Evaluation of factors affecting juvenile chinook salmon fish guidance efficiency

CZES

Coastal Zone and Estuarine Studies Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

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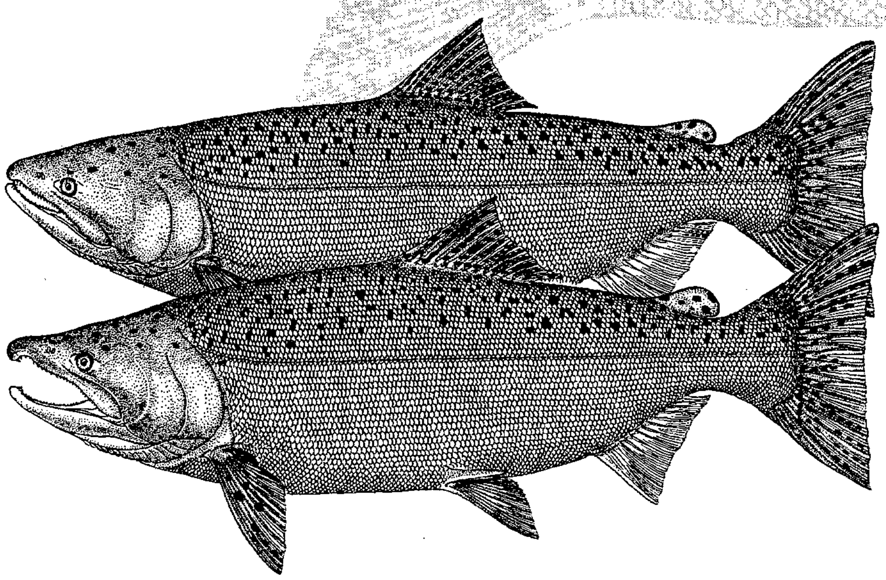

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EXECUTIVE SUMMARY

Measurement of mortalities to juvenile salmonids that pass through turbines at hydroelectric dams have ranged from 6-19%. As one means to decrease the number of fish that pass through turbines and thus decrease this mortality, the U.S. Army Corps of Engineer has installed screens in turbine intakes at most of their dams on the Snake and Columbia Rivers. Although turbine intake screens have successfully diverted a large percentage of fish from turbines at some dams, at others they have not. Also, the percentage varies among projects, within seasons, and among years. This study looked at three aspects related to turbine screens to provide insight into why different conditions affect performance of screens.

Firstly, fish behavioral studies were conducted in an oval flume at the NMFS Field Station at Pasco. The goal was to determine how changes in water velocities affected fish movement. Since turbine intake screens decrease water velocities, we hypothesized that in some cases fish avoided conditions created by the screens. For the study, fish were released, one at a time, into a moving body of water into which different porosity barriers were placed. Fish did not avoid barriers as long as water velocities upstream from them did not decrease too abruptly. However, we observed that when a barrier caused water velocities to decrease by approximately 10 cm/second over a distance of approximately 10 cm, fish avoided the area. Design of screens to divert fish should take this fish behavior into account.

Secondly, we considered a number of physical factors that potentially affect FGE to look for correlations between the factors and FGE. However, there was too little data to conduct an analysis with most of the proposed factors. Sufficient data existed to evaluate the following six factors: 1) River temperature on the day of each FGE test, 2) turbidity (measured by Secchi disk) on the day of each FGE test, 3) test duration (number of hours),

4) number of fish (all species) collected during each FGE test, 5) the number of fish (all species) collected per hour of each FGE test, and 6) the proportion of yearling chinook salmon in the total collection. No consistent correlations were found between fish guidance efficiency and any of these factors. It is unlikely that sufficient data will ever become available to predict changes in fish guidance related to changes in physical factors that may affect FGEs.

Thirdly, a review of past FGE test designs was conducted to explain differences between prototype results and actual performance after the final installation of equipment. In the early years, the techniques used for prototype FGE measurements did not include fyke nets under the screens to recover unguided fish. In these cases, FGEs were often overestimated. In latter years, techniques for prototype tests and evaluations after final installation were the same. However, some research in recent years has indicated that values of FGE were possibly overestimated when derived with techniques where the fyke net was placed directly under the STS. We also speculate that changes in physical conditions at dams may change the vertical distribution of fish that arrive at the dam, or that fish sometimes move deeper in the water column when approaching a dam to avoid predator populations in the forebays of dams. Both of the factors could effect vertical distribution and might result in lowered FGE.

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INTRODUCTION

Over the past 20 years, submersible traveling screen studies have been conducted at all U.S. Army Corps of Engineer (COE) hydroelectric dams on the lower Snake and Columbia Rivers. On the average, more than 70% of the yearling juvenile salmonid (*Oncorhynchus* spp.) migrants were intercepted and diverted from turbine intakes by the screens, although fish guidance efficiency (FGE) generally varied at most dams during the migration season. Also, at some dams, FGE was consistently lower than 70%. Field studies at these dams were unable to establish causal mechanisms for the low FGE.

Past research on juvenile salmon has shown they have the ability to detect flow changes as low as 0.4 to 1.0 cm/second (Gregory and Fields 1962) and they sense changes rheotactically (Hocutt and Edinger 1980). Studies conducted with louvers as a guiding device provide some insight into fish behavioral responses to flows. Bates and Vinsonhaler (1957) found that juvenile salmonids avoided louvers when water velocities were high. Fish apparently sensed abrupt changes in velocity as flow moved through the louvers and the velocity change formed a barrier which fish did not pass (Ruggles and Hutt 1984). Ruggles and Ryan (1964) and Thompson and Paulik (1967) found that velocities in the bypass systems associated with louvers had to be greater than 1.4 times the velocity of the water flowing through the louvers for the bypass systems to be effective. Further, fish would avoid the bypass systems if the flow into them was turbulent. Although they were not looking directly at flow effects on guidance, Marquette and Long (1971) concluded from laboratory studies that the porosity of screens was more important than the length of screens in the effectiveness of the screens to guide fish.

Based on field results and laboratory hydraulic model studies, we hypothesized that low FGEs were related to the behavior of fish approaching the screens under varying water velocities. Some members of the fisheries community have expressed an alternative hypothesis: that changes in physical factors, other than water velocities associated with screening devices, within the migration corridor and at the face of the dam strongly affected fish guidance results during FGE studies at different dams.

To address the first hypothesis, we conducted research in 1991 and 1992 at the NMFS Pasco Field Station at Pasco, Washington to analyze the response of naturally migrating juvenile salmonids to changing water velocities. The goal was to develop criteria that could predict fish movement in areas of changing water velocity. To address the second hypothesis, as much information as possible was gathered from past studies to evaluate possible correlations between physical factors and FGE results.

Finally, in some instances a difference existed between FGE obtained during prototype evaluations and FGE obtained after a complete bypass system was installed. Past research results were evaluated to determine if there were explanations for these differences.

OBJECTIVE 1 - EVALUATE JUVENILE SALMON BEHAVIOR RELATIVE TO CHANGES IN WATER VELOCITY

Approach

Observations were made on fish movement/behavior under differing flow conditions in a test flume at the NMFS Pasco Field Station. The flume is approximately 1 m wide, 2 m deep, and 24 m in circumference (Fig. 1). Fish were observed from an enclosed viewing room on the inside of the flume through a 2 x 2-m clear-plastic window in the wall of the

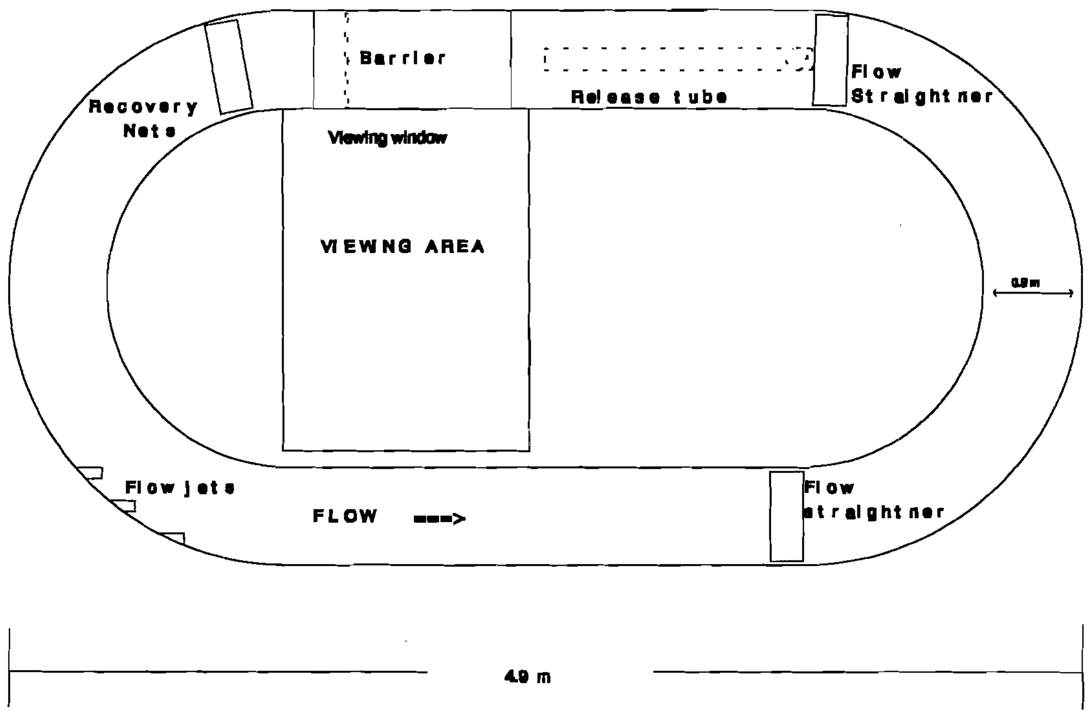

Figure 1. Plan view of the oval flume at the NMFS Pasco Field Station.

flume. Fresh water was pumped into the flume daily from a nearby groundwater source which has a year-round temperature of approximately 15°C. Pumps within the flume re-circulated the water. With two pumps, the water velocity at the viewing area ranged between approximately 70 and 80 cm/second. To balance the flow across the width of the channel, flow straighteners (structures made of various diameter pipes that were 0.2-m long) were positioned at the beginning and the end of the curved section leading into the viewing area .

Downstream migrant juvenile yearling and subyearling chinook salmon (*O. tshawytscha*) in a smolted condition were used for tests. Migrant fish were collected at either McNary Dam in 1991 or Priest Rapids, Wanapum, or Rock Island Dams in 1992 and transported to Pasco for observation. The fish were generally held in floating cages in a raceway for 24 hours prior to testing; tests for individual fish were not repeated. The fish were collected when river temperatures ranged from 13 to 17°C so that the water temperature in the flume (15°C) was within 2°C of the river temperatures.

Fish were singly released into a modified "T-shaped" tube at a fixed point approximately 2 m upstream from a 0.6 x 1-m barrier (Fig. 2). The upstream end of the tube was screened to allow flow to enter, but prevent fish from exiting upstream. Fish exiting tail first at the downstream end of the tube were considered to have a normal migrant orientation to flow. Fish that exited the tube head first generally darted shortly after their exit. These fish and a few that exhibited erratic sideways movements were excluded from the analysis as we felt these behaviors indicated that the fish probably were reacting to some stimuli other than water velocities. The excluded fish represented less than 15% of the fish we released.

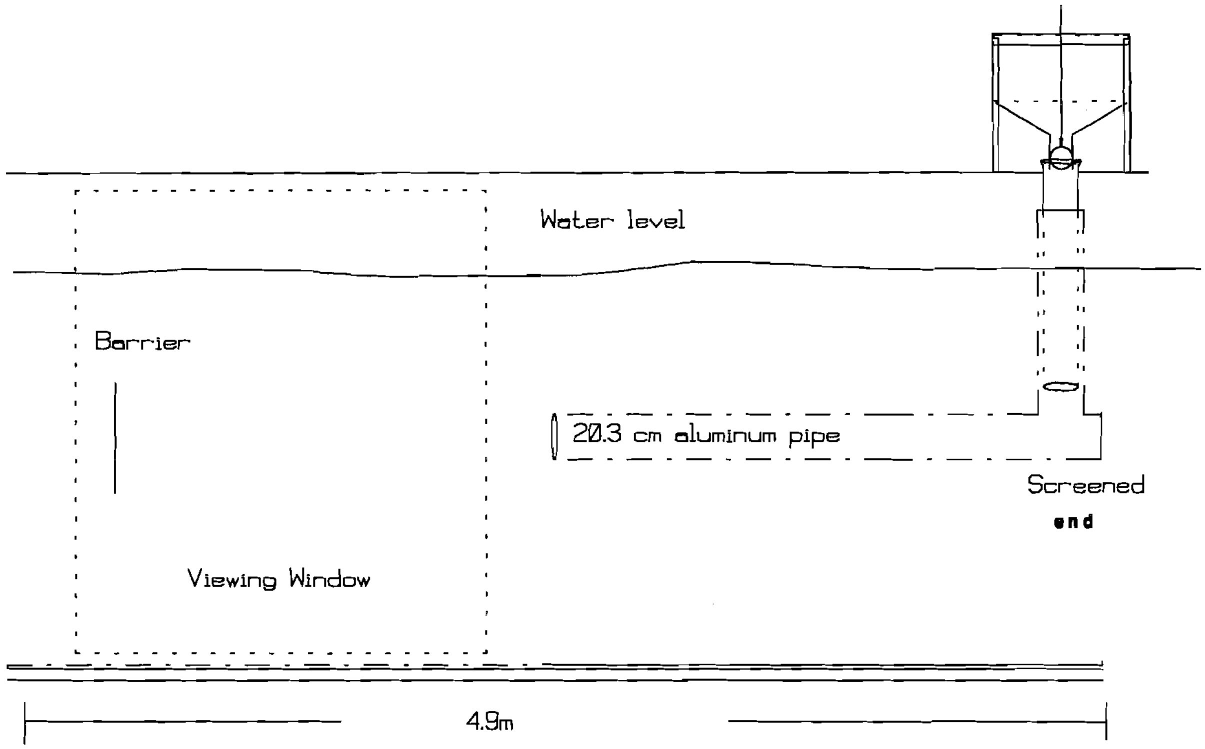

Figure 2. Schematic of the release configuration and viewing window of the oval flume at the NMFS Pasco Field Station.

Porosity of the downstream barrier ranged from 0% (solid barrier) to 100% (no barrier in place). Equally spaced 2.5-cm holes in a piece of steel plate were used to attain porosities of about 35 and 53%. We hypothesized that as porosity of the barrier decreased and more flow diverted around it, fish would begin to react to the changing flows farther upstream from the barrier. The movement of each fish was videotaped and later reviewed to determine the path followed by each test animal. In 1991, a grid was placed over the video monitor and with a computer-aided drawing and design (CADD) program, frames of the video were stopped, positions of the fish were identified, and resultant "tracks" of each fish were made. An area centered (vertically) and just posterior of the operculum was used to identify the position of each fish as the tracks were delineated. Also, in 1991, personnel from the Corps of Engineers Waterways Experiment Station (WES) used a laser doppler flow meter to determine water velocities between the release site and the barrier location for 0, 35, and 100% barriers. The velocity profiles generated by WES were plotted with the averaged fish tracks obtained from the videos for each test condition.

In 1992, some fish were anesthetized with MS-222 to use as velocity controls for test (alert) fish. The video tapes were run through a time generator and with the use of a video-analysis software program, a time/distance relationship was determined frame by frame for each fish. The velocity of test (alert) and control (anesthetized) fish was estimated for 10-cm increments between the release tube and the barrier location and a comparison was made between the movement behaviors of the two groups of fish.

All test results in both years were based on studies conducted under subdued, but natural light conditions. The test/viewing area was an enclosed room with no light penetration. The area at the top of the flume, adjacent to the viewing area and for 5 m in each direction, was also covered to prevent any direct lighting. At times it was difficult to identify the exact movement of each fish from the videotapes because of the very low light under which the tests were conducted. We also tried using infrared lighting, but were unable to sufficiently illuminate the viewing area to monitor the fish's movement. We were, therefore, unable to directly measure fish behavior in total darkness.

Results

Test fish (which constituted more than 85% of the total fish released through the funnel and into the "t"-tube configuration) moved downstream tail first with their heads oriented into the current on exit from the release tube. Their swimming speed into the current increased as they approached the barrier, which then resulted in a decrease in their downstream movement. As hypothesized, fish released into the flume with the 100% barrier in place reacted to changes in water velocity farther upstream of the barrier location than did fish that approached lower porosity barriers with their correspondent lesser effects on upstream water velocities. Additionally, once fish moved to higher velocity areas, they rarely moved back to an area with lower velocity. With no barrier (100% porosity), fish moved directly downstream from the release tube with little movement either above or below the initial release elevation (Figs. 3-4). Although not shown because it was tested only in 1991 and water velocity measurements were not taken, with the 53% porosity barrier, most fish also moved directly downstream toward the barrier and in nearly all cases, the caudal fins of the fish came into contact with the barrier. As the barrier porosity was decreased, fish

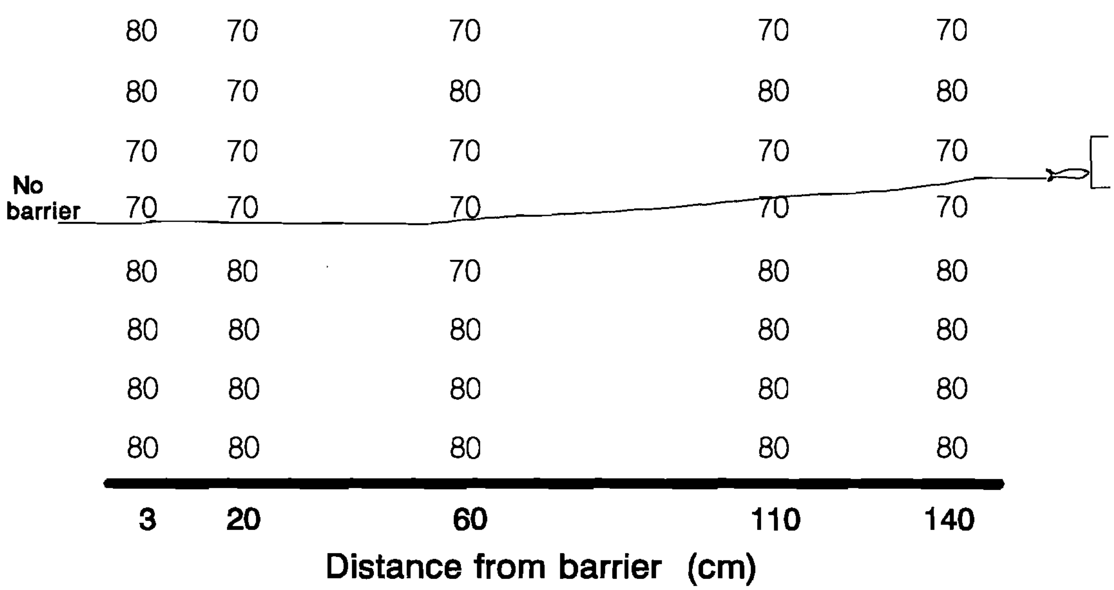

Figure 3. The average track for yearling chinook salmon in 1991 with no barrier in place, superimposed over averaged water velocities (cm/sec) derived from WES studies.

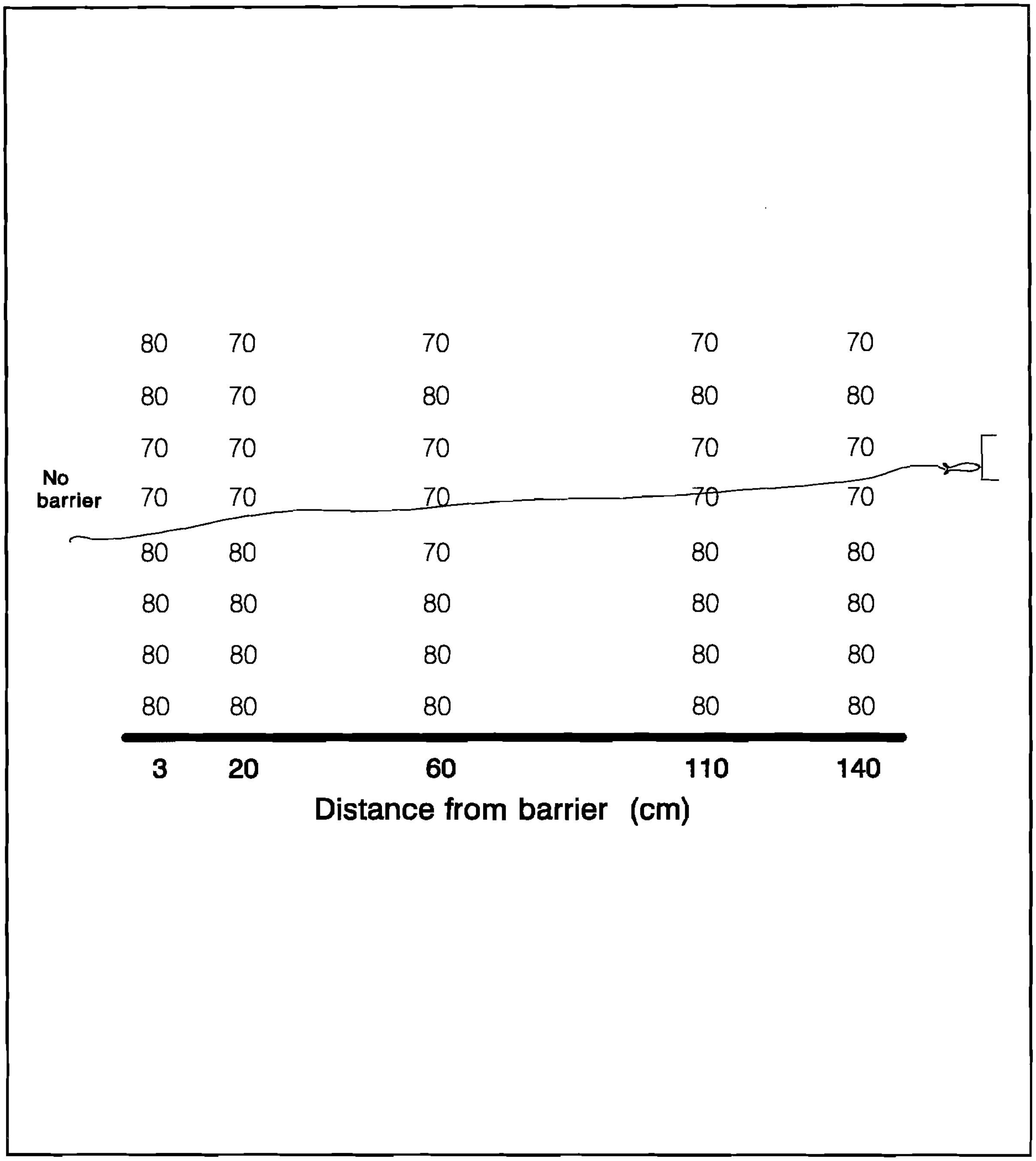

Figure 4. The average track for subyearling chinook salmon in 1991 with no barrier in place, superimposed over averaged water velocities (cm/sec) derived from WES studies.

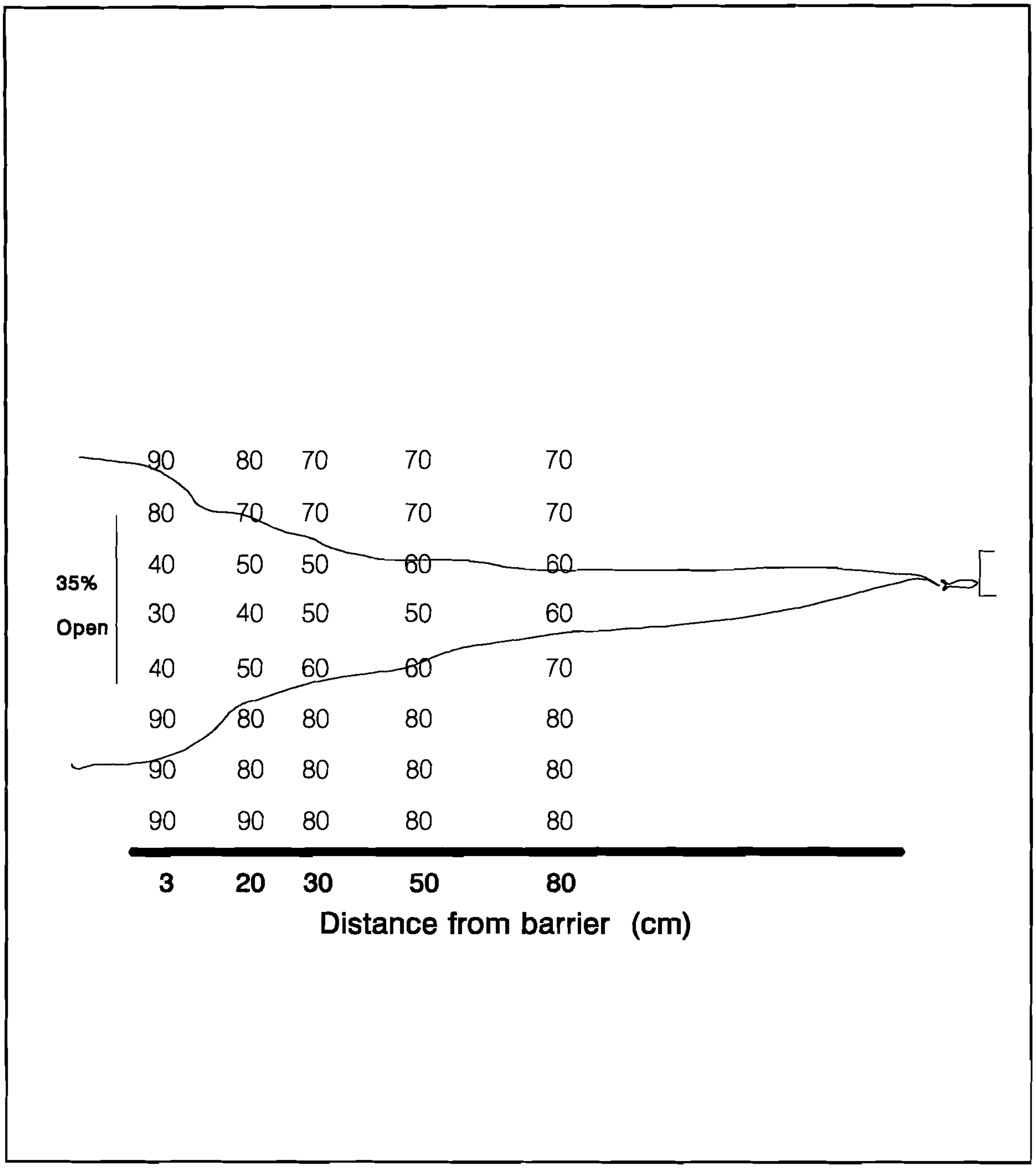

Figure 5. The average tracks for yearling chinook salmon that moved above and below a 35% porosity barrier in 1991, superimposed over averaged water velocities (cm/sec) derived from WES studies.

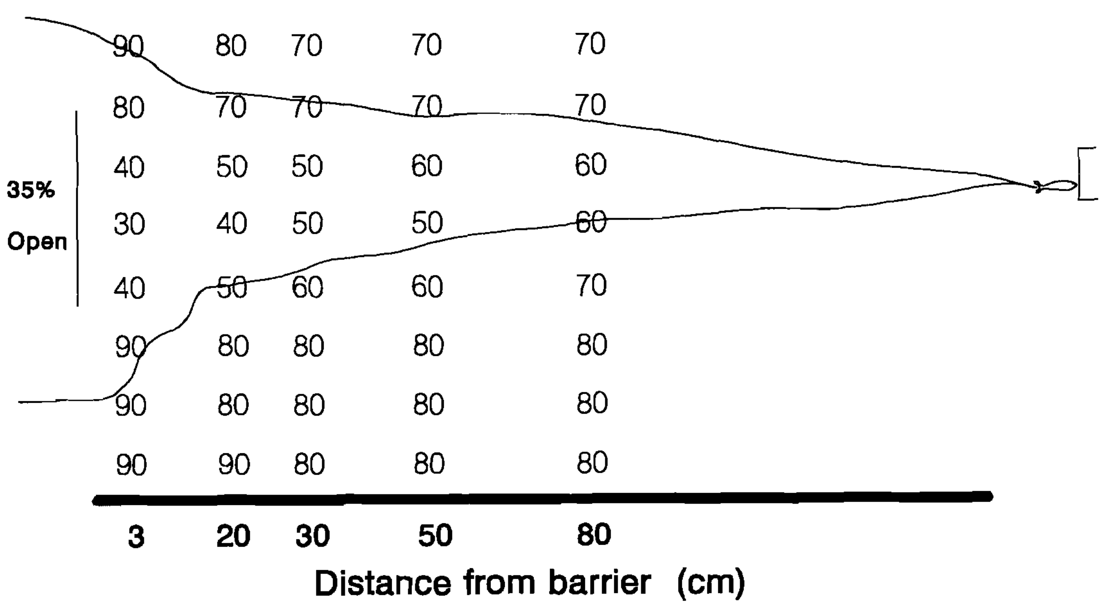

Figure 6. The average tracks for subyearling chinook salmon that moved above and below a 35% porosity barrier in 1991, superimposed over averaged water velocities (cm/sec) derived from WES studies.

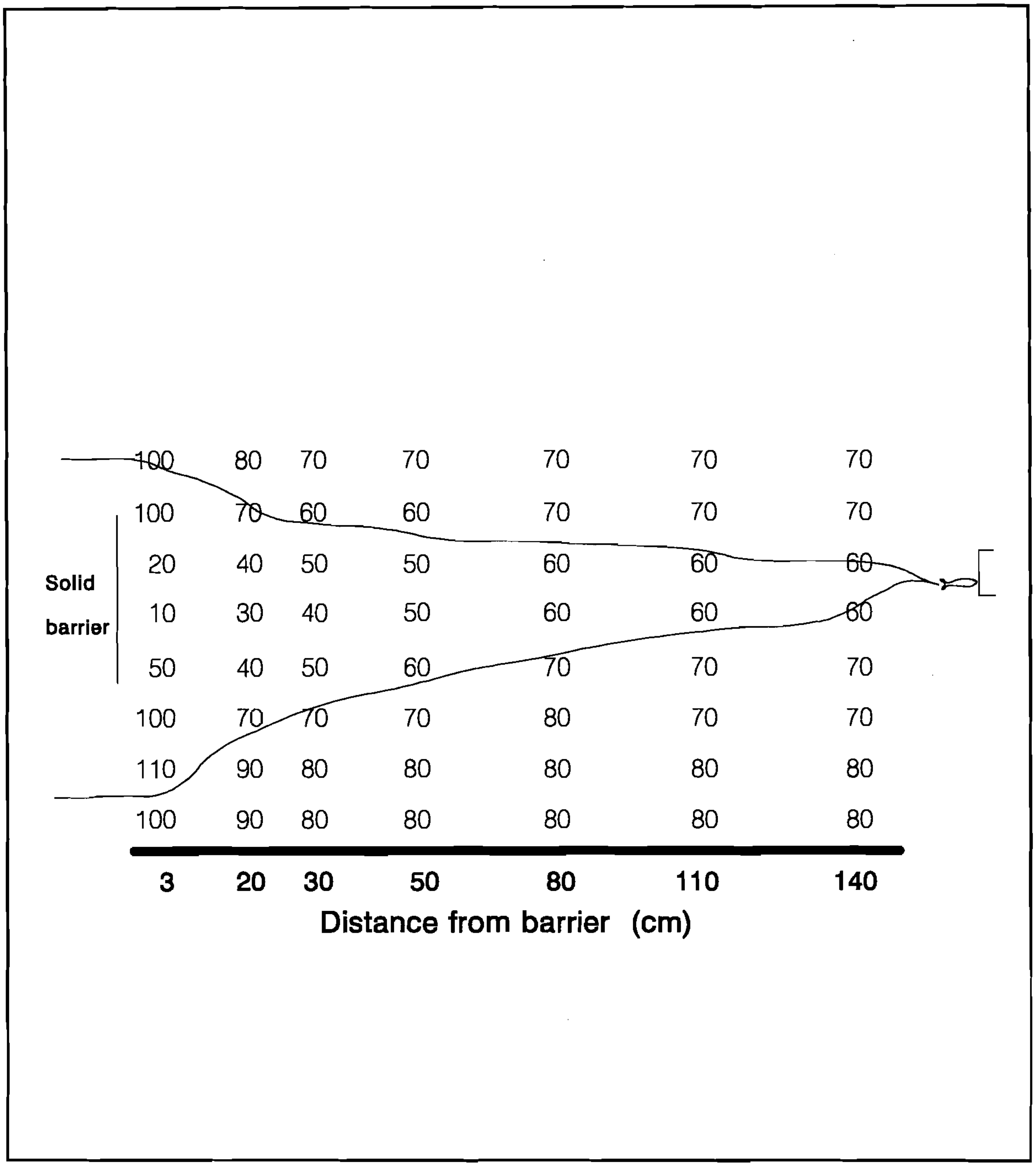

Figure 7. The average tracks for yearling chinook salmon that moved above and below a solid barrier in 1991, superimposed over averaged water velocities (cm/sec) derived from WES studies.

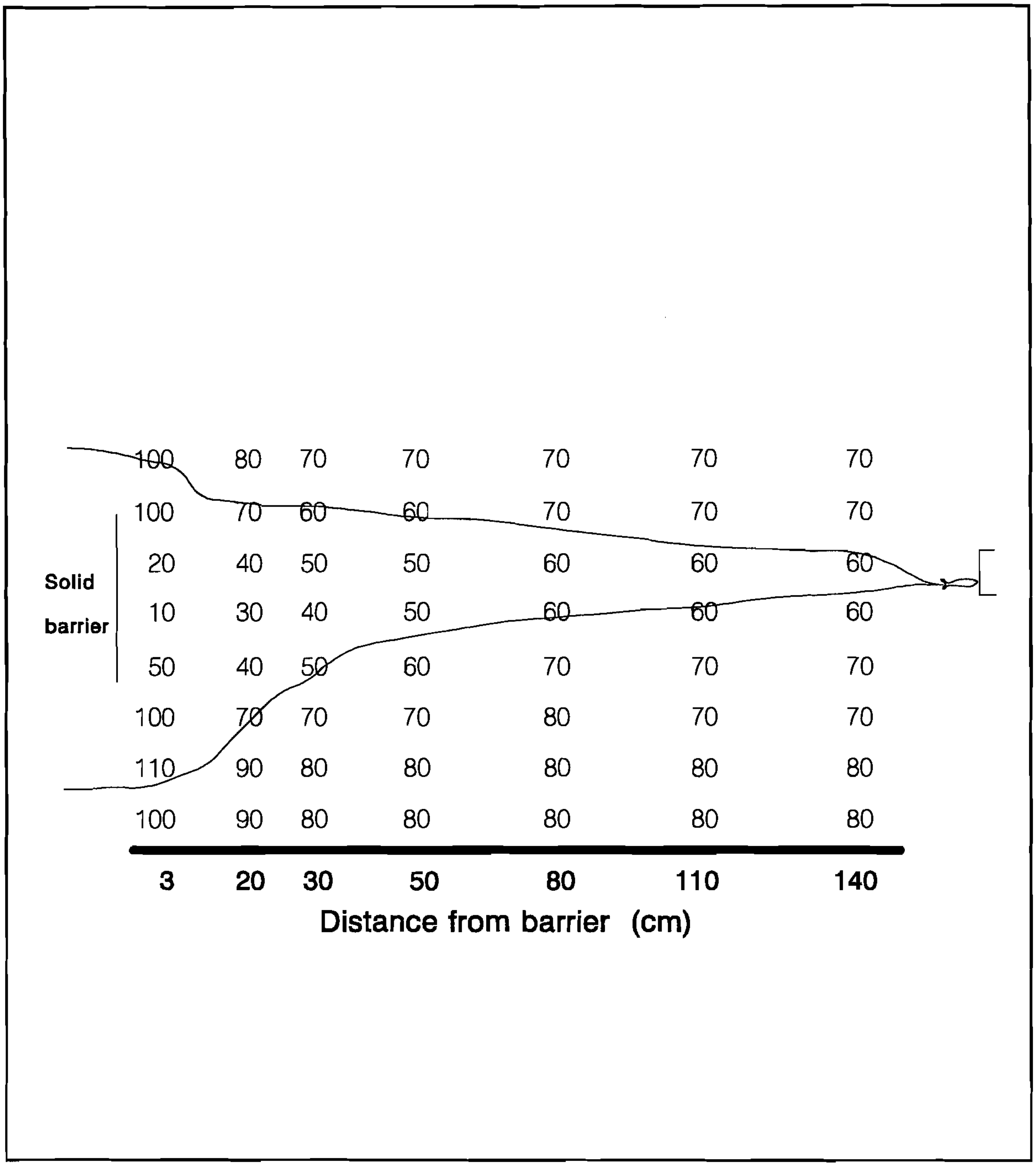

Figure 8. The average tracks for subyearling chinook salmon that moved above and below a solid barrier in 1991, superimposed over averaged water velocities (cm/sec) derived from WES studies.

appeared to sense the decrease in water velocity at the initial release elevation and subsequently moved either above or below the barrier (Figs. 5-8). We postulate that these fish were actively searching for and attempting to remain in flow where the least amount of change was occurring as they migrated downstream.

In 1992, the test fish exhibited the same avoidance behavior as the fish in 1991 (see Fig. 7). Anesthetized fish used in 1992 as a measure of water velocity in the flume drifted downstream at a relatively constant rate (Fig. 9), while the downstream velocity of the test fish indicated their increased swimming movement as they encountered areas with decreased water velocities (Fig. 10).

Discussion

In general, fish moved downstream with the current in a tail-first orientation when water velocities were somewhat uniform. This is the general orientation of fish to currents that the authors have observed numerous times at fish collection facilities. Smith (1982) proposed that this is the general orientation in the river of all Columbia River migrants. That fish moved with the flow was also expected since as fish become more smolted, their overall swimming ability lessens and their reactions change with respect to flow (Thorpe 1989). A reaction to the barriers by the test fish was expected because as a fish approaches a stationary object, the current pattern around the fish undergoes a change that is reflected by a change in the pressure on the fish's body which is then detected by the lateral line (Kuiper 1967). As the change in water velocity approached 10 cm/second over a distance of approximately 10 cm, fish elicited the largest swimming response. This likely relates to the size of the fish and

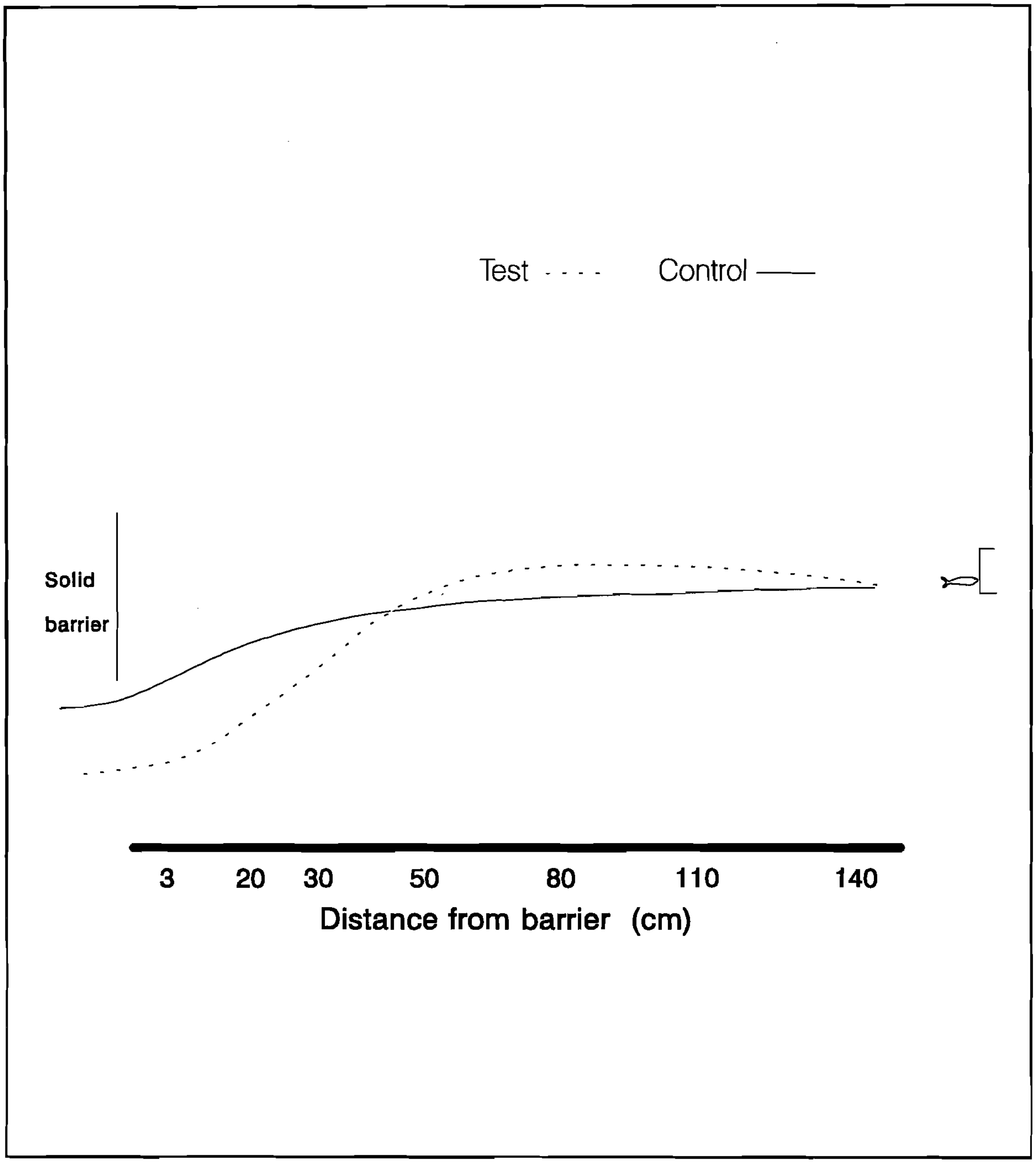

Figure 9. Average track of control (anesthetized) and test (alert) yearling chinook salmon in 1992 with a solid barrier in place.

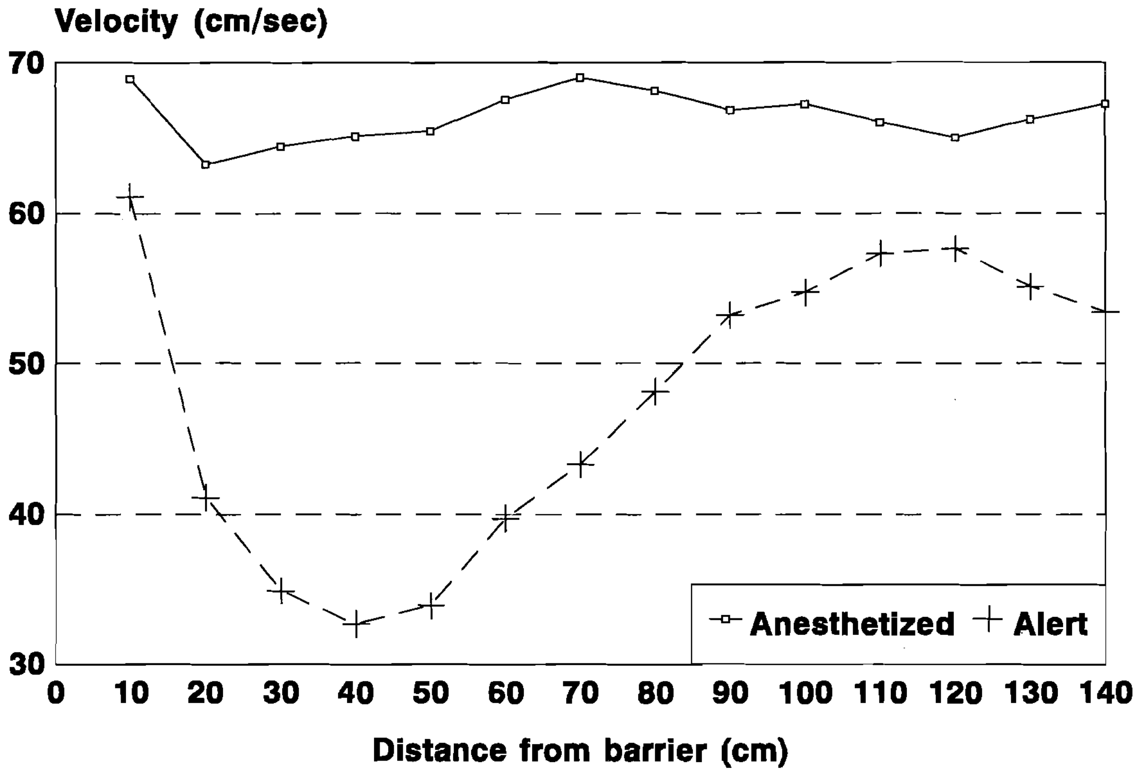

Figure 10. Comparison of the average downstream velocities of test (alert) and control (anesthetized) yearling chinook salmon in the Pasco flume, 1992.

the ability of the lateral line to detect differences in adjacent water velocities when pronounced local water velocity differences existed (Dijkgraaf 1967). The length of fish used in these studies ranged from 10 to 16 cm. Their lateral line lengths were approximately 8 to 12 cm. It appeared that as the fish detected areas where the water velocity was decreasing at a rate of approximately 10 cm/second over a 10 cm distance (about the average length of the lateral line for most fish), they moved to areas where changes in water velocities were less pronounced. We believe this reflected a normal and evolutionarily-derived response to changes in water velocity for migrant salmon smolts from upper Columbia River basin areas. Without this reaction to flows, smolts that must migrate hundreds of kilometers to the ocean would likely reach the ocean too late (or not at all) to survive and return as adults.

Although our research identified apparently consistent responses in downstream migrant chinook salmon as they encountered areas with decreasing water velocities, we recognize that the tests were conducted under a limited range of conditions. Most tests were conducted in water velocities of approximately 0.7 m/s. It is possible that fish entrained in much higher water velocities would react differently to water velocity changes, particularly if the changes were abrupt. However, if the fish behavior we observed results from a response to changes in water velocity, and they rely on their lateral lines to detect these differences, we would expect that the behaviors we observed would occur under most conditions. Fish released into higher velocity conditions would likely react more quickly and their reaction quite possibly would occur farther upstream from the barriers.

We were unable to observe fish behavior in total darkness; therefore, we can not say with certainty that fish behavior in those conditions would equal what we observed. Tests with blinded fish might provide some insight, but we did not try them. The tests with the 53% porosity barrier do provide some insight. Since most fish moved directly downstream of the release tube and contacted the barrier with their tails, we believe that when we did observe responses, they were related to changes in water velocities and not the result of behavior related to visual cues. Additionally, since the fish behavior we observed generally correlated with the behavior that we hypothesized fish would occur, we feel that our tests and the test facilities provided useful and meaningful results.

The effectiveness of screening systems to divert juvenile migrant salmon is highest when the least amount of deflection (flow and fish) occurs. However, high porosity screens also impinge fish. As screen porosity is decreased to minimize fish impingement, water velocities above the screens are also decreased. If screens decrease water velocities too quickly, juvenile migrants will likely attempt to avoid the areas to which the screens were designed to divert fish. The results from this study indicate that juvenile salmonid migrants of the size commonly observed in the Columbia River system (fork length range of approximately 10-16 cm) when migrating in flows of approximately 0.7 to 0.8 m/s likely will avoid areas where water velocities decrease by approximately 10 cm/second over a distance of 10 cm and move toward areas with constant or increasing water velocities. Although we believe that similar responses will occur under conditions where flows are outside what we tested, additional laboratory studies conducted over a wider range of water velocities, in a larger test facility, and possibly under different lighting conditions could possibly affirm our conclusions.

OBJECTIVE 2 - EVALUATE THE RELATIONSHIP BETWEEN FISH GUIDANCE AND CHANGES IN PHYSICAL FACTORS SUCH AS WATER TEMPERATURE, TURBIDITY, OR FLOW

Approach

As much data as possible were compiled from FGE studies conducted during the 1980s and 1990s. This included FGE percentages for the different salmonid species under various test conditions and the available physical data corresponding to the various tests. These data were then analyzed for correlations between FGE and the physical factors.

To determine the scope of the data set, this objective was discussed with NMFS and COE personnel who are or have been involved with FGE studies. A list of physical and biological factors potentially affecting FGE was developed as a result of these discussions (Table 1).

With such a large number of variables, insufficient numbers of FGE replicates existed to evaluate correlations with all of the possible factors. Thus, the list was pared down to six factors for which data were available, which were considered potentially important, and for which data could be compiled through a reasonable effort (Table 2).

Several other factors that could have affected FGE results were also initially considered potentially important, particularly turbine discharge. However, on reviewing the field tests, it was found that FGE studies generally used constant megawatt (MW) loads throughout a season. Since the head on the units varied little, the discharge also varied little. Few cases existed where turbine discharge was altered specifically to test if it affected FGE, and in those cases, results varied so much that no conclusions could be drawn. Other

Table 1. Physical and biological factors potentially affecting fish guidance efficiency.

RIVER FLOW

Unit discharge (kcfs)
Unit head (feet)
Adjacent unit discharge (kcfs)
Upstream project operation (spill/powerhouse proportional flow)
Spill (kcfs)
Debris (location in relation to test unit as well as amount)
Flow up gatewell (cfs)
Total powerhouse flow (kcfs)

WATER/WEATHER CONDITIONS

Temperature (river)
Turbidity
Dissolved oxygen
Dissolved nitrogen
Barometer change during each day
Overcast day/evening
Moon phase
Surface conditions (calm versus windy)

FISH/BEHAVIOR/PHYSIOLOGY

Early or late portion of outmigration
Degree of smoltification, Na^+-K^+ gill ATPase
Disease (e.g., bacterial kidney disease)
Predation
Number of fish in test
Number of fish (all species) per hour of test
Percentage of individual salmon species
Percentage hatchery versus wild
Fish size
Removal of transported fish from the river (e.g., subyearlings at McNary Dam which could mean potentially fewer guidable fish at the downstream dams--John Day, The Dalles, and Bonneville)

Table 1. continued

DAM/GUIDING DEVICE/TEST FEATURES

Intake approach structure (curved versus flat face of dam)
Distance of guiding device from trashrack (in conjunction with the intake approach structure)
Pivot point elevation (how far guiding device extends into the bulkhead slot)
Flow intercept
Type of barrier screen (fixed or traveling)
Position of operating gate
Number and configuration of nets used to capture unguided fish
Gatewell dipnet efficiency
Distance from reservoir shoreline to turbine unit used in tests
Distance from original river channel to turbine unit used in tests
Test duration
FGE and vertical distribution run simultaneously
Angle of guiding device
Porosity of guiding device
Use of trashrack deflector
Height of turbine intake in relation to the length of the guiding device

Table 2. Factors used to test fish guidance efficiency (FGE) correlations.

River temperature on the day of each FGE test[a]
Turbidity (measured by Secchi disk) on the day of each FGE test[b]
Test duration (number of hours)[b]
Number of fish (all species) collected during each FGE test[b]
The number of fish (all species) collected per hour of each FGE test[b]
Yearling chinook salmon proportion of all fish collected[b]

[a] Data compiled from U.S. Army Corps of Engineers Annual Fish Passage Reports.
[b] Data from field notes taken during individual fish guidance efficiency tests.

potentially important factors included fish condition (level of smoltification or disease incidence), percentage of hatchery fish versus wild fish in the population, the influence of predators on the vertical distribution of fish arriving at the face of dams, and change in barometric pressure. However, insufficient data were available to analyze these factors.

Results

The magnitude, rank (based upon absolute values of a correlation compared to other correlations within years), and sign direction were variable, even at the same dam, for yearling and subyearling chinook salmon (Tables 3 and 4). The variables analyzed did not appear to have a consistent effect on FGE test results. Temperature ranked high for all data combined for both yearling and subyearling chinook salmon, but between-year variability was large. However, there was an increasing trend in FGE with increasing temperatures during the spring, although FGE decreased during the summer as temperatures continued to increase. As the proportion of yearling chinook salmon decreased compared to steelhead, in many cases, guidance of chinook salmon also decreased, but these results were also not consistent in all years at all projects.

Discussion

The within year correlations of FGE with the tested variables were inconsistent between years. Thus, there were no trends that could be used to predict FGEs. There were a large number of factors that were we unable to evaluate because too little data was available. A huge number of factors likely affect FGE and we conclude that FGEs will always vary. Further,

Table 3. Correlations of FGE with several variables for yearling chinook salmon.

Dam	Year	n[a]	Hours[b]	Temp[c]	Secchi[d]	All Tot[e]	Per hour[f]	YC Prop[g]
L. GRANITE	ALL	189	-0.0439[h]	0.3998	0.0416	0.0457	0.1293	-0.3939
			5[i]	1	6	4	3	2
L. GRANITE	1982	19	0.5243	0.3813	-0.2248	-0.0214	-0.3248	-0.4219
			1	3	5	6	4	2
L. GRANITE	1983	38	-0.3712	-0.3169	-0.2584	0.1784	0.3278	0.0892
			1	3	4	5	2	6
L. GRANITE	1984	24	0.5378	0.5738	-0.1282	-0.0429	-0.3178	-0.8729
			3	2	5	6	4	1
L. GRANITE	1985	50	0.1391	0.5560	-0.3383	0.1384	0.1164	-0.6677
			4	2	3	5	6	1
L. GRANITE	1987	40	0.0753	0.1609	-0.2570	-0.1709	-0.1023	-0.2690
			6	4	2	3	5	1
L. GRANITE	1989	18	-0.4701	0.5117	0.4197	-0.1798	-0.0375	-0.7096
			3	2	4	5	6	1
L. GOOSE	ALL	42	-0.3460	-	-	-0.0368	0.1260	0.2024
			1	-	-	4	3	2
L. GOOSE	1986	36	-0.3288	-	-	-0.0260	0.1589	0.3476
			2	-	-	4	3	1
L. GOOSE	1987	6	-0.6760	-	-	0.3351	0.4996	-0.7288
			2	-	-	4	3	1
L. MONUMENTAL	1986	15	0.0671	0.1771	-0.0175	-0.0495	-0.0866	-0.2533
			4	2	6	5	3	1
ICE HARBOR	1987	5	0.5490	-0.2816	-	-0.5454	-0.7508	-0.7388
			3	5	-	4	1	2
MCNARY	ALL	38	-0.4334	-0.1797	-0.0262	-0.2283	-0.0689	0.0088
			1	3	5	2	4	6
MCNARY	1979	26	-0.1361	-0.0121	-0.1477	0.0869	0.1191	-0.1612
			3	6	2	5	4	1
MCNARY	1982	6	0.1844	-0.2857	-0.4615	0.5695	0.4814	-0.1795
			5	4	3	1	2	6
MCNARY	1987	6	-0.6824	-	-0.2022	-0.8538	-0.7981	0.9262
			4	-	5	2	3	1
JOHN DAY	1985	12	-0.0132	0.5349	0.3442	-0.3609	-0.2562	-0.6183
			6	2	4	3	5	1
THE DALLES	ALL	28	0.0872	0.2536	0.0999	-0.2610	-0.3742	-0.5888
			6	4	5	3	2	1
THE DALLES	1985	12	0.3082	0.3698	0.3036	-0.1960	-0.1429	-0.8452
			3	2	4	5	6	1
THE DALLES	1986	16	-0.4141	0.7109	0.0175	-0.0059	-0.4879	-0.7135
			4	2	5	6	3	1
BONNEVILLE I	ALL	36	0.5750	-0.5086	-0.0411	0.3074	0.1106	0.1084
			1	2	6	3	4	5
BONNEVILLE I	1981	29	-0.1361	0.0228	-0.1848	0.4276	0.4300	-0.2580
			5	6	4	2	1	3
BONNEVILLE I	1989	7	0.2657	-0.4993	-0.0194	-0.7808	-0.6928	0.4147
			5	3	6	1	2	4
ALL	ALL	365	0.2748	0.4725	0.1389	-0.1108	-0.1098	-0.2774
			3	1	4	5	6	2

[a] Number of tests.
[b] Number of hours FGE test was run.
[c] River temperature during FGE test.
[d] Secchi disk turbidity during FGE test.
[e] Total of all fish sampled during FGE test.
[f] Number of fish sampled per hour during FGE test.
[g] Yearling chinook salmon proportion of all fish collected.
[h] Correlation of FGE and explanatory variable.
[i] Correlation rank in that data set.

Table 4. Correlations of FGE with several variables for subyearling chinook salmon.

Dam	Year	n[a]	Hours[b]	Temp[c]	Secchi[d]	Total[e]	Per hour[f]
L. MONUMENTAL	1986	5	0.3452[g]	0.4005	-0.6955	0.3439	-0.0650
			3[h]	2	1	4	5
MCNARY	ALL	99	-0.3485	-0.1122	0.1308	-0.1930	0.0833
			1	4	3	2	5
MCNARY	1982	3	-	-	-	0.9127	0.9127
			-	-	-	-	-
MCNARY	1984	13	0.2752	-0.2733	-0.0556	0.1437	0.0124
			1	2	4	3	5
MCNARY	1986	54	-0.2478	0.0992	-0.1565	-0.1311	-0.0138
			1	4	2	3	5
MCNARY	1987	29	-0.6729	-0.6985	0.4075	-0.3318	0.2273
			2	1	3	4	5
JOHN DAY	ALL	18	0.3603	-0.4115	-0.3585	-0.3546	-0.3096
			2	1	3	4	5
JOHN DAY	1985	3	0.0999	-	0.1350	0.8452	0.8267
			4	-	3	1	2
JOHN DAY	1986	15	0.0293	0.1489	-0.1969	-0.4273	-0.2137
			5	4	3	1	2
THE DALLES	1985	6	-0.1992	0.2747	-0.5746	-0.9104	-0.8737
			5	4	3	1	2
BONNEVILLE I	ALL	64	0.5961	-0.7356	-0.7886	0.0110	-0.0341
			3	2	1	5	4
BONNEVILLE I	1981	31	-0.0858	0.5510	-0.5700	0.2048	0.2204
			5	2	1	4	3
BONNEVILLE I	1988	15	-0.2128	-0.8862	-0.8872	-0.6356	-0.6268
			5	2	1	3	4
BONNEVILLE 1	1989	18	-0.2373	-0.7977	-0.5504	-0.7540	-0.7506
			5	1	4	2	3
ALL	ALL	192	0.1978	-0.4714	-0.4344	-0.1641	-0.0837
			3	1	2	4	5

[a] Number of tests.
[b] Number of hours FGE test was run.
[c] River temperature during FGE test.
[d] Secchi disk turbidity during FGE test.
[e] Total fish sampled in FGE test.
[f] Number of fish sampled per hour in FGE test.
[g] Correlation of FGE and explanatory variable.
[h] Correlation rank for that data set.

there were no indications that changing the time or methods for FGE measurement would provide any likelihood of changing conclusions on which type of screens were recommended for installation.

OBJECTIVE 3 - REVIEW PAST FISH GUIDANCE EFFICIENCY TESTING DESIGNS TO EXPLAIN DIFFERENCES BETWEEN PROTOTYPE RESULTS AND ACTUAL FACILITY PERFORMANCE

Approach

The NMFS conducted FGE research with prototype submersible traveling screens (STS) at Lower Granite Dam in 1976-77, McNary Dam in 1978, and at Bonneville Dam First Powerhouse (Bonneville I) in 1981. Tests concentrated on yearling spring/summer chinook salmon during the spring outmigration because these fish were generally guided less efficiently than steelhead. Information was also collected on subyearling chinook salmon passing during the same period. Based on initial FGE measurements, which were generally greater than 65-70% for yearling fish, full complements of screens were installed for collection and bypass systems at the dams. After completing final STS installations, NMFS reevaluated FGE.

The initial FGE evaluations at Lower Granite and McNary Dams did not attach a net frame with fyke nets to the bottom of the STS to collect unguided fish, as in later years. Therefore, the measurement of FGE from early studies was based on the percentage of marked fish recovered in the gatewell compared to the total number of fish released. The test fish in 1976 were hatchery-reared, pre-smolt, yearling chinook salmon; in subsequent years, they were natural migrant yearling chinook salmon. Fish were collected in the forebay of

Lower Granite Dam by purse seine in 1977 and by dipnet from the gatewells at McNary Dam in 1978. The fish were placed in tanks on a flat-bed truck located on the powerhouse deck. A 10-cm hose from the tanks extended down the face of the dam, through the trashrack, and into the turbine intake. The end was held in place by a steel cable passing through the turbine intake and up into the bulkhead slot, so that the point of release was about 6 m upstream from the STS and about 2 m from the intake ceiling.

Reevaluation tests at Lower Granite and McNary Dams and all testing at Bonneville I used the present standard methods for determining FGE. Guided fish were removed by a dipnet from the gatewell. Fyke nets below and behind the STS captured unguided fish. Fish guidance efficiency expressed as a percentage was calculated by dividing the number of fish guided by the total number of fish entering the turbine intake: FGE = guided fish/(guided fish + unguided fish) x 100%.

Finally, since nearly all FGE studies prior to 1983 were conducted during the spring outmigration, the estimates of FGE for subyearling chinook salmon did not include the summer period, when most subyearling chinook salmon migrate.

Results

The prototype tests indicated that STSs would provide high FGE for spring/summer (yearling) chinook salmon (Table 5). Estimates for steelhead were generally 10-20% higher. However, the results from Lower Granite Dam were questioned as early as 1980 when less than 50% of marked fish released at the head of the Lower Granite reservoir were recovered at the dam. In the early 1980s, FGEs measured across the season at Lower Granite Dam

Table 5. Comparison of fish guidance efficiency (FGE) between prototype and final installation of submersible traveling screens for yearling chinook salmon.

Dam	Year	FGE prototype	FGE final installation[a]	FGE reevaluation[b]
Lower Granite	1976-77	85%		
	1982-85		50 to 70%	none
McNary	1978	68 to >70%		
	1982-87		>70%	61%
Bonneville I	1981	>70%		
	1989		38 to 48%	none

[a] Fyke net placed under the STS to capture unguided fish.

[b] Fyke net placed in downstream slot to capture unguided fish.

with the present techniques averaged approximately 50%, but ranged from a low of 30% early in the migration to 70% toward the end. At McNary Dam, FGE measurements after final STS installation remained the same for yearling smolts; however, tests conducted over the entire subyearling chinook salmon migration indicated that FGE dropped from 60-70% in the spring to 20-40% in the summer.

Because of the differences observed between initial (1981) and final STS testing at other dams, the STSs at Bonneville I were subsequently retested and fish guidance for all species, except coho in 1991, was lower than 70% (Fig. 11). During the summer, FGE for subyearling chinook salmon averaged only 8%.

Discussion

The initial FGE measurements with hose releases at Lower Granite Dam did not provide accurate estimates of fish guidance. Subsequent testing with fyke net frames below the STS resulted in lower estimates of FGE; although, depending on the time of the migration, FGE ranged from quite low values (<35%) to over 70%. This may have related to the smoltification level of the fish passing the dam, which in turn was a product of their origin. Hatchery fish now provide the bulk of migrating populations. Fish passing the dam early in the migration season generally have lower smoltification levels than those passing later, and hatchery fish may have lower smoltification levels than wild migrants. Giorgi et al. (1988) found a correlation between degree of smoltification and increased FGE. Smoltification levels may also explain why FGE at McNary Dam remained consistent throughout the migratory period. By the time fish reach McNary Dam, smoltification levels for most fish are likely high. In addition to, or in combination with smoltification, the consistently high measurements of FGE at McNary Dam may have resulted from 1) the basic structure of the project, which may be more conducive to high levels of FGE; 2) selectivity of fish that survived spill or were guided when passing prior dams (fish less susceptible to guidance or spill at upriver Snake and mid-Columbia River dams and passed through the turbines likely survived at a lower rate to McNary Dam); 3) techniques used to measure FGE at the dam; or 4) a combination of the three.

Recent research , however, has cast doubt on the validity of absolute values of FGE when measured with fyke net frames under the STS. Research in 1992 at McNary Dam determined that the FGE of an STS when measured with a fyke net frame in the downstream slot averaged only 61% (McComas et al. 1994), compared to estimates >70% for studies between 1982 and 1987 when fyke nets were under the STS. Further, recent research to estimate survival of juvenile salmon that pass through dams and reservoirs on the lower Snake River found that the probability of recapture (a slightly higher estimate than FGE) at Lower Granite and Little Goose Dams under a no-spill conditions was generally less than 50% (Muir et al. 1996.) This compares to FGE estimates made with fyke nets under the STS of 55-70% (Ledgerwood et al. 1988.)

We believe that the fyke net frames placed directly below the STS may create changes in flow conditions that fish detect, which results in some fish avoiding the area. The consequence is an overestimate of the absolute FGE. There is no apparent effect of fyke nets in the downstream slot on measurements of FGE.

The difference between prototype FGE at Bonneville I and subsequent testing has no obvious cause. Identical research methods were used during both test periods. The drop in guidance occurred for all species (Fig. 11). Thus, differences in smoltification levels were unlikely to have caused the observed changes, unless the percentage of hatchery fish in the population passing the dam increased tremendously. We were unable to determine if this occurred. Other potential explanations of the differences include changes in forebay hydraulic conditions as a result of the construction of the new navigation lock or the changes in northern squawfish (*Ptychocheilus oregonensis*) abundance.

Beginning in the mid-1980s, as part of construction for the new navigation lock, substantial dredging and placement of rock groins altered the river current upstream from the dam. This possibly affected migrants approaching the dam. Fish approaching the dam deeper in the water column compared to earlier years could account for the reduced fish guidance.

Uremovich et al. (1980) estimated that the northern squawfish population in the Bonneville Dam forebay was <18,000 in 1980. This was prior to completion of the Bonneville Dam Second Powerhouse. In 1989, Gessel et al. (1994) estimated that the northern squawfish population in the Bonneville Dam First Powerhouse forebay alone was between 55,000 and 60,000. Migrant salmonids approaching the dam deeper in the water column to avoid predation would likely also guide at a lower rate. No direct test has been made of this hypothesis.

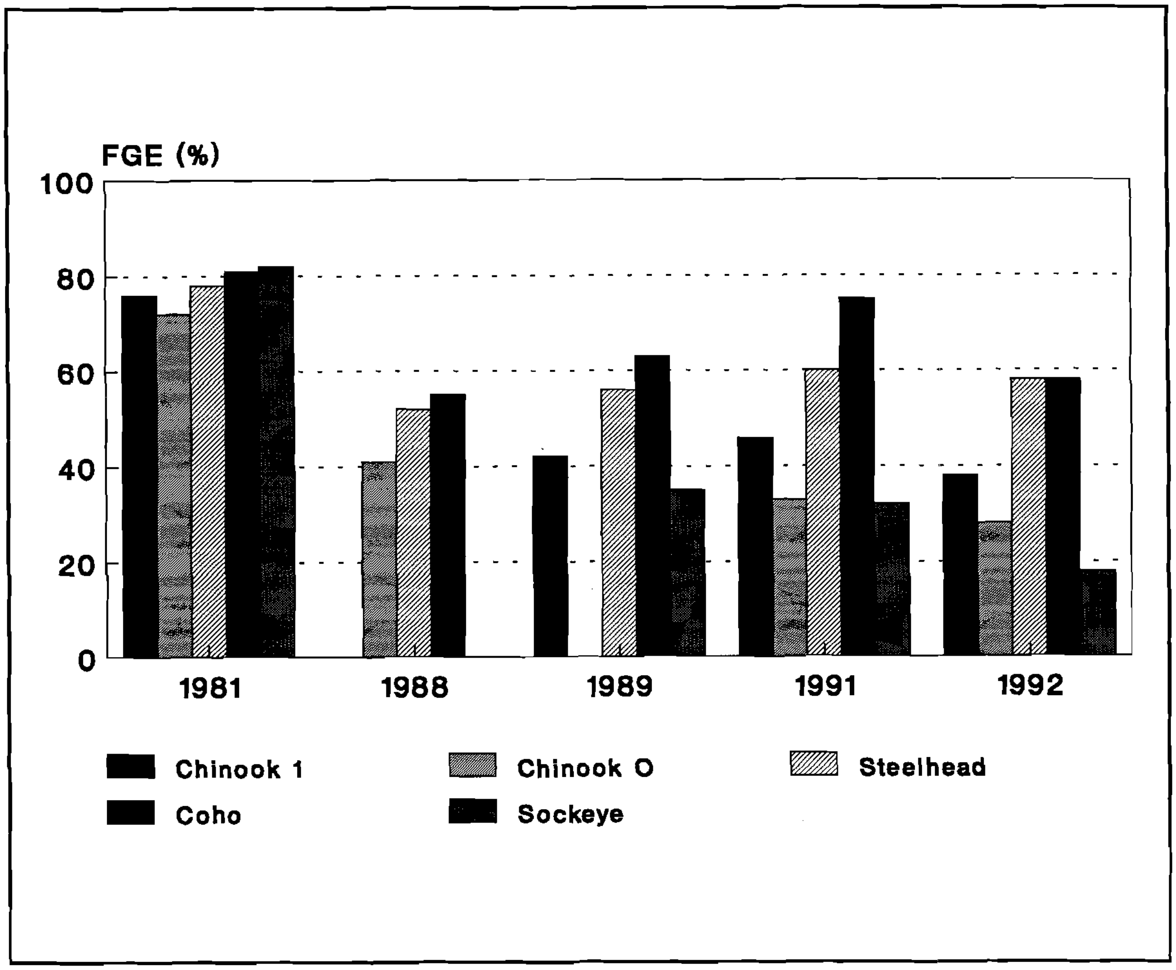

Figure 11. Fish guidance efficiency (FGE) estimates for salmonids at Bonneville Dam First Powerhouse during the spring migration period.

CONCLUSIONS

1. In the research facility, juvenile salmonids reacted to changes in water velocity over a short distance. When water velocities decreased by approximately 10 cm/second over a distance of approximately 10 cm, fish avoided the area and stayed in (or moved toward) areas with either higher velocities or where velocity differences were not as pronounced. Further testing might confirm these results for a broader range of conditions. In the interim, design of screens to divert fish should consider this fish behavior.

2. No direct correlations were found between fish guidance efficiency and physical factors analyzed such as turbidity or water temperature. It is unlikely that sufficient data will ever become available to predict changes in fish guidance related to changes in physical factors that may affect FGEs.

3. Fish guidance at dams may vary between years when migrant smoltification levels at the dam change or a selectivity for guidable fish has occurred. They may also vary due to water temperature changes or the size of predator populations in the forebays of dams.

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