PRELIMINARY EVALUATION OF
THE BLACK RIVER JUVENILE FISH BYPASS SYSTEM

A COOPERATIVE STUDY

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BLACK RIVER JUVENILE FISH BYPASS
Evaluation

INTRODUCTION

The Black River watershed (Figure 1) drains the northeast portion of the Kent Valley in south King County, Washington. This valley has historically experienced flooding conditions during high rainfall. The threat of floods has been further increased due to urbanization and industrialization of large portions of the valley, particularly the north end. Flood threat has been reduced by construction of a dam with the associated discharge pumping facilities at the mouth of the Black River (Figure 2, pg. 3). The pumping facility was completed in 1972 and provides partial flood water control through a combination of a water storage pond and pumping capacity of about 3,000 cubic feet of water per second (cfs). Since the water level in the storage pond is maintained at a lower elevation than water downstream from the pump station dam, gravity flow is prevented and pumping is necessary. Such pumping could transport fish downstream through the dam but debris screens prevent fish from entering the intake ports. If fish did enter the pump intakes, mortality may result due to physical damage from the pump impellers.

To provide fish passage and alleviate the mortality potential, an "air-lift" juvenile fish bypass system (Roach et al, 1964) was incorporated into the structure of the dam. Basically, the bypass consists of two parallel 77

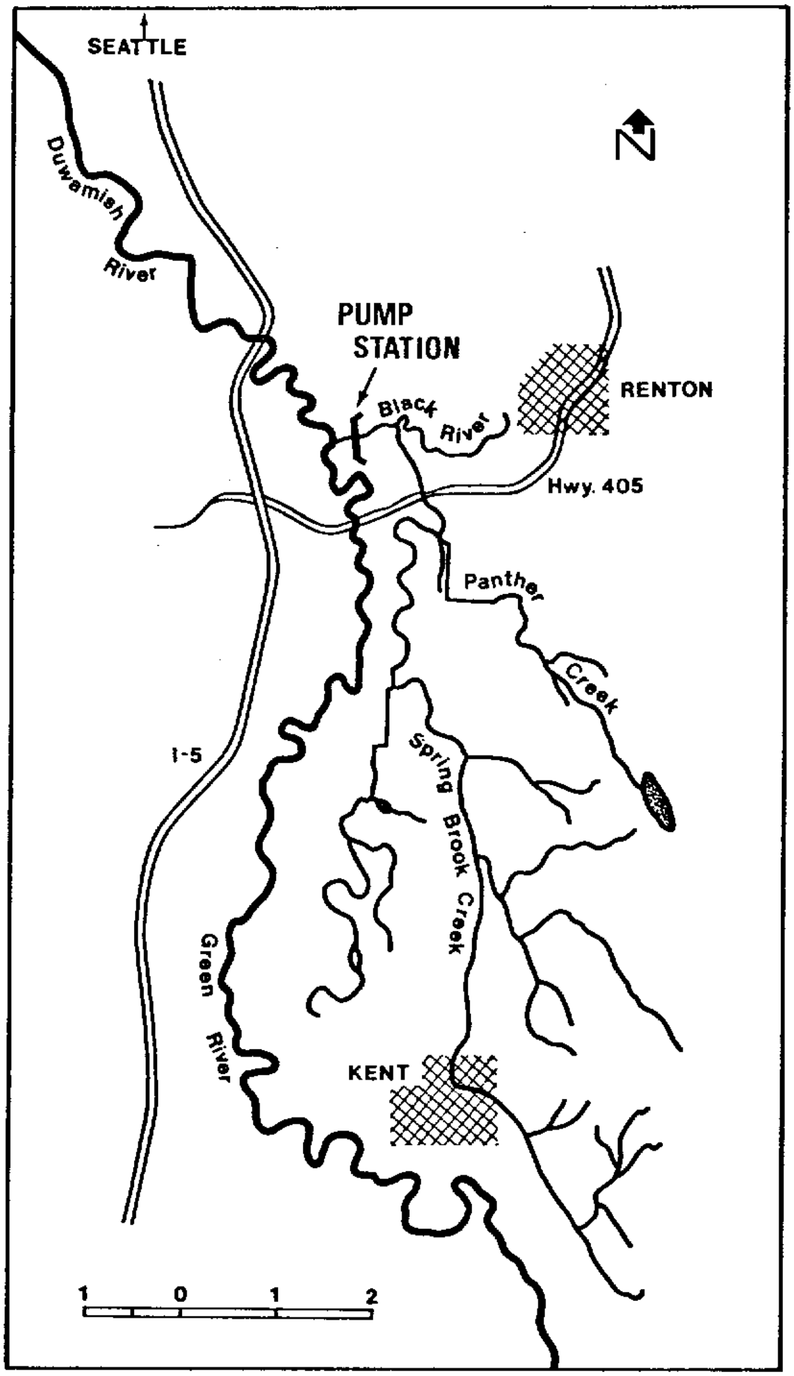


Figure 1. Black River Watershed and pump station location.

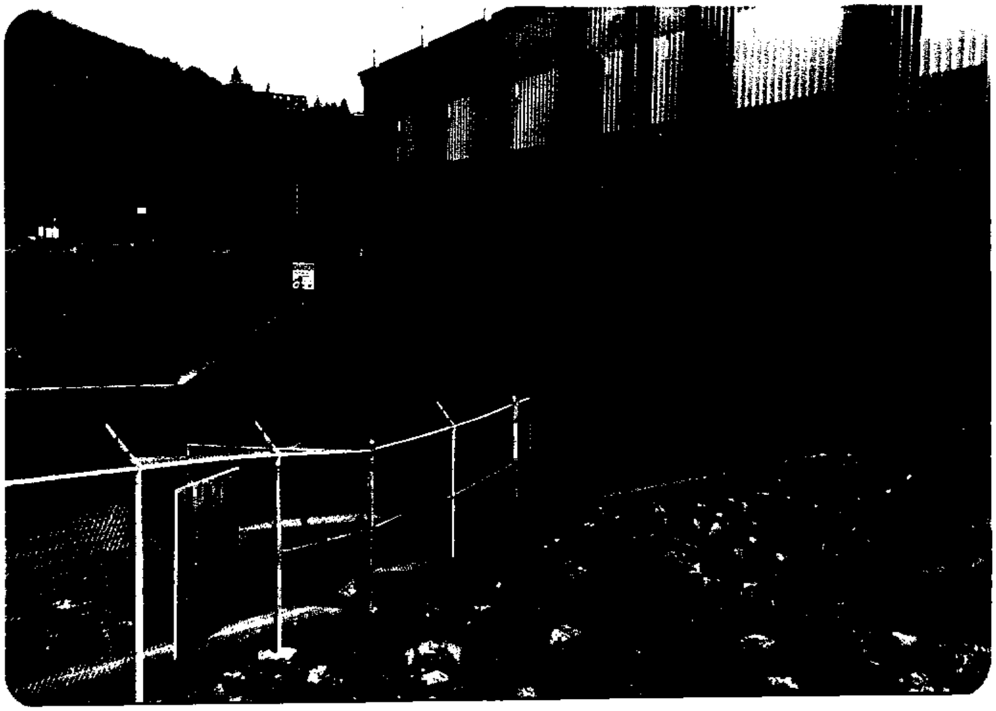


Figure 2. Downstream face of the pump station dam.

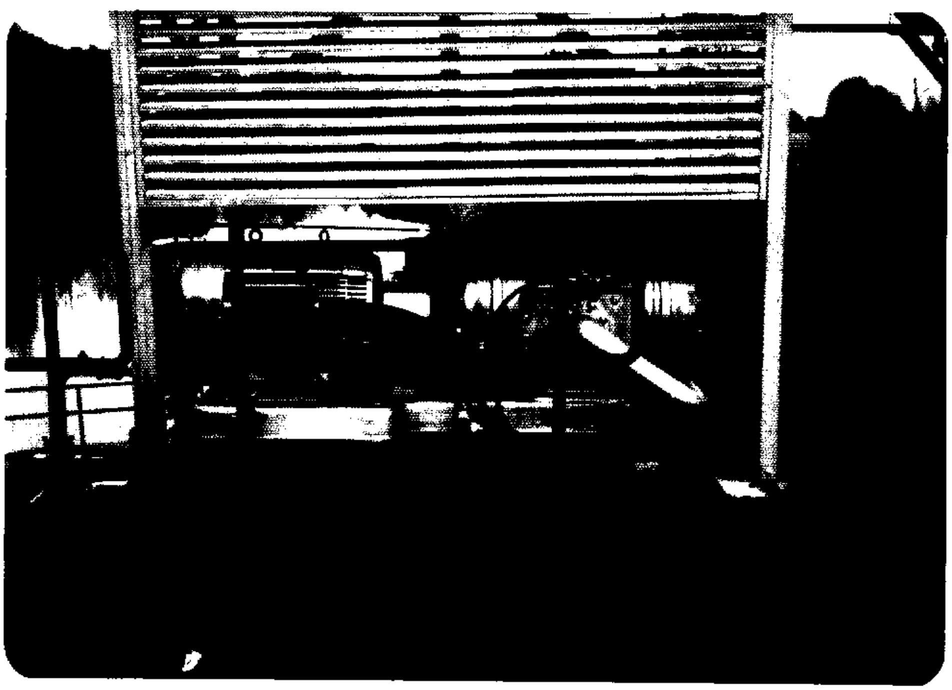


Figure 4. C-2, a 100 hp motor and air pump, supply the compressed air for operation of the juvenile fish bypass system.

foot long pipes which pass through the base of the south half of the upstream face of the dam. From each of these, 8 vertical pipes (11 foot spacing) extend toward the surface of the storage pond, and these terminate at intake orifices (Figure 3). One set of the vertical pipes ends at a "high" water elevation, the other at a "low" elevation, the difference being 4 feet. Water intake is automatically shunted from one or the other of the sets of intake ports based on the storage pond water depth. C-2, a 100 hp air pump (Figure 4, pg. 3) provides compressed air which is released into either the "high" or "low" bypass system, producing the driving force for water intake (totaling about 5 cfs) and transport of fish. The systems empty into a common basin from which water and fish are transported by gravity flow through a single 18 inch diameter outlet pipe. Although the pump station has been in operation since 1972, the effectiveness of the juvenile bypass system has never been determined.

Management efforts to enhance and rehabilitate salmon and steelhead stocks throughout the Pacific Northwest have intensified because anadromous fish stocks have declined while their social and economic value has increased. The Black River watershed represents one of many fish habitats which has undergone extensive change. Alteration of natural fish environment, such as channelization, surface runoff from developed areas, dams and pollution collectively transform once productive fish streams into areas where anadromous fish are but memories. The increased awareness of managers, that maximizing use of one resource at the cost of another has no long range benefit, has created an atmosphere of balanced resource management. This attitude is

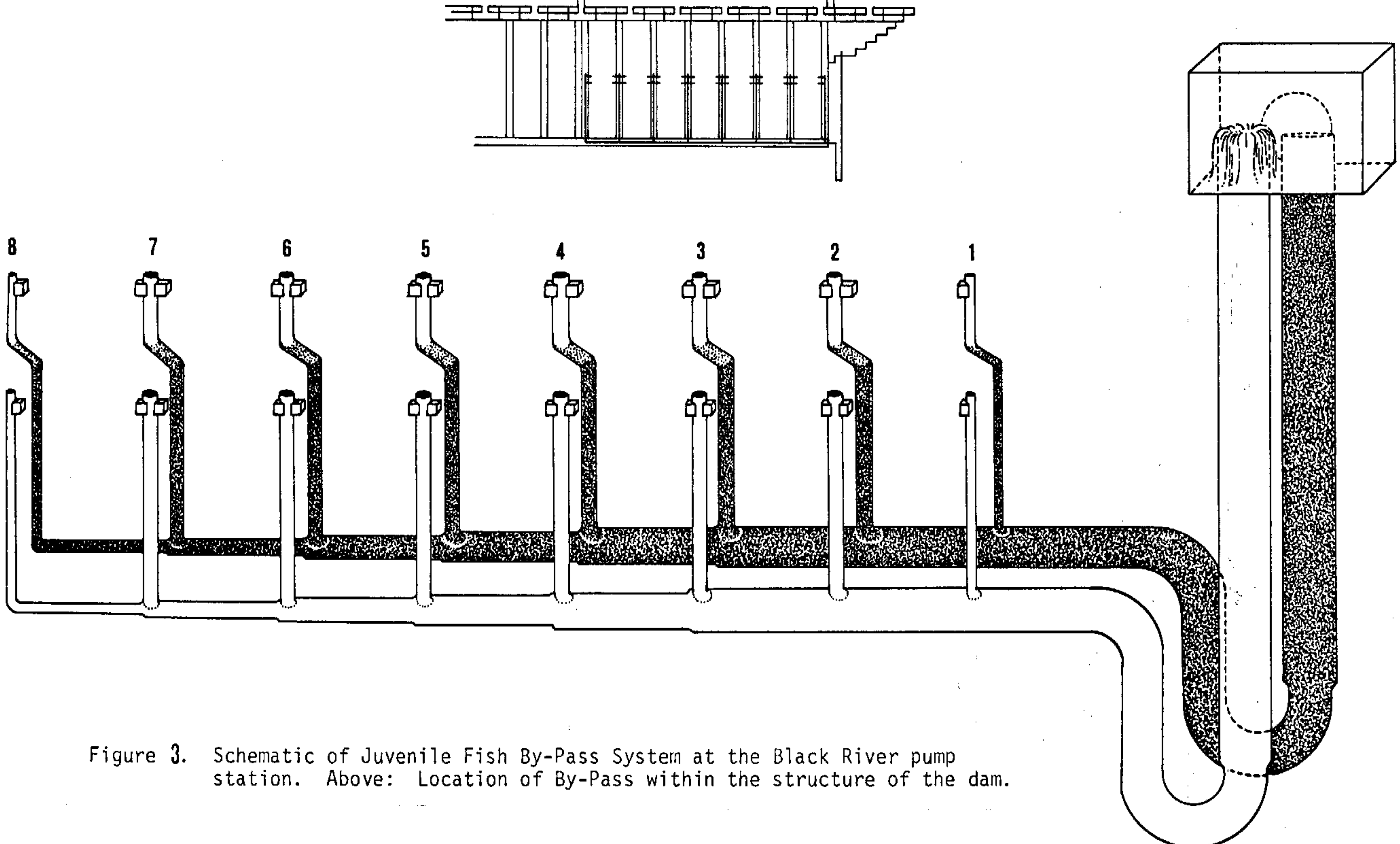


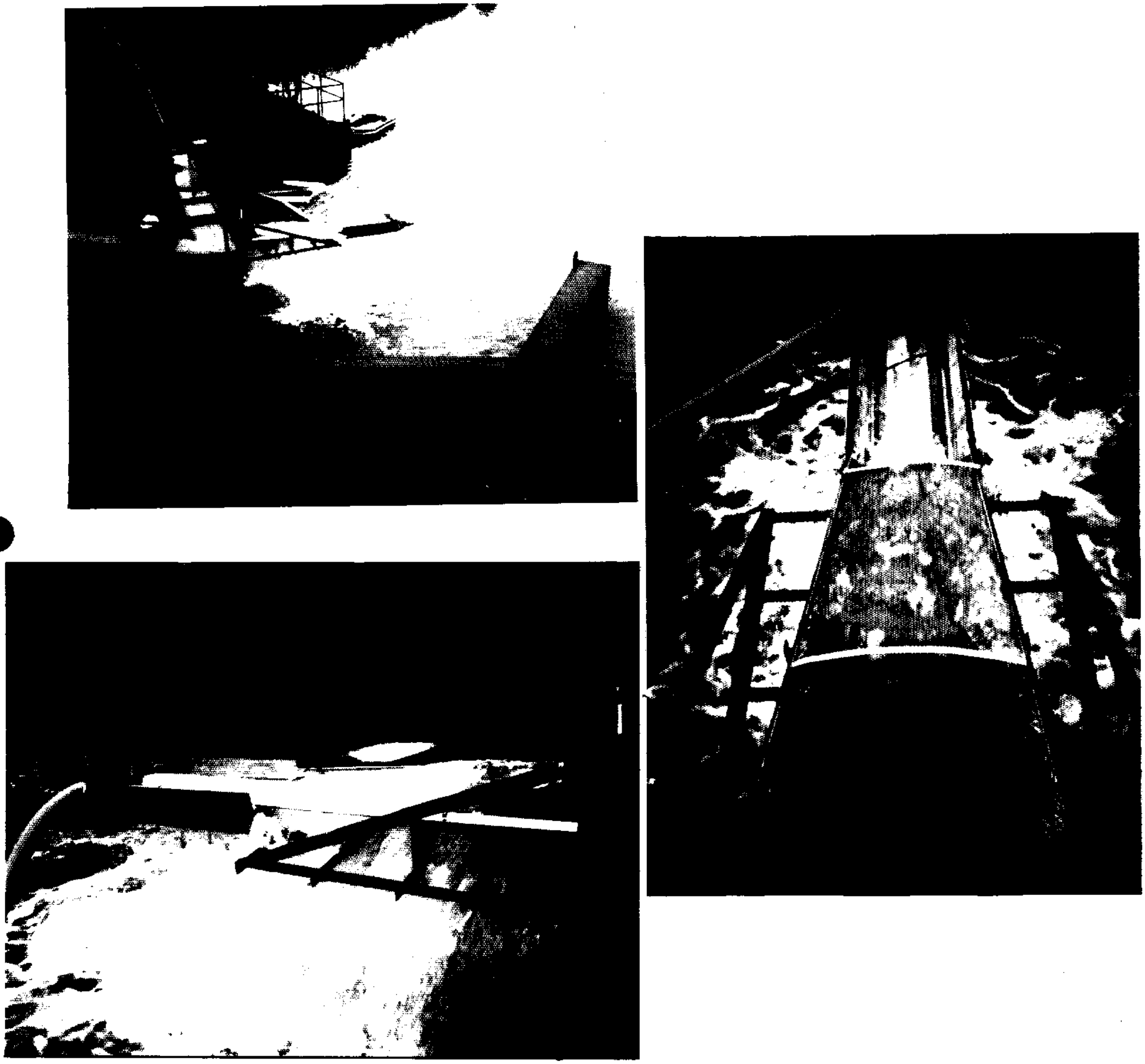
Figure 3. Schematic of Juvenile Fish By-Pass System at the Black River pump station. Above: Location of By-Pass within the structure of the dam.

at the heart of efforts to create fish habitat while controlling waterways; to make dams, if not beneficial to fish, at least nuetral; and to rebuild anadromous fish runs into improved habitat. In response to these efforts, the U.S. Soil Conservation Service (SCS) and the King County Department of Public Works have joined with the Muckleshoot Indian Tribe, the Young Adult Conservation Corps (YACC) and the U.S. Fish and Wildlife Service (FWS) in a cooperative study to evaluate the normal operation of the pump station juvenile bypass system and develop recommendations for improvements in the system's fish passage efficiency.

MATERIALS AND METHODS

This preliminary study began on April 11 and ended with shut-down of the bypass system on June 11, 1979. Our first task, prior to data collection, was to devise a juvenile capture device capable of reducing a water outflow of about 2,200 gallons per minute (gpm) to 20 gpm while retaining very small (about one inch) fish without damaging them. The capture system developed is essentially a fine slotted mesh (1/8" - 3/16" diameter) water sieve, 8 feet long and tapering from about 3 feet at the bypass outlet pipe to 4 inches at the small end (Figure 5). The reduced water flow, containing fish, was then directed via flexible hose into a floating pen fitted with 1/8" mesh netting, 4 feet square and 4 feet deep. Periodically during the normal operation of the bypass system (8 AM - 4 PM, Monday through Friday) the contents of the floating pen were netted out and, after anesthetization with MS-222, visual condition, fork length and species of each fish were recorded, along with the time the sample was taken. Similar data was collected during four night

Figure 5. Pictures of the juvenile fish capture device and holding pen at the outlet of the bypass system.



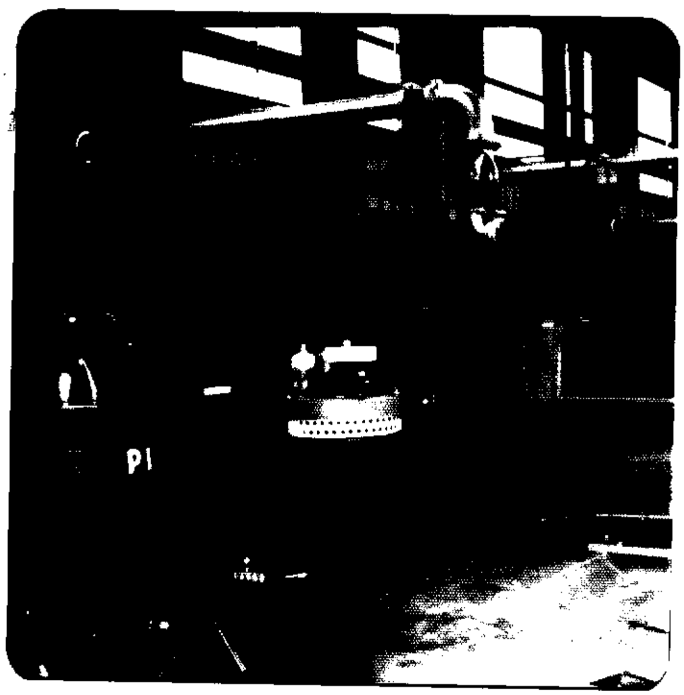


Figure 6. P-1, a 75 cfs water pump which operated periodically during the study to maintain the storage pond water elevation within prescribed limits.

shifts of bypass operation, once beginning on April 25th and again beginning on May 2nd. Following data collection, the fish were fully revived in fresh water prior to release downstream from the pump station.

The transport efficiency of the bypass system was evaluated by planting 10,000 chum salmon fry on April 17 and again on May 3rd. Since chum are not found in the Black River system, no artificial marking was required. Any chum not accounted for at the bypass outflow capture facility were assumed to be retained in the storage pond where planted. This assumption was tested by seining in the pond; any chum caught were then fin-clipped. After allowing a day for the marked fish to mix randomly with unmarked chum, the pond was again seined to obtain a ratio of marked to unmarked fish. The simple Petersen model (Ricker, 1975) was then used to estimate the populations of chum which remained in the pond. Confidence intervals were determined as recommended by D.G. Chapman. Data processing and statistical evaluation was accomplished by computer analysis using standard methods. The relationship of P-1, a relatively small 75 cfs maintenance pump (Figure 6), and juvenile transport was determined by emptying the floating pen just prior to and after P-1 operation.

Additional observations included an evaluation of attraction flows in the immediate vicinity of the bypass intake ports, and assessment of basic water chemistry (O_2, temperature, pH, and total gas saturation) using standard field methods.

RESULTS AND DISCUSSION

At the end of this study, on June 11, fish transported via the bypass system and native to the Black River included 614 coho, 3 trout, 157 stickleback and 1 squawfish. In addition, out of 20,000 chum fry planted into the storage pond upstream from the pump station, 1,159 were captured at the bypass outfall. Condition of the fish transported was only fair, with 26% of the chum and coho reported to have abnormalities ranging from slight scale loss to more serious abrasions (Figure 7). A few fish were found dead in the floating pen, particularly sticklebacks. The condition of the transported fish was in part due to the netting in the pen. This material was a flat weave which resulted in relatively sharp edges. The netting, in combination with the strong currents produced by P-1 operation was believed to be the primary cause of injuries. However, we were not able to conclusively determine the effect of the juvenile bypass system on the condition of the fish.

Based on the unadjusted chum fry plant and recapture data, the juvenile bypass system either does not efficiently attract or does not retain chum once attracted. Our evaluation of the bypass shows that only 6% (1,159) of the planted chum were transported, and 61% of these were passed after a minimum of 20 days delay after planting (Figure 8). To insure that our evaluation of the bypass was reliable, the disposition of the 19,000 unaccounted for chum was necessary. Using data (Appendix, Table 1) from the mark-recapture of chum, we were able to use a simple Petersen model to estimate that 11,890 chum were still present in the pond after May 26th (95% confidence interval

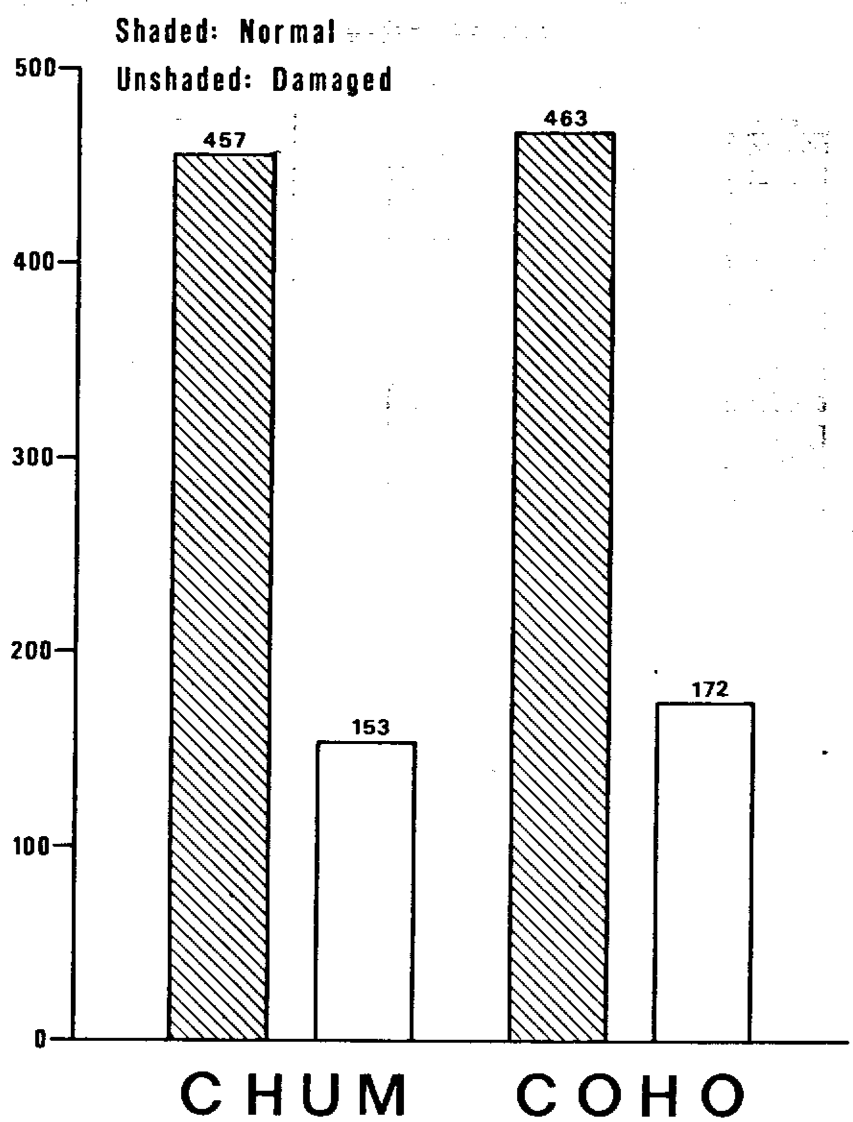


Figure 7. Visual condition of transported fish from floating pen.

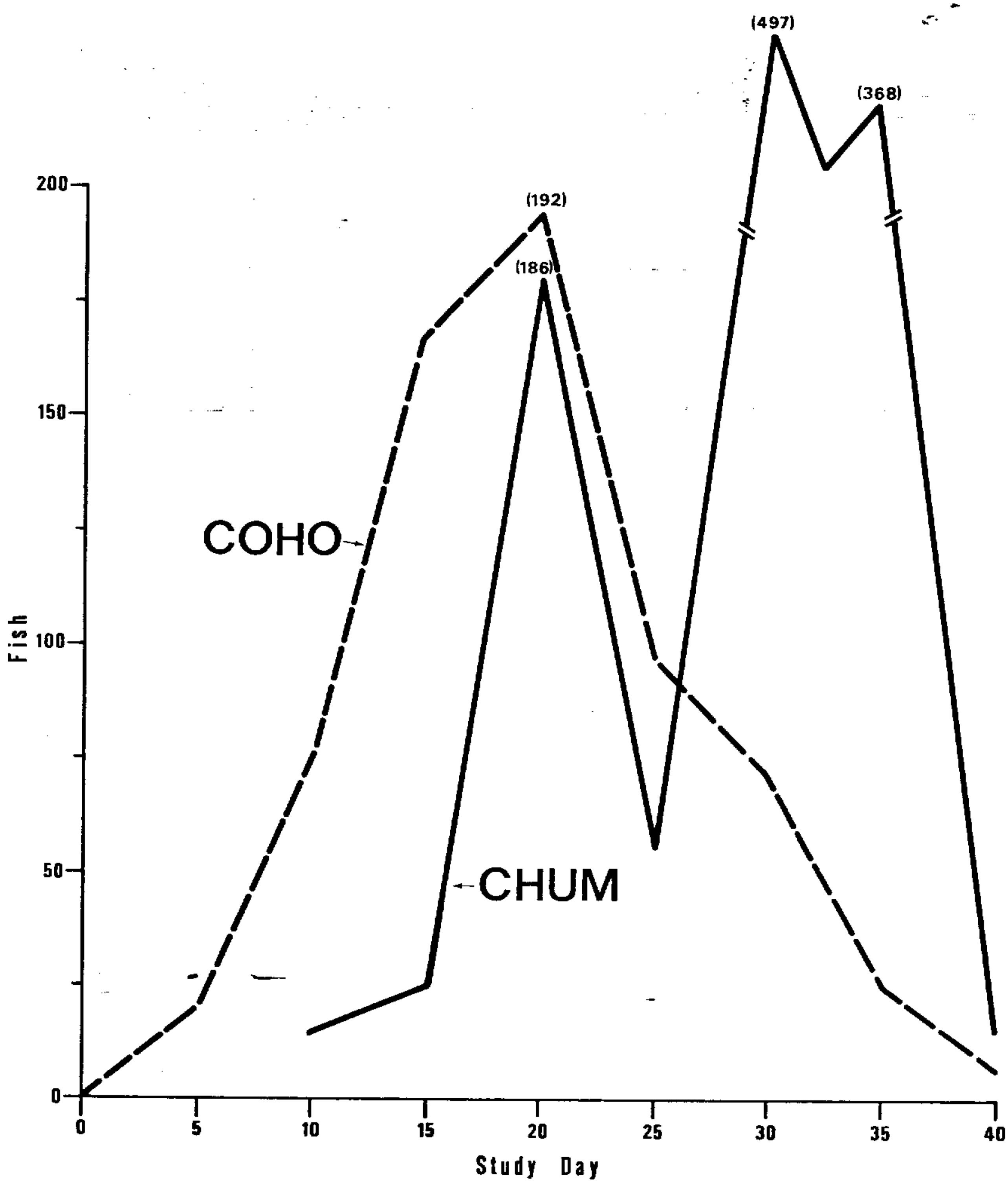


Figure 8. Five day accumulated catch of coho and chum transported through the juvenile by-pass system from April 11 to June 11, 1979.

at P = .05; 8,370 to 16,231 fish). Still, some 7,000 planted chum were unaccounted for. The probable fate of some of these fish was indicated by comparing the lengths of planted to transported chum. As shown in the appendix (Tables 2 and 3), 22% of the first chum plant was less than 50 mm in length, whereas only 2% of those transported between April 18 and May 2 were less than 50 mm. Growth was not considered a factor because the second group of planted chum, reared under optimum hatchery conditions grew only 2.5 mm during the time the above data was collected; the planted chum were assumed to grow much less than hatchery fish, hence an apparent size selectivity had occurred. We determined that the ¼ inch openings in the debris screens separating the storage pond planting site from main pump intakes (including P-1) were sufficiently large to allow chum passage and therefore removal of the small fish from the original planted population. Substantiation of this observation comes from experience gained during pen culture of chum where netting with mesh no greater than 1/8" is necessary to prevent escape of similar sized fish. Since none of the second plant were less than 50 mm, a maximum of 2,000 (20%) chum from the first plant were eliminated from the study via the debris screens.

In summary, we can reasonably account for about 15,000 of the original population. The fate of the balance (5,000 fish) was not determined; some may have been removed through predation, disease, pollution, or they may have migrated upstream out of the pond where the sample for the population estimation was taken. In the final analysis, the bypass efficiency must be adjusted to account for any fish which were not available for passage through the system. In this regard, of the 20,000 chum planted, approximately 13,000 were potentially available for passage; since 1,159 were transported, the adjusted bypass system efficiency for chum could be as high as 11%.

Although the migratory timing of chum was delayed and transport efficiency low, the relationship to coho or anadromous trout may not be directly applicable. When we contrasted the daily transport of chum and coho it was apparent that coho passage resulted in a normal bell-shaped distribution, while chum migration was skewed toward the end of the study period (Figure 8). This relationship suggests that coho transport was at least in a coordinated relationship with normal migration. We cannot address coho passage efficiency or delays but two additional observations may lend insight. First, the low transport efficiency of chum is in part due to the strong propensity for nighttime migration. We were able to make only four night operations of the bypass during this study but significantly more chum were caught during these than during comparable day time observations. However, of equal importance, a considerable number of coho were also transported at night (Appendix , Table 4). Secondly, after a minimum of 20 days, unexpectedly large numbers of chum began to be transported. This suggests that the older chum may have begun to more actively seek out water currents compared to earlier life. It seems plausible that migrating coho seek out currents in an aggressive fashion similar to that of the older chum. Yet, when the largest daily catch of the delayed chum (245 fish) was expanded by the total days of bypass operation, only 9,065 fish (45%) would have been transported.

In addition to the above, normal chum salmon physiology was believed to optimize chances for an accurate evaluation of the bypass efficiency compared to coho. Unlike coho, chum do not undergo a complex parr-smolt-transformation (Wedemeyer, 1979). This complicated physiological change, which directly controls coho migratory behabior, can be adversely affected by water chemistry, transportation stress, and normal hatchery practices. Since a reduction in migratory urge would also reduce the apparent bypass efficiency, chum were considered a more reliable test animal. Chum migrate to the sea immediately upon emergence from spawning gravels and hatchery reared chum released at a size comparable to those used in this study, have been recovered 7 miles downstream within 6 hours of liberation (fishwheel catches of juvenile salmonids, preliminary report, USFWS). Considering the facts that night migration and transport of planted chum was low, the maximum expanded transport of chum was low and that coho will move at night as well as during the day, we feel that the chum passage data is indicative of fundamental problems with the bypass system and these problems are relative to other anadromous species.

The most probable cause of reduced system efficiency was found to be insufficient attraction water flow. At the Black River facility, with C-2 in operation alone, only 0.08 f/s water flow was measured at the bypass intake orifices. When C-2 operated in combination with P-1, the flow increased to 0.3 f/s (Figure 9). Studies on Columbia River dams clearly indicate that flows of 8-12 f/s for juvenile bypass systems were required to transport 90% of fish within a 24-hour period (Long et al, 1977). Excessive mortality resulted when fish

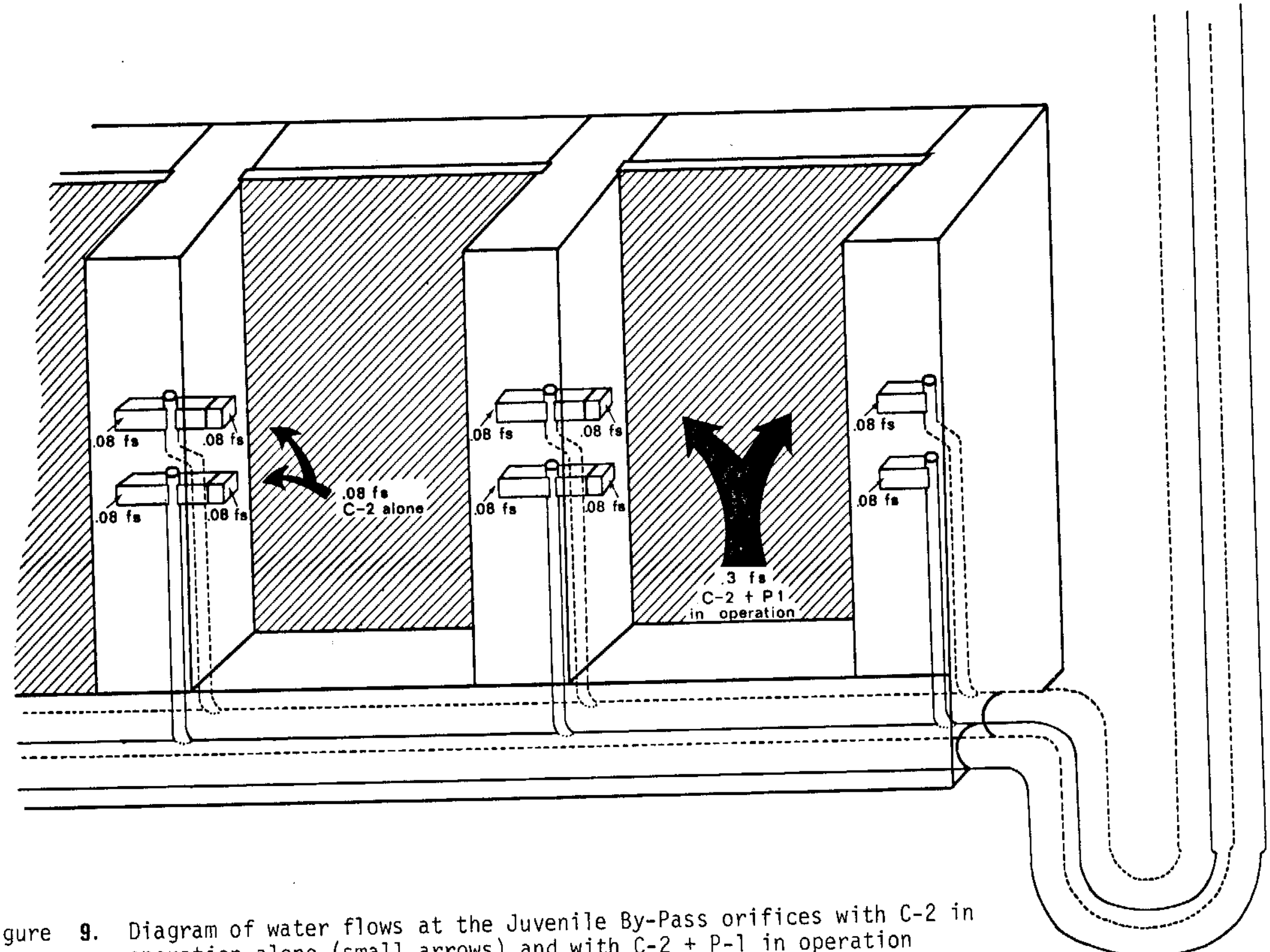


Figure **9**. Diagram of water flows at the Juvenile By-Pass orifices with C-2 in operation alone (small arrows) and with C-2 + P-1 in operation together (large arrows).

were not expediently passed through the passage facilities on Columbia River dams. Minimum migration delays are also desirable at the Black River pump station due to:

1. Potential reduction of fish health and increased mortality due to apparent poor water quality. Although the water quality we monitored (O_2, temperature, pH, and total gas - Appendix, Table 5) were within acceptable limits for fish, extreme turbidity indicated runoff from industrialized and urban areas in the Black River watershed.
2. Avoidance of exposure to predators. Both ducks and large fish (squawfish and trout) inhabit the storage pond and can significantly reduce juvenile salmon populations.
3. Assure timely entry into estuarine feeding areas. Prolonged retention in the storage pond may result in fish entering salt water rearing areas during times of reduced food supplies or increased predator abundance.

Although prolonged exposure in the storage pond environment at the Black River station is not considered conducive to fish health it does not seem imperative that passage occur within 24 hours as at Columbia River bypass facilities. Perhaps transport within 3 days is a point of departure and reasonable goal to strive toward.

Data gathered in this study indicates that minor changes in the bypass system will improve juvenile passage. As shown in Figure 10, when C-2 and P-1 operate simultaneously (flow = 0.3 f/s) for about 2 to 4 fifteen minute periods during a day, significantly more ($P = .01$) coho or chum were transported than when C-2 operated alone for up to 5 periods of 1½ hours

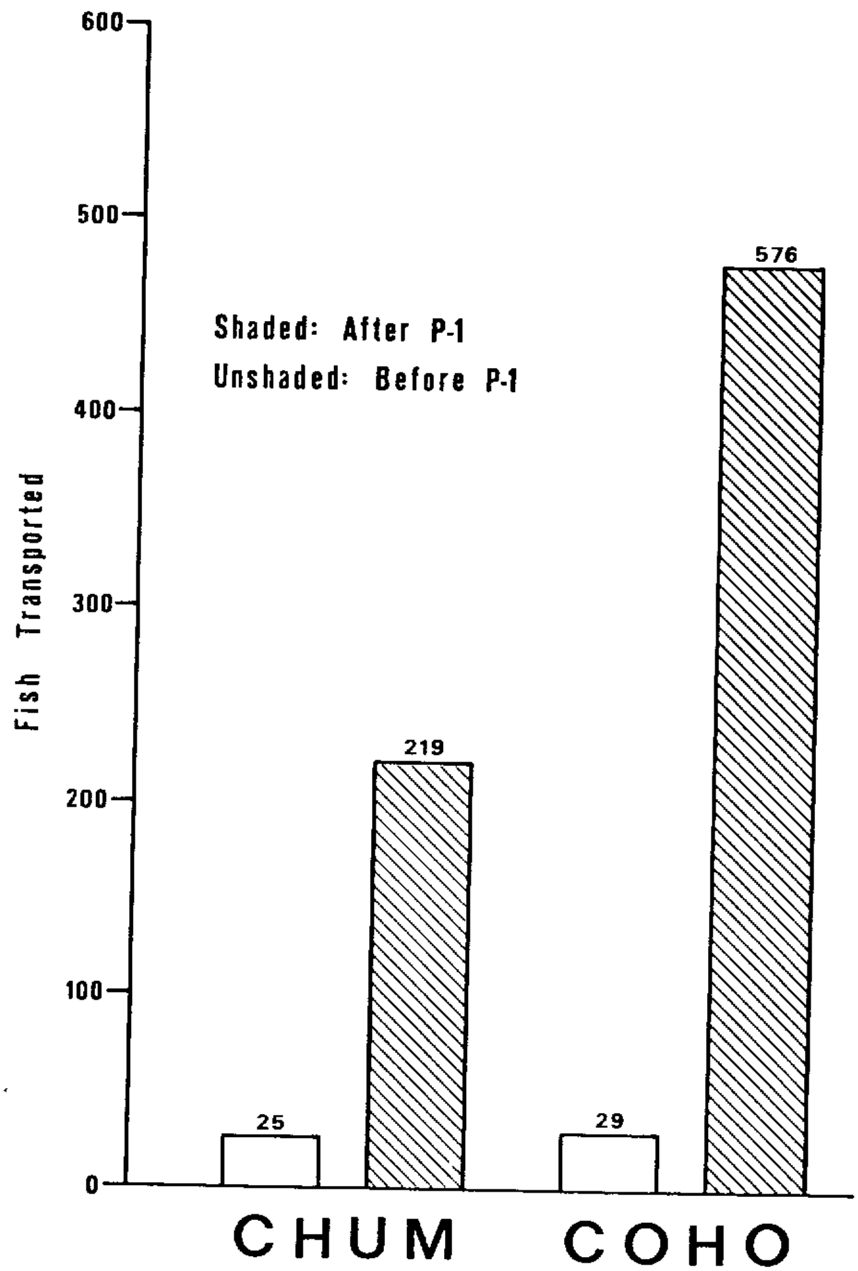


Figure 10. Relationship between P-1 operation and fish transport. Fish were sampled within 20 minutes before and 15 minutes after P-1 operation. Juvenile by-pass (C-2) operated continuously.

per day. This data indicates a significant system improvement at water flows of only 0.3 f/s. In this regard, we suggest that increasing water flows as much as reasonable be attempted, achieving operational conditions between the 0.3 f/s currently realized, and the 8.0 f/s recommended on Columbia River bypass systems. Although we consider increasing the bypass intake water flows essential in order to produce more attraction current and to insure fish avoidance responses are exceeded once in the bypass system, it is necessary to point out that this study was completed during an unusually dry season. As mentioned above, when C-2, the bypass drive pump, was coupled with P-1, fish transport was significantly improved. Since P-1 operates automatically based on the storage water elevation, when surface runoff increases P-1 will operate more and for longer periods. We predict this situation would create conditions which would decrease migration delays and increase the bypass system efficiency.

In summary, we found that the current operation of the Black River juvenile bypass can be improved upon, considering the low rainfall conditions experienced during this study. We predict the problem is insufficient water flow into the bypass intake orifices and this problem is relative to all species of anadromous fish which are expected to be transported by this system. Also, even if overall system transport efficiency were high, delays in fish migration longer than three days is inadvisable due to poor conditions in the storage water pond and delayed emigration to salt water.

The results of our investigation indicate that minor operational changes in the bypass may enhance transport efficiency and decrease migration delays.

First, and perhaps the simplest improvement, is to activate C-2 only during automatic operation of P-1, day and night 7 days per week, from April 1 to June 15. We feel that C-2 should lead and lag P-1 by 15 minutes to insure flows are established prior to activation of P-1 and fish attracted to the vicinity of the bypass intake orifices can be transported after P-1 shut-down. Another option, particularly in years of low flow, is that the storage pond be allowed to fill beyond existing limits, resulting in fewer activations of P-1, but longer pumping duration. We predict that the longer pumping time would establish directional flows for improved attraction and consequently transport of fish. During years of low flow it may be desirable to manually activate P-1 during times of optimum migratory behavior of coho; perhaps early morning, 6 to 9 AM, and again at 3 to 5 PM as indicated on Columbia River studies (Cliff Long, personal communication). However, optimum daily migration behavior should be determined in future studies.

A second modification which we believe would be very effective toward improving bypass efficiency, particularly during low flow conditions, is diversion of 50 to 75 % of the output of P-1 back into the headwaters of the storage pond (Cliff Long, personal communication). This change would also increase the operation time of P-1, improve attraction current duration and, as our data show, fish transport efficiency. Finally we suspect that the bypass system flows are insufficient to hold fish from escaping once they enter the intake ports. This problem can be rectified by increasing the bypass flows from the current 0.08 f/s to a maximum of 8 f/s.

The above recommendations were developed from the analysis of data gathered during this study and literature from Columbia River juvenile bypass research. In addition, we recommend that the following theoretical operational changes be tested in combination with the recommendations outlined above, using coho salmon as a test animal. These fish should be clearly identified and their physiological status determined to insure maximum migratory behavior prior to planting. We also suggest that the system efficiency standards be established such that 90% of test fish be transported within three days of planting. Further possible modifications include, in order of importance:

1. All bypass orifices except 1, 2, and the southern portion of 3 be closed and P-1 be blocked off such that all intake water be directed past these orifices.
2. Orifices 1, 2, and 3 be backlighted as recommended in Columbia River research results (Sims et al, 1976).
3. Flows into intake orifices 1, 2 and 3 be increased in a stepwise (P-1 in operation) fashion to determine optimum velocities.
4. The fish transport efficiency of the lower orifice (-2 feet) of 1, 2 and 3 be tested and compared to the higher orifice (2+ feet).
5. Water quality be assayed for contaminants from industrial and urban areas.

As a final note, we understand that further modification of the Black River is planned to achieve improved flood water control. We strongly believe that any changes to the configuration of the storage water pond will directly influence the efficiency of the bypass system. We believe if properly designed, both fish migration and water storage will be accomodated without undue sacrifice of either of these functions.

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Table 1. Mark-recapture data used for estimation of chum population residing in the pump station water storage pond.

Marking Data

Pond Capture Location	Type of Fin Clip	Number Marked
Upper Right	Upper Caudal (UC)	435
Lower Left	Anal (A)	24
Mid Left	Lower Caudal (LC)	65
	Total	524

Recapture Data

Pond Capture Location	Type of Fin Clip	Number Marked
Upper Right	LC	1
	None	86
Lower Right	UC	24
	LC	13
	A	1
	None	760
	Total Marked	39
	Total Unmarked	760

Note: Validity of the Petersen estimate was tested as described by Darroch, In Biometrika (1961), 48-3 & 4 p. 241.

Petersen Estimate: $\frac{39}{524} = \frac{846}{X}$ = 11,367 unmarked
+ 524 marked

11,891 chum

Chapman confidence interval: ($p = .05$)

$$.01805 < \frac{N}{ne} < .0350$$

$$8371 < N < 16231$$

Wedemeyer, G.A. et al. 1979. Environmental factors during rearing limiting smoltification and early marine survival of salmonid fishes.

APPENDIX

Table 2. Random sample of chum fry planted into the Black River pump station water storage pond on April 17, 1979.

Length									
54	55	59	58	59	53	57	49	50	55
53	60	51	57	54	56	48	57	54	56
57	47	58	57	52	58	53	57	52	51
47	47	57	50	57	52	53	54	54	47
56	45	48	48	44	45	54	57	51	57
61	50	56	54	45	51	53	52	49	56

N = 60 X = 53.12 mm R = 44-61 mm

Table 3. Random sample of chum fry planted into the Black River pump station water storage pond on May 3, 1979.

Length				
58	56	61	57	60
56	56	52	54	56
56	56	54	58	57
56	54	58	56	58
51	54	50	53	54
54	60	58	50	53

N = 30 X = 56 mm R = 50-61 mm

TABLE 4. Comparison of day and night passage of chum and coho during continuous operation of the juvenile bypass system from April 25th to April 27th and again from May 2nd to May 4th.

	Day (8 AM - 4 PM)	Night (4 PM - 8 AM)	Total
COHO	111 (79%)	30 (21%)	141
CHUM	2 (3%)	65 (97%)	67

TABLE 5. Water chemistry values from samples taken in the storage pond (upstream) and in the vicinity of the floating pen (downstream).

	UPSTREAM				DOWNSTREAM			
Date	O_2 1/	pH	Temp °C	Sat 2/	O_2 1/	pH	Temp °C	Sat 2/
4-16-79	8	8.4	9	-	9	8.4	9	-
4-17-79	8	8.3	9	-	10	7.7	9	-
4-18-79	8	8.0	9	-	9	8.0	9	-
4-19-79	8	7.8	10	-	10	7.5	10	-
4-20-79	8	9.1	11	-	10	9.2	11	-
4-23-79	8	8.2	13	-	10	7.8	11.5	-
4-24-79	6	7.3	13.5	-	9	7.0	13	-
4-25-79	7	8.6	13.5	102	10	8.6	13.5	100
4-26-79	9	7.2	14	-	9	7.0	13.5	-
4-27-79	7	7.2	12	-	11	7.4	12	-
4-30-79	6	6.0	-	-	8	6.9	-	-
5-01-79	8	6.0	-	-	7	6.0	-	-
5-02-79	7	8.6	-	106	7	8.4	-	100
5-03-79	6	7.5	14	-	8	8.4	14	-
5-04-79	9	8.0	14	-	10	8.2	14	-
5-07-79	8	8.4	15.5	-	11	8.5	14	-
5-08-79	9	8.7	18	-	10	8.8	17	-
5-09-79	7	8.5	15	-	10	8.8	15	-
5-10-79	7	8.5	14.5	100	9	8.8	14.5	101
5-11-79	6	8.4	14	-	9	8.4	14	-
5-14-79	5	8.7	14	-	8	8.5	14	-
5-15-79	7	8.5	14	-	9	8.7	13	-
5-16-79	10	8.7	15	-	11	8.6	13	-
5-17-79	6	8.2	14	90	10	8.1	13	100
5-22-79	8	7.8	12	-	9	8.1	14	-
5-29-79	7	8.0	16	-	10	8.1	17	-
6-05-79	7	8.4	18	-	9	8.3	17	-

1/ Dissolved oxygen in parts per million. 2/ Total gas saturation in percent.

ACKNOWLEDGEMENTS

This study has evolved from the efforts of numerous concerned individuals who collectively have contributed significantly to this joint project. We can certainly point a thanking finger to Rolf Edstam, the manager of the Black River pump station. Rolf's knowledge of the operations of the station was enthusiastically taught to us in order to fully appreciate the relationship between juvenile fish bypass and the mechanical operation of the dam. We equally appreciate the full support given to the study by George Wannamaker.

The very professional and creative work, from design and implementation of the fish capture device to daily data collection, of Kari Rokstad, Jonathon Wright, Mary Beth Walter, Chuck Warren, Rachel Burke, Jim Weber, Alice Noordhoff and Swede Larson of the YACC, is especially appreciated.

Thanks are extended to Rich Lincoln (WDF) who contributed significant changes in his critical review of the study proposal. In addition, thanks are due to Steve Dilley (USFWS), who not only contributed his valuable time but also creative insight for improving the fish capture facility; Carol DeMent for the high quality typing job and Gloria Maender for outstanding graphics.