $\geq$50,000 cfs during the peak period of migration.

Tests with hatchery coho salmon indicated that spilling at John Day Dam at a rate of 40,000 cfs between 2200 and 2400 hours in conjunction with SLD resulted in a relative survival of 85% to The Dalles Dam as compared to 65% during periods of similiar levels of spilling without SLD. A similiar test using 0-age chinook salmon smolts from gatewell catches measured survival to The Dalles Dam at 87% during periods of spill with SLD and 35% during periods of no spilling or SLD.

LITERATURE CITED

Bentley, W. W. and H. L. Raymond.
1968. Collection of juvenile salmonids from turbine intake gatewells of major dams in the Columbia River system. Trans. Amer. Fish. Soc. 97:124-126.

Raymond, H. L.
1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966 to 1975. Trans. Am. Fish Soc.,: 108 (6):565-529.

Raymond, H. L. and C. W. Sims.
1979. Assessment of smolt migration and passage enhancement studies for 1979. U.S. Army Corps of Engr. Report. NOAA, NMFS, NWAFC, Seattle, Wa. 46 p.

Raymond, H. L., W. W. Bentley, and C. S. Thompson.
1974. Effects of power peaking operations on juvenile salmon and trout migrations, 1973. U.S. Army Corps of Engr. Report. NOAA, NMFS, NWAFC, Seattle, Wa. 31 p. 2 fig. 12 tables.

Raymond, H. L., C. W. Sims, R. C. Johnsen, and W. W. Bentley.
1975. Effects of power peaking operations on juvenile salmon and steelhead trout migrations, 1974. U.S. Army Corps of Engr. Report. NOAA, NMFS, NWAFC, Seattle, Wa. 96 p.

Schoeneman, D. E. and C. O. Junge, Jr.
1954. Investigations of mortalities to downstream migrant salmon at two dams on the Elwha River. State of Washington, Department of Fisheries, Res. Bul. No. 3:51 p.

Sims, C. W., R. C. Johnsen, and W. W. Bentley.
1976. Effects of power peaking operations on juvenile salmon and steelhead migration, 1975. Progress report to U.S. Army Corps of Engr. Contract No. DACW57-76-F-0303. NOAA, NMFS, NWAFC, Seattle, Wa. 36 p. 3 fig. 14 tables 15 app. tables.

Sims, C. W., W. W. Bentley, and R. C. Johnsen.
1977. Effects of power peaking operations on juvenile salmon and steelhead trout migrations; progress 1976. Final report to U.S. Army Corps of Engr. Contract No. DACW68-77-0025. NOAA, NMFS, NWAFC Seattle, Wa. 18 p. 6 fig. 11 tables 7 app. tables.

Sims, C. W., W. W. Bentley, and R. C. Johnsen.
1978. Effects of power peaking operations on juvenile salmon and steelhead trout migrations, 1977. Final report financed by U.S. Army Corps of Engr. Walla Walla District. Del. Ord. DACW68-77-C-0025. NOAA, NMFS, NWAFC, Seattle, Wa. 52 p.

APPENDIX A

Table A1.--Regression analysis of flow and chinook salmon smolts travel time, 1973-79.

Year	(a) Avg. travel time per project (days)	(y) ln (a)	(b) Avg. flow at Ice Harbor Dam (cfs x 1,000)	(x) ln (b)
1973	4.4	1.482	71	4.263
1974	2.4	0.875	158	5.063
1975	2.0	0.693	140	4.942
1976	2.8	1.030	110	4.700
1977	6.5	1.872	40	3.689
1978	2.2	0.788	106	4.663
1979	2.5	0.916	85	4.443

$\hat{y} = a + bx$ $\hat{y} = 4.89 - 0.84x$ $r = -0.91$ $\bar{x} = 4.54$ $\bar{y} = 1.09$

Test of significance of r: $H_o: P_r = 0$ $t = \frac{r-0}{\sqrt{(1-r^2)/(n-2)}}$

$t = \frac{0.91}{0.19} = 4.79$ $t = {}_{0.5}\ 5df = 2.015$

Confidence interval (90%) r: z transformation $r \pm \frac{1}{\sqrt{n-3}}\ (t_{0.10}\ 4df)$

$1.528 \pm \frac{1}{\sqrt{4}}(2.132)$, 1.528 ± 1.066 $z = 0.46,\ 2.59$ $r = -0.21,\ -0.98$

95% confidence interval of y (travel time) at point x (flow):

$y \pm S_{\bar{y}}\ (t_{0.05}\ 5df)$ where $S_{\bar{y}} = \sqrt{S^2_{\bar{y}}}$ and $S^2_{\bar{y}} = S^2_{yx}\left[\frac{1}{n} + \frac{(x-\bar{x})^2}{\Sigma(x-\bar{x})^2}\right]$

where $s^2_{yx} = (\Sigma y^2 - \frac{(\Sigma y)^2}{n} - b\ (\Sigma xy - \frac{\Sigma x \Sigma y}{n})\ /n-2$

(a) flow (cfs)	x In (a)	$\hat{y}$	y	$\bar{y}$	a (days)	$\bar{a}$ (days)
40	3.69	1.80 ± 0.37	1.43	2.17	4.2	8.8
60	4.09	1.47 ± 0.24	1.23	1.71	3.4	5.5
80	4.38	1.23 ± 0.18	1.05	1.41	2.9	4.1
100	4.61	1.03 ± 0.17	0.86	1.20	2.4	3.3
120	4.79	0.88 ± 0.19	0.69	1.07	2.0	2.9
140	4.94	0.76 ± 0.23	0.53	0.99	1.7	2.7
160	5.08	0.64 ± 0.27	0.37	0.91	1.4	2.5
180	5.19	0.55 ± 0.31	0.24	0.86	1.3	2.4

Table A2.--Regression analysis of flow and steelhead smolt travel time, 1973-79.

Year	(a) Avg. travel time per project (days)	(y) ln (a)	(b) Avg. flow at Ice Harbor Dam (cfs x 1,000)	(x) In (b)
1973	4.0	1.386	68	4.220
1974	2.8	1.030	103	4.635
1975	1.7	0.531	136	4.913
1976	3.2	1.163	167	5.118
1977	6.7	1.902	40	3.689
1978	2.0	0.693	106	4.663
1979	2.5	0.916	89	4.489

$\hat{y} = a + bx$ $\hat{y} = 4.50 - 0.75x$ $r = -0.77$ $\bar{x} = 4.53$ $\bar{y} = 1.09$

Test of significance of r: $H_o: P_r = 0$ $t = \dfrac{r-0}{\sqrt{(1-r^2)/(n-2)}}$

$t = \dfrac{0.72}{0.29} = 2.66$ $t = {}_{0.05}\ 5df = 2.015$

Confidence interval (90%) r: z transformation $r \pm \dfrac{1}{\sqrt{n-3}}$ $(t_{(0.10)}\ 4df)$

$1.020 \pm \dfrac{1}{\sqrt{4}}(2.132)$, 1.020 ± 1.066 $z = 0.05, 2.09$ $r = 0.05, -0.97$

95% confidence interval of y (travel time) at point x (flow):

$y \pm S_{\bar{y}}\ (t_{0.05}\ 5df)$ where $S_{\bar{y}} = \sqrt{S^2_{\bar{y}}}$ and $S^2_{\bar{y}} = S^2_{yx}\left[\dfrac{1}{n} + \dfrac{(x-\bar{x})^2}{\Sigma(x-\bar{x})^2}\right]$

where $S^2_{yx} = (\Sigma y^2 - (\Sigma y)^2/n) - b\ (\Sigma xy - \dfrac{\Sigma x \Sigma y}{n})\ /n-2$

(a) flow (cfs)	x In (a)	$\hat{y}$	$\underline{y}$	$\bar{y}$	$\underline{a}$ (days)	$\bar{a}$ (days)
40	3.69	1.72 ± 0.67	1.05	2.39	2.9	10.9
60	4.09	1.42 ± 0.43	0.99	1.85	2.7	6.4
80	4.38	1.20 ± 0.32	0.88	1.52	2.4	4.6
100	4.61	1.03 ± 0.31	0.72	1.34	2.1	3.8
120	4.79	0.89 ± 0.36	0.53	1.25	1.7	3.5
140	4.94	0.79 ± 0.42	0.36	1.20	1.4	3.3
160	5.08	0.68 ± 0.49	0.19	1.17	1.2	3.2
180	5.19	0.59 ± 0.56	0.03	1.15	1:0	3.2

Table A3.--Regression analysis of chinook salmon smolt survival, flow, and spill data, 1973-79.

Year	Overall survival (%)	(Y) Average survival per dam (%)	(X_1) Flow (cfs x 1,000)[a/]	(X_2) Average spill per dam (cfs x 1,000)
1973	5	55	71	8.6
1974	40	86	158	102.8
1975	25	79	140	102.8
1976	24	79	110	67.0
1977	2	52	40	2.0
1978	37	85	106	34.7
1979	24	79	85	8.3

a/ Average flow at Ice Harbor Dam.

Regression analysis

The models used are:

(1) $Y = A X_1^{B}$, survival vs flow.

(2) $Y = A X_2^{B}$, survival vs spill.

(3) $Y = A X_1^{B} X_2^{C}$, survival vs flow and spill.

Confidence bands for models (1) and (2) were calculated from:

$$\hat{Y}_n - Ws(\hat{Y}_n) \le \hat{Y}_n \le \hat{Y}_n + Ws(\hat{Y}_n)$$

where:

$$s^2(\hat{Y}_n) = MSE\left[\frac{1}{n} + \frac{(X_n - \bar{X})^2}{\sum (X_i - \bar{X})^2}\right]$$

$$W^2 = 2F(1 - \alpha; 2, n - 2)$$

ANOVA for chinook salmon model (1): survival vs flow

source	df	SS	MS	F	P
Regression	1	0.2008	0.2008	16.06	$\simeq$ 0.01
Residual	n-2=5	0.0625	0.0125		
Total	n-1=6	0.2633			

Table A3.--Continued.

Regression equation:

$$\hat{Y} = 12.033\ X_1^{\ 0.395}$$

Coefficient of determination:

$$R = \left(\frac{SSR}{SST}\right)^{1/2} = 0.87$$

ANOVA for chinook salmon model (2): survival vs spill

source	df	ss	MS	F	P
Regression	1	0.1717	0.1717	9.38	< 0.05
Residual	5	0.0916	0.0183		
Total	6	0.2633			

Regression equation:

$$\hat{Y} = 50.903\ X_2^{\ 0.112}$$

$R = 0.81$

ANOVA for chinook salmon model (3): survival vs flow and spill

source	df	ss	MS	F	P
Regression	2	0.2052	0.1026	7.08	< 0.05
Residual	4	0.0580	0.0145		
Total	6	0.2632			

Regression equation:

$$\hat{Y} = 5.654\ X_1^{\ 0.608}\ X_2^{\ -0.0676}$$

$R = 0.88$

Table A4.--Regression analysis of steelhead smolt survival, flow, and spill data, 1973-79.

Year	Overall survival (%)	(Y) Average survival per dam (%)	(X_1) Flow (cfs x 1,000)[a]	(X_2) Average spill per dam (cfs x 1,000)
1973	5	55	68	9.5
1974	23	75	103	80.8
1975	42	87	136	102.3
1976	29	81	167	122.5
1977	1	46	40	1.0
1978	24	79	106	34.7
1979	12	70	89	10.6

a/ Average flow at Ice Harbor Dam.

Regression analysis models and confidence bands are the same as those for chinook salmon (see Table A3).

ANOVA for steelhead model (1): survival vs flow

source	df	ss	MS	F	P
Regression	1	0.2904	0.2904	47.92	< 0.01
Residual	5	0.0303	0.0061		
Total	6	0.3207			

Regression equation:

$$\hat{Y} = 8.269\, X_1^{\,0.468}$$

$R = 0.95$

ANOVA for steelhead model (2): survival vs spill

source	df	ss	MS	F	P
Regression	1	0.2721	0.2721	28.05	< 0.005
Residual	5	0.0486	0.0097		
Total	6	0.3207			

Table A4.--Continued.

Regression equation:

$$\hat{Y} = 43.907\ X_2^{\ 0.139}$$

R = 0.92

ANOVA for steelhead model (3): survival vs flow and spill

source	df	ss	MS	F	P
Regression	2	0.2914	0.1457	19.96	< 0.01
Residual	4	0.0294	0.0073		
Total	6	0.3207			

Regression equation:

$$\hat{Y} = 11.018\ X_1^{\ 0.386}\ X_2^{\ 0.027}$$

R = 0.95

Table A5.--Calculation of 95% confidence interval on the point estimate of passage survival at John Day Dam, 1978. (Test 1)

x = No. test fish recovered = 1,494
y = No. control fish recovered = 866
n = x + y = 2,360

N_E = No. test fish released = 98,138
N_c = No. control fish released = 48,510
N_c/N_E = 0.4943

The 95% confidence interval for p is given by:

$$Pr \left\{ \frac{x-np}{\sqrt{np\ (1-p)}} \leq 1.96 \right\} = 0.95 \quad \text{or}$$

$$Pr \left\{ (n + 3.8416)\ p^2 - (2\ x + 3.8416)\ p + \frac{x^2}{n} \geq 0 \right\} = 0.95 \quad \text{or}$$

$$x^2 - (2\ x + 3.8416)\ np + (n^2 + 3.8416\ n)\ p^2 \geq 0 \quad \text{or}$$

$$(1494)^2 - \left[2(1494) + 3.8416\right]\ 2360\ p + \left[(2360)^2 + 3.8416\ (2360)\right]\ p^2 \geq 0$$

$$\text{or}\ \underset{c}{\underline{1}} - \underset{b}{\underline{(3.1634)}}\ p + \underset{a}{\underline{(2.4994)}}\ p^2 \leq 0$$

$$\text{Solving the quadratic}\ \bar{p},\ \underline{p} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\bar{p},\ \underline{p} = \frac{(3.1634) \pm \sqrt{(3.1634)^2 - 4\ (2.4994)}}{2\ (2.4994)} = 0.6523,\ 0.6133$$

$$\text{Point estimate of survival (S)} = \frac{(1,494)/(98,138)}{(866)/(48,510)} = 0.8528$$

$$\bar{s} = \left(\frac{\bar{p}}{1-\bar{p}}\right)\left(\frac{N_c}{N_E}\right) = \frac{(0.6523)}{(1-0.6523)}\ (0.4943) = 0.9273$$

$$\underline{s} = \left(\frac{\underline{p}}{1-\underline{p}}\right)\left(\frac{N_c}{N_E}\right) = \frac{(0.6133)}{(1-0.6133)}\ (0.4943) = 0.2848$$

Table A6.--Calculation of 95% confidence interval on the point estimate of passage survival at John Day Dam, 1978. (Test 2)

x = No. test fish recovered = 1,380 $\quad$ N_E = No. test fish released = 94,525

y = No. control fish recovered = 1,077 $\quad$ N_c = No. control fish released = 47,791

$n = x + y = 2,457$ $\quad$ $N_c/N_E = 0.5067$

The 95% confidence interval for p is given by:

$$Pr \left\{ \frac{x-np}{\sqrt{np\ (1-p)}} \right\} \leq 1.96 \quad = 0.95 \quad \text{or}$$

$$Pr \left\{ (n + 3.8416)\ p^2 - \ (2 \times 3.8416)\ p + \frac{x^2}{n} \geq 0 \right\} = 0.95 \quad \text{or}$$

$$x^2 - (2\ x + 3.8416)\ np = (p^2 + 3.8416\ n)\ p^2 \geq 0 \quad \text{or}$$

$$(1.380)^2 - \left[2(1380) + 3.8416\right]\ 2457\ p + \left[(2457)^2 + 3.8416\ (2457)\right]\ p^2 \geq 0$$

$$\text{or}\ \underset{c}{1} - \underset{b}{(3.5658)}\ p + \underset{a}{(3.1749)}\ p^2 \leq 0$$

$$\text{Solving the quadratic}\ \bar{p},\ \underline{p} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2b}$$

$$\bar{p},\ p = \frac{(3.5658) \pm \sqrt{(3.5658^2 - 4(3.1749)}}{2\ (3.1749} = 0.5421,\ 05817$$

$$\text{Point estimate of survival (S)} = \frac{(1380)/(94,325)}{(1077)/(47,791)} = 0.6497$$

$$\bar{s} = \left(\frac{\bar{p}}{1-\bar{p}}\right)\left(\frac{N_c}{N_E}\right) = \frac{(0.5817)}{(1-0.5817)}\ (0.5067) = 0.7046$$

$$\underline{s} = \left(\frac{p}{1-\underline{p}}\right)\left(\frac{N_c}{N_E}\right) = \frac{(0.5421)}{(1-0.5421)}\ (0.5067) = 0.5999$$

Table A7.--Calculation of 95% confidence interval on the point estimate of passage survival at John Day Dam, 1978. (Test 3)

x = No. test fish recovered = 98
y = No. control fish recovered = 37
n = x + y = 135

N_E = No. test fish released = 15,960
N_c = No. control fish released = 5,274
N_c/N_E = 0.3305

The 95% confidence interval for p is given by:

$$Pr\left\{\frac{x-np}{\sqrt{np\ (1-p)}} \le 1.96\right\} = 0.95 \quad \text{or}$$

$$Pr\left\{(n + 3.8416)\ p^2 - (2\ x + 3.8416)\ p + \frac{x^2}{n} \ge 0\right\} = 0.95 \quad \text{or}$$

$$x^2 - (2\ x + 3.8416)\ np + (n^2 + 3.8416\ n)\ p^2 \ge 0 \quad \text{or}$$

$$(0.98)^2 - \left[2(\ 98) + 3.8416\right] 135\ p + \left[(135)^2 + 3.8416\ (135)\right] p^2 \ge 0$$

$$\text{or}\ \underset{c}{\underline{1}} - \underset{b}{\underline{(2.8091)}}\ p + \underset{a}{\underline{(1.9516)}}\ p^2 \le 0$$

solving the quadratic $\bar{p}, \underline{p} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$$\bar{p}, \underline{p} = \frac{(2.8091) \pm \sqrt{(2.8091)^2 - 4\ (1.9516)}}{2\ (1.9516)} = 0.7414,\ 0.6980$$

Point estimate of survival (S) = $\frac{(98)/(15.960)}{(37)/(5.274)}$ = 0.8752

$$\bar{s} = \left(\frac{\bar{p}}{1-\bar{p}}\right)\left(\frac{N_c}{N_E}\right) = \frac{(0.7414)}{(1-0.7414)}\ (0.3305) = 0.9475$$

$$\underline{s} = \left(\frac{\underline{p}}{1-\underline{p}}\right)\left(\frac{N_c}{N_E}\right) = \frac{(0.6980)}{(1-0.6980)}\ (0.3305) = 0.7639$$

Table A8.—Calculation of 95% confidence interval on the point estimate of passage survival at John Day Dam, 1978. (Test 4)

x = No. test fish recovered = 66
y = No. control fish recovered = 72
n = x + y = 138

N_E = No. test fish released = 14,004
N_c = No. control fish released = 5,367
N_c/N_E = 0.3832

The 95% confidence interval for p is given by:

$$Pr \left\{ \frac{x-np}{\sqrt{np\ (1-p)}} \leq 1.96 \right\} = 0.95 \quad \text{or}$$

$$Pr \left\{ (n + 3.8416)\ p^2 - (2\ x + 3.8416)\ p + \frac{x^2}{n} \geq 0 \right\} = 0.95 \quad \text{or}$$

$$x^2 - (2\ x + 3.8416)\ np + (n^2 + 3.8416\ n)\ p^2 \geq 0 \quad \text{or}$$

$$(0.06)^2 - \left[2(66) + 3.8416\right]\ 138\ p + \left[(138)^2 + 3.8416\ (138)\right]\ p^2 \geq 0$$

$$\text{or}\ \underset{c}{\underline{1}} - \underset{b}{\underline{(4.3035)}}\ p + \underset{a}{\underline{(4.4936)}}\ p^2 \leq 0$$

Solving the quadratic $\bar{p}$, $\underline{p} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$$\bar{p}, \underline{p} = \frac{(4.3035) \pm \sqrt{(4.3035)^2 - 4\ (4.4936)}}{2\ (4.4936)} = 0.5610,\ 0.3967$$

$$\text{Point estimate of survival (S)} = \frac{(66)/(14{,}004)}{(72)/(5{,}363)} = 0.3513$$

$$\bar{s} = \left(\frac{\bar{p}}{1-\bar{p}}\right)\left(\frac{N_c}{N_E}\right) = \frac{(0.5619)}{(1-0.5616)}\ (0.3832) = 0.4897$$

$$\underline{s} = \left(\frac{\underline{p}}{1-\underline{p}}\right)\left(\frac{N_c}{N_E}\right) = \frac{(0.3967)}{(1-o.3967)}\ (0.3832) = 0.2520$$