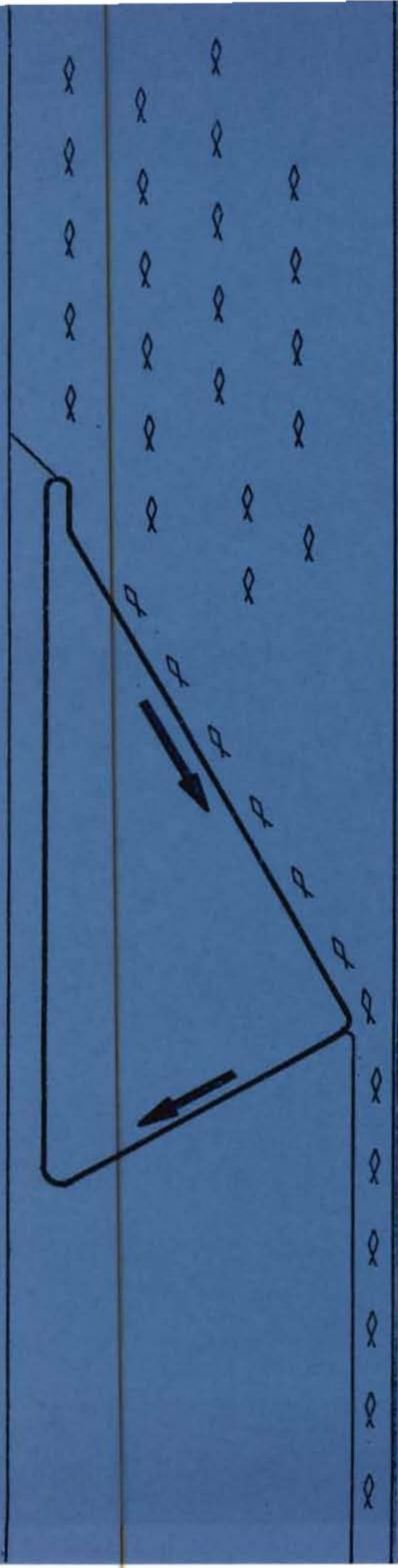

SUMMARY REPORT

BIOLOGICAL INVESTIGATION OF HORIZONTAL TRAVELING SCREEN MODEL VII

By

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HIGHLIGHTS

(1) Biological evaluations of Horizontal Traveling Screen (HTS) Model VII were made in a hydraulic flume on the Grande Ronde River near Troy, Oregon, using fingerling and fry chinook salmon. The triangular-shaped screen array was 27 feet long on the fish guiding leg (upstream face) (32 feet between centers of upstream and downstream turns) and traveled horizontally at a speed of 1.34 fps. Channel velocities in the flume were approximately 1.0 and 3.0 fps, whereas the normal velocity components at the screen array (30° to flow) were 0.5 and 1.5 fps.

(2) Conventional operation of HTS VII indicated that from 97 to 100 percent of all fingerling and fry chinook salmon can be safely diverted into a bypass at normal velocities of 0.5 and 1.5 fps.

(3) Fry impinging on the screen suffered no appreciable losses during exposure periods of up to 60 minutes at 0.5 fps normal velocity (approach velocity 1.0 fps).

(4) At a normal velocity of 1.5 fps (3.0 fps approach velocity), virtually no loss of impinged fry occurred until the fish were exposed on the screen for more than 6 min. (A screen traveling at 1.34 fps would traverse about 480 feet during a 6-min period).

(5) Injuries (hemorraghing) were noted among impinged fry at normal velocities of 1.5 fps and greater following prolonged exposure on the screen. Evidence of oxygen stress was observed among fry impinged on a screen for 15 minutes and longer at a 1.0 fps velocity, but no losses of fish occurred until impingement exceeded 30 min. Most of the observed injuries among surviving fry disappeared after 48 hours.

INTRODUCTION

To prevent fish from entering hazardous areas such as water intake canals, the National Marine Fisheries Service has been experimenting with various models of horizontal traveling screens (HTS) since 1965 (Bates, 1970 and Bates et al., 1970). A model VII HTS has evolved from this research. This model consists of a series of continuously moving rectangular screen panels hung vertically in a 30-60° triangular configuration with the panels traveling diagonally in the downstream transverse and parallel to the intake channel in the returning upstream direction. Fish migrating downstream are carried or guided into a bypass from which they can be diverted to safe areas.

Effectiveness of the traveling screen in diverting juvenile salmonids was tested under various controlled conditions in 1972. Biological tests began in May and continued until July when low river flow and high water temperatures prevented further efforts; testing was resumed in the fall and completed in December. The mechanical operation of the HTS VII was also observed but is covered in a separate report.

Most testing was done with the traveling screen at the experimental facility on the Grande Ronde River, but some additional tests were conducted with a stationary screen at the Northwest Fisheries Center, Seattle, Washington to further examine the effects of impingement on young fish. This report summarizes the results of the biological investigations.

MATERIALS AND METHODS

Experiments using HTS VII were run in a hydraulic flume (Figure 1) on the Grande Ronde River near Troy, Oregon. The flume was 250 ft long, 40 ft wide and 13 ft deep and could be partitioned into 20-foot wide channels. The horizontal traveling screen, bypass and inclined plane collection traps were installed in the downstream end of one of the 20-foot wide channels of the flume (Figure 2). Head gates at the upper end provided control for obtaining different water approach velocities to the screen.

The screen consisted of 48 panels with a total circumference of 96 feet and a fish guiding leg measuring 27 feet (total length from center of upstream and downstream turns was 32 ft). Each of the panels was covered with an 8 mesh, 0.028-inch-diameter galvanized wire cloth having a 0.097-inch clear opening yielding a 60.2 percent total open area.

In the diversion and impingement tests the water approach velocity was adjusted to prescribed experimental conditions (Tables 1 and 2) and test groups of fish were released upstream from the screen. Screen travel speed was 1.34 fps. Smaller fish would impinge on the screen and be carried downstream to the bypass, whereas the larger fish would be guided to the bypass collection area and recovered in an inclined screen trap as were the small fish. Fish which passed through the traveling screen were recovered in main channel traps located immediately downstream from the traveling screen (Figure 2). If test conditions required that the duration of impingement for the smaller fish be extended beyond the normal screen operation cycle (approximately 20 seconds for

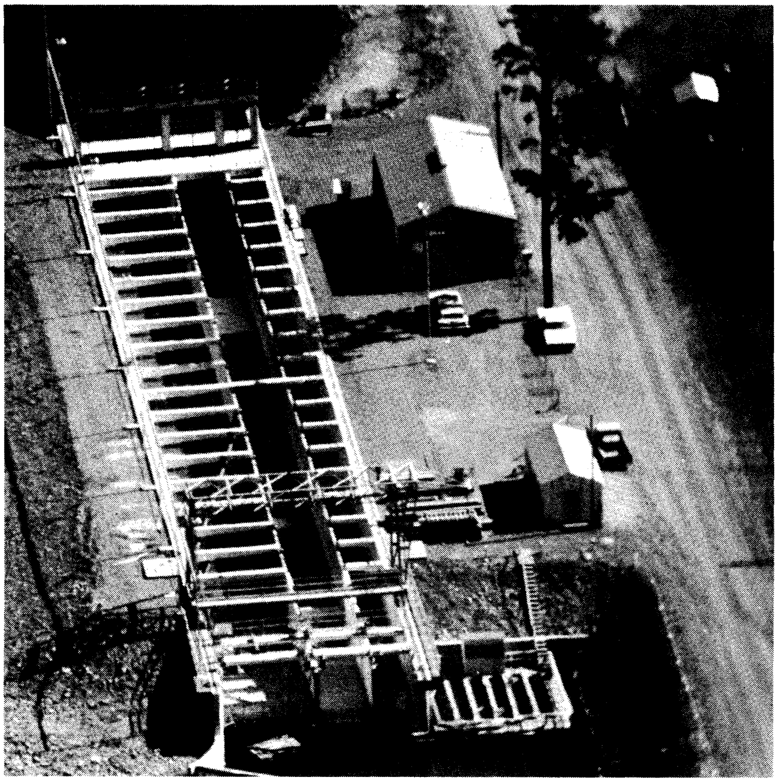

Figure 1.--Flume used for testing the HTS VII, located on the Grande Ronde River near Troy, Oregon.

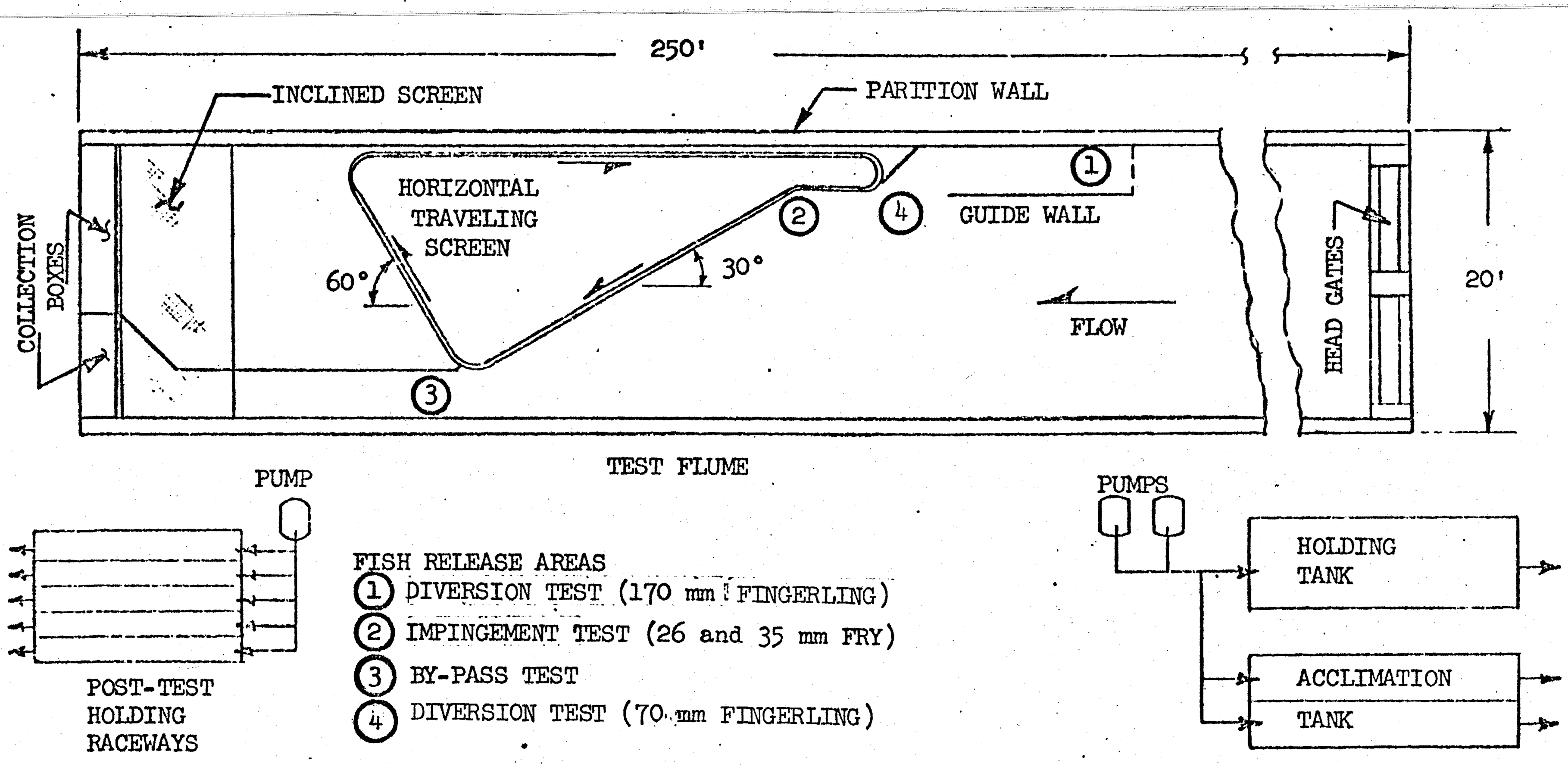

FIGURE 2.--PLAN VIEW OF TROY TEST FLUME--SHOWING INSTALLATION OF HTS VII, INCLINED SCREEN, AND FISH HOLDING AREAS.

Table 1.--Biological test plan to determine diversion efficiency of horizontal traveling screen Model VII for two-size groups of spring chinook salmon fingerling.

Normal approach velocity[1]	Light condition	Type of test	70 mm size group		170 mm size group	
			Number of replicates	Number of fish per replicate	Number of replicates	Number of fish per replicate
0.5 fps	Day	Diversion	-	-	5	300
		Bypass (Control)	-	-	1	300
		Handling (Control)	-	-	1	300
	Night	Diversion	3	300	4	300
		Bypass (Control)	3	300	1	300
		Handling (Control)	2	300	-	-
1.5 fps	Day	Diversion	5	300	2	300
		Bypass (Control)	3	300	2	300
		Handling (Control)	5	300	-	-
	Night	Diversion	6	300	5	300
		Bypass (Control)	3	300	-	-
		Handling (Control)	2	300	-	-

1/ In the tables and text the normal velocity component perpendicular to the face of the screen is used. The normal velocity component is a function of screen angle and channel velocity. For example for a channel velocity of 3 fps with a screen set at a 30° angle to the flow the normal velocity component is 1.5 fps.

Table 2.--Biological test plan for determining effects of impingement on two size groups of spring chinook salmon fry.

Normal approach velocity[1/]	Light Condition	Type of test	Duration of impingement (Minutes)	26 mm size group: Number of replicates	26 mm size group: Number of fish per replicate	35 mm size group: Number of replicates	35 mm size group: Number of fish per replicate
0.5 fps	Day	Impingement	6	12	300	-	-
		"	30	11	300	-	-
		"	60	12	300	-	-
		Bypass (Control)	-	13	100	-	-
		Handling (Control)	-	6	100	-	-
1.5 fps	Day	Impingement	2	9	300	-	-
		"	6	14	300	9	300
		"	15	12	300	6	300
		"	30	6	300	2	300
		"	60	2	300	2	300
		Bypass (Control)	-	19	100	11	100
		Handling (Control)	-	6	100	3	100

1/ In the tables and text the normal velocity component perpendicular to the face of the screen is used. The normal velocity component is a function of screen angle and channel velocity. For example for a channel velocity of 3 fps with a screen set at a 30° angle to the flow the normal velocity component is 1.5 fps.

traverse of upstream leg at 1.34 f.p.s. travel speed), the screen was stopped until the prescribed time of impingement was obtained. Fish recovered in traps were counted and examined for mortality and injury and the live fish were placed in holding tanks for 48 hours to determine delayed effects.

Effects of the bypass and collection operation on fish were examined by releasing fish in the entrance of the bypass and subsequently treating them in the same manner as fish guided into the bypass by the traveling screen. The effects of the handling operations were determined by simulating the processing of fish collected in a screen test and then transferring the fish directly to holding tanks for observation. These fish were not exposed to the screen, the bypass area, or collection traps.

At the Seattle Laboratory fish were impinged against a stationary screen placed perpendicular to flow (Figure 3). A series of tests were performed at water velocities of 1, 2, and 3 feet per second and for impingement times of 3, 6, 9, 12, 15, 30, and 60 minutes for spring chinook swim-up and buttoned-up fry. The fish were examined for type of injury immediately after testing and again after a post-test holding period of 48 hours. Handling tests, which simulated the operations of a regular test sequence except the fish were not released, were also conducted.

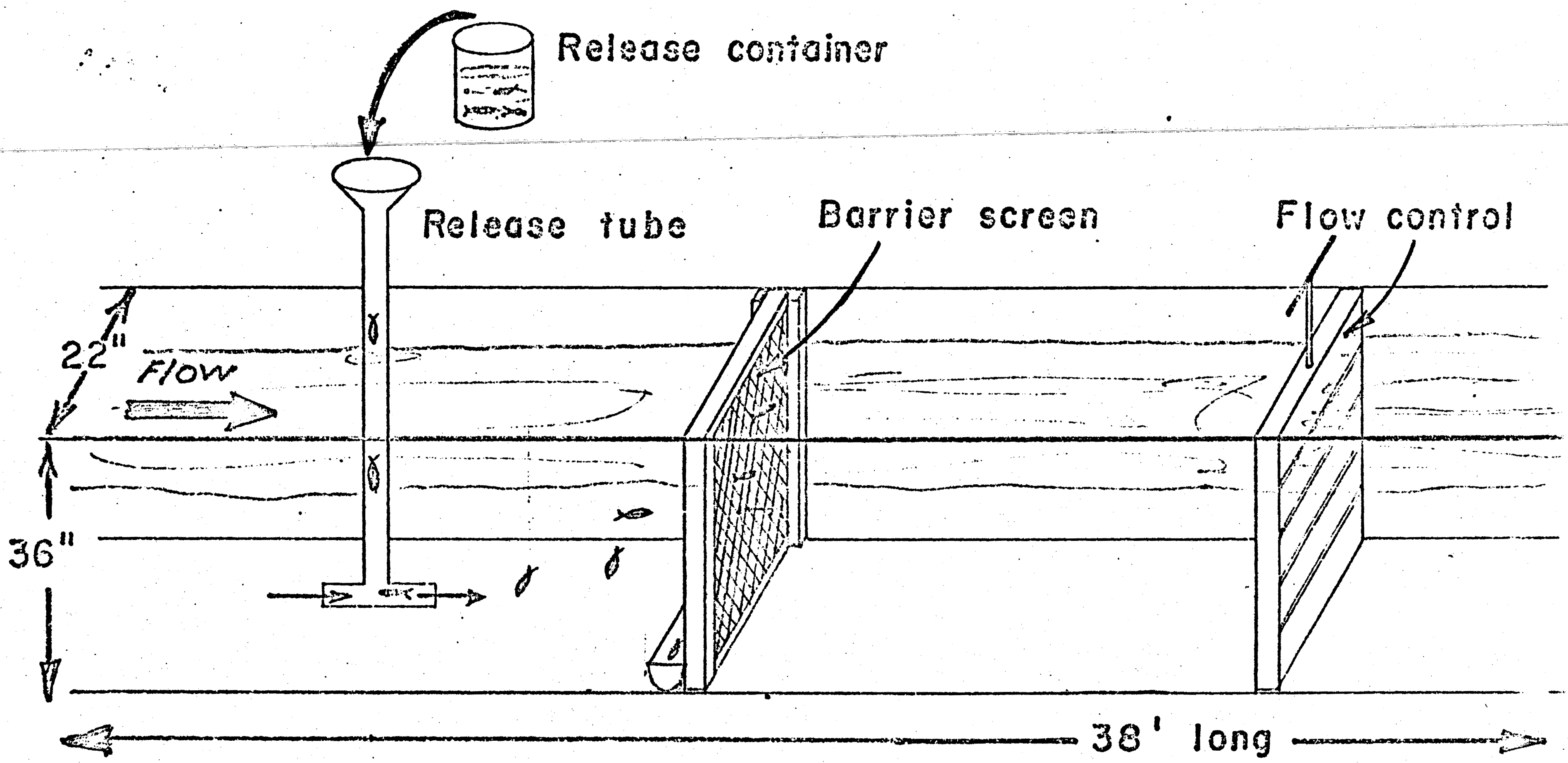

FIGURE 3.--SEATTLE LABORATORY FLUME USED TO TEST EFFECTS OF IMPINGEMENT ON CHINOOK SALMON FRY.

Hatchery-reared spring chinook, Oncorhynchus tshawytscha, were used in the HTS VII tests. The spring chinook were of four size groups: 170 mm, 70 mm, 35 mm, and 26 mm mean total length. The larger two size groups were fingerling and the latter two groups buttoned-up and sac fry. The fish were transported to the test site by tank truck and were held in separate compartments of a large holding tank for an acclimation period prior to testing. The sac and buttoned-up fry were contained in floating pens within the tank. Each compartment contained 380 cu ft of water and was continuously supplied with river water at a rate of 100 to 275 gpm depending upon the number of fish being held. Fish from the holding tank were counted into test groups and placed into 8 cu ft screen holding pens. These pens were submerged in another holding tank containing 760 cu ft river water which was continuously replaced at 400 gpm. The fish were held from 2 to 4 days prior to testing. A subsistence diet of Clark's dry food was fed to the fish.

In the Seattle Laboratory tests, spring chinook swim-up and buttoned-up fry measuring 37 mm mean total length were used. The fry were held in separate troughs according to stage of development and fed starter mash three times daily. A continuous supply of fresh water was supplied to the troughs.

ANALYSIS OF DATA

Recovery of fish in the bypass collection traps and main channel traps provided data for calculating the diversion efficiency of the traveling screen and effects of the screen on the physical condition of the fish.

The guiding efficiency, E, was calculated as:

$$E = X_{12}/(X_{12} + X_{18})$$

where,

X_{12}: total number of fish recovered in the bypass collection area

X_{18}: total number of fish recovered in the main channel collection area

The effects of impingement and guiding on fish were obtained by first calculating the gross effects of the entire experimental operation from release through recovery for the diversion tests and also for the bypass control tests. The diversion tests calculations were then adjusted for the bypass control effects to isolate the direct effects of the traveling screen.

The gross effect, GD, from release through post test holding for a diversion test was calculated as:

$$GD = (X_{13} - X_{14})/X_{11}$$

where,

X_{13}: number of live fish in the bypass recoveries after post test holding

X_{14}: number of dead fish in the bypass recoveries after post test holding

The gross effect, GC, from release through post test holding for a bypass control test was calculated as:

$$GC = (X_{22} - X_{23})/X_{21}$$

where,

X_{21}: total number of fish recovered in the bypass area

X_{22}: number of live fish in the bypass recoveries after post test holding

X_{23}: number of dead fish in the bypass recoveries after post test holding

The direct effect of the screen as adjusted for the bypass collection and handling operations was calculated as:

$$DE = GD/GC.$$

If GD was equal to or greater than GC the direct effect of the screen was taken to be one (e.g., no mortality upon encounter of a fish with the screen).

Percent survival and injury of the spring chinook swim-up and buttoned-up fry were calculated for each test velocity and impingement time.

RESULTS

Diversion efficiency and survival of spring chinook fingerling are shown in Table 3. The diversion efficiency for fingerling was 97 percent or greater in all except one test at 1.5 fps approach velocity using 70 mm fish during a night test. A series of bypass seal failures accounted for the lower efficiency (91.5 percent) in this test. Less than one percent of all the fingerling tested showed external injury. These injuries (small areas of descaling) could be attributed to the collection of fish. The overall survival (after 48-hour post-test holding) of the fingerling under all test conditions was greater than 97 percent. No impingement of fingerlings was observed during these tests.

Table 3.--Diversion efficiency and survival of spring chinook in relation to approach velocity and light condition on the horizontal traveling screen.

Normal approach velocity (fps)	Light condition	70 mm size fingerling			170 mm size fingerling		
		Number of tests	Diversion efficiency (Percent)	Survival (Percent)	Number of tests	Diversion efficiency (Percent)	Survival (Percent)
0.5	Day				5	99.8	97.4
	Night	3	98.4	97.6	4	98.6	100.0
1.5	Day	5	97.9	98.5	2	99.6	99.7
	Night	6	91.5	99.7	5	99.8	99.9

The minimum diversion efficiency of sac and buttoned-up fry was 91.1 percent for the series of tests conducted at 0.5 fps normal approach velocity for 60 minutes impingement (Table 4). An increased number of recaptures in the main channel traps during these tests indicated that the sac fry were not being efficiently diverted into the bypass. It was found that the fish were able to move vertically down the screen while impinged and finally escape between the screen panels and bottom guide track. This would be prevented by installing a bottom seal.

Survival of sac fry diverted at 0.5 fps approach velocity was virtually 100 percent for impingements up to 60 min (Table 4). Oxygen stress was not observed after 12 minutes of impingement; however, after 15 minutes about 25% of the fish showed stress. Tests with buttoned-up fry at 0.5 fps were excluded because of the high survival obtained with the sac fry. Survival of sac fry at 1.5 fps was 99 percent for impingement times of 2 to 15 minutes; this dropped to 39 percent at 60 minutes impingement. Survival of buttoned-up fry was 100 percent at 6 minutes impingement and dropped to 21.5 percent at 60 minutes impingement (Table 4); tests at 15-,30-, and 60-minute impingement times were conducted during sub-freezing weather and many fish froze to death during post test holding. It was not possible to separate these deaths from test mortalities. Oxygen stress was not observed in either size group of fish after 6 minutes of impingement, however after 15 minutes about 100% showed stress.

The data for sac and buttoned-up fry show a drop in survival for an increase in impingement time at 1.5 fps normal velocity, particularly for periods of 30 and 60 minutes. The fry tested at all velocities were progressively less active upon collection after the longer impingement periods. This behavioral change could be due to oxygen stress characterized by the fish surfacing in a vertical position with their mouths protruding

Table 4.--Diversion efficiency and survival of spring chinook fry in relation to approach velocity and the duration of impingement on Horizontal Traveling Screen Model VII.

Normal approach velocity (ft/sec)	Duration of impingement (Minutes)	26 mm Sac fry			35 mm Buttoned-up fry		
		Number of tests	Diversion efficiency (Percent)	Survival (Percent)	Number of tests	Diversion efficiency (Percent)	Survival (Percent)
0.5	6	12	99.4	100.0	--	--	--
	30	11	99.5	100.0	--	--	--
	60	12	91.1	99.4	--	--	--
1.5	2	9	99.8	98.5	--	--	--
	6	14	97.8	99.7	9	98.7	100.0
	15	12	98.9	99.6	6	97.6	94.3
	30	6	96.5	90.6	2	99.8	82.1
	60	2	96.6	39.1	2	98.4	21.5

out of the water while gasping. The condition disappeared within an hour of post-test holding.

Additional tests on the effect of impingement on swim-up and buttoned-up fry were conducted on the stationary screen at the Seattle laboratory facilities. Data relating injury and survival by approach velocity and impingement time are shown in Table 5. At an approach velocity of 1 fps, virtually all swim-up and buttoned-up fry survived a 30-minute impingement. Following a 60-minute impingement survival dropped to 97.5 and 88.1 percent, respectively, for swim-up and buttoned-up fry. After a 15-minute impingement at 1 fps approach velocity about 25% of the fry began to show oxygen stress; one-half of them showed it at 30-minutes. The fry struggled to get off the screen throughout all the impingement periods.

Survival rate for both sizes of fry was approximately the same at 2 fps approach velocity for impingement times up to 9 min. (100-98%). Mortality increased markedly in both groups after 15 min. Few fish showed oxygen stress at 6 min; this sympton increased until nearly all fish exhibited it at 15 min. After 9 min. impingement some fish lost equilibrium and by 15 min. the fish were non-responsive. Fish impinged for 6 min. showed greater activity and response than those tested for 9 min. when compared 48 hours later. No behavioral differences were observed between control fish and those impinged for 3 or 6 min. upon examination 48 hours later. The swim-up fry showed a higher percentage immediate injury (20 to 40 percent) than the buttoned-up fry (0 to 6 percent), but after the 48-hour holding period the percentage injury of the survivors for both groups was about the same (0 to 9 percent for swim-up fry and 0 to 6 percent for buttoned-up fry). It may be noted that immediate injuries were always higher than the delayed injuries. This will be explained in a subsequent discussion on the injury condition of hemorrhaging.

Table 5.--Percent injury and survival of spring chinook fry in relation to approach velocity and duration of impingement.[1]

Duration of impingement (minutes)	Swim-up fry: Percent Injury, Immediate	Swim-up fry: Percent Injury, Delayed[2]	Swim-up fry: Percent Survival[2]	Buttoned-up Fry: Percent Injury, Immediate	Buttoned-up Fry: Percent Injury, Delayed[2]	Buttoned-up Fry: Percent Survival[2]
			1 fps normal approach velocity			
Control	3/	3/	100.0	3/	3/	100.0
3			100.0			100.0
6			100.0			100.0
9			100.0			100.0
12			100.0			100.0
15			100.0			100.0
30			100.0			99.0
60			97.5			88.1
			2 fps normal approach velocity			
Control	-	-	100.0	-	-	100.0
3	34.0	0	100.0	4.0	0.0	100.0
6	30.6	0	98.3	0.0	0.0	98.4
9	20.8	2.9	98.4	3.2	3.2	97.6
12	30.2	3.0	96.8	3.1	2.4	94.4
15	40.4	6.5	98.4	6.4	5.5	87.8
30	26.1	8.7	73.4	6.3	4.2	39.5
60	-	-	28.5	-	-	8.0
			3 fps normal approach velocity			
Control	-	-	99.9	-	-	100.0
3	88.9	8.6	98.3	33.6	5.3	97.3
6	91.0	11.7	98.3	33.9	4.4	97.4
9	87.4	11.1	96.1	24.8	8.2	87.7
12	94.4	9.5	92.6	33.3	12.5	83.3
15	70.2	6.4	76.0	42.5	8.5	40.0
30	-	-	-	-	-	-
60	-	-	-	-	-	-

1/ The percentages given are the mean of four or five replicates of 25 fish per replicate.

2/ After a 48-hour holding period.

3/ Insignificant injury in the 1 fps tests.

At 3 fps the survival rate declined for both groups of fry after 6 min. impingement with the buttoned-up fry showing a greater mortality. At 3 min. the fish showed oxygen stress; the operculum was often bent back, and mouths gaped. Some fish lost their equilibrium and showed greater oxygen stress at 6 min. impingement. As duration of impingement increased the condition of the fish rapidly deteriorated. Injuries among both groups followed the same pattern as at 2 fps but at a higher level of incidence. Immediate injury was 70 to 94 percent for swim-up fry and 25 to 43 percent for buttoned-up fry. After the 48-hour holding period the percent injury was about the same for both groups (6 to 12 percent for swim-up fry and 4 to 12 percent for buttoned-up fry) (Table 5).

Figure 4 shows the relationship between survival and impingement time for sac, swim-up and buttoned-up fry at various normal approach velocities tested under field and laboratory conditions. These curves show a progressive increase in the rate of mortality with an increase in normal velocity and duration of impingement. The 0.5 and 1.5 fps curves are from the field experiments and the 1.0, 2.0, and 3.0 fps curves are from the laboratory experiments. The results from these experiments are compatible and the progression of mortality increase with velocity is retained.

The pressure head against the screen increases with the square of the normal velocity, and thus, impinged fish suffered an increase in injury and mortality with each increase in velocity. As the time of impingement was increased up to 60 minutes at an approach velocity of 1.5 fps, the damage to the fish accumulated with the eventuality of a very low survival after extended exposure.

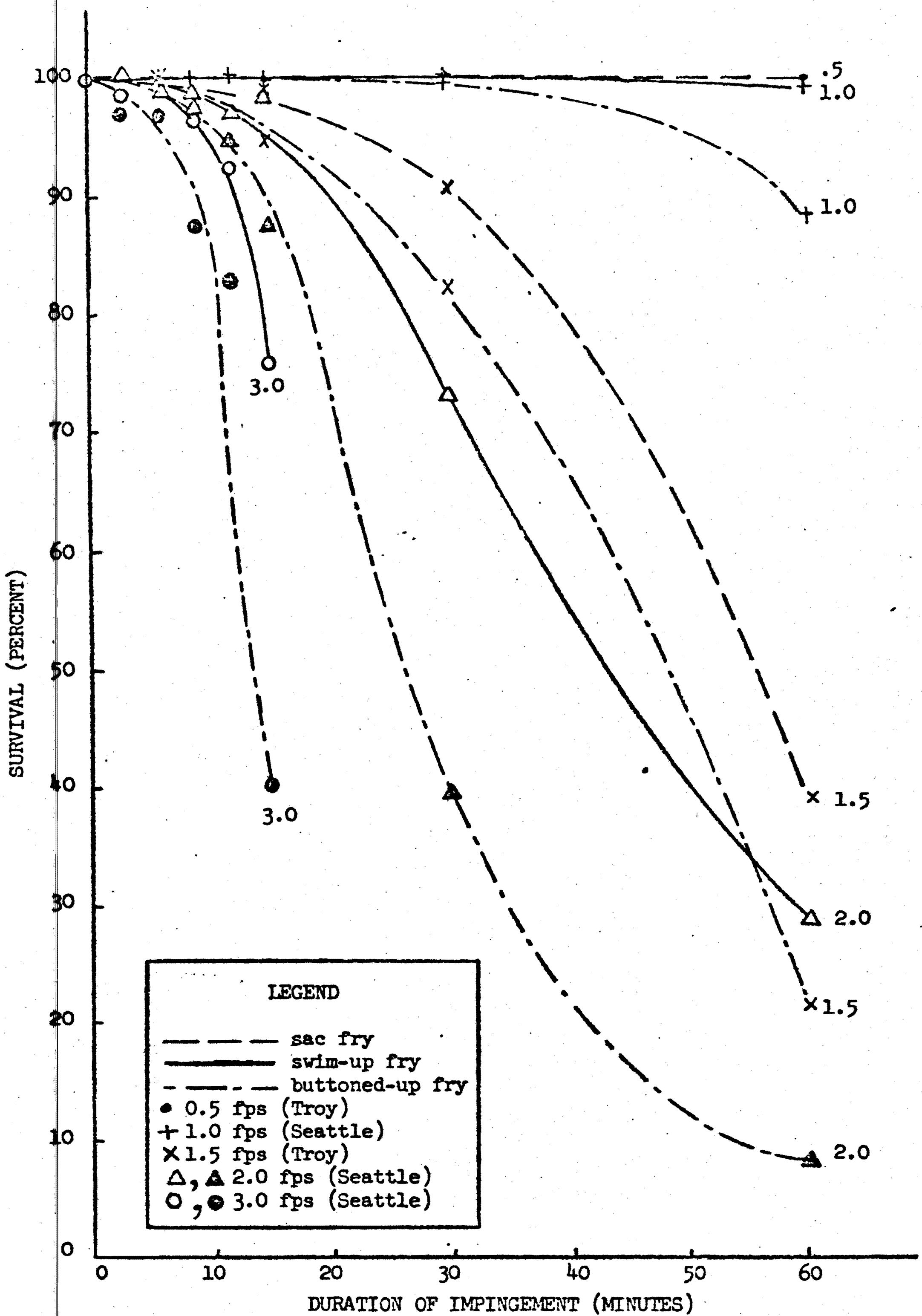

FIGURE 4. RELATIONSHIP BETWEEN DURATION OF IMPINGEMENT AND PERCENT SURVIVAL OF SALMONID TEST GROUPS AT VARIOUS NORMAL VELOCITIES.

One of the injury conditions observed upon immediate examination of impinged chinook fry was the occurrence of internal hemorrhaging in the area of the yolk sac and caudal peduncle. Immediate examination of swim-up and buttoned-up fry tested at 1, 2, and 3 fps velocity on the stationary screen at the Seattle Laboratory showed that hemorrhaging did not occur in the 1 fps tests, but was present in the 2 and 3 fps tests (Table 5). In the Troy tests, hemorrhaging occurred during the 1.5 fps tests but not during the 0.5 fps tests. This suggests that the minimal normal velocity at which hemorrhaging began to occur was about 1.5 fps.

A series of exploratory tests at 2 fps approach velocity was conducted using swim-up fry to determine the time at which hemorrhaging occurred. Fish were impinged upon a stationary screen for 15, 30, 45, and 60 seconds. Hemorrhaging began at 30 seconds and increased to 33 percent occurrence at 60 seconds (Table 6). This is comparable to the Troy and Seattle laboratory impingement experiments in which we observed a high hemorrhaging within 3 minutes for 1.5 fps and greater velocities.

Examination of the hemorrhaged fish 24 hours after testing showed that blood clots had formed in the area of the injury. After 48 hours the hemorrhaged condition was difficult to detect and appeared in only 0.5 percent of the injured fish. This indicated that the blood had been reabsorbed and hence the previously observed injury was no longer visible. No behavioral differences could be detected between hemorrhaged and non-hemorrhaged fish as based upon visual observations.

Table 6.--Occurrence of hemorrhaging spring chinook swim-up fry at 2 fps water velocity for various durations of impingement.

Duration of impingement (Seconds)	Number of fish per test	Number of fish showing hemorrhage	Percent hemorrhage
60	46	15	32.6
	49	16	32.7
45	49	14	28.6
	64	17	26.6
30	48	5	10.4
	41	4	9.8
15	48	0	0.0
	50	2	4.0
	64	0	0.0

SUMMARY AND CONCLUSIONS

Biological tests were conducted with the HTS VII at a test facility in the Grande Ronde River near Troy, Oregon. Groups of spring chinook salmon ranging in size from 26 mm to 170 mm were released upstream from the screen and recovered in inclined traps downstream from the screen to obtain information on diversion efficiency and survival, and the effect of impingement on physical condition of sac and buttoned-up fry. Experiments were also run in the laboratory to further examine effects of impingement on small fish.

On the whole, diversion efficiencies of the traveling screen were about 97 percent or greater at normal velocities of 0.5 and 1.5 fps for fingerling and fry. No impingements were observed among fingerlings, but fry readily impinged on the screen. At 0.5 fps velocity survival of fry was independent of impingement time, but at 1.5 fps velocity survival decreased as impingement time increased from 6 to 60 minutes. Buttoned-up fry appeared to be more severely affected than sac fry. The pretest condition of the buttoned-up fry was not felt to be as good as that of the sac fry and this may have contributed to the difference in survival.

The following recommendations regarding duration of impingement are based upon the behavior of the fish after impingement, immediate and delayed injury including effects of oxygen stress, and mortality after 48 hours of post test holding:

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Tests on chinook fry indicate that the duration of impingement should not exceed 15 minutes at 0.5 fps velocity, 12 minutes at 1.0 fps velocity, 6 minutes at 2.0 fps velocity, and 3 minutes at 3 fps velocity. The major injury symptom was internal hemorrhaging in the yolk sac and caudal peduncle areas of fry tested at 1.5 fps and greater velocities. The hemorrhaged areas showed almost complete recovery after 48 hours.

We conclude from these tests that the HTS VII can effectively divert a high percentage of young salmonids with minimal adverse effect in the ranges of water velocities and impingement times that may be encountered in actual applications. However the results must be considered in perspective with the specific conditions under which the tests were conducted.

ACKNOWLEDGMENTS

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FIGURES