# EFFECTS OF HYDRAULIC SHEARING ACTIONS ON JUVENILE SALMON

(Summary Report)

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To test the hypothesis that hydraulic shearing actions could injure fish, we subjected juvenile salmon to abrupt contacts with the margins of jets of water moving at various speeds. Results are summarized in this report.

The tests were conducted in an open tank, 12-feet long, 6-feet high, and 6-inches wide. The sides were of 1-inch-thick plexiglass supported in a steel framework. To create the shearing effects, water was jetted into still water in the tank from submerged nozzles formed to deliver streams at calculated speeds ranging from 30- to 120-feet-per-second. Water for the jets was supplied by a 600-gallon-per-minute pump and regulated by a fast-acting valve. Jet velocities were calculated by the formula $V = \frac{Q}{A}$. Q was the quantity of water delivered by a particular nozzle, and A was the cross sectional area of the nozzle outlet. Thus, each calculated velocity (V) was an average value for the entire stream at the nozzle exit, and not necessarily the velocity actually contacted by the fish.

Tests were conducted using juvenile coho, chinook, and sockeye salmon of hatchery origin. In each test, 5 to 25 fish, depending on their size, were flushed consecutively through a submerged tube into the tank to contact the side of the moving water jet within the first 3 inches after its emergence from the nozzle (Figure 1). This was at the estimated moment that the jet was at full speed, but as yet had not set the tank water into motion. Thus, the contacts were arranged to occur at the widest differences between the speeds of the jet and the fish, which moved at approximately 3-feet-per-second. Each test lasted only for the time to introduce the fish, usually less than a second.

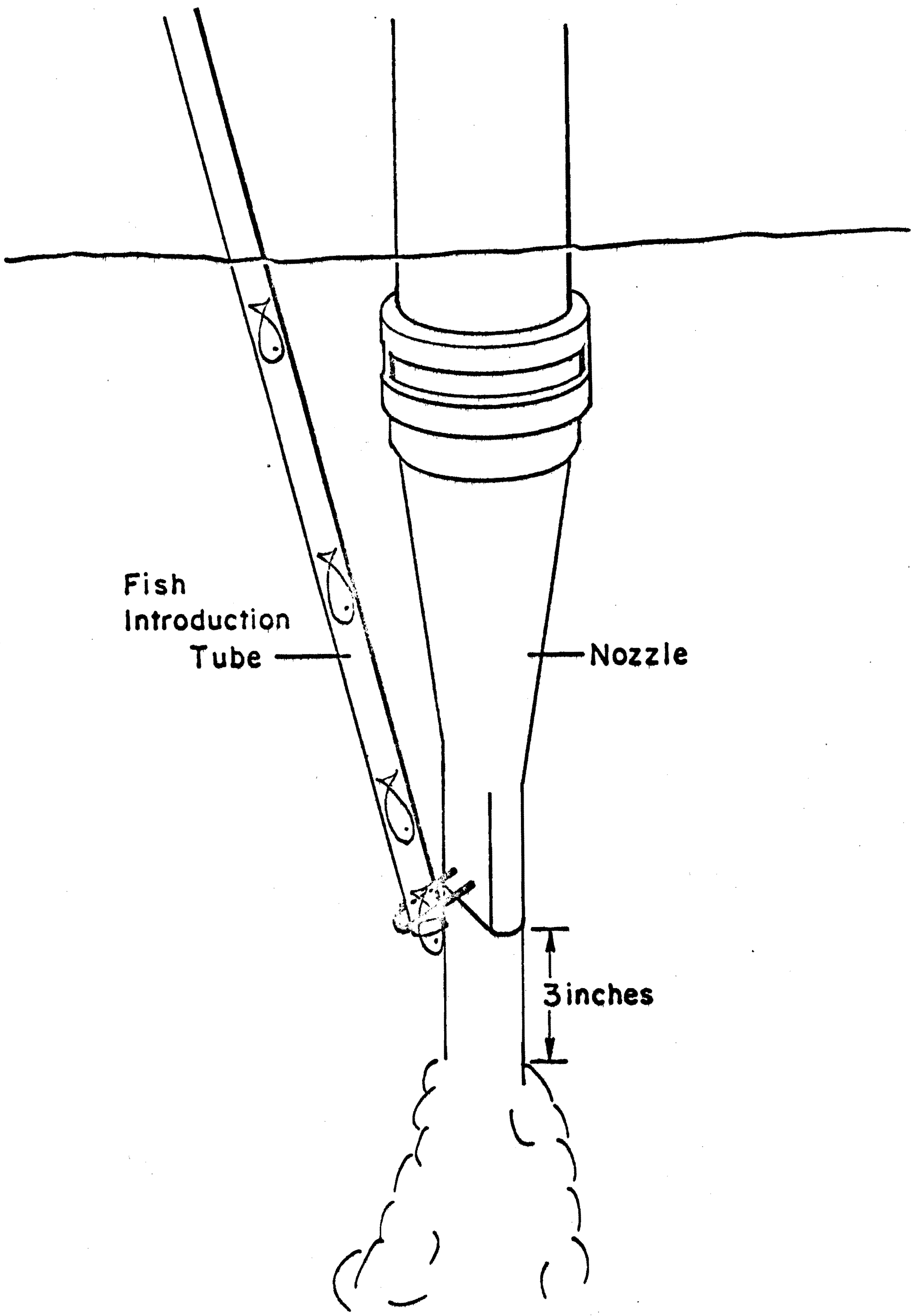


Figure 1.--Fish introduced into relatively still water to contact margin of high velocity jet emerging from submerged nozzle.

Three groups of tests were conducted. The first determined that shearing did injure fish and that the effects were related to velocity. In the second series, the occurrences of injury were recorded by high-speed motion pictures. The third group of tests related size of fish to occurrence of injury. The testing was in 1967 and early 1968.

Results of the first test series are summarized in Table 1. At each calculated velocity, 10 separate tests were run with five fish in each test. Thus, a total of 50 fish were exposed to each jet. Fish were unaffected in tests with jets calculated at 30-feet-per-second, but fish were disabled at all higher calculated test velocities with the effects generally increasing with higher jet speed. Disabilities ranged in severity from temporarily impaired orientation and responses to visible injuries and death. Fish disabled but without visible injuries usually regained normal capacities in 5 to 30 minutes. Visible injuries were mostly in the head region. Eyes were bulged or missing. Gill covers were broken and ripped. Gills were bleeding and torn. Such damage usually showed on fish killed outright, but other dead fish bore no outward signs of injury. Internal bleeding was seen in some of these. Mortally injured fish usually died within 48 hours after the test. At higher velocities, greater damage was caused and injuries were more often fatal. Fish unaffected in each test appeared completely normal.

Results of the second test series are summarized in Table 2. Injuries were the same as those seen in the first series and similarly were more numerous at the higher jet velocities. In general, proportionally more smaller fish were injured. The tests were recorded with high-speed

TABLE 1.--Effects of exposure of yearling coho salmon to the margins of jets of water moving at various calculated velocities. Size, 100 mm average, range 85 to 110 mm.

| Jet velocity feet per second | No. fish, 10 tests, 5 fish each | Percent disabled, includes injured and killed | Percent visibly injured | Percent killed and dead + 48 hours |
|---|---|---|---|---|
| 30 | 50 | 0 | 0 | 0 |
| 50 | 50 | 18 | 8 | 2 |
| 70 | 50 | 42 | 28 | 8 |
| 90 | 50 | 56 | 24 | 16 |
| 100 | 50 | 62 | 20 | 22 |
| 120 | 50 | 74 | 14 | 32 |

TABLE 2.--High speed motion pictures filmed of these effects of exposure of two size ranges of juvenile salmon to margins of water jets at three calculated velocities.

| Jet velocity feet per second | Fish size: 30 to 60 mm | | | Fish size: 90 to 130 mm | | |
|---|---|---|---|---|---|---|
| | No. tests | Total no. fish | Percent injured | No. tests | Total no. fish | Percent injured |
| 30 | 1 | 10 | 0 | 6 | 27 | 0 |
| 50 | 4 | 32 | 59 | 7 | 31 | 16 |
| 70 | 1 | 5 | 100 | 7 | 34 | 38 |

motion pictures filmed at the rate of 1,600 frames-per-second. Thus, when viewed at the standard rate of 16 frames-per-second, the events appeared 100 times slower, and therefore could be studied in detail.

The films showed that injuries occurred within milliseconds of time and only from contact with the edge of the jet within the first 2 to 3 inches from the nozzle. This was where the jet margins were most sharply defined and the relative velocity differences were greatest between the speeds of the fish and the jet. Although the water in the center of each jet was seen moving at speeds approximating the calculated velocities, the fish contacted only the outer margins of the stream where the water moved at lower speeds.

Injury was related to the part of the fish contacted and to the position of the fish relative to the jet flow direction at the time of contact. When contact was made, the effect was to suddenly pull or push the fish along the edge of the stream with the impelling force momentarily focused on the initial contact area. When such contact was in the head region, with the jet moving from rearward of the fish (fish A, Figure 2), then the greatest damage occurred. Size of the fish also affected the degree of injury. With the larger fish, no damage was seen if initial contact was on other parts of the body or toward the tail. Also with the larger fish, less damage occurred from the contact with the jet stream approaching from in front of the fish (fish B, Figure 2). In these cases, the natural streamlining and flexibility of the fish seemed able to offset the forces of contact. On the other hand, the smaller fish were damaged irrespective of their orientation to the jet stream

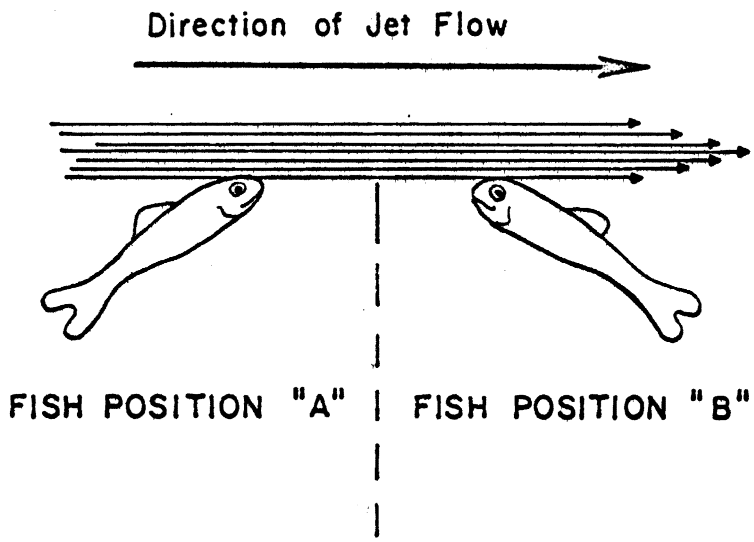


Figure 2.—Injury more frequent and severe from contact in position "A."

flow. The films showed that this was because a much greater portion of their total length was in initial contact with the 2-3 inch region of sharp velocity difference. The larger fish simply did not fit as completely into this region. Therefore, they were injured more in relation to whether or not initial contact was with the more protruding or less rigidly attached parts of their head region, such as the gill structures or eyes.

Velocity differences at which injuries were seen to occur ranged from 16- to 40-feet-per-second, but as observed, injuries were related to the manner of contact rather than particular velocity differences. Contacts without injury were seen at apparent velocity differences up to 60-feet-per-second, but in these cases the initial contact involved less vulnerable parts of the fish. Immediately after contact, the fish were accelerated along the path of the jet stream at speeds up to 45-feet-per-second. Although they were rapidly flexed, twisted, and gyrated during this brief period, no injuries were observed during this exposure.

Results of the third test series are summarized in Table 3. The increase of injury with higher test velocity and the greater effects on smaller fish are apparent. Injuries are similar to those seen in the first two series. With the smaller fish, more were killed outright and visible damage was greater. Some were literally torn apart. The increased severity of damage to the smaller fish probably was related to involvement of more of their bodies with the margin of sharp velocity differences as had been seen on film. Also, the comparatively greater damage may have reflected lesser actual tissue strength of smaller fish with respect to the physical forces encountered in the tests.

TABLE 3.--Effects of exposure of three size ranges of juvenile salmon to the margins of water jets moving at three calculated velocities.

| Jet velocity feet per second | Fish size: 35 to 50 mm | | | 60 to 80 mm | | | 95 to 135 mm | | |
|---|---|---|---|---|---|---|---|---|---|
| | No. tests | Total no. fish | Percent injured | No. tests | Total no. fish | Percent injured | No. tests | Total no. fish | Percent injured |
| 30 | 3 | 75 | 0 | 6 | 50 | 0 | 10 | 50 | 0 |
| 50 | 3 | 75 | 37 | 13 | 174 | 26 | 15 | 75 | 9 |
| 70 | 7 | 164 | 52 | 31 | 201 | 35 | 14 | 100 | 29 |

In summary, some conclusions follow.

1. Hydraulic shearing actions that exist along sharply defined margins of velocity differences can kill and injure fish. The injuries are similar to those described for fish that pass through turbines, or more recently, slotted bulkheads.

2. Injury occurs when just the part of the fish that contacts the velocity difference is thereby differentially accelerated. The head region is the most susceptible to tearing injuries resulting from such differential acceleration.

3. Velocity differences are what injure and kill. Thus, higher overall velocities produced more damage, because these in turn caused greater differences to be contacted by the fish.

4. Injuries can occur in 1 millisecond of time, in an area 1-inch square. This suggests that fish can be damaged in any high energy flow situation that may create momentary localized points of sharp velocity difference. Such rapid, transitory events would be difficult to assess or pinpoint in specific field conditions, and impossible for fish to detect or avoid.