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The measurement of performance of salmon in fishways

FACED with the prospect of providing fishways for a large number of dams, knowing that upon our success or failure depends the success or failure of important fishery resources, we must carefully assess our present knowledge of the behavior, abilities and requirements of fish as they relate to fish passage.

What are "fishways"? As we use the term in its broadest sense, fishways include a wide variety of structures and devices used to assist in passing migrating fish over or around obstacles such as dams. Fishways may consist of pools, collecting systems, channels, orifices, locks, hauling cars, brails, tunnels, weirs, traps, elevators, live cars, barges, louvers or baffled flumes, in all sorts of combinations.

To properly design "fishways" we should be able to predict the behaviour and performance of migratory fish in all of the diverse situations with which they may be confronted. To do this a detailed knowledge of all the factors that can modify the direction or rate of fish movement is required. We should know, for example, the water properties that are attractive to fish, the spatial relationships that affect fish movement, the hydraulic conditions conducive to or interfering with fish passage, the role of light and vision in the ascent of fish ladders, the reaction of fish to change in light and flow conditions, and the importance of sequential experience. We should know the seasonal and diurnal patterns of fish activity, fish swimming abilities and persistence, their metabolic requirements and limits of stress, their sensory capabilities and their ability to learn, their reactions to various degrees of crowding by other fish and the number of fish per unit time that can pass through various types of fishways.

These are but examples of the broad range of items on which we need information, precise information. If our concern were for only one dam and we were uncertain of the size of fishway required, we might design it with huge safety factors in size and thus build it two or three (or perhaps five) times as large as it need be. If we were uncertain of the reaction of the fish to one type of fishway, we might include a second set of fishways of a different type (e.g., both fish ladders and fish locks). If we were not sure that fish would remain in a particular type of collection channel, we might provide a separate transportation channel in back of the collection channel as insurance that fish on the far side of the system would not leave the fishway. The lack of precise information on fish behavior can in this way result in enormously increased fishway costs. Multiplied by the large number of dams that might be erected on a major river system, the total cost of over-designed fish passage facilities could reach such staggering proportions that they might no longer be economically justifiable in terms of the resources we are attempting to protect. Similarly, lack of precise information could permit the design of inferior fishways and minor delays or injuries that would be unnoticed or of little significance at one or a few dams might prove disastrous to a fishery when repeated at many dams. Detailed, accurate information on salmon behavior and performance is essential if we are to design economical fishways with confidence.

How to acquire this information is our problem. The subjects of our interest are large, active migrating fishes available for only a few months of the year. They are not convenient laboratory animals and there is always the danger that the shock of capture, removal from its natural medium and transportation to a conventional laboratory might modify the very responses we wish to measure. A logical thought is to attempt to study the fish in our present fishways. This also has severe drawbacks. If we depend on observation alone, we are limited to fishway conditions that already exist. If, however, we resort to experimenting in a functioning fishway there is the constant threat that if an unfavourable condition is created it may seriously impede or block the fish run. An alternative to this latter approach has been undertaken at Bonneville Dam on the Columbia River. There a special type of laboratory has been constructed on a bypass into which salmon are diverted from one of the major fishways. Salmon swim into this unique laboratory where they can then be subjected to full scale fishway situations under controlled experimental conditions without jeopardizing the passage of the main fish run. After fish pass through the experimental fishways and their performance has been recorded, they swim out of the laboratory and re-enter the main fishway.

The laboratory, called the Fisheries-Engineering Research Facility, consists of a level experimental flume (Figure 1) 104 ft. long, 24 ft. wide and 17 ft. deep, with a fish collection pool 50 ft. long and 24 ft. deep at the downstream end, and a flow introduction pool 40 ft. long at the upstream end. It has a water supply and discharge system that is independent of the main fishway and is capable of delivering and discharging more than 200 cubic feet per second for tests involving high water velocities. Light control is provided by a completely covered building and eighty 1000-watt mercury vapor lamps that under standard operating conditions produce illumination approximately equivalent to a cloudy bright day. Various types of fishway structures are erected in the experimental flume while it is dry, then water is introduced and the gates to the main fishway are opened to permit the entry of fish.

Funds for the laboratory were provided by the U.S. Army Corps of Engineers as a part of their effort to find an economic solution to their fish passage problems in the Columbia River. The selection of research items to be assigned priority or to be studied in greatest detail is therefore guided by the Corps' recommendations as to which have the greatest potential importance from the standpoint of construction and operation costs. For the first year's research three items were assigned priority, a measure of fishway capacity in a conventional pool type fishway, a study of the effect of gradient on rates of fish passage, and information on the relative attraction of water velocities.

The study of the effect of gradient on rates of fish passage was conducted by comparing rates of fish passage in two 12 ft. wide fishways. After tests for uniformity in the rates of passage when the two fishways were identical, the gradient of one of the fishways was modified while the other remained as a control in which to detect diurnal and seasonal variations. In this way the rate of passage through a "standard" fishway (similar to fishways at Bonneville Dam, 16 ft. pool length, 1 ft. rise between pools) with a gradient of 1:16 was compared with the rate of passage through three varieties (pool length 16 ft. and rise 2 ft. between pools, pool length 12 ft. and rise 1.5 ft., pool length 8 ft. and rise 1 ft.) of pool type fishways with a gradient of 1:8.

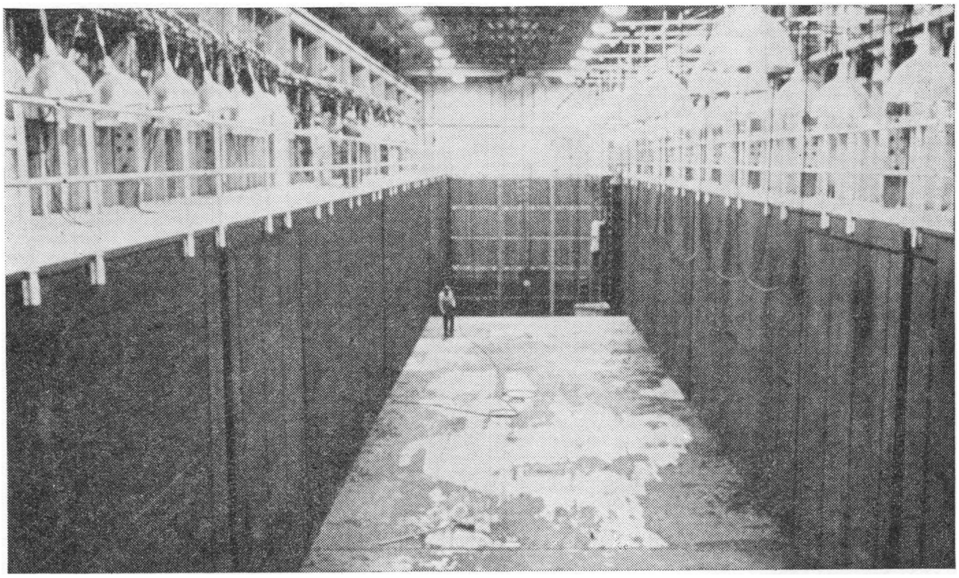

FIGURE 1.
EXPERIMENTAL FLUME (LOOKING TOWARD FISH COLLECTION POOL).

The "capacity", or maximum number of fish that can be passed per unit time, of a standard pool type fishway was measured in a fishway 6 ft. wide (Figure 2) that was created by installing a wall in the 12 ft. fishway used as a control in the gradient studies. Fish entering the laboratory were accumulated in the fish collection pool below the test fishway and then released as a group into the fishway. A brail was raised from the floor of the fish collection pool to within 2 ft. of the holding pool surface just prior to release to insure that the fish left the collection pool and entered the test fishway.

In experiments to determine which water velocities are most "attractive" to fish a choice technique was used in which the fish were presented with a choice between two channels with different water velocities. The relative number of fish selecting each channel was used as an index of the relative "attractiveness" of each water velocity.

The information that is available from the first season's operation of the laboratory at Bonneville is most encouraging from the standpoint of potential economies in fishway design. However, each series of tests is designed to provide specific information bearing directly on a part of a larger fishway problem and it may require several seasons of research before enough data is assembled to apply the information with confidence. For example, in the fishway gradient study the data show a higher rate of passage in one of the fishways with a gradient of 1:8. This is of great interest from the standpoint of construction cost for a fishway with a gradient of 1:8 would only need to be half as large as a fishway with a gradient of 1:16. However, because the tests were made with only a short segment of a fishway the possibility that the accelerated rate may be due to increased turbulence must

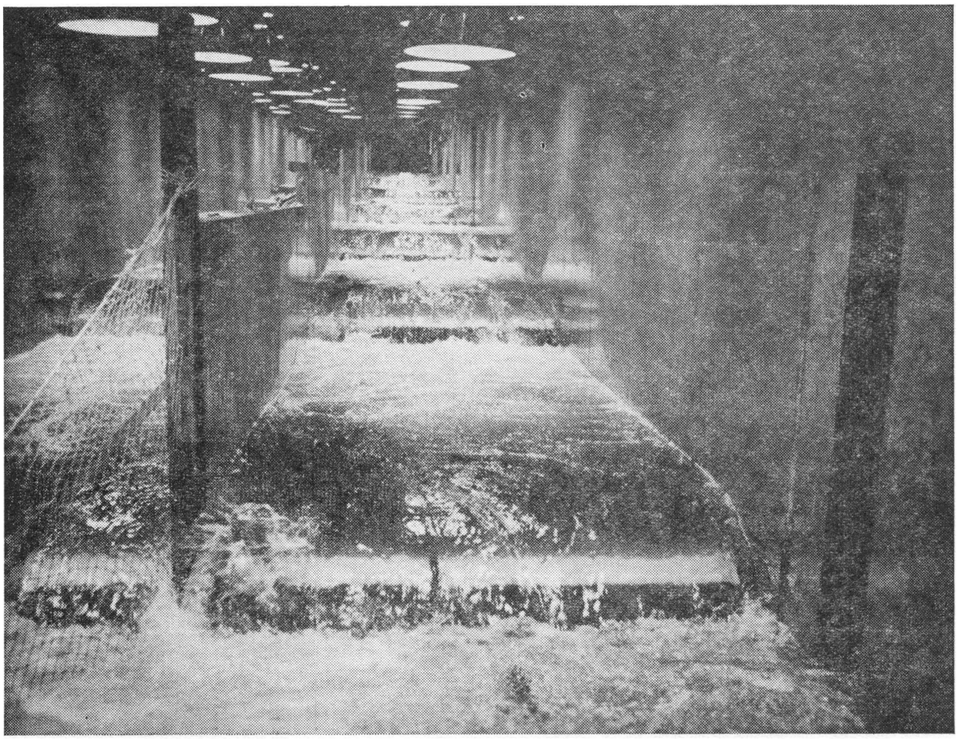

FIGURE 2.
FISHWAY USED FOR STUDY OF FISHWAY "CAPACITY" (LOOKING UPSTREAM TOWARD FLOW INTRODUCTION POOL).

be considered. Experiments of a different sort, using a "continuous" fishway technique are planned to determine if fish might become excessively fatigued in a longer fishway with a gradient of 1:8. Data from the tests of fishway capacity indicate that surprisingly large numbers of fish can be passed by a fishway of modest size. This information also gives promise of sizeable reductions in fishway construction costs if the information is verified under circumstances closer to those prevailing in longer fishways.

Other observations were made that have potential significance from the standpoint of fishway design. In measuring the performance of salmon in the experimental fishways throughout the season, it becomes apparent that performance may vary with the season. Fall chinooks were faster and more consistent than spring chinooks, while the rate of passage for steelhead appeared to slow down as the season progressed. This would seem to indicate that the "capacity" of a fishway could also vary with the season. The effect of a change in flow pattern was demonstrated on several occasions during capacity tests when fish movement almost ceased for several minutes when the flow patterns changed from plunging flow to a streaming flow. Such responses emphasize the importance of stable flow conditions as a design criterion. Individual fish showed a tendency to cross weirs next to a wall; however, the selection of a wall at each weir seemed to be almost at random, suggesting a tendency to explore each pool. This tendency to explore might result in unnecessary delay if a fishway were too large. As an example, in conducting experiments at the Fisheries-Engineering Research Facility, it was necessary to have fish swim in and out of the laboratory with a minimum of delay. One of the most effective methods of keeping the fish moving was to restrict the area in which the fish could explore by means of nets or brails.

(At this point a 15-minute portion of the motion picture film record of the 1956 experiments at the Fisheries-Engineering Research Facility was shown).

The measurement of fish performance in full scale fishway situations should be an important part of any comprehensive research program involving fish passage. There is probably no other way to breach the enormous gap between our knowledge of the performance of salmon in basic laboratory studies of fish physiology and psychology and our knowledge of the performance of fish in actual fish passage facilities. It is entirely possible and reasonable to measure the performance of fish in full scale fishway structures in the Fraser and in Alaskan rivers even before any dams are constructed. Solutions have been proposed for fish passage problems at high dams and at low dams. These should be tested before they are accepted as solutions and set in concrete. By acquiring a knowledge of fish reactions to specific fishway situations beforehand much of the guess and gamble of new fishway designs could be eliminated.

DISCUSSION

MR. CAMPBELL: (Referring to an experiment shown in the motion picture film record): How long was that area of eight feet per second velocity?

DR. COLLINS: The length of the channel having a velocity of 8 ft. per second was about 60 feet. In addition, the fish approached the channel through water velocities at approximately 8 ft. per second so that the fish actually had to swim a distance of about 80 ft. at that velocity. We plan to measure the response to even higher velocities this year. Last year's tests were made with fall run fish that were rather large fish.

DR. HOURSTON: If offered a choice between four feet per second and eight feet per second, which would they take?

DR. COLLINS: More of the fish were choosing the higher velocity in the experiments last fall. The tests were run at the very end of the season when few fish were available so that we tested all that came along. Our sample was small and included both steelhead and chinook salmon. There was also a wide variation in fish size with a greater number of large fish. It is possible that the response was due to the larger fish selecting the higher velocity. We will have an opportunity to examine the relation of fish size to choice of water velocity in more detail this year.

MR. VERNON: In regard to the difference between fall chinooks and spring chinooks, is there any indication that this would be caused by temperature?

DR. COLLINS: It may be related to temperature. However, there is also a difference in the state of maturity that may be important. The spring chinooks have a longer way to migrate and they are not as mature as the fall chinook when they pass Bonneville. On the basis of our exploratory tests in the fall of 1955, we anticipated that it would take about 2 or 3 minutes per pool for chinooks to pass through our control fishway. We were puzzled to find them taking from 5 to 20 minutes per pool in the spring of 1956. However, the pattern of slow movement with great individual variation was repeated again in the spring of this year.

MR. ALDERDICE: Is there much range in temperatureà

DR. COLLINS: Yes, the water warms up from about 50° to 65°F. during the season. Unfortunately, we are unable to regulate either water temperature or turbidity for our experiments. We have to take the river water as it comes.

MR. VERNON: Do the coarse fish successfully negotiate at eight feet per second?

DR. COLLINS: I doubt if we have any information on coarse fish in water of that velocity. There may have been a few coarse fish, but the tests were made at the very end of the salmon run and as far as I can recall, our only data is on the reactions of a few late steelhead and fall chinooks. We expect to run velocity tests in July or August this year when more coarse fish are present.

DR. FOERSTER: Do you anticipate carrying out any chemical blood or fat tests?

DR. COLLINS: We hope to get the collaboration of specialists for that. It is difficult to see what we can do of that nature with the type of experiments we are running this year. There is no indication of any fish fatigue in the short segments of fishway with which we are working. Next year we plan to examine fish persistance in ascending fishways by means of "continuous" fishway techniques and we hope that we can interest the group from the University of Washington in making related chemical studies.

DR. FOERSTER: Would you kindly relate your work on this point now?

MR. PAULIK: One of the relatively interesting points was the different swimming abilities of the various species. We tested steelhead and coho from the same streams under identical conditions at a number of different water velocities. The steelhead were able to swim much longer than coho at more than ten feet per second. Steelhead were able to hold their position in water velocities up to 12 ft. per second whereas coho were not.

We sampled a sockeye run at a number of dams on the Columbia River as they migrated upstream last summer. We transferred these fish back to the University and measured their swimming abilities at the various sites. We found a tremendous variation between Bonneville Dam and Rock Island Dam during the first part of the migration. After the first 450 miles up the river they seemed to at least maintain a stable level of ability. After that they turned up the Wenatchee River. We took samples after they left Lake Wenatchee and after they had entered the spawning streams and at that time their swimming ability was at a much lower level.

DR. BRETT: I wonder whether you would care to define what is meant by attraction?

DR. COLLINS: Going on the assumption that fish have a preference for some range of water velocities, the water velocities that would cause fish to approach a channel or a fishway could be said to have attraction. The term attraction water is commonly applied to the auxiliary water supplied at fishway entrances to gain the attention of fish and to stimulate them to enter the fishway. The velocity of water coming from the entrance of a fishway can be controlled at, let us say, two, four or six feet per second.

However, large volumes of attraction water are tremendously expensive. If we find that fish are attracted by higher velocities it may be possible to use a high velocity jet. Even in luring fish from the fishway into our Research Facility we have to consider the relative velocity of the entrance water.

DR. FOERSTER: In regard to your remarks about the ferrying of fish—to withstand temperature and current, is there not an emotional stress there when you take these fish back to the University of Washington. They are then several hundred miles away from their spawning grounds. I am interested particularly in emotional want.

DR. COLLINS: I think one of the answers to that question might be obtained by comparing the results of tests made after fish actually swim into the test area. This would give us a relative scale of abilities which might possibly be an indirect measure of emotional stress.

DR. FOERSTER: If there is any homing tendency, might it not be stronger as the fish mature and as the water quality becomes different? I think most of the tests at the University are forced—are they not, Gerry?

DR. COLLINS: Yes, the fish are motivated by both a light and a barrier which forces them to swim until they are exhausted.

MR. PAULIK: When we transport the fish we don't lose any, and after two days they seem fully recovered. However, realizing this problem, we are going to try to do some work right at the river to see if we can duplicate the experiment at the laboratory.

DR. COLLINS: One of the differences in the two techniques is the difference in motivation. In the laboratory the fish are compelled—so far in the Research Facility simple swimming tests have used a voluntary response. We need to know both what a fish can do and what it will do.

DR. THOMPSON: Did you say how soon a fish would present itself again after once turning back?

DR. COLLINS: No. Actually, I don't believe we know. I think, talking about the entire group sounding, that it would be difficult to know when a particular fish did present itself again unless it was a tagged fish. When there is a fright reaction, though, it takes at least 15 minutes before any fish will come out of the pool.

DR. THOMPSON: From my own experience, a period of delay before presentation of a thoroughly exhausted fish is more than 30 minutes; it is more like three days. I am particularly interested in the rate of recovery, not only in regard to our fish in Alaska, but in regard to the general problem of deep sea tagging. When a fish is thrown overboard after thorough exhaustion, when does he recover? You are not only facing a lethal affect, but you are also facing the ability of the fish to recover.

DR. COLLINS: We should have some information on that. Mr. Trefethen has been working at Bonneville trying to measure the effect of tagging fish with sonic tags. As I recall, he thought it took about 24 hours for the fish to recover.

MR. TREFETHEN: Yes, about 24 hours, that is, if the fish were not excited or were not disturbed in any other way. We did find that for the excited fish, the rate of movement was much less than if they were not disturbed.

DR. JOHNSON: I am interested in the basis for your judgment—your criteria as to what are considered favorable results. For example, if we called for lunch here, the rate of passage out of here might be one figure—I was wondering if you shouted "FIRE" it might be a different one. I had in mind also that if I went out of here at the shout of "FIRE" I might be somewhat out of breath and perhaps I shouldn't be as able to "migrate" successfully to lunch.

DR. COLLINS: I assume you are referring to the technique of using a brail to crowd fish in the tests of fishway capacity. The result may be a not completely voluntary action on the part of the fish. The raising of the brail and the resultant crowding probably acts as a stimulus that starts fish moving. However, this was a way of getting enough fish into the test fishway to crowd it. I have seen large schools of fish at the foot of a fishway apparently acting in much the same way as the fish do in entering our test fishway. As to the possible after-effects of an unusual expenditure of energy in a fishway, I can only speculate.