PERFORMANCE OF SALMON IN EXPERIMENTAL "ENDLESS" FISHWAYS WITH SLOPES OF 1 ON 8 AND 1 ON 16

by

G. B. Collins

C. H. Elling

A preliminary report. Research for the 1958 season comparing the performance of salmon and steelhead trout in fishways with slopes of 1 on 8 and 1 on 16 is still in progress at the Fisheries-Engineering Research Facility at Bonneville Dam. The research is financed by the U. S. Army Corps of Engineers as a part of their Fisheries-Engineering Research Program. (Cont. DA-35-026-Eng-25142).

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The slope of a pool type fishway is a major factor in determining the cost of its construction. A fishway that rises one foot for every eight feet of length (1 on 8 slope) needs to be only one half as long as a fishway that rises one foot for every 16 feet of length (1 on 16 slope) to gain the same elevation. Enormous reductions in fishway costs would be possible if satisfactory fishways could be designed with slopes steeper than the present standard slope of 1 on 16.

To investigate the feasibility of steeper fishway slopes the effect of fishway slope on the rate of passage of chinook (Oncorhynchus tshawytscha), blueback (O. nerka) and steelhead (Salmo gairdneri) was studied at the Fisheries Engineering Research Facility at Bonneville Dam during 1956 and 1957. This was done by comparing the passage times of the salmon~~o~~ids through short experimental fishways with slopes of 1 on 8 and 1 on 16. Both fishways were of the pool and overfall type without submerged orifices, and both achieved a total gain in elevation of 6 feet. The results of these experiments (reported by J. R. Gauley[2] "The Effect of Fishway Slope on the Rate of Passage of Salmon~~o~~ids" and J. R. Gauley and C. S. Thompson "Further Studies on Fishway Slope and its Effect on the Rate of Passage of Salmon~~o~~ids") were quite favorable. For all three species of fish the rate of passage through a 1 on 8 slope fishway having 1 foot overfall between pools was as fast or faster than the rate of passage through the conventional 1 on 16 slope fishway.

This was true whether the tests were made with individual fish or with groups of fish. However, because the tests in 1956 and 1957 were made with only short segments of fishway, the question still remained as to whether the steeper slopes were suitable for longer fishways. The possibility that the steeper slope might dangerously fatigue fish in a long fishway had to be investigated.

A study of the effect of fishway slope on fish performance in long fishways ~~is being undertaken~~ at the Bonneville laboratory during the 1958 season. The method of study utilizes two specially designed "endless" fishways with slopes of 1 on 8 and 1 on 16. These endless fishways are experimental pool and overfall fishways constructed so that each makes a complete circuit, with the highest pool connected to the lowest pool by means of a lock. When a fish has ascended to the top of one of these fishways it is then rapidly locked to the lowest pool to ascend again. By continuing this process, fishways of any desired length can be simulated. Knowledge of the effect of fishway slope on fish passage is sought through a comparison of the performance and behavior of the fish in the two endless fishways and through a study of the related biochemical phenomena associated with fatigue, ~~and~~ energy ~~utilization.~~

DESCRIPTION AND OPERATION

Features of the 1 on 16 and 1 on 8 slope endless fishways and essential auxiliary channels and pools (entrance channel, collection pool, release compartment, introductory pool and exit by-pass) are shown in plan view figure 1. An enlarged view of the 1 on 8 slope unit showing pool elevations appears in figure 2. The same pool elevations apply to the 1 on 16 slope unit. Perspective views of the two fishways are presented in figures 3, 4, 5 and 6.

Each fishway was comprised of 16 pools including two turns and a locking pool. There was a 1 foot rise between pools and a total rise of 16 feet in the complete circuit. With the exception of the lock and turn pools, the average water depth in each pool was approximately 6.5 feet. Pools were 3 feet wide and either 8 or 16 feet long depending on the slope of the respective fishway. A 3-foot freeboard prevailed throughout the fishway. Weir crests were square, 2 inches wide and painted white on the top to aid in the observation of fish. All other interior surfaces were painted camouflage brown. There were no orifices in the weirs, but a single 2" weep hole was provided in the base of each weir to permit draining during shutdowns. A steel, flap plate covered each hole when the fishway was operative.

All principal structures were of wood with the exception of the exterior steel supports on the lock and certain gates in the two fishways. A cross-sectional view of a typical pool in the 1 on 8 slope unit showing the box-type construction with level floor is presented in figure 7.

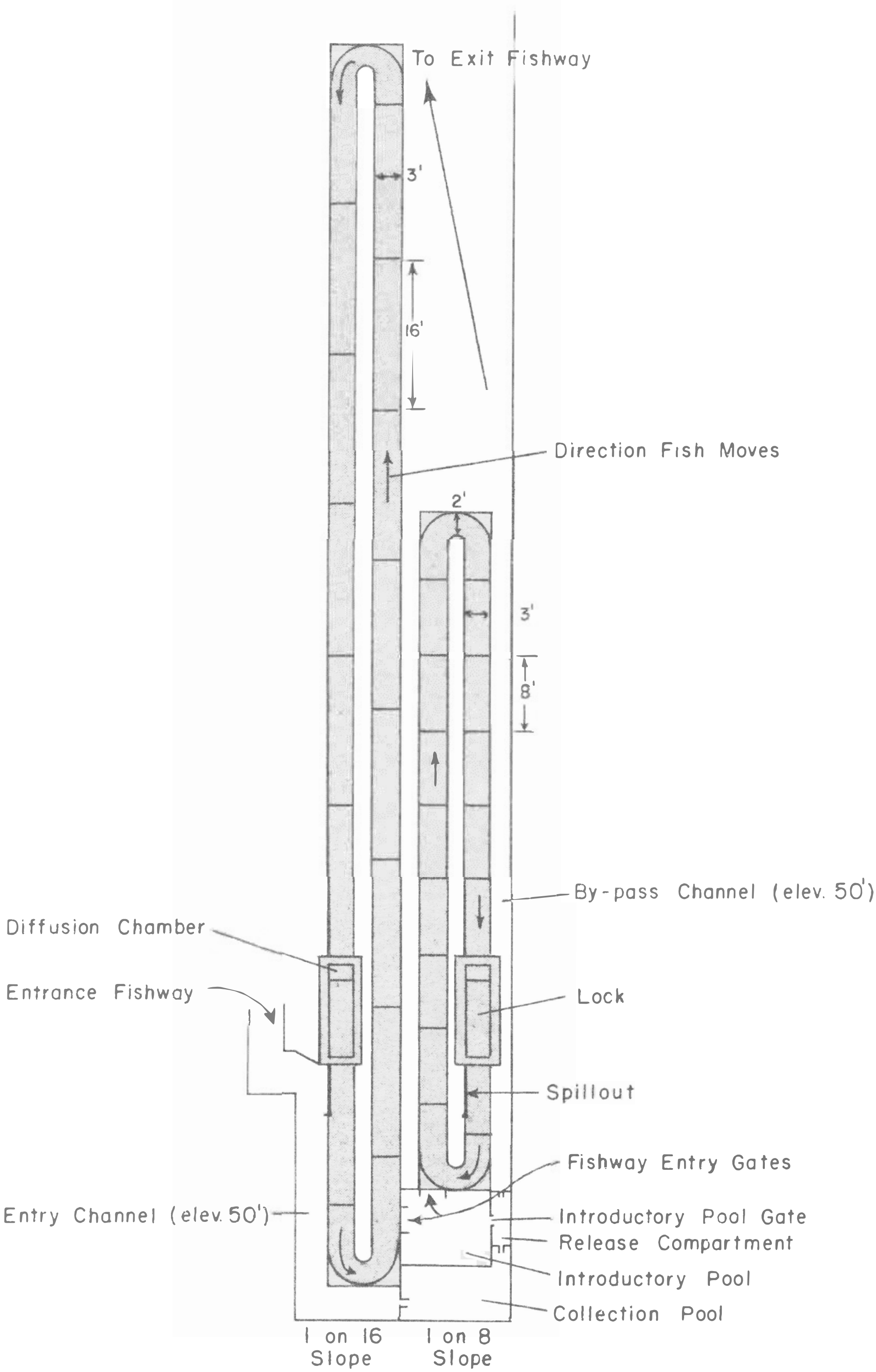

Figure 1.--Plan view of the 1 on 16 and 1 on 8 slope endless fishways with auxiliary approach channels and pools.

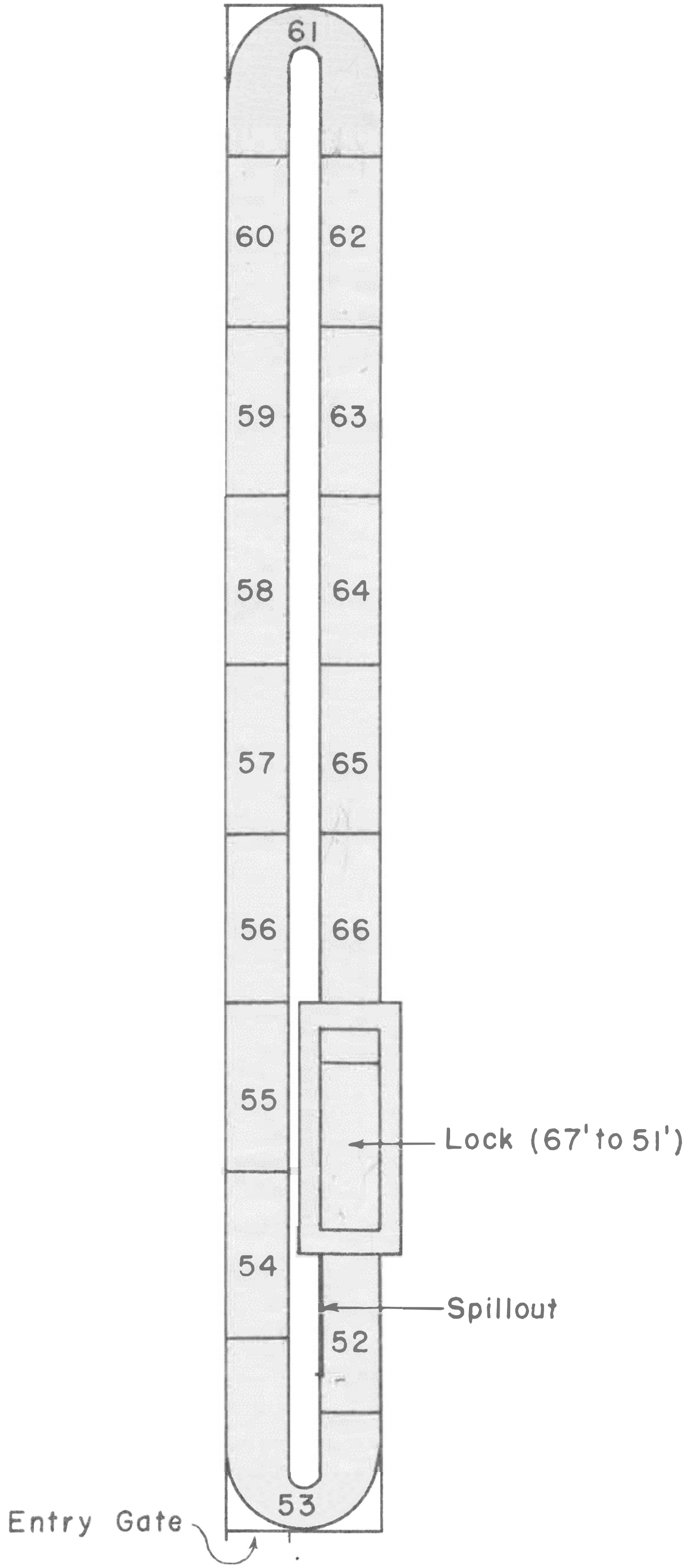

Figure 2.--Plan view of 1 on 8 slope fishway showing pool elevations in height above mean sea level.

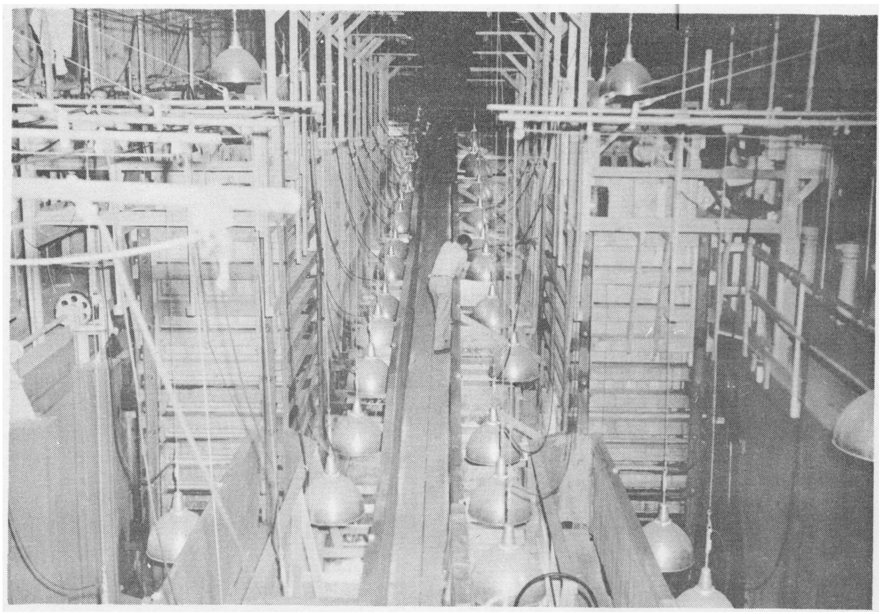

Figure 3.--Looking upstream at the 1 on 16 (left) and 1 on 8 (right) slope endless fishways. The locking units in each fishway appear in the right and left foreground.

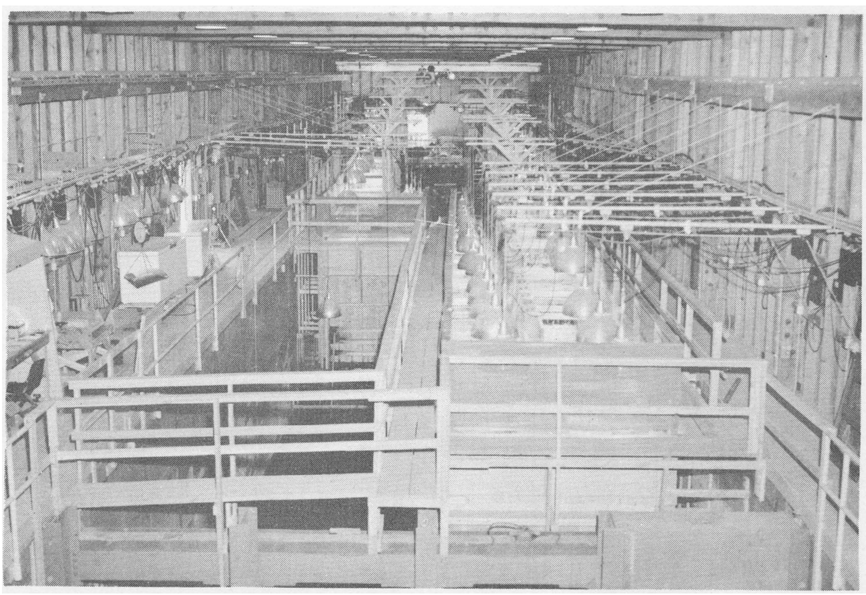

Figure 4.--View from the upper turn pool (61') showing respective lengths of the 1 on 16 (right) and 1 on 8 (left) slope endless fishways. Each fishway rises 16 feet.

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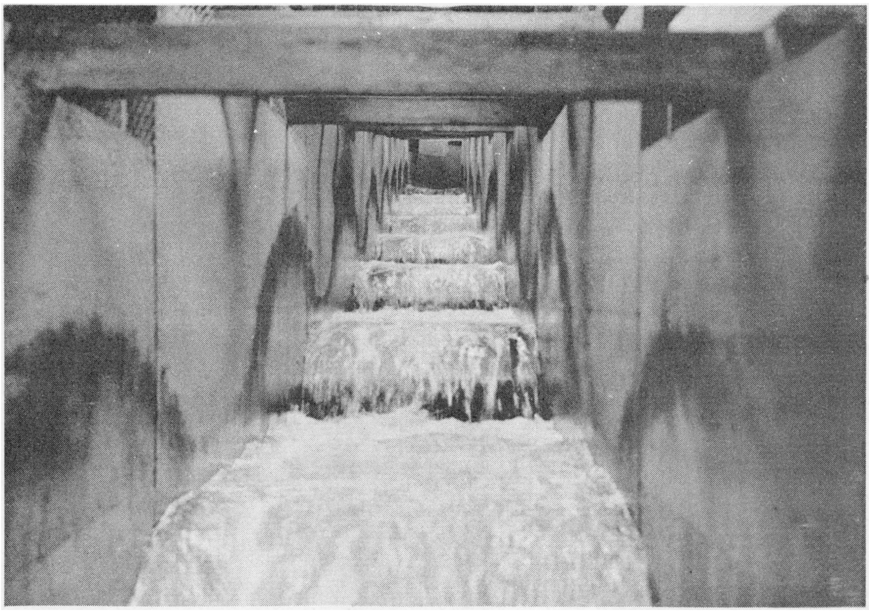

Figure 5.--Looking upstream from pool 53' in the 1 on 8 endless fishway.

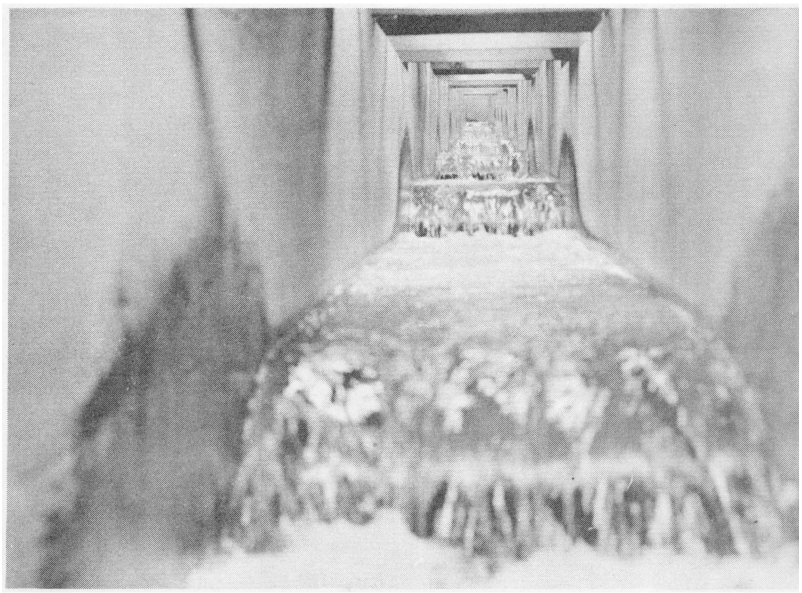

Figure 6.--The 1 on 16 slope endless fishway viewed from pool 53'.

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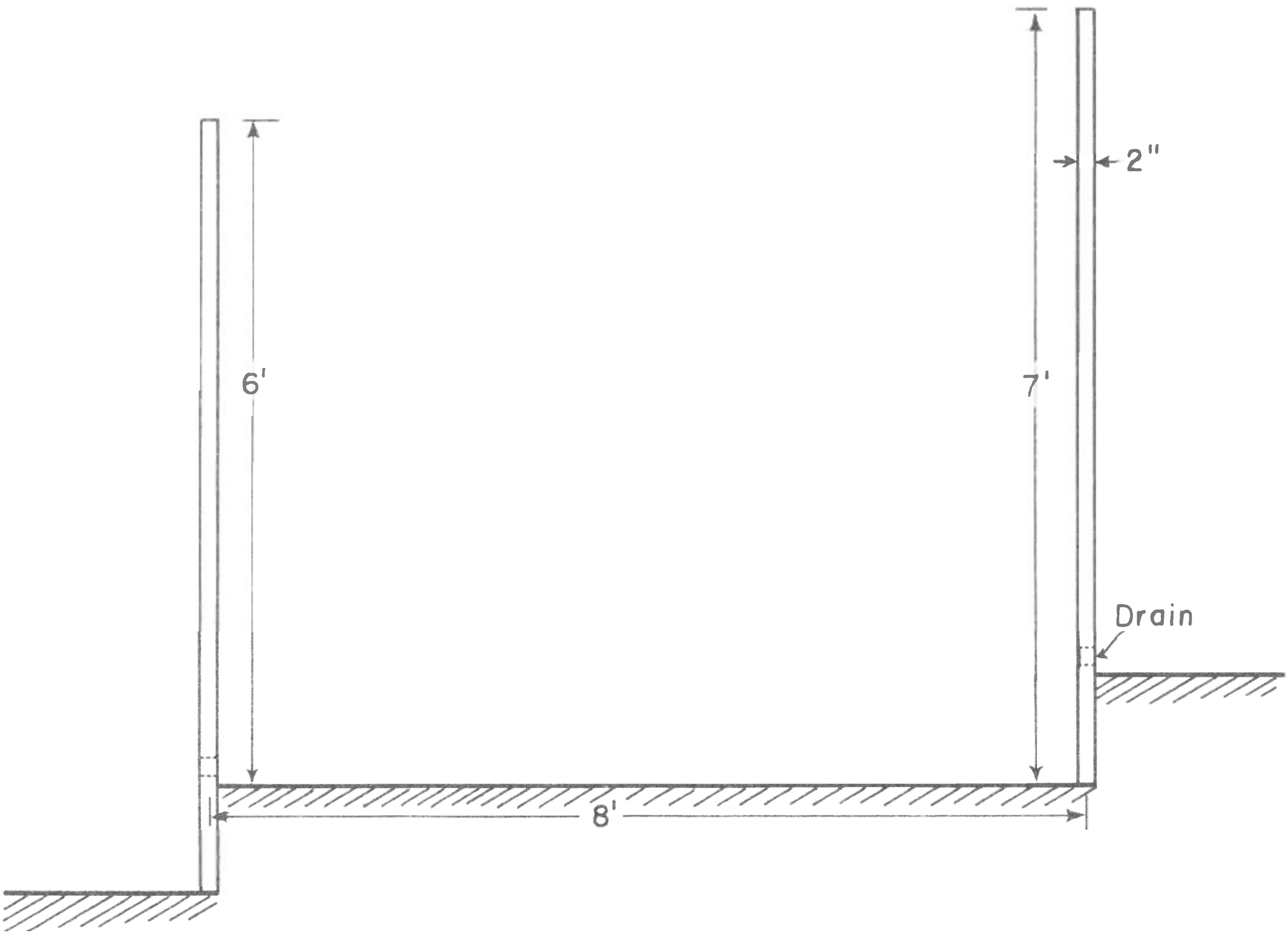


Figure 7.--Sectional view of a typical pool in the 1 on 8 slope fishway. Note level floors.

Dimensions of the turn pools (53' and 61') were in keeping with the established slope in each fishway; i.e., the inside longitudinal footage, totaled 8 feet in the 1 on 8 slope fishway and 16 feet in the 1 on 16 slope fishway. The pool depth was approximately 6.5 feet, but passage area available to the fish was limited to the upper 2 feet of the pool by a grill. The corners were coved and the pool width at the 90° point was reduced from 3 to 2 feet (see figures 1 48).

The lock pool (elev. 67' to 51') in each fishway was 8 feet long, 3 feet wide, and 23 feet deep when filled and 7 feet deep when drained. When drained, the lock was a typical pool with normal hydraulic conditions. A picketed barrier was installed at the downstream weir to prevent fish from entering the drain area. Ideally, to be consistent with the slope design, the lock in the 1 on 16 slope fishway would have been 16 feet long. Since space limitations and structural considerations posed definite barriers to the construction of a 16 foot unit, the lock in the 1 on 16 fishway was built identical to that in the 1 on 8 slope unit.

To encourage the passage of fish from the lock pool after it had been drained, the pool was grilled to limit the depth available to fish to 2 feet as was done in the turn pools. This alteration very definitely served to expedite the movement of fish from the lock into the succeeding upstream pool (52').

Operational features of the endless fishway units may best be described by visualizing the passage of a fish through the various sections of the facility. The following account will serve to acquaint the reader with the series of steps involved in a fish's movement as it approached, entered and completed a circuit through the fishway:

(1) After being diverted from the Washington shore fishway at elevation 47' the fish ascended the entrance fishway to the entry channel and then moved on into the collection pool (see figure 1). This pool was 5 feet wide, 12 feet long and 6 feet deep and had a surface elevation of 50'.

(2) From the collection pool the fish swam into the release compartment where it was diverted into the introductory pool. Water flow from the by-pass channel provided the necessary attraction for movement into the release compartment.

(3) As the fish entered the introductory pool a drop gate was lowered at the junction of the release compartment and the introductory pool. This isolated the fish in a quiet pool which was 6 feet wide by 9 feet long and approximately 2 feet deep. Waterelevation at this point remained at 50'.

(4) Passage of the fish from the introductory pool to one of the endless fishway units was facilitated by raising a fishway entry gate joining pool 53' with the introductory pool. This permitted the water in the fishway to spill into the introductory pool, filling it to an approximate elevation of 52.5'. At this level, the water spilled out over the rim of the pool through a grill and into the collection pool. The fish was now in a position to swim from the introductory pool into the fishway. Figure 9 presents a view of the introductory pool showing the "swim in" condition providing for entry into the 1 on 16 slope fishway.

(5) Immediately after the fish passed into pool 53', the fishway entry gate was dropped, isolating the fish in the now closed circuit of the endless fishway.

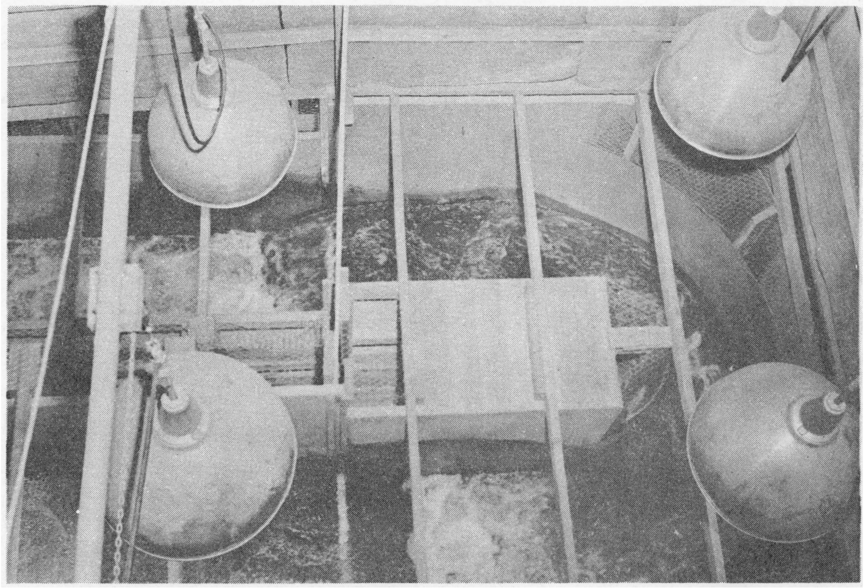


Figure 8.--Upper turn pool (elev. 61') in the 1 on 8 slope fishway.

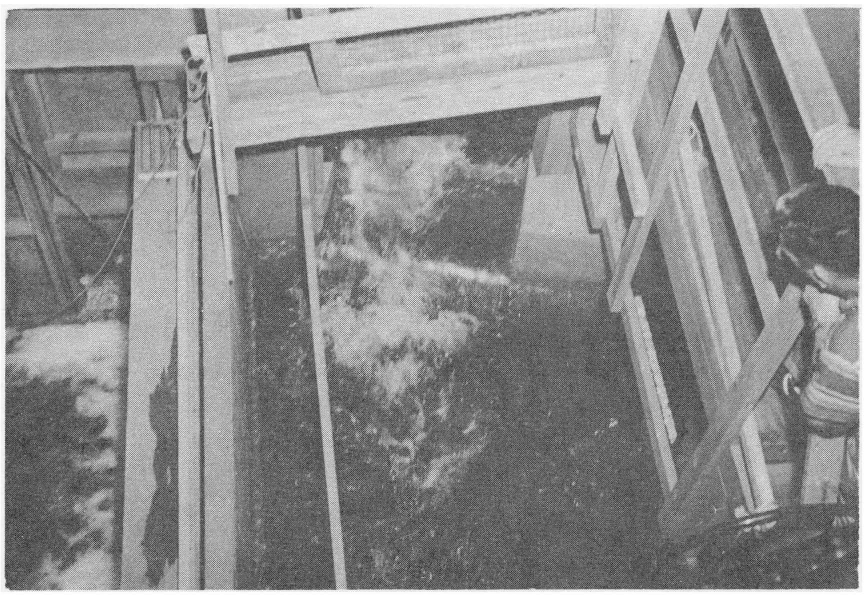


Figure 9.--Introductory pool "filled" and fishway entry gate "open" ready for entry of fish.

(6) From pool 53' (see figure 2 for pool elevations) the fish ascended the straightaway section through pools 54'-60' and then around the turn pool (61') and again up a straightaway section to pool 66'. At this point the fish was ready to enter the lock. Figure 10 gives a view looking upstream from pool 66 over the diffusion chamber and into the lock. Dimensions of the diffusion chamber were 3' x 3' x 7'. A 16-inch pipe with grill openings on the under side entered the base of the chamber and provided a constant water supply for the fishway. Diffusion baffles were placed above the pipe and a finger grill, submerged approximately 6 inches beneath the surface, prevented the fish from sounding into the chamber as it passed from pool 66' into the lock.

(7) After the fish passed over the diffusion chamber grill, the drop gate ("A" - figure 10) was lowered to seal off the lock from the diffusion area. A motor driven winch, connected to a steel cable ("B" - figure 10), raised a steel flap gate at the base of the drain field directly beneath the diffusion chamber. This permitted drainage of the lock to elevation 51'. Discharge of water was normally accomplished in about 40 seconds. Figure 11 shows the drop gate "A" in a "down" position, isolating the diffusion chamber and remainder of the fishway from the lock which has been drawn down in this view.

(8) Figure 12 presents a view of the lock after discharge of water from elevation 67' to 51'. The vertical gate "C" has been raised and water from pool 52' may be seen spilling into the lock. (Previous to the opening of the vertical gate "C", all water in the fishway had been spilling out an overflow in pool 52'.) The fish was now ready to move out of the lock into pool 52'.

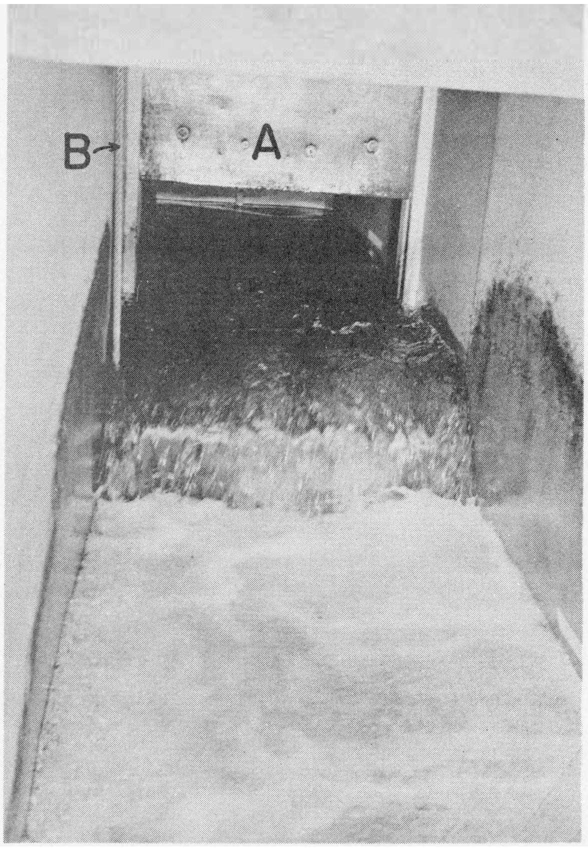
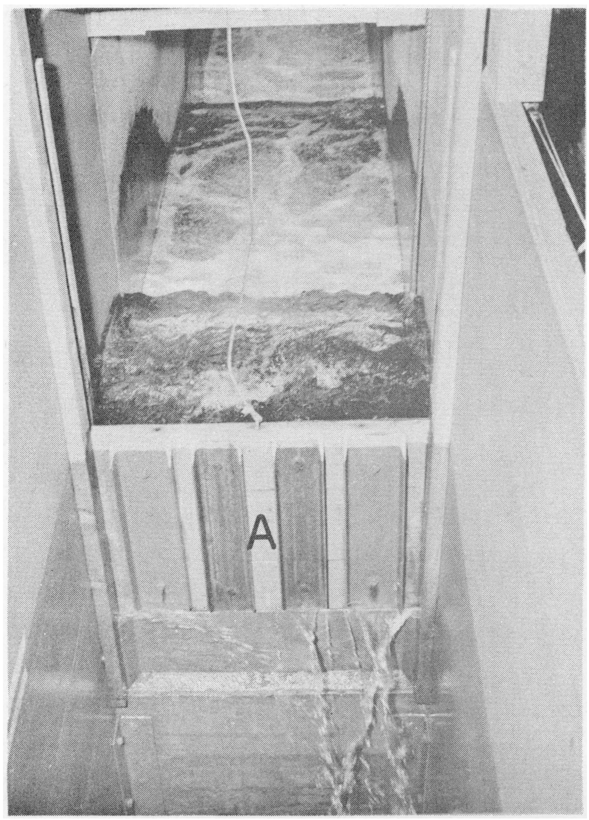


Figure 10.--Looking upstream from pool 66' over diffusion chamber and into lock. As a fish enters the lock, the drop gate (A) is lowered and a motor driven winch connected to the cable (B) raises a gate at base of lock to discharge water.

Figure 11.--Drop gate (A) in "down" position separating diffusion chamber from lock (foreground). Lock water has been discharged.



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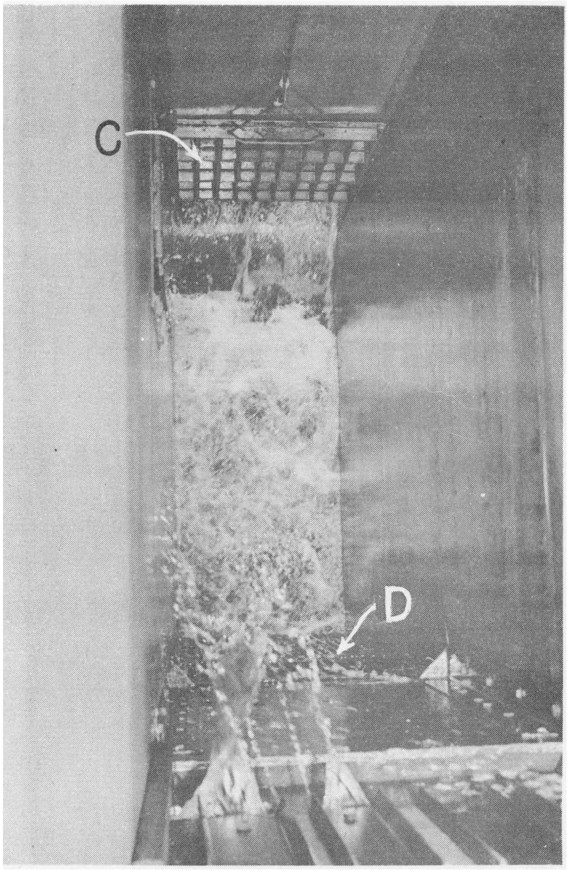

Figure 12.--Looking down into lock. Vertical gate (C) has been raised to permit exit of fish from lock into pool 52. Water passes from lock through drain field grill (D) and out gate opening behind grill.

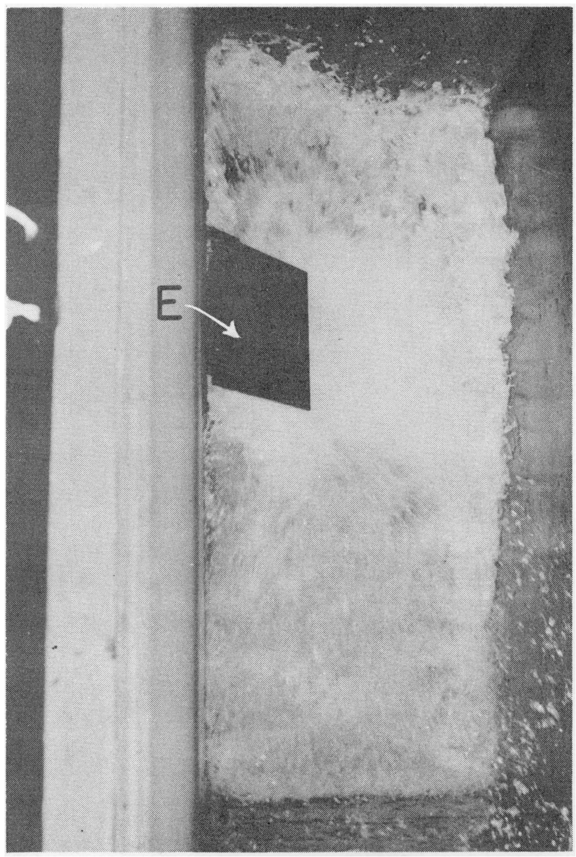

Figure 13.--Filling lock. Flap plate (E) returns to down position as water level reaches elevation 67'.

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(9) When the fish had passed through pool 52' and the lower turn (pool 53') the vertical gate "C" was lowered and the lock drainage gate closed. This readied the lock for filling as the fish began another circuit of the fishway. Figure 13 shows the lock being filled, an operation which normally required about 1 minute. As the water level in the lock approached elevation 67', the 16-inch supply valve was gradually closed as the desired elevation was reached. At this level the drop gate "A" (figures 10 and 11) was raised and the lock was now ready to receive the fish when it once again ascended to this level.

Lighting and Hydraulics

Constant light supply approximating an average intensity of 800 ft. cdls. at the water surface prevailed during all experiments. This was provided by a battery of 1000-watt fluorescent, mercury vapor lamps placed at 6-foot intervals throughout the course of each fishway. The distance from the lamp reflectors to the water surface was 6 feet.

Water supply for operation of the fishway units came from the forebay of Bonneville Dam which during these experiments fluctuated from elevation 82.5' to 72.5'. This provided a minumum operating head of 5.5 feet (72.5' to 67.0' - level of lock and diffusion chamber when filled). Water for the by-pass channel came from the Washington shore fishway which was joined with the facility by an exit fishway.

Head on the weirs (measured 2.5H upstream of the weir crest) was controlled by adjusting the valve supplying water to the diffusion chamber. This head was set at .8 foot which was the approximate upper limit at which a plunging flow could be maintained under the prevailing non-orifice condition. Total discharge in each fishway was approximately 7.1 c.f.s.

Flows into the lock pool were changed from the established plunging condition to a streaming motion by raising the lip of the lock spill-out slightly above elevation 50'. This was done to increase the surface velocity and encourage the exit of fish from this pool.

PROCEDURE

The comparison of the two fishway slopes--1 on 8 and 1 on 16--was to be based on an analysis of (a) the performance of individual salmonoids in the respective fishways and (b) the biochemical state of the fish after exposure to passage through a fishway. Performance was measured in terms of time (minutes) required to negotiate a specified ascent and the biochemical state comprised of measures of lactate of whole blood, inorganic phosphate of blood plasma, lactate of the muscle tissue and inorganic phosphate of the muscle tissue.

Fish Collection

Fish used for experimental purposes in the endless fishways were diverted from the Washington shore fishway each day and ascended to the collection pool (see Figure 1). The time required to collect a sufficient number of fish generally was not more than several hours. Normally the collection period commenced at about 2:00 PM and by 4:00 PM, 6 to 20 fish would be present in the collection pool. The pool entrance was then closed and covers were placed over the pool to keep the fish quiet during the hold-over period which extended to the following morning. Thus, each fish present in the pool was held from 12 to 20 hours depending on the time it entered the pool and the time it subsequently left the pool to enter the experimental area on the following day. This procedure was presumed to place each fish in a relatively equal state of rest prior to its release into one of the endless fishways. Figure 14 presents a view of the collection pool during the period fish

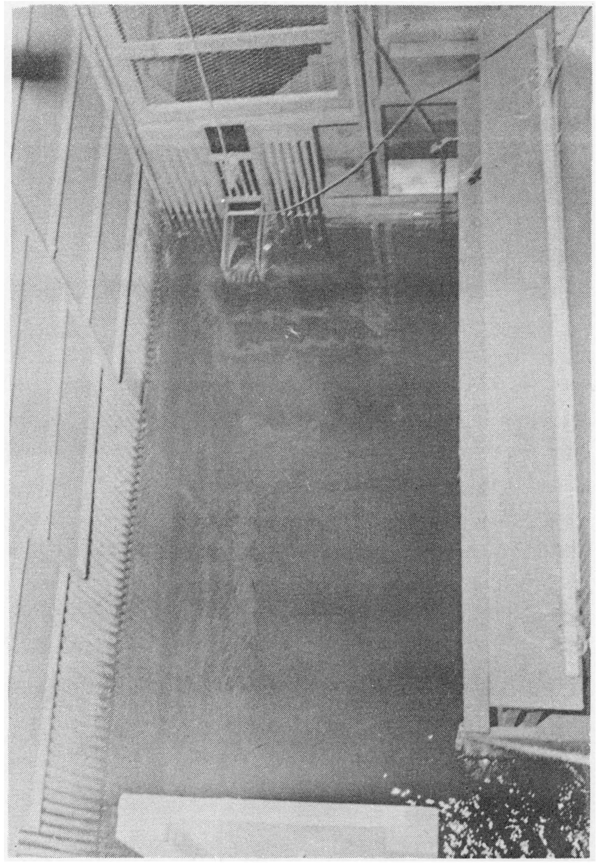

Figure 14.--Collection pool in "fishing" condition. Note fyke at entry point.

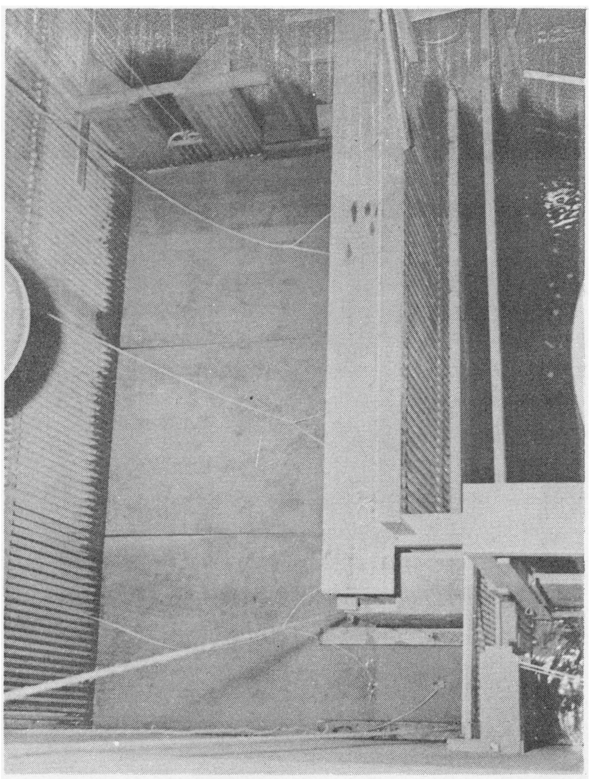

Figure 15.--Collection pool showing covers in place during hold-over period.

were entering and Figure 15 shows the pool with covers in place for the hold-over period.

All fish not used in the daily experiments were released into the by-pass, from which point they passed on through the facility and continued their ascent back into the Washington shore fishway. A brail in the collection pool was raised to insure the exit of all remaining fish prior to the entry of a new group for use in the succeeding day's experiments.

Release and Timing

For each test, an individual fish from the collection pool was permitted to enter the release compartment where it was identified by species and then passed into the introductory pool. Only those fish bearing visible evidence of serious injury were rejected. A number of fish with minor, open wounds or visible fungus infection were passed through the fishways. There was no selection on the basis of size.

As the fish swam from the introductory pool into the fishway, this signalled the "start" of a test. Timing of the ascent was accomplished by a pair of observers who moved along with the fish as it proceeded up the fishway A switch was located above each weir in the fishway and as the fish passed from pool to pool an observer pressed the switch button at the respective weir. This signal was in turn transmitted to an operations recorder which noted the exact time of passage on a continuously revolving tape. A third observer stood by to operate the lock and transferred the chronological record of ascent to an operations sheet.

Performance

Two types of performance tests were conducted during the spring chinook and blueback salmon migrations. One test consisted of permitting a fish to ascend through 104 pools ($6\frac{1}{2}$ circuits of the endless fishway) at which point the fish was immediately removed from the fishway and killed for biochemical analysis. The total ascent chosen was arbitrary but nevertheless in keeping with a simulated passage over most low-head, run-of-the-river type dams. The foregoing tests were conducted on Sunday, Wednesday, Thursday and Saturday of each week. On the remaining days--Monday, Tuesday and Friday--a "prolonged ascent" test was carried on. These trials were designed to examine the nature of performance and the biochemistry of fish subjected to an indefinite ascent. Since the latter tests often times required lengthy periods of observation, they were normally discontinued after (a) approximately 13 hours or (b) after a fish had spent 60 minutes in a single pool.

Individuals removed from the fishway immediately following a specified ascent were called "terminated" fish as contrasted to "volitional" fish which were those which had stopped for 60 minutes in a pool and were then removed. Thus, the former can be considered as having been in an "actively moving" state and the latter in a "resting" state at the time of their removal. All fish removed immediately after ascending 104 pools were therefore, "terminated" while those ascending in excess of 104 pools were either in a "terminated" or "volitional" state, depending on the conditions prevailing at the conclusion of the test. Occasionally, due to time limitations or operational difficulties, a test was "terminated" before a 104-pool ascent was completed. There were also instances in which fish came to a "volitional" stop before reaching 104 pools. Subsequent biochemical comparisons will treat all fish in the "terminated" state as one group and all fish in the "volitional" state as another group, regardless of the number of pools negotiated.

Biochemistry

Immediately following the completion of a performance test, the fishway water supply was shut off and the fish was dipped from the fishway and killed by a sharp blow on the head. In successive steps, and as rapidly as possible, 5 cc of blood and a muscle tissue core were extracted. Muscle cores were always taken from the area directly between the dorsal fin and the lateral line on the right side of the fish. A heart puncture made with a hypodermic syringe inserted through the body wall served to extract the blood. Similar samples were taken each day from a "control" fish netted from the collection pool. Records were kept of the time required from the moment the fish was netted from the fishway until (1) the blood was extracted and (2) the tissue was weighed and placed in cold 5% trichloroacetic acid.

Following extraction of the blood and tissue samples, they were processed and placed in individual polyethylene containers and stored in a deep freeze for subsequent biochemical determinations. The length and sex of each fish were recorded, and the gonads were weighed for the purpose of determining sexual maturity.

RESULTS

The first experiments in the endless fishways were conducted with spring chinooks and these revealed definite and relatively consistent patterns of behavior (Figure 16). In the 1 on 8 slope fishway the fish appeared to pick up a rhythm of movement through the straightaway pools and passed through most pools in a matter of seconds. In the turn pools, however, the fish usually remained for over fifteen minutes before starting to ascend again. This pattern of work and rest was much less pronounced in the 1 on 16 fishway where the chinooks tended to take more than a minute in the straightaway pools but averaged less than five minues in the turns.

Locking the fish appeared to cause relatively little delay in both fishways. The average time from the moment the fish crossed the upper weir (66') until it actually left the lock (weir 51') was less than two minutes. The time spent in the pool following the lock, however, was greater than in the other normal pools. This may have been due to the change in hydraulic pattern encountered after leaving the lock.

The behavior pattern for blueback (Figure 17) was similar to that for the chinook. In the 1 on 8 fishway the pattern of work and rest was more pronounced than in the fishway with the 1 on 16 slope. Blueback spent on the average about 23 seconds in straightaway pools and approximately 11 minutes in the turn pools in the 1 on 8 fishway compared to an average 54 seconds on straightaway pools and about 5 minutes in the turns in the 1 on 16 fishway.

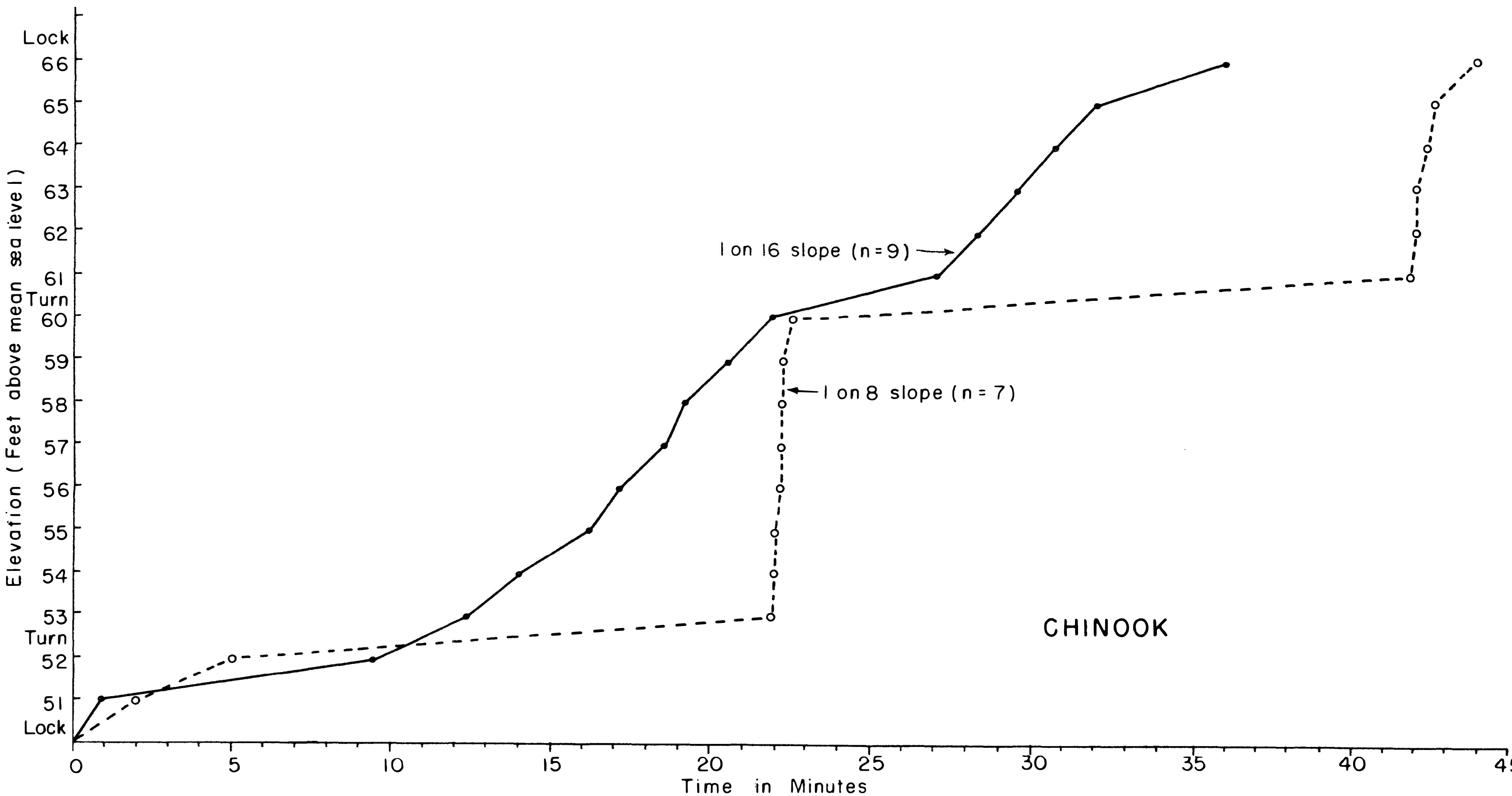

Figure 16.--Rate of ascent of chinook salmon in endless fishways having slopes of 1 on 8 and 1 on 16. Based on mean pool times of fish completing six or more circuits. June 9-21, 1958.

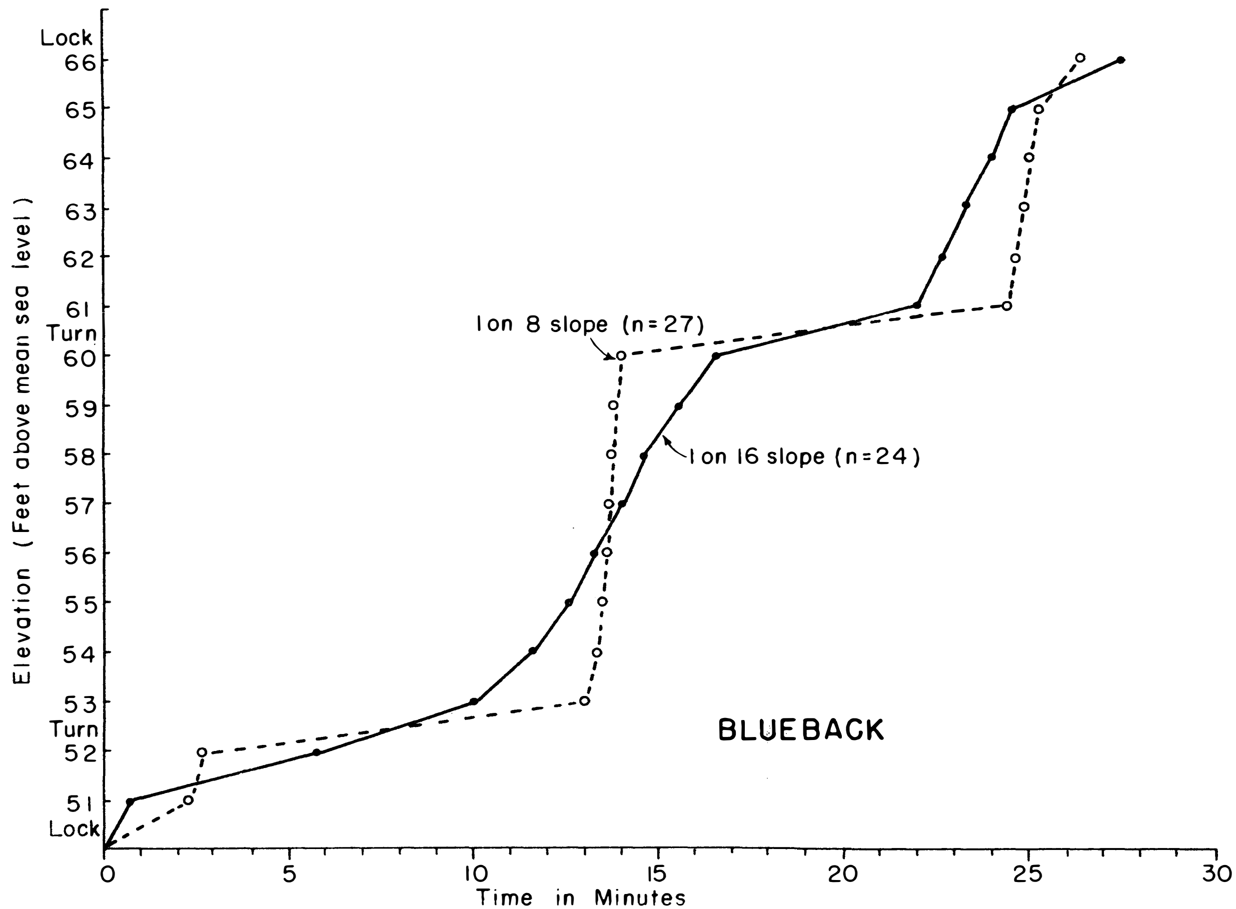

Figure 17.--Rate of ascent of blueback salmon in endless fishways having slopes of 1 on 8 and 1 on 16. Based on mean pool times of fish completing six or more circuits. June 21-July 20, 1958.

The willingness to ascend the two fishway slopes appeared to be about equal for both species of fish. Figure 18 shows the percent of fish ascending 70 and 100 pools without stopping for one hour. With the small number of fish sampled the differences are not significant.

A comparison of the performance of both chinook and blueback in the two fishways through the 104-pool ascent level is shown in Table 1. While there appears to be no difference in the rates at which the blueback ascend the two fishways, there does [redacted] seem to be a difference between the rates of ascent for chinook. With the small sample size available, this difference is not statistically significant. However, evidence that a real difference does exist can be found in Figure 19. The data on the time taken by chinook to complete each of the first six circuits in the test fishway show a consistent (significant) difference between the rate of ascent in the two fishways. Inspection of Figure 16 will show that this difference is due to the long time taken by chinooks in the turns.

To examine the possibility that ascending the experimental fishways might be fatiguing to the fish, and that the fatigue might be reflected in lowered performance as the total work accomplished increased, the mean times per circuit for the first six circuits were plotted in figure 19 for chinook and in figure 20 for blueback. Inspection of these graphs shows no evidence that fish were slowing down in either fishway.

In the search for a work level at which fatigue would become apparent in the performance of the fish, a number of fish were permitted to ascend beyond the 104-pool ascent level. Portions of the performance record of the fish that was permitted to ascend the greatest number of pools are shown in figure 21. This blueback salmon ascended the 1 on 8 endless

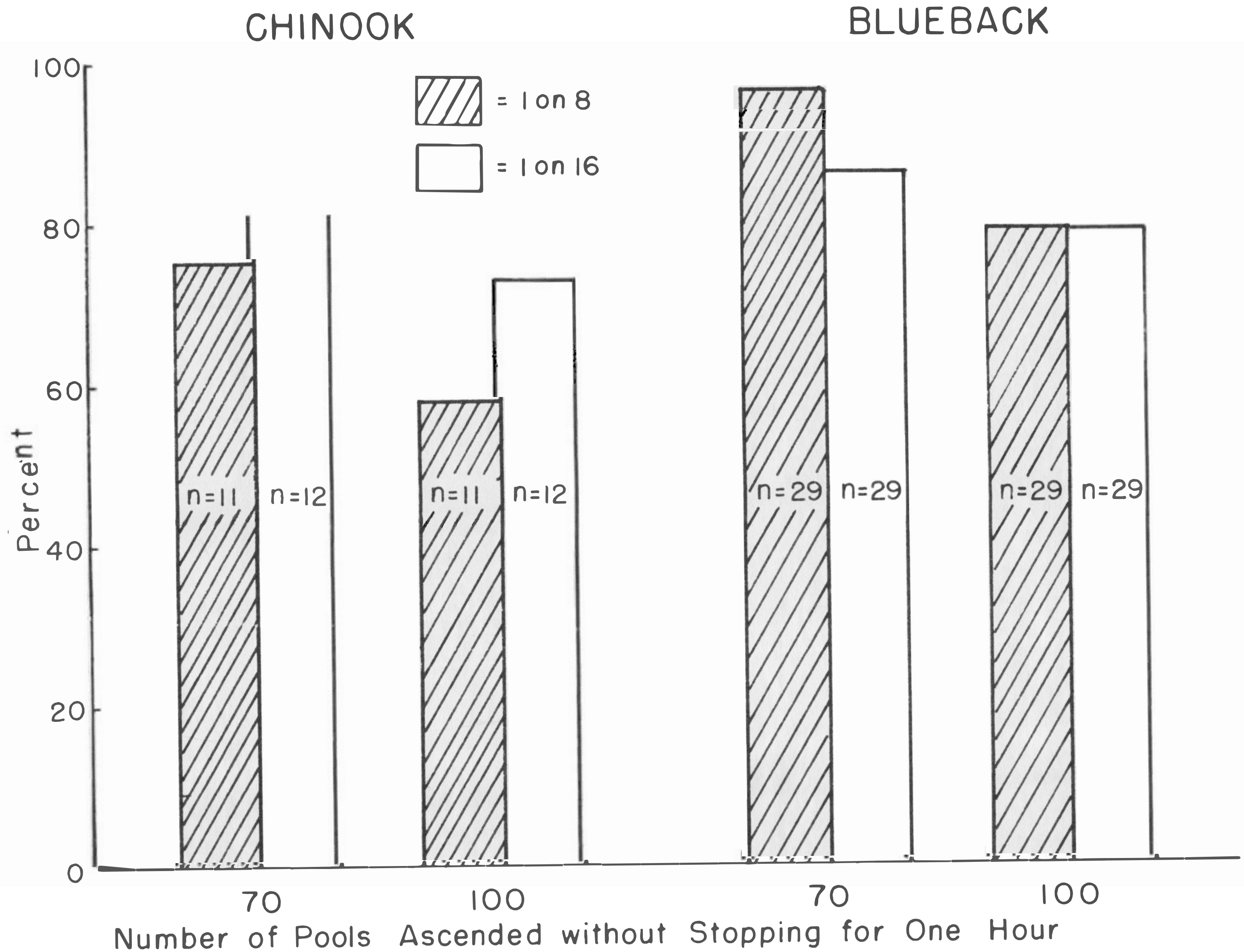

Figure 18.--Percent of fish ascending 70 and 100 pools without stopping for one hour. June 9 to July 21, 1958.

Table 1.--Time in minutes to ascend 104 pools in endless fishways having slopes of 1 on 8 and 1 on 16. June 9 - July 21, 1958.

	Chinook		Blueback	
	1 on 8	1 on 16	1 on 8	1 on 16
	321	148	167	159
	430	198	155	139
	152	237	149	214
	251	171	177	132
	207	334	192	138
	362	308	198	182
	273	329	167	180
		135	204	159
			151	187
			134	173
			175	213
			150	127
			151	94
			179	214
			176	303
			179	173
			169	136
			198	123
			197	129
			168	217
			143	184
			143	179
			130	155
				180
				184
				162
Mean	285	232	168	175

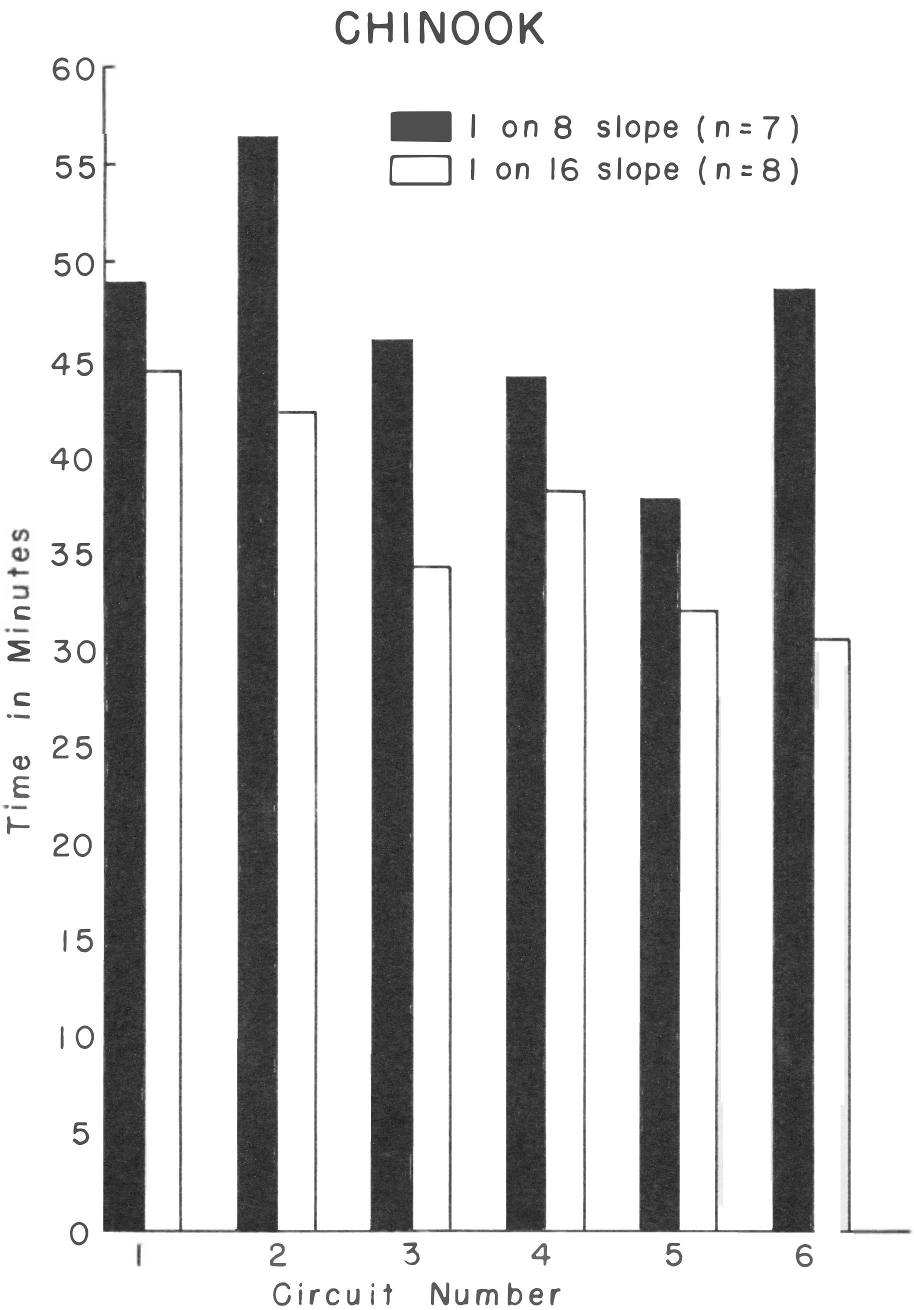

Figure 19.--Mean time per circuit (16 pools) taken by chinook salmon negotiating "endless" fishways having slopes of 1 on 8 and 1 on 16. June 9-21, 1958.

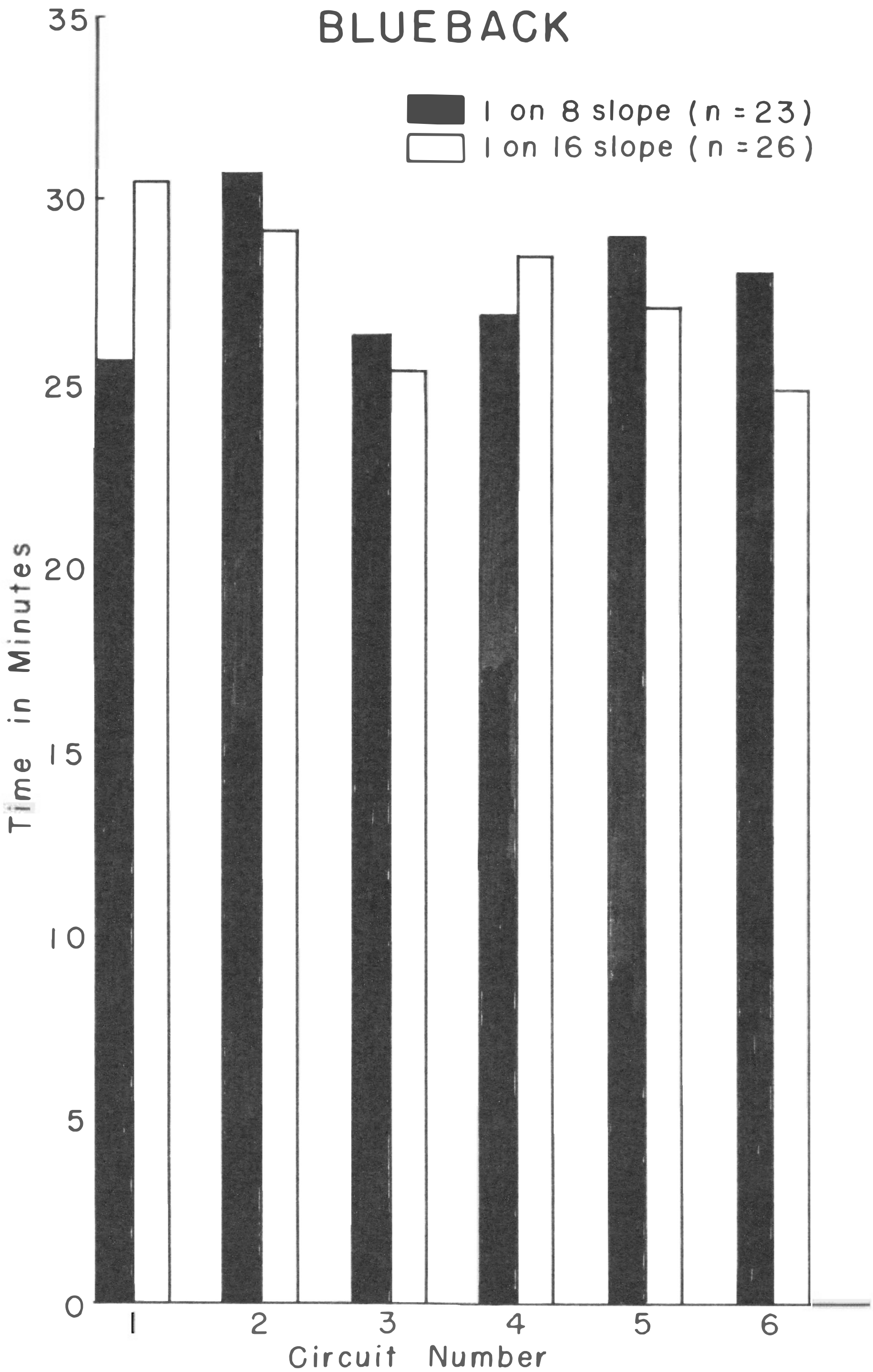

Figure 20.--Mean time per circuit (16 pools) taken by blueback salmon negotiating "endless" fishways having slopes of 1 on 8 and 1 on 16. June 21-July 20, 1958.

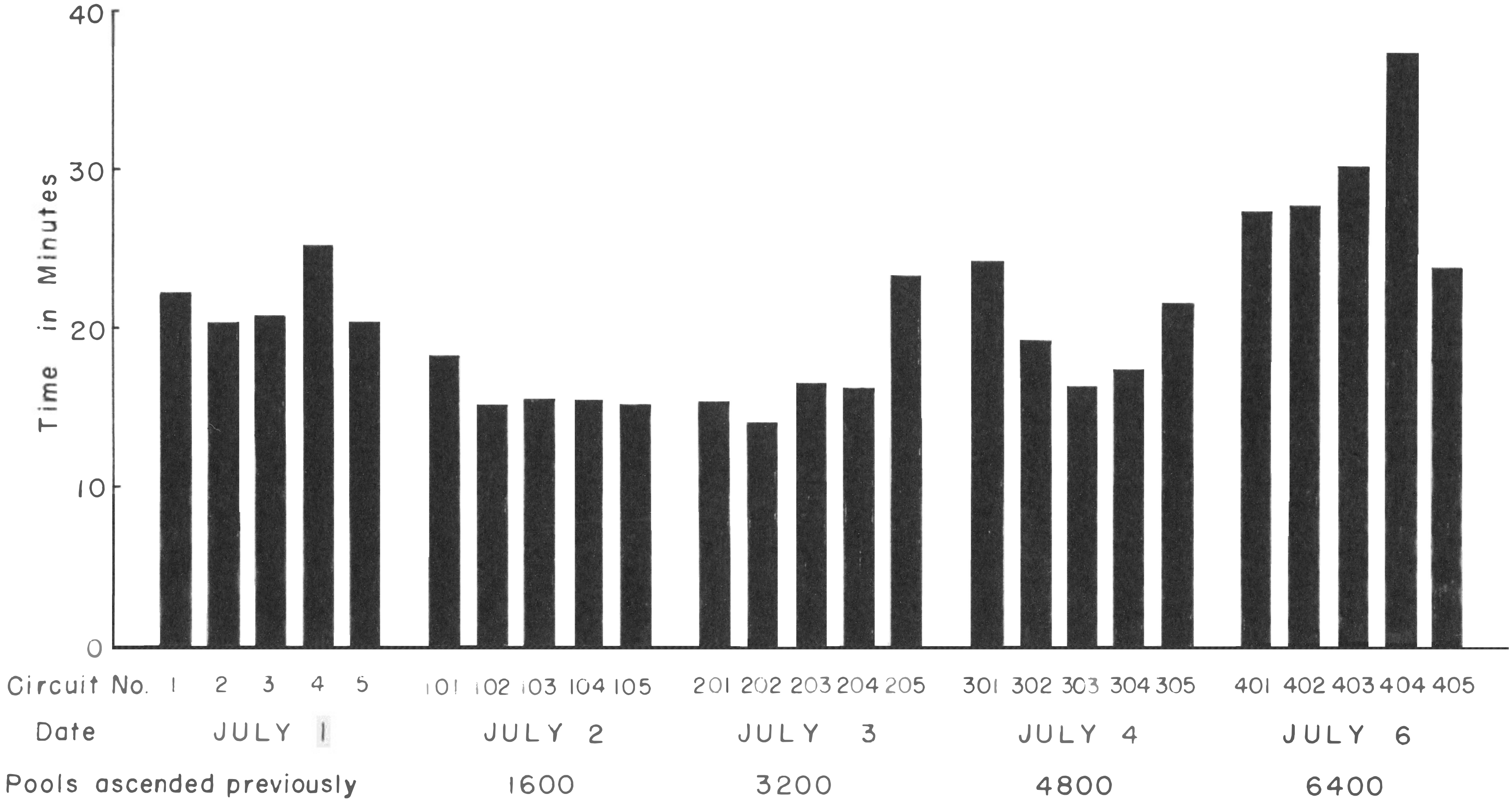

Figure 21.--Performance of an individual blueback salmon in "endless" fishway with 1 on 8 slope. July 1 to 6, 1958.

fishway for $5\frac{1}{2}$ days without stopping. There was no evidence of fatigue visible through impaired performance until the fish had ascended over 5000 feet.

In further search for evidence that one fishway slope might be more fatiguing than another, lactate and inorganic phosphate levels, generally recognized as indices of the state of fatigue, were measured in the blood and muscle tissue of the experimental fish. Results of these tests are shown in tables 2, 3 and 4. A pattern can be observed in the blood lactate measurements which appear to be most sensitive of the four chemical measurements.

Exercised fish "terminated" while still actively moving in the fishway, regardless of the height ascended (tables 2 and 3), have a significantly higher blood lactate level in both fishways than the unexercised control fish. This was equally true for all fish terminated above the 104-pool ascent level (table 4). It is of particular interest that for the fish terminated above the 104-pool ascent level, there was no significant difference between the 1 on 8 slope and the 1 on 16 slope.

The blood lactate level of fish that stopped for an hour on their own "volition" (at a variety of ascent levels) does not differ significantly in either fishway from that of the unexercised control fish. This suggests that the fish can rest in either fishway slope, and that they recover from exercise within an hour.

Table 2.--Biochemistry of chinook salmon ascending 1 on 8 and 1 on 16 slope endless fishways. Mean values in mg. %. June 9-June 20, 1958

Substance	1 on 8 slope n	terminated	n	volitional	1 on 16 slope n	terminated	n	volitional	Controls n	unexercised
Lactate of whole blood	7	39.2	6	29.3	8	38.4	4	23.1	11	24.3
Lactate of muscle tissue	8	336	6	293	8	334	4	347	11	306
Inorganic phosphate of blood plasma	8	12.2	6	10.3	7	10.8	4	11.4	11	12.2
Inorganic phosphate of muscle tissue	8	180	6	163	6	179	4	173	13	171

Table 3.--Biochemistry of blueback salmon ascending 1 on 8 and 1 on 16 slope endless fishways. Mean values in mg. %. June 21 - July 20, 1958.

Substance	1 on 8 slope				1 on 16 slope				Controls	
	n	terminated	n	volitional	n	terminated	n	volitional	n	unexercised
Lactate of whole blood	22	61.5	9	25.1	20	57.0	11	28.5	19	21.8
Lactate of muscle issue	21	375	10	261	19	392	12	332	18	298
Inorganic phosphate of blood plasma	22	14.2		10.4	16	13.2	11	12.9	18	11.8
Inorganic phosphate of muscle tissue	23	152	9	152	19	139	12	147	18	137

Table 4.--Lactate of whole blood (mean values in mg. %) from chinook and blueback salmon "terminated" above the 104 pool level in 1 on 8 and 1 on 16 slope fishways. June 9 - July 20, 1958.

Species	Terminated 1 on 8 slope	Terminated 1 on 16 slope	Controls unexercised
Chinook	39.2	38.4	24.3
Blueback	63.5	57.8	21.8

Inspection of the data from the muscle lactate and inorganic phosphate measurements suggests the possibility that similar patterns may exist for these measurements. However, the sample sizes are so small and the variation between individuals so great that only gross differences are measurable with any degree of confidence.

DISCUSSION

One of the most significant aspects of the information gained from the foregoing experiments is the complete lack of evidence for any serious fish "fatigue" in either test fishway. The biochemical tests, admittedly from very small numbers of fish and with large individual variations, were sensitive enough to detect significant species differences and differences between treatments "terminated" and "volitional", yet were unable to detect a difference between the "volitional" fish that had stopped for 1 hour and the unexercised control fish. The implication is that the fish stopped either for reasons other than muscular fatigue or their fatigue was so slight that they recovered very quickly. The performance of the fish in the fishways appears to bear this out. A review of the performance records of all fish ascending 96 pools or more shows that the fish did not slow down in six complete circuits. In the case of the blueback that was allowed to continue for over five days, there was no indication of fatigue or slowing down for at least 5000 pools. All the evidence seems to point to the conclusion that the ascent of either of the two fishways is only a moderate exercise for the fish, possibly similar to swimming at a "cruising" speed that can be maintained for long periods of time.

A study of the exaggerated work-and-rest pattern of ascent in the 1 on 8 endless fishway raises a serious question. For both species of fish, over 70 percent of the time in this fishway was spent in the turn pools. Because of the manner in which the endless fishways were constructed every eighth pool is a turn pool. Thus the experimental fishway determined the pattern of work and rest and effectively paced the fish. Whether or not the experimental fish would have successfully paced themselves if the turn pools were not present at such short intervals is not known. Tests now in progress at Bonneville may provide an answer to this question. The turn pools have now been modified to be so extremely turbulent that they no longer can be used as resting areas. If fish performance with these turbulent turn pools is comparable to the performance in the tests described in this report, the 1 on 8 slope would appear to be satisfactory for use in designing fishways. If, however, the fish fail to pace themselves satisfactorily without the "resting" turn pools then attention should be focused on the hydraulic features of the 1 on 8 fishway that control the pace of fish movement.

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