FURTHER EXPERIMENTS IN FISHWAY CAPACITY, 1957

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by

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FURTHER EXPERIMENTS IN FISHWAY CAPACITY, 1957[1/]

by

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ABSTRACT

This is the second progress report on studies to determine the maximum number of fish that a fishway may pass per unit time (capacity). The test fishway was a pool-and-overfall type, 4 feet wide, with a slope of 1 on 16 and a mean depth of 6.3 feet. Maximum observed entry and exit of salmonids are discussed as they relate to the determination of capacity. A sustained passage of 50 fish a minute was observed in a test in which the average weight per fish was 9 pounds.

Behavior and performance of the fish were also examined. Results cited suggest that certain experimental techniques may have influenced behavior of fish in the fishway.

Experiments in 1956 to measure the capacity of a pool-and-overfall-type fishway were continued during 1957. A report of the initial work has been published (Elling and Raymond, 1959). The recent experiments sought further information on fishway capacity, which is defined as the "maximum number of fish (size and species considered) that a fishway of given size and hydraulic conditions may pass per unit time."

Basically, these experiments have attempted to answer the question "How large should a fishway be to accommodate a known or anticipated number of migrating fish?" Because of limited information regarding space requirements for migrating salmonids and the desire to provide a margin of safety for the fish, fishways in some instances may have been constructed of larger dimensions than needed to accommodate the runs effectively. Appreciable savings in construction costs might be realized by reducing fishway size, provided, of course, that these reductions would not impair fish passage. It is the purpose of these experiments to determine how many fish can be passed per unit time in smaller fishways than now in use at large dams on the Columbia River and what effect, if any, limited space may have on fish behavior.

After following initial attempts to measure fishway capacity in 1956, it was concluded that several changes in the physical structure of the test fishway would be desirable before undertaking the 1957 tests. These revisions included a reduction in fishway width from 6 to 4 feet and a change in weir crest design. On the basis of 1956 experiments it was concluded that considerably more fish than could be readily accumulated would be required to even approach capacity in a fishway 6 feet wide. As there was no assurance of increasing the supply of fish, the logical recourse was to reduce fishway size. The shape of the weir crest was altered to eliminate unstable flow patterns which had developed with use of a flat weir crest, 8 inches in width.

1/ Research financed by the U. S. Army Corps of Engineers as a part of a broad program of fisheries-engineering research for the purpose of providing design criteria for more economical and more efficient fish-passage facilities at Corps projects on the Columbia River.

Figure 1.--Looking upstream on test fishway (on right). Mesh barrier in foreground prevented fish from entering section of fishway to the left of partition wall.

MATERIALS

The Test Fishway

All experiments were conducted in the Fisheries-Engineering Research Laboratory located on the north shore of the Columbia River at Bonneville Dam, approximately 140 miles from the river mouth. Fish enter the bypass at an elevation of 47 feet above sea level and leave it at an elevation of 60 feet.

The test fishway used in the 1957 experiments is shown in figure 1. This unit included six pools, each 16 feet long (weir center to weir center), 4 feet wide, and 6.3 feet deep. With a 1-foot rise between pools, the slope was 1 on 16. The calculated water volume per pool was 380 cubic feet. Head on the weirs, measured 4 feet upstream of the weir crest, was 0.8 foot. There were no orifices in the weirs. The flat weir crest (8-inch width) which had been used in the 1956 experiments was replaced with a Dalles-type crest (fig. 2). Tests at the Bonneville hydraulic laboratory[2] had previously demonstrated that the Dalles-type crest was superior to the broader, square-crested weir in maintaining flow stability. The desired flow pattern which had been established for these tests was plunging, but in the 1956 trials, flows often changed from a plunging to a streaming or shooting pattern, resulting in a surface rather than submerged motion within the fishway pool. Observations indicated that fish passage was delayed when a change in flow pattern developed. Installation of the Dalles-type crest provided a controlled, stable flow throughout all recent experiments, eliminating the undesirable features of changing hydraulic conditions during experimental periods. The calculated flow in the test fishway was 11.8 c.f.s.

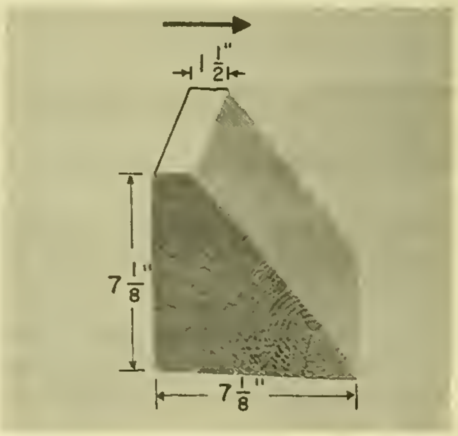

Figure 2.--Sectional cut of the Dalles-type weir crest. Arrow indicates direction of flow.

[2] Theus, Harry P. Memoradum report 1-3, The Dalles fish ladder surge studies, March 30, 1955. Ozalid.

Other Features

Aside from the two major changes noted in the test fishway (i.e., width reduction and weir crest modification), the essential components within the laboratory were identical to those of the 1956 experiments (fig. 3). There was a large collection pool 24 feet by 30 feet by 14 feet into which the fish ascended from the entrance fishway, a 5-foot-wide release gate through which the fish passed to enter the introductory pool immediately downstream of the test fishway, and the large, flow introduction pool into which the fish passed after leaving the test area. From this point they continued their movement upstream through the exit fishway and back into the main Washington shore fishway, thus completing the bypass.

The collection pool was again equipped with a brail which was used to encourage the fish to exit from this pool. The brail was not employed in all tests, however.

A standard light condition approximating outdoor conditions on a bright, cloudy day prevailed in all experiments. Light was provided by fluorescent, mercury-vapor lamps (1000 watt) spaced at 6-foot intervals and hung 6 feet above the water surface throughout the fishway (fig. 1).

A continuous record of fish passage during an experiment was transmitted to an operations recorder. An observer pressed a switch button each time a fish passed a particular weir in the fishway, and the observation was simultaneously noted on a revolving time tape within the recorder.

METHODS

Experimental Approach

Essentially, the approach to the determination of capacity was similar to that taken in 1956. Two major factors influencing fishway capacity were to be examined. The first was the maximum number of fish which may enter the fishway per unit time. This we assumed would be governed by (1) fishway width, (2) fishway hydraulics and entrance conditions, and (3) differential reactions among the fish with respect

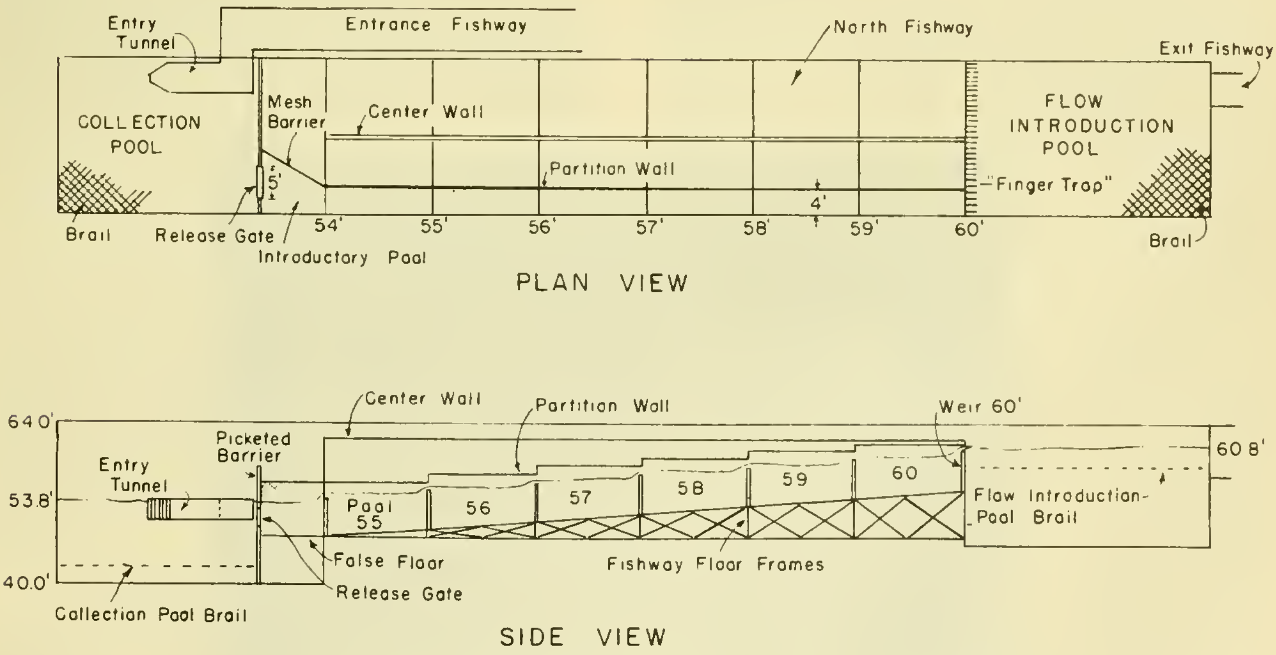

Figure 3.--Diagrammatic plan and side views of the experimental equipment.

to kind of fish passed, average size of fish, and season of migration. To determine the maximum entry per unit time, we planned to observe the point at which a further increase in numbers available for entry failed to produce a further increase in entry rate.

A second element to be examined was the maximum number of fish (size considered) that can be accommodated (i.e., provided ample moving and resting space) in an individual pool. If the maximum number of fish that can be accommodated in a single pool is exceeded, the capacity of the fishway will be determined by the number of fish leaving that pool per unit time. The extent to which fish will accumulate in a given pool will depend on (1) the number of fish entering per unit time (entry rate) and (2) the speed at which fish pass through the pool (rate of movement). If the fish move rapidly enough and the pools are of sufficient size to accommodate all fish entering, the maximum accommodation of a pool may never be exceeded. In this event, we should conclude that the capacity of a fishway would be related solely to the number of fish which can enter per unit time.

By way of illustration, we may cite two hypothetical cases. In case 1, the maximum entry into the fishway is 50 fish of a given size per minute, the maximum number which can be accommodated in a single pool is 125 fish, and the rate of movement, constant for all pools, is one pool every 2 minutes (30 pools an hours). Thus, only 100 fish will accumulate in each pool, and entry and exit will remain constant at 50 fish a minute, since maximum accommodation in a pool (125) has not been exceeded. In case 2, the potential maximum entry is 50 fish a minute and the maximum number which can be accommodated in a single pool is again 125 fish, but rate of movement is one pool every 3 minutes (20 pools an hour). Thus, each pool must carry 150 fish. Since this is 25 fish in excess of the established maximum number that can be accommodated in a single pool, the result is that only 41 fish may enter and leave each pool per unit time if maximum accommodation is not to be exceeded.

Collection and Release Procedure

Fish were collected for experimental purposes in much the same manner as in 1956. Fish were diverted from the Washington shore fishway during peak migration periods into a bypass fishway which leads to the collection pool (fig. 4) at the downstream end of the test facility.

It was again necessary to accumulate fish for a period of time so that sufficient numbers would be available for experimental purposes. In 1957 the collection period was confined to approximately 48 hours after which preparations were made for release of

Figure 4.--View of collection pool (foreground). Barrier extends 8 feet above water surface to prevent fish from jumping into fishway area upstream of pool.

the fish. No additional fish were permitted to enter the collection pool after tests were under way.

Fish were released from the collection pool by raising a 5-foot gate in the grill forming the upstream face of the collection pool. The gate sill was approximately 2 feet below the water surface, allowing for a water area 5 feet by 2 feet through which the fish could pass to enter the introductory pool immediately downstream of the test fishway. This area exceeded the total entry area into the fishway (4 feet by 1 foot) by approximately 6 square feet, assuring ample access to the fishway entrance.

Two methods were employed to release fish from the collection pool: a "brail type" release and a "free" release. In the brail release the collection-pool brail was raised to within 4 feet of the surface just before the release gate was opened. Once the gate was opened and fish began to ascend the fishway, the brail was tilted forward gradually to encourage continued movement out of the collection pool. This method provided for a virtually complete utilization of all fish in the collection pool since the fish had no recourse but to move into the fishway introductory pool and thence into the fishway. However, the brail method of clearing the collection pool raised questions relative to the creation of an unnatural stimulus during the release period and its possible effect on the subsequent behavior of the fish once they had entered the fishway. Would fish which had been somewhat artificially removed from the collection pool perform in a normal manner? Were we creating an artificial entry maximum as a result of the brail technique? To obtain answers to these queries an alternative method, the free release, was employed. This technique simply called for the entry gate to be opened and for the fish to pass from the collection pool and enter the fishway on their own volition. At no time was the brail used during the experimental period. Two releases were conducted in this manner.

Another procedural change adopted in some 1957 tests was to close the entry gate when the observed maximum entry rate had appreciably declined. In 1956 the gate had remained open for the full 60-minute test period. The new procedure called for gate closure generally within 30 minutes after the initial release (start of test). This technique permitted more realistic determination of mean passage time through the fishway since nearly all fish entering the fishway introductory pool in the first 30 minutes could be expected to enter and pass through the fishway by the end of the 60-minute test period.

Recording Procedure

Observers, stationed at each of the seven weirs in the fishway, recorded upstream and downstream movement over the weirs. These observations were transmitted by push-button switch to an operations recorder, the signals appearing instantaneously as individual blips on a revolving time tape. An additional observer was stationed at the final weir (60) to maintain a tally by species. All tests were arbitrarily concluded 60 minutes after the entry gate had been opened.

Estimation of Passage Time

Estimations of the average passage time required to ascend the 6-pool fishway were based on the observed entry and exit per unit time in each trial. They are considered estimates rather than absolute determinations because any error in the observed counts would naturally affect the passage-time calculations. Two methods were used to estimate passage time. One, called "median elapsed time," based on median entry and median exit times was simply the difference in the time at which half of the fish had entered the fishway and the time at which half of the total entered has passed through the fishway. The "mean passage time" was derived in the usual manner by taking the difference between the mean entry and mean exit times for all fish passed during the 60-minute test period. Since the total number that negotiated the fishway was rarely 100 percent, the estimate of mean exit time was adjusted to account for all fish remaining in the fishway at the conclusion of the 1-hour test. This was done by arbitrarily assigning the 61st minute as the time at which all remaining fish completed their ascent of the fishway. The resulting estimates of mean passage time are biased (underestimated) by this procedure, the extent of the bias depending on (1) the percentage of fish remaining after 60 minutes and (2) the actual times that fish would have remained before leaving.

Table 1.--1957 fishway capacity test summary. Number and percentage of fish passed, passage time[1], and species composition. All tests for 60-minute duration.

Test	Date	Number of fish entering fishway	Number of fish leaving fishway	Percent completing fishway	Elapsed passage time (minutes) Median	Mean	Species composition (percent) Chinook	Jacks	Steelhead	Blueback	Other
1	May 1	1211	1059	87.4	19.0	18.3	92.1	4.5	1.3	-	2.1
2	May 8	951	907	95.4	14.2	11.7	66.2	32.0	1.2	0.1	0.5
3	2/ June 25	1647	3/ 1653	100.0	9.2	9.4	51.4	13.6	6.8	27.5	0.7
4	2/ June 25	619	597	96.4	10.0	10.4	56.8	10.9	8.4	23.2	0.7
5	June 25	675	656	97.2	13.1	10.8	56.1	20.6	7.8	14.7	0.8

1/ Time required to ascend 6 pools.

2/ Free release (no brail used in collection pool area).

3/ The discrepancy of 6 fish (more leaving than entering) was due to count error.

Table 2.--Number of fish available for passage and related entry and exit in five fishway capacity trials, 1957.

Test	Date	Number of fish: Total available for passage	Maximum entry per min.	Maximum exit per min.	High average entry/min. 20-minute period	High average exit/min. 20-minute period	Estimated weight in pounds: Average weight per fish	Total available for passage	Total entered	Maximum entry[1] per minute
1	May 1	1615	61	40	42	28	14.0	22,610	16,954	812
2	May 8	1100	53	31	34	25	8.7	9,570	8,274	426
3	June 25	3085	165	85	64	50	9.2	28,382	15,152	1242
4	June 25	1430	71	30	24	20	9.8	14,014	6,066	568
5	June 25	810	64	30	26	21	9.8	7,938	6,615	588

1/ Based on average of the maximum number entering in a 3-minute period.

Rate of ascent may be expressed in terms of pools per hour or as vertical ascent in feet per minute. In these tests, which apply to a 6-pool fishway having an overall rise of 6 feet (excluding the initial 1-foot rise into the fishway), a simple division of passage time by 6 will give the mean time per pool. Vertical ascent in feet per minute may be obtained by dividing the height ascended (6 feet) by the passage time. Thus, if the mean passage time for 6 pools is 12 minutes, the rate of ascent becomes 30 pools an hour (1 pool every 2 minutes), the vertical rise 1/2 foot per minute.

Average Size Determination

A specific measure of fishway capacity must consider the average size of the fish passed. Obviously, any estimate of maximum passage per unit time will have little meaning unless it is further qualified in terms of a unit measure of fish size. While the average displacement per fish may be the most desirable measure of fish size, the physical handling which would be necessary to obtain such a determination is readily apparent.

In these tests estimates of the average length of each species were obtained from sample observations as the fish entered the collection pool. Estimated lengths were converted to pounds and applied as a unit of average fish size in the different trials. Seasonal length-weight relationships for chinook salmon (*Oncorhynchus tshawytscha*) during 1957 were kindly provided by the Oregon and Washington state fisheries departments. Appendix table A-1 gives these data for the period April 30 to August 25.

In the absence of specific length-weight data for species other than chinook salmon, an estimated average poundage was assigned for each on the basis of visual observation. Steelhead (Salmo gairdneri) were estimated at 6 pounds and blueback salmon (O. nerka) at 2.5 pounds. Other species, including suckers (Catostomus sp.), squawfish (Ptychocheilus oregonensis), carp (Cyprinus carpio) and chubs (Acrocheilus alutaceus) were summarily estimated to average 1 pound.

RESULTS

Review of 1957 Fishway Capacity Trials

Five fishway-capacity trials conducted during 1957 are summarized in tables 1 and 2. The trials of May 1 and May 8 used chiefly spring-run chinook salmon, while the three tests on June 25 included a mixture of summer-run chinook salmon[3], blueback salmon, and steelhead trout.

Differences in average estimated weights of fish in the various trials (table 2) may be explained mainly by differences in species composition (table 1). Generally, chinook salmon were the largest of all species tested. An exception to this occurred in the May 8 trial when a rather high percentage of jacks[4] appeared in the run, materially reducing the average size of chinook salmon in this test.

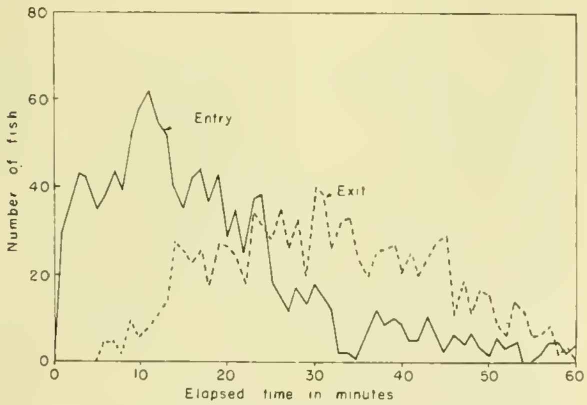

Figure 5.--Observed entry and exit during 60-minute capacity trial on May 1, 1957. Chinook salmon (O. tshawytscha) averaging 14 pounds were the predominant species.

Total numbers entering the test fishway during the 60-minute test periods ranged from 619 to 1,647 fish, or approximately 6,000 to 17,000 pounds, in the five trials. In the discussion, particular emphasis is placed on the May 1 and June 25 tests.

Maximum Entry and Exit

Table 2 gives the maximum numbers observed to enter and leave the test fishway per minute. Graphic presentation of the 60-minute entry and exit observed in tests 1 and 3 is shown in figures 5 and 6. (Further data on observed counts in all tests may be found in table A-2). For fish (predominantly spring chinook) averaging 14 pounds, the maximum entry was 61 fish a minute. This compares with a maximum observed entry of 75 fish a minute during a 1956 trial (Elling and Raymond, 1959) when fish (predominantly fall chinook) averaged 13 pounds and the fishway was 6 feet wide.

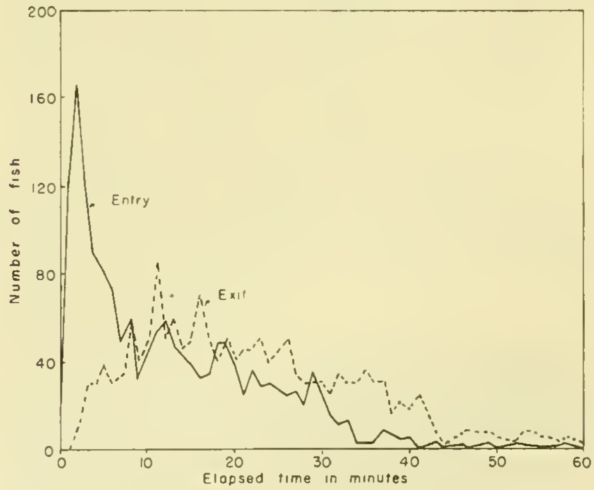

Figure 6.--Observed entry and exit during test No. 3 (June 25, 1957). Fish passed were a mixture of chinook salmon (O. tshawytscha), blueback salmon (O. nerka) and steelhead trout (S. gairdneri). The average estimated weight was 9.2 pounds.

3/ Columbia River chinook salmon runs have been arbitrarily divided into spring, summer, and fall migrations with the the respective periods ending on May 31, August 15, and December 31.

4/ The term "jack" salmon on the Columbia River generally applies to a mature male chinook salmon returning upstream after one year or less ocean residence. While several size distinctions are in use, in these experiments all chinook salmon 20 inches and under were arbitrarily classified as jacks.

By comparison, in another trial (June 25 - No. 3) in which the fish averaged 9.2 pounds, the observed maximum entry was 165 fish a minute. Entry rates given imply net entry, i.e., the total passing the first weir in the fishway less the number drifting or swimming back downstream.

Different release techniques were employed in tests Nos. 1 and 3. Fish released in the May 1 trial were subjected to the brail-raising procedure to achieve a complete exit from the collection pool, but no brail was used to encourage exit from this area in the June 25 test. The surprisingly high entry rate achieved in test 3 is noteworthy inasmuch as no unusual means were employed to create a maximum influx of fish to the fishway.

To examine further the entry characteristics in each of the tests, the high average entries for continuous 20-minute periods were determined (table 2). The 20-minute observation period was selected since this was usually the longest period in which appreciable numbers were available for entry. By the time 20 minutes had passed, entry rate usually fell off markedly because of declining numbers in the collection pool. For the two tests in which the largest numbers of fish were passed (May 1 and June 25), the high average 20-minute entry was 42 fish a minute when fish averaged 14 pounds, and 64 fish a minute when the average weight was 9.2 pounds. Converted to an hourly basis, the expected entry rates would become 2,520 and 3,840 fish an hour for the respective size groups noted.

The numbers leaving per unit time in tests 1 and 3 (figs. 5 and 6) apply to the observed passage over the last weir in the fishway. For fish averaging 14 pounds, the maximum observed exit was 40 fish a minute and the high 20-minute average was 28 fish a minute. Similarly, the maximum exit for fish averaging 9.2 pounds was 85 fish a minute and the high 20-minute average was 40 fish a minute. On an hourly basis, the observed exits for the respective size groups would become 1,680 and 3,000 fish an hour.

The observed maximum exit in each trial was somewhat less than the observed maximum entry. A possible explanation may be that the number of fish available for passage was continually decreasing as fish began to enter and ascend the fishway. Thus, during the brief period that a maximum entry was in effect, the exit was just beginning to rise. By the time appreciable numbers had accumulated in the upper levels of the fishway and the exit approached a maximum, the entry already had begun to decline (figs. 5 and 6) because of depletion of the original supply available for passage. Therefore, the observed maximum exits may be less than might have been attained had it been possible to sustain the high entries for a longer time.

Entry Capacity

Entry capacity is defined as the point at which a further increase in number available for passage fails to produce a corresponding increase in the entry per unit time. The number of fish available for passage in each of the five 1957 capacity tests was converted to pounds so that each test could be evaluated in terms of average fish size (table 2). Then the maximum entry per minute in terms of pounds was determined for each test. This was based on an average of the high 3-minute entry. The average of a 3-minute period was selected in preference to the maximum entry in a single minute to dampen the possible effect of size fluctuations between minutes.

Figure 7 indicates a linear relation between number of fish (in pounds) initially available for passage and maximum entry rate achieved. It is not patently clear that an entry capacity was reached in any of the tests. This observation is made with caution, since it is based on a limited number of trials conducted during different periods of the season. Additional comparisons, particularly at higher availability levels, will be necessary to substantiate this observation. Since the present comparisons cover 2 months within the migrational period, species composition and environmental conditions (water temperature and turbidity) did not remain constant for all tests. These factors may have had considerable bearing on maximum entries realized within individual tests. For this reason the three trials (Nos. 3, 4, and 5) conducted on June 25 may not be directly comparable with those of May 1 and 8.

Maximum Number of Fish Present in the Fishway

We have previously noted that the

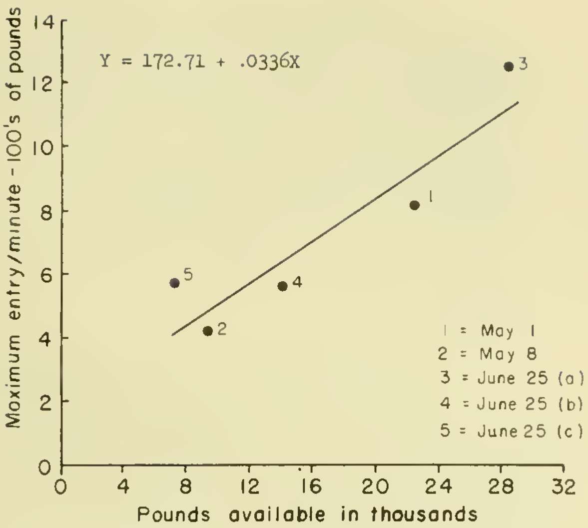

Figure 7.--Relation between initial availability and maximum entry rate during five 1957 fishway capacity trials. Number of fish expressed in pounds.

initial control on the capacity of a fishway will be the number of fish which may enter per unit time. Once the fish have entered, it becomes important to examine the extent to which they may accumulate in the fishway. Maximum numbers of fish observed in the test fishway during the five 1957 trials are given in table 3. Also included are the observed maximums in the first pool of the fishway.

Tests 1 and 3 are of greatest interest since the observed maximum number of fish (size considered) in the fishway in these tests was usually nearly double that noted in the other three trials. Test 1 shows that for fish (predominantly spring chinook salmon) averaging 14 pounds in weight, the maximum number observed in the first pool was 148 fish and the maximum in the fishway was 640, an average of 107 fish per pool. Apportioning these figures on the basis of available space (388 cu. ft. per pool), there was 1 fish per 2.6 cu. ft. in the first pool, and the average for 6 pools was 1 fish per 3.6 cu. ft. Similarly, in test 3 in which the fish (chinook, blueback, and steelhead) averaged 9.2 pounds, there was 1 fish per 2.2 cu. ft. in the first pool, and the average for the fishway was 1 fish per 4.5 cu. ft.

Actually, fewer fish accumulated in the fishway during test 3 than during test 1, even though the entry per unit time was higher. This may be explained by the fact that the fish in test 3 ascended the fishway almost twice as rapidly as those in test 1.

As used here, the analysis of space per fish has considered the entire pool volume (388 cu. ft.) to be available to the fish. In all likelihood, not all of the pool will provide suitable moving and resting areas, and, as such, may never be utilized. Until we actually know how large numbers of fish distribute themselves within a fishway pool (this will require a series of observations through viewing windows on the sides of pools), the present method of assessing space per fish must be considered with some reservation.

For complete data on the number of fish present in the fishway at a given time during the five trials, see table A-3 in the appendix.

Table 3.--Observed maximum number of fish in fishway (6 pools) and in first pool, average weights, and space per fish.

Test number	Average weight per fish (pounds)	Fishway: Maximum number of fish	Fishway: Space per fish (cu. ft.)	First pool: Maximum number of fish	First pool: Space per fish (cu. ft.)
1	14.0	640	3.6	148	2.6
2	8.7	374	6.2	89	4.4
3	9.2	522	4.5	178	2.2
4	9.8	236	9.9	70	5.5
5	9.8	308	7.6	88	4.4

Effect of Fish Density on Rate of Ascent

A number of factors may conceivably influence the rate at which fish ascend fishways. Some are inherent in the fishway structures; others may be related to environmental and biological conditions. Experiments at Bonneville have shown, for instance, that the speed at which certain species move in fishways may vary with season. Chinook salmon required more than twice as long to ascend a 6-pool, 1-on-16-slope fishway in spring as in late summer[5/].
Conceivably, temperature and turbidity of

5/ Monthly progress reports Nos. 10, 14, and 22 on research on fishway problems conducted at the Fisheries-Engineering Research Laboratory at Bonneville Dam under Contract No. DA-35-026-25142 with the U. S. Fish and Wildlife Service.

Table 4.--Maximum number of fish present in fishway and mean passage time (minutes) required to ascend fishway in each of five fishway capacity trials, 1957.

Test number	Date	Maximum number in fishway	Mean passage time (minutes)	Mean time per pool (minutes)	Rate pools per hour
1	May 1	640	18.3	3.1	19.4
2	May 8	374	11.7	1.9	31.6
3	June 25	522	9.4	1.6	37.5
4	June 25	236	10.4	1.7	35.3
5	June 25	308	10.8	1.8	33.3

the water, sexual maturity, and spawning locale of the migrants may be some of the underlying causes.

Differences in the performance of various species of migrating fish have also been observed. Experiments in June 1956 give insight into the variability among the performances of several species of salmonids. The following average passage times (minutes) were required to ascend a 6-pool, 1-on-16-slope fishway with a width of 11.5 feet and a mean pool depth of 6.4 feet: chinook salmon 14.3, blueback salmon 7.6, and steelhead 5.9. Although specific passage rates have not been obtained for non-salmonids (carp, suckers, squawfish, and chubs), our observations indicate these fish do not ascend fishways as rapidly as the salmonids.

Variation in light intensity may also govern fish behavior in fishways. Long (1959) has noted that salmonids (principally steelhead) passed through a darkened fishway significantly faster than through an identical well-lighted structure.

Aside from the foregoing conditions, all of which may influence the capacity of a fishway, it is important that we assess the effect of numbers of fish present in the fishway (fish density) on the rate of ascent. Do fish travel at comparable speeds regardless of the number of fish in a fishway at a given time, or is there some limiting density at which movement is encumbered sufficiently to reduce the rate of ascent, so that we may expect an increasing accumulation of fish in the fishway? Eventually there may then be a point at which maximum entry can no longer be sustained because of limited space within the fishway pools. This, in effect, would indicate that the capacity of a fishway had been exceeded.

A comparison of the maximum number of fish present in the fishway during each trial and the corresponding mean passage time and rate of ascent are presented in table 4. The mean passage time for a 6-pool ascent is expressed as a rate in terms of pools ascended per hour. An arbitrary measure of fish density in terms of the observed maximum number of fish in the fishway during each 60-minute test was used.

A direct comparison of the rate of ascent as related to density is not possible for all five trials because of inherent differences in performances which may be attributable to season and species, but three trials conducted on June 25 may be compared. Temperature and turbidity of the water remained relatively constant throughout the day. Although species composition varied slightly, the differences were not considered sufficient to appreciably affect the passage times. The tests in question began successively at 9 a.m., 1 p.m., and 3 p.m. and continued for 60-minute periods. On the basis of previous work,[6] the difference in time of day was not considered a factor likely to affect rate of ascent.

Proceeding, then, on the assumption that a general uniformity prevailed in the three experiments, one variable that might have affected rate of ascent was the number of fish present in the fishway during each test. Inspection of this relation in the June 25 tests (table 4) suggests that crowding apparently did not impede the rate of ascent. Indeed, ascent in the test with the largest number of fish (No. 3) was slightly faster than that in the other two trials (Nos. 4 and 5). It may be added that the minor differences in rate could have been related to incidental variation in the species composition (table 1) rather than to the number of fish involved in the respective tests.

Fallbacks

The term "fallback", as used here, applies to fish which enter a pool and then drift or swim back into the pool below.

6/ Gauley, Joseph R., and Clark S. Thompson. Further studies on fishway slope and its effect on the rate of passage of salmonids. Manuscript in preparation.

Examination of fallback activity is of particular interest in this discussion since there is a suggestion that the phenomenon may be associated in some way with capacity, i.e., an unusually high fallback frequency may be taken as an indication that the fishway pools have become excessively crowded and can no longer accommodate all fish entering.

Observations in the Bonneville facility during the past 2 years have shown that moderate fallback occurred even at times when crowding could not possibly have been a contributing factor. This leads us to believe that fish may move "to and fro" in a fishway as they do in other areas of their natural environment. The point in question then becomes one of differentiating between normal and unusual fallback activity.

A summary of fallback observations made during the five 1957 fishway capacity tests is presented in table 5. By far the greatest number of fallbacks occurred in the downstream or entry area of the fishway, and there was a marked decline in fallbacks as the fishway was ascended. Of all fallbacks, 91 percent occurred at the lower three weirs of the fishway. A similar distribution of fallbacks was indicated in 1956. This suggests that there may be an initial period of learning or adaptation of fishway conditions. Once the fish have ascended several pools, orientation may become more complete and there may be much less inclination to drift back from pool to pool in the succeeding upstream areas of the fishway.

To assess the magnitude of fallback activity in each test, the total number of fallbacks was converted to a percentage of the total entry. The resultant values are of particular interest. In tests 1, 2, and 5, fallback percentages were virtually identical despite the fact that there was a considerable difference in the number of fish entering the fishway in each test. Significantly, these values were almost three times as high as those shown for tests 3 and 4. An interesting feature of this comparison is that the brail-type release was employed in tests 1, 2, and 5, while the free release was used in tests 3 and 4. Clearly, the use of the brail appears to have been a contributing factor in markedly increasing fallback activity.

Graphic comparison of fallback frequency in the five 1957 trials is shown in figure 8. Thus far in the experiments there is no suggestion that fallbacks increased in proportion as the number of fish entering the fishway increased.

Table 5.--Total numbers entering fishway and fallbacks at each weir 1/ during five 60-minute capacity tests, 1957.

[Note: A "brail type" release was employed in tests 1, 2, and 5. No brail was used in the release during tests 3 and 4.]

Test	Date	Total entry	Number of fallbacks, Weir 1	2	3	4	5	6	Total fall-backs	Fallbacks in percent of total entry
1	May 1	1211	91	39	2/ 30	19	1	4	184	12.5
2	May 8	951	90	30	5	6	6	6	143	15.0
3	June 25	1647	50	19	13	1	2	3	88	5.3
4	June 25	619	20	4	10	0	1	0	35	5.6
5	June 25	675	69	18	14	0	0	0	101	15.0
Totals			320	110	72	26	10	13	551	

1/ There were 7 weirs in the fishway but a finger trap was installed on the last weir (No. 7) to prevent fallbacks.

2/ Estimate in part.

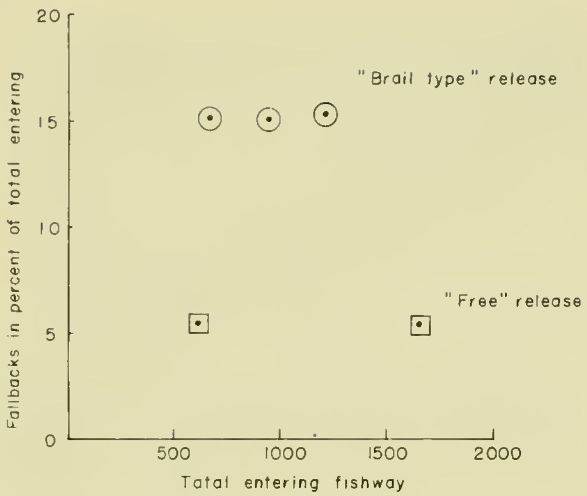

Figure 8.--Proportion of fallbacks as related to total fish entering fishway in five 60-minute fishway capacity trials, 1957.

DISCUSSION

It is perhaps well to emphasize some of the factors to be considered in evaluating the results of these tests. Much of our effort to demonstrate capacity in a fishway was handicapped by an inability to secure ample numbers of fish for test purposes. In practice, there are perhaps only three or four periods during the annual migrations at Bonneville Dam during which fish are sufficiently abundant to justify tests of this design. Even then it has been necessary to collect fish for a period of time to provide ample numbers for testing. This technique may have had some influence on the behavior of fish after their release into the fishway. Further, we are aware that performance in fishways may vary with season and species. This has complicated the process of comparing tests conducted at different times of the season, and therefore has necessarily restricted the number of observations that may be compared with confidence.

The effect of fishway width upon the passage of fish will require additional study. In the 1957 experiment, a fishway 4 feet wide was used while a preliminary experiment in 1956 utilized a fishway 6 feet wide. Fluctuation in passage time due to reduction in width cannot be adequately assessed because of differences in hydraulics and species composition of the respective experiments.

Despite these limitations, the recent tests have demonstrated that surprisingly large numbers of fish may pass through a fishway of comparatively modest size. To cite an example for comparison, the record hourly count in a 1-on-16-slope fishway at Bonneville Dam is 4,296 salmonids (Bradford Island Ladder, September 10, 1946).[7/] The upper section of this ladder is 42 feet wide and is joined by two lower branches, each 40 feet wide. In our recent tests, a fishway only 4 feet wide passed 50 salmonids per minute (3,000 per hour), or roughly two-thirds of the record hourly count in the large Bradford Island ladder.

SUMMARY AND CONCLUSIONS

The 1957 experiments to measure fishway capacity (maximum number of fish passed per unit time) were conducted in a 6-pool, 1-on-16-slope fishway only 4 feet wide. Each pool was 16 feet long (weir center to weir center) and averaged 6.3 feet deep. There was a 1-foot rise between pools, and head on the weirs was 0.8 foot. No orifices were present in the fishway. Weir crests were a Dalles-type design, and flows were uniformly plunging throughout the fishway. The total calculated flow was 11.8 c.f.s.

All test facilities were housed in the Fisheries-Engineering Research Laboratory, which is the principal component of a specially constructed bypass on the Washington shore fishway at Bonneville Dam. Fish were allowed to enter the laboratory and collect in a large pool at the base of the fishway structure. Collection periods were limited to approximately 48 hours, after which the fish were permitted to enter the fishway. Lighting, approximating outdoor conditions on a bright cloudy day, was supplied by a batter of 1,000-watt mercury-vapor lamps.

The following observations were made during the course of five 60-minute trials in May and June:

1. The maximum observed entry for chinook salmon averaging 14 pounds was 61 fish per minute. In the same trial the high average entry for a continuous 20-minute period was 42 fish per minute.

7/ Daily operation reports, U. S. Army Corps of Engineers, Bonneville Dam.

In another trials, with a mixture of chinook and blueback salmon and steelhead trout, the maximum entry was 165 fish per minute. These fish averaged 9.2 pounds. The 20-minute high average entry was 64 fish per minute.

2. Maximum observed exits applicable to the above size groups (14 and 9.2 pounds respectively) were 40 and 85 fish per minute. The high average exits for 20-minute periods were 28 and 50 fish per minute respectively for the two size groups.

3. Total pounds of fish available in the five tests ranged from 7,938 to 28,382. Maximum entry in pounds (average of high 3-minute entry) ranged from 426 to 1,242. A trend indicating increased entry with increased availability was observed, but additional tests, particularly with higher levels of availability and during comparable periods of the season, will be necessary to establish the point at which a further increase in fish available for passage fails to produce an increase in the entry rate.

4. The maximum number of fish observed in the first pool of the fishway was 178. These fish (chinook, blueback, and steelhead) averaged 9.2 pounds. On the basis of total available space per pool (388 cu. ft.), the average space per fish was 2.2 cubic feet. Similarly for chinook salmon averaging 14 pounds, the maximum number observed in the first pool was 148 fish. This yields an average space of 2.6 cubic feet per fish.

5. The relation between rate of ascent and number of fish present in the fishway was examined in three trials conducted on the same day. Results of these tests suggest that crowding did not impede rate of ascent. Maximum numbers of fish in the fishway during the trials were 522, 236, and 308, and the respective rates of ascent were 37.5, 35.3, and 33.3 pools per hour. Minor differences in rate were believed to be associated with species composition in the tests rather than with the number of fish present.

6. Of all fallback activity, 91 percent occurred at the lower three weirs of the fishway. The percentage of fallbacks was independent of the number of fish entering the fishway, suggesting that other factors may influence fallback activity.

While the capacity of the test fishway was not established in these trials, it is believed to be in excess of 50 salmonids (averaging 9.2 pounds) per minute.

The limited number of trials, and the differences in performance that may occur between trials owing to season and species composition, are factors to be considered in evaluating the results of these tests.

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LITERATURE CITED

ELLING, CARL H., AND HOWARD L. RAYMOND
1959. Fishway capacity experiment, 1956. U. S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 299, 26 pp.

LONG, CLIFFORD W.
1959. Passage of salmonoids through a darkened fishway. U. S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 300, 9 pp.

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APPENDIX TABLES

Table A-1.--Chinook salmon length--weight relations for the period April 30 to August 25, 1957 as determined from Columbia River gill-net catches.

Fork length (inches)	Weight (pounds)		
	Apr.-May 1/	June-July 2/	July-Aug. 3/
10	0.6	0.5	0.6
2	1.0	0.9	1.0
4	1.6	1.5	1.6
6	2.3	2.2	2.4
8	3.3	3.1	3.3
20	4.4	4.2	4.5
2	5.8	5.6	5.9
4	7.4	7.3	7.6
6	9.3	9.2	9.6
8	11.5	11.5	11.9
30	14.0	14.1	14.6
2	16.9	17.1	17.6
4	20.0	20.5	20.9
6	23.6	24.3	24.7
8	27.5	28.5	28.9
40	31.8	33.2	33.5
2	36.6	38.4	38.6
4	41.7	44.1	44.1
6	47.4	50.4	50.2
8	53.5	57.2	56.8
50	60.0	64.5	63.9

	Length-weight Formulae	Season
1/	Log Weight = (2.84671) (Log length) - 3.05807	Apr. 30-May 25
2/	Log Weight = (2.97430) (Log length) - 3.24343	June 20-July 15
3/	Log Weight = (2.89502). (Log Length) - 3.11328	July 29-Aug. 25

NOTE: Above table and formulae courtesy of Fish Commission of Oregon. The Washington State Department of Fisheries contributed in the collection of data utilized in this table.

Table A-2.—Entry and exit per minute for 60-minute period in five fishway capacity trials, 1957.

Minute	Test 1 Entry	Test 1 Exit	Test 2 Entry	Test 2 Exit	Test 3 Entry	Test 3 Exit	Test 4 Entry	Test 4 Exit	Test 5 Entry	Test 5 Exit
1	29	0	18	0	121	0	71	0	61	0
2	36	0	34	1	165	11	55	1	64	0
3	43	0	33	9	120	30	49	5	54	1
4	41	0	34	12	90	30	35	5	48	5
5	35	0	53	12	80	40	24	5	46	5
6	38	4	50	13	73	30	30	15	41	10
7	44	5	45	12	49	35	14	20	25	10
8	38	2	39	11	60	60	29	20	24	30
9	53	9	50	17	33	40	20	20	10	30
10	58	6	48	8	45	50	13	25	22	20
11	61	8	42	9	54	85	15	30	24	30
12	56	11	35	22	59	50	19	30	9	30
13	51	14	27	22	47	60	18	20	9	20
14	39	28	26	21	43	45	19	30	19	20
15	34	25	27	21	39	50	15	20	12	20
16	42	23	26	25	32	70	16	20	1	25
17	44	26	23	31	34	50	16	15	9	25
18	36	18	29	19	48	40	9	25	17	15
19	42	28	18	31	49	50	9	20	13	20
20	28	27	17	25	39	40	12	17	11	20
21	35	25	17	25	25	45	10	16	3	25
22	25	18	20	29	37	45	12	20	10	19
23	37	35	11	24	29	50	12	6	11	12
24	38	31	20	25	30	40	15	10	1	19
25	18	27	8	28	27	45	11	10	6	13
26	15	35	11	21	24	50	13	23	8	11
27	11	26	11	29	27	35	10	17	8	16
28	16	33	12	26	19	30	12	19	11	11
29	13	19	9	19	35	30	6	13	10	12
30	18	40	13	24	24	30	3	5	-1	13
31	15	38	9	16	15	25	4	12	1	11
32	11	26	11	30	11	35	4	4	5	13
33	1	32	4	21	13	30	3	4	6	8
34	2	33	8	22	3	30	2	11	3	5
35	-1	24	10	19	2	35	1	16	4	6
36	6	20	6	14	3	30	0	8	0	10
37	11	25	8	12	8	30	3	8	2	5
38	8	26	5	20	7	15	4	11	8	7
39	9	27	4	17	4	21	1	5	4	4
40	8	21	8	11	5	18	0	11	4	3
41	4	25	7	11	-1	24	1	3	9	13
42	5	20	8	14	1	18	0	0	7	9
43	11	22	4	14	3	8	0	0	9	7
44	5	27	4	9	0	1	0	2	-1	5
45	1	29	1	11	1	3	0	2	4	9
46	6	11	2	9	2	6	1	1	4	7
47	4	18	1	7	0	7	0	5	1	4
48	6	11	4	10	1	7	0	1	9	3
49	2	17	7	5	2	7	0	0	2	4
50	1	16	-3	10	1	5	1	4	0	4
51	5	9	3	7	0	4	0	1	4	5
52	2	6	1	3	2	1	-1	0	1	5
53	4	14	5	5	1	7	0	0	-3	3
54	-1	12	4	6	1	8	2	1	0	1
55	0	6	4	9	0	5	0	1	4	3
56	1	6	3	3	1	5	1	1	0	5
57	4	8	4	3	1	3	0	1	3	6
58	3	2	3	7	2	6	0	1	-1	1
59	1	3	2	6	1	4	0	0	0	2
60	3	2	8	5	0	1	0	1	0	1
Total:	1211	1059	951	907	1647	1653 1/	619	597	675	656

1/ The fact that more fish exited than entered is probably due to minor count error at either entry or exit points or both.

Table A-3.—Number of fish present in first fishway pool and 6-pool total for each minute during one-hour test period in five capacity trials, 1957.

Minute	Test 1 Pool 1	Test 1 Fishway Total	Test 2 Pool 1	Test 2 Fishway Total	Test 3 Pool 1	Test 3 Fishway Total	Test 4 Pool 1	Test 4 Fishway Total	Test 5 Pool 1	Test 5 Fishway Total
1	24	29	12	18	85	121	60	71	45	61
2	50	65	19	51	150	275	70	125	74	125
3	72	108	35	75	170	365	59	169	88	178
4	87	149	45	97	165	425	54	199	76	221
5	85	184	57	138	175	465	43	218	77	262
6	92	218	66	175	178	508	43	233	88	293
7	103	257	72	208	172	522	42	227	63	308
8	97	293	71	236	162	522	41	236	68	302
9	124	337	84	269	145	515	41	236	53	282
10	128	389	85	309	146	510	35	224	56	284
11	143	442	89	342	1/	479	35	209	55	278
12	146	487	81	355	-	488	34	198	50	257
13	148	524	70	360	-	475	32	196	45	246
14	144	535	61	365	-	473	31	185	55	245
15	132	544	52	371	-	462	21	180	51	237
16	134	563	45	372	-	424	21	176	31	213
17	134	581	44	364	-	408	21	177	27	197
18	121	599	51	374	-	416	21	161	30	199
19	116	613	44	361	-	415	22	150	34	192
20	103	614	35	353	-	414	23	145	30	183
21	99	624	28	345	-	394	20	139	21	161
22	100	631	21	336	-	386	24	131	28	152
23	105	633	14	323	-	365	23	137	25	151
24	105	640	13	318	-	355	22	142	15	133
25	84	631	6	298	-	337	21	143	16	126
26	65	611	9	288	-	311	25	133	18	123
27	62	596	4	270	-	303	21	126	17	115
28	63	579	3	256	-	292	18	119	15	115
29	65	573	-	246	-	297	12	112	15	113
30	56	551	-	235	-	291	9	110	7	99
31	58	528	-	228	-	281	10	102	2	89
32	53	513	2	209	-	257	6	102	8	81
33	41	482	-	192	-	240	10	101	11	79
34	39	451	-	178	-	213	12	92	7	77
35	35	426	3	169	-	180	10	77	11	75
36	34	412	-	161	-	153	7	69	7	65
37	41	398	6	157	-	131	7	64	3	62
38	39	380	5	142	-	123	9	57	8	63
39	36	362	3	129	-	106	6	53	8	63
40	36	349	1	126	-	93	5	42	8	64
41	36	328	6	122	-	68	6	40	11	60
42	35	313	6	116	-	51	5	40	7	58
43	40	302	1	106	-	46	4	40	8	60
44	40	280	-	101	-	45	5	38	4	54
45	33	252	-	91	-	43	5	36	7	49
46	35	247	-	84	-	39	5	36	3	46
47	35	233	-	78	-	32	3	31	2	43
48	33	228	-	72	-	24	2	30	10	49
49	33	213	-	74	-	19	2	30	7	47
50	27	198	-	61	-	15	3	27	6	43
51	29	194	-	57	-	11	4	26	7	42
52	28	190	-	55	-	12	3	25	6	38
53	29	180	-	55	-	6	3	25	1	32
54	24	167	-	53	-	0	5	26	0	31
55	25	161	-	48	-	0	4	25	2	32
56	21	156	-	48	-	0	5	25	2	27
57	24	152	-	49	-	0	3	24	4	24
58	26	153	-	45	-	0	3	23	1	22
59	25	151	-	41	-	0	3	23	1	20
60	26	152	-	44	-	0	3	22	0	19

1/ Incomplete count after minute 10.

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