THE SIZE AND LOCATION OF ESCAPE PORTS FOR BYPASSING SALMONID FISH AT A SCREENED DIVERSION CANAL

by

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THE SIZE AND LOCATION OF ESCAPE PORTS FOR BYPASSING SALMONID FISH AT A SCREENED DIVERSION CANAL

INTRODUCTION

Experiments on the comparative efficiency of escape ports of various sizes and at different locations for bypassing three species of downstream migrant salmonids at a screened hydroelectric diversion were conducted in the Spring of 1958 at Marmot Dam on the Sandy River, Oregon. In the last 25 years, progress has been made in the development of efficient screens for arresting the movement of fish into diversions where they may be wasted, and it is generally recognized that a bypass is required where the screen location does not permit fish to continue their movement in natural channels. Yet, there is little information available concerning escape port location and size, or the volume and velocity of water necessary for an efficient bypass system.

Bypasses have been constructed with openings near the screens and provided with relatively small flows of water in the hope that they would be found and utilized by fish. These bypasses apparently have been successful to some degree in the smaller irrigation diversions, as no mention was found in the available literature of difficulty in diverting fish back to the natural channels. The problem of bypassing fish may be different at the larger diversions or at diversions whose structure and location are such that simple openings in the canal wall are not suitable.

The fish screens and bypass system at Marmot Dam on the Sandy River were installed for the purpose of halting and returning to the river fish which had entered the diversion canal from the forebay of the dam. Research has been directed toward obtaining greater understanding of various factors influencing fish bypassing in large, screened diversions. The Marmot Dam screen was selected for study as it was the first "Rex Traveling Water Screen"[1] installed in Oregon for the purpose of fish protection. It was believed that research could provide information which would be useful in designing future installations. The study[2] has been carried out under contract by the Oregon State Game Commission and, later, by the Oregon Cooperative Wildlife Research Unit.[3]

Early work was concerned with gathering information regarding the time and magnitude of the downstream migrations of salmonid fishes entering the canal.

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[1] Trade name for screens built by the Chain Belt Company, Milwaukee, Wisconsin.

[2] Sponsored by the U. S. Army Corps of Engineers since 1952 as part of their Fisheries Engineering Research Program for the lower Columbia River Basin.

[3] Oregon State Game Commission, U. S. Fish and Wildlife Service, Wildlife Management Institute, and Oregon State College cooperating.

Experiments in 1954-1955 were primarily concerned with (1) the amount of water necessary to attract and carry fish from the mechanical screens into bypasses, and (2) the effects of the velocity of the water entering bypass ports on various sizes and species of migratory fish (4, p. 75).

The work during 1956 and 1957 was concerned primarily with the development of experimental apparatus for studying the effects of port location and size on fish bypassing. Sixteen of the thirty-two ports used in the 1954-1955 study were modified and a preliminary experiment was conducted (3, p. 253-255).

Part of the fish collecting device employed at the Marmot Dam installation is the "vertical riser", which has also been studied in other places (2, p. 1-66; 5, p. 1-96). Essentially, the riser consists of a vertical pipe or duct located between or near the screens which has access openings provided at intervals on and along its leading surface. Water flows into the riser due to either gravity or suction from a pump; at Marmot Dam it is due to gravity. Limited testing of this fish collecting device has been done by the U. S. Fish and Wildlife Service and the Bureau of Reclamation at the Tracy Pumping Plant, Tracy, California (5, p. 19-22), and the Pacific Gas and Electric Company at the Contra Costa Steam Plant near Antioch, California (2, p. 42-52). The vertical risers at Tracy were not satisfactory for collecting fish, and further research on their development was abandoned when the louver principle of guiding fish showed promise. The risers were found to be inefficient also at the Contra Costa Steam Plant, but here they did play a part in the development of a satisfactory "fish collector".

HYDROELECTRIC FACILITIES AND SCREENING SYSTEM

Marmot Dam

Marmot Dam is located in Clackamas County, Oregon, on the Sandy River, which is a small tributary of the lower Columbia River. The dam and the canal leading from it were constructed in 1913-1914 for the purpose of diverting water to a hydroelectric plant on the Bull Run River. The facilities are owned and operated by the Portland General Electric Company. The dam is a rock-filled, timber crib which is 30 feet high and 195 feet long. The forebay has become filled with silt which makes canal flow now dependent on immediate river discharge. Water is diverted on the north side of the dam and flows through canals, tunnels and flumes five miles to the power house forebay. The screen installation is located in the canal, 712 feet below the dam. A pool-type fishway is located on the south side of the dam.

The Sandy River is characterized by its extreme turbidity during the summer months. This turbidity is caused by erosion of deposits of volcanic ash by melting snow and ice. From 1948 to 1958, the mean monthly rate of discharge varied from a low of 405 c.f.s. (cubic feet per second) in September to a high of 2,294 c.f.s. in May. There was a mean annual discharge rate of 1,526 c.f.s.

during this ten year period. These measurements are from the U. S. Geological Survey gauging station located two miles above the dam.

Three species of anadromous salmonids migrate above the dam to spawn. Steelhead trout, Salmo gairdnerii gairdnerii (Richardson), and coho salmon, Oncorhynchus kisutch (Walbaum), are the predominate fish. There is only a remnant run of spring chinook salmon, Oncorhynchus tshawytscha (Walbaum). Coastal cutthroat trout, Salmo clarkii clarkii (Richardson), are present in the river above the dam, and enter the canal in sufficient numbers to warrant consideration in this investigation.

Hydroelectric Canal

The portion of the canal which extends 712 feet from the dam to the fish screens will be described in detail because of its relation to the screens and bypass system. The canal is concrete lined, trapezoidal in cross-section, with a top and bottom width of 27 and 13 feet, respectively, and $9\frac{1}{4}$ feet deep. Its gradient is 0.10 percent. Flow in the canal is controlled by two headgates which can be operated either manually or automatically. The mean discharge rate of water in the canal is 540 c.f.s., and the mean velocity is 6.5 f.p.s. (feet per second).

At a point 83 feet upstream from the screens, the canal begins a two-way expansion for reducing the approach velocity of the water at the screens. The canal has a top and bottom width of 37½ feet and a depth of 18½ feet at the screens. The bay downstream from the screens narrows to the original canal dimensions in 48 feet. A set of vertical baffles located where the canal begins to expand helps to provide a more even flow of water at the screens. Before these baffles were installed, a whirlpool existed in the forebay. The baffles have been only partially successful, and the water velocities at the sides of the canal remain higher than at the center. Water approaching the screens tends to flow from the sides toward the center, resulting in a slight reverse current in the middle of the forebay. The approximate water velocity two feet in front of the screens is 1.8 f.p.s. at the canal sides, while at the canal center it is 0.5 f.p.s. in the opposite direction. Two troughs in the canal floor, which are 4½ feet deep and 5½ feet wide, cross the canal three feet upstream and three feet downstream from the screens and serve as sand traps. They also facilitate forebay drainage. The troughs are separated by headgates from two 36-inch pipes which unite before emptying into the Sandy River.

Fish Screens

The installation consists of three "Rex Traveling Water Screens" of the commercial link belt type, which are installed side by side across the canal at a 90-degree angle to the direction of flow (fig. 1). Each of the three units consists of 26 linked screen panels that measure 10 feet in width and 2 feet in height. The panels are fitted with No. 16 galvanized wire cloth having 4.5 meshes per inch, leaving 0.16-inch square openings. Screens are individually propelled by 2 horse-power electric motors with reduction gears that move the screens at a rate of 8 feet per minute. A pump with a 50 horse-power electric motor supplies water at a pressure of 70 pounds per square inch to a spray system which washes accumulated debris from the screens as they revolve. A metal trough carries debris to a settling tank from which the water enters the bypass at the trapping compartment. The spray and screens operate automatically when the head differential at the screens reaches 3 to 4 inches, and they continue to operate for several minutes until the screen surface is free of debris.

The screens at Marmot Dam have been in operation since 1951. There are at present two similar installations in the state. Pacific Power and Light Company has an installation of five screens at the Powerdale Canal on the

Figure 1. Fish screens and vertical riser ports (Photo by Einar Wold)

Hood River, and a unit of two screens is in use by the U. S. Bureau of Reclamation at the Savage Rapids Dam on the Rogue River. At both locations, the bypass system is of the vertical riser design employing gravity flow.

Traveling water screens have been used by industry for many years where debris-free water supplies were required, but only recently have they been used specifically for fish protection. The screens are designed to strain large volumes of water in a relatively confined area.

Bypass System

The bypass system will be described first as it was originally constructed, and then the various modifications will be presented separately and chronologically.

Entrances to the bypass system consisted of 32 circular ports which were 6 inches in diameter. Eight openings were spaced two feet on centers on the face of each of the two vertical risers between the screens (fig. 2). Eight openings were also spaced two feet on centers in the concrete side walls on each side of the canal, 15 inches in front of the screens. The south side ports (four covered with plates) can be seen to the left of the riser ports in figure 2.

Water entering the eight ports on the south side of

Figure 2. Vertical riser with unmodified ports
(Photo by Einar Wold)

the canal flows directly and horizontally into the first of two flow regulating chambers. Water entering the other 24 ports turns abruptly downward and flows into a common collection pipe (horizontal duct) beneath the floor of the canal. The horizontal duct has a cross-section of $1\frac{1}{2}$ by $3\frac{1}{2}$ feet and enters the first flow regulating chamber at a depth of 23 feet.

The vertical risers are steel ducts, 18 feet high, 2 feet wide and $1\frac{1}{4}$ feet deep, located on the concrete guide walls between the screens. The port entrances on the leading face of the risers are approximately 15 inches forward from the screen surface (fig. 2). On the north side of the canal, a similarly sized duct is formed by a depression in the concrete wall which is covered with a steel plate having eight circular openings. The eight south side ports, as stated previously, lead directly through the concrete wall into the first flow regulating chamber.

The two flow regulating chambers are approximately the same size, 8 feet in length, 4 feet wide and 23 feet in depth. There are two openings in the wall separating the chambers. A submerged orifice, 1 foot wide and $2\frac{1}{2}$ feet deep, is located $7\frac{1}{2}$ feet beneath an overflow weir which is 4 feet wide and 5 feet deep. Both openings are equipped with gates to control the volume of water flowing through the bypass.

Water spills over the stop logs of a rectangular weir at the end of the second flow regulating chamber into the trapping compartment. From the trapping compartment, water flows over another set of stop logs into a trough which leads to a 24-inch collecting pipe, returning the water to the Sandy River, 400 feet away. Figure 3 is a schematic section of the fish bypass system.

In the trapping compartment, an inclined plane fish trap can be lowered into position to strain all water coming through the bypass system (fig. 4 and 5). Therefore, all fish utilizing the bypass system can be captured. Fifteen cubic feet per second is the maximum flow for the trap. Greater volumes result in turbulence and in water spilling over the upper end of the trap.

The first modification of the bypass was made soon after the screens were placed into use. It was noted that fish, especially spent steelhead, were not bypassing but were remaining in the low velocity water in the forebay. It became necessary during the peak of the downstream migration to drain the canal weekly to remove these fish. In an attempt to improve the efficiency of the bypass system, a rectangular opening 15 inches wide and 50 inches in depth was cut into the side wall of the canal. This opened directly into the first flow regulating chamber,

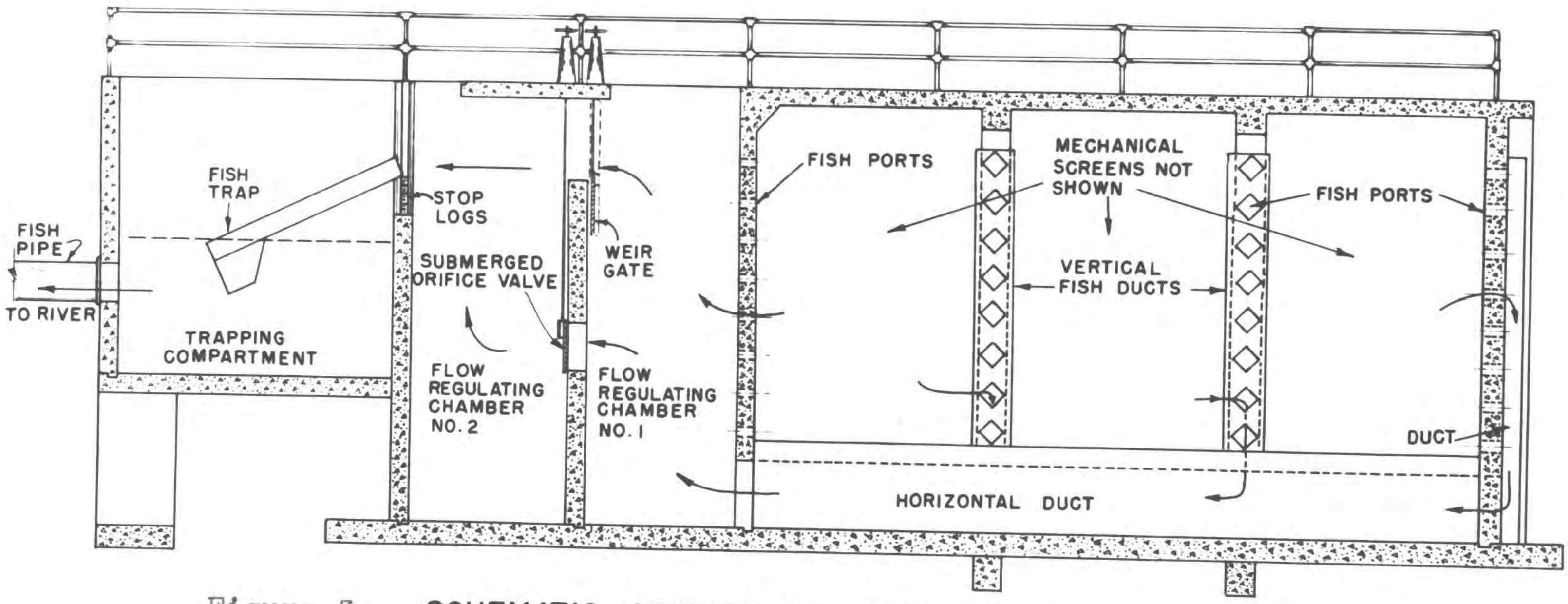

Figure 3. SCHEMATIC SECTION OF FISH BYPASS

Figure 4. Upper part of bypass trap leading from second flow regulating chamber (Photo by Einar Wold)

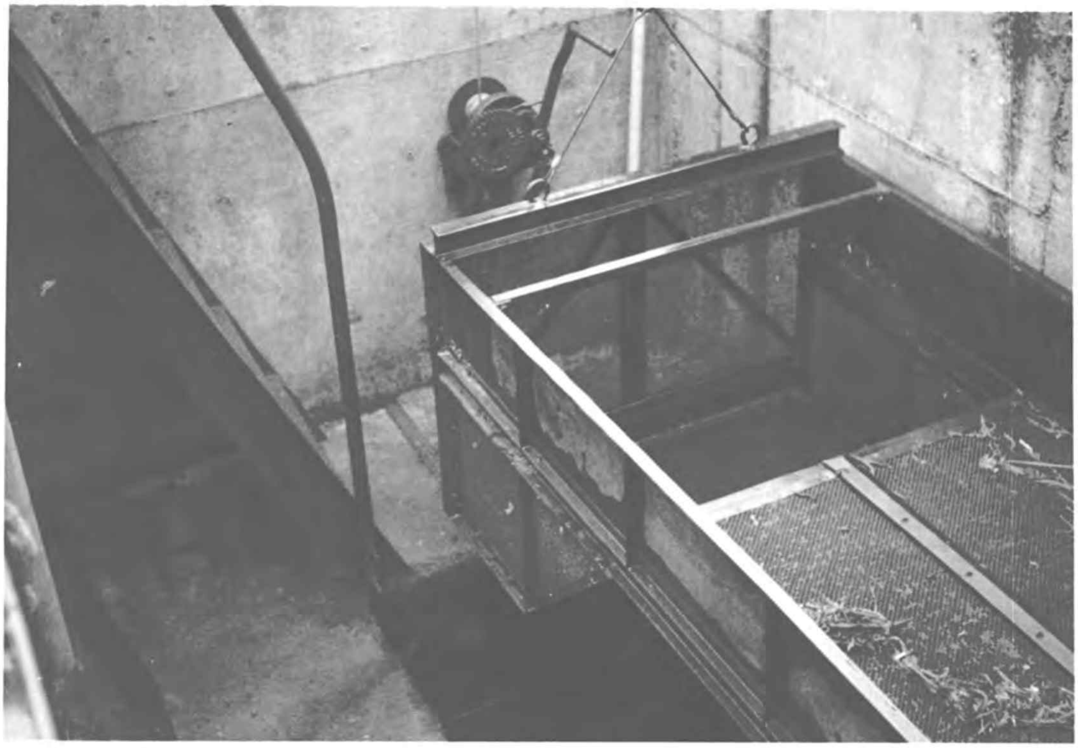

Figure 5. Live box of bypass trap (Photo by Einar Wold)

near the water surface at normal level, approximately eight feet upstream from the screen. The opening can be seen toward the top on the left side of the canal in figure 1. Water flow through the opening is regulated by a headgate. This escape port proved very satisfactory for bypassing fish.

As originally outlined, the program initiated by the U. S. Army Corps of Engineers in 1952 included studies of the effects of various locations and sizes of ports on fish bypassing. The structural limitations of the screening facility largely prevented such studies. There was no means of varying the size of the ports, and to open or close a group of ports to test locations, the canal had to be drained.

The vertical riser ports were modified in 1957 so that any one or a combination of the 16 ports could be opened, closed or adjusted to any intermediate size. Each of these ports was enlarged to a 14-inch square and provided with a sliding cover plate (fig. 6). The plates were on runners, and could be moved back and forth across the entrances with a mechanism of pulleys, cables and winches.

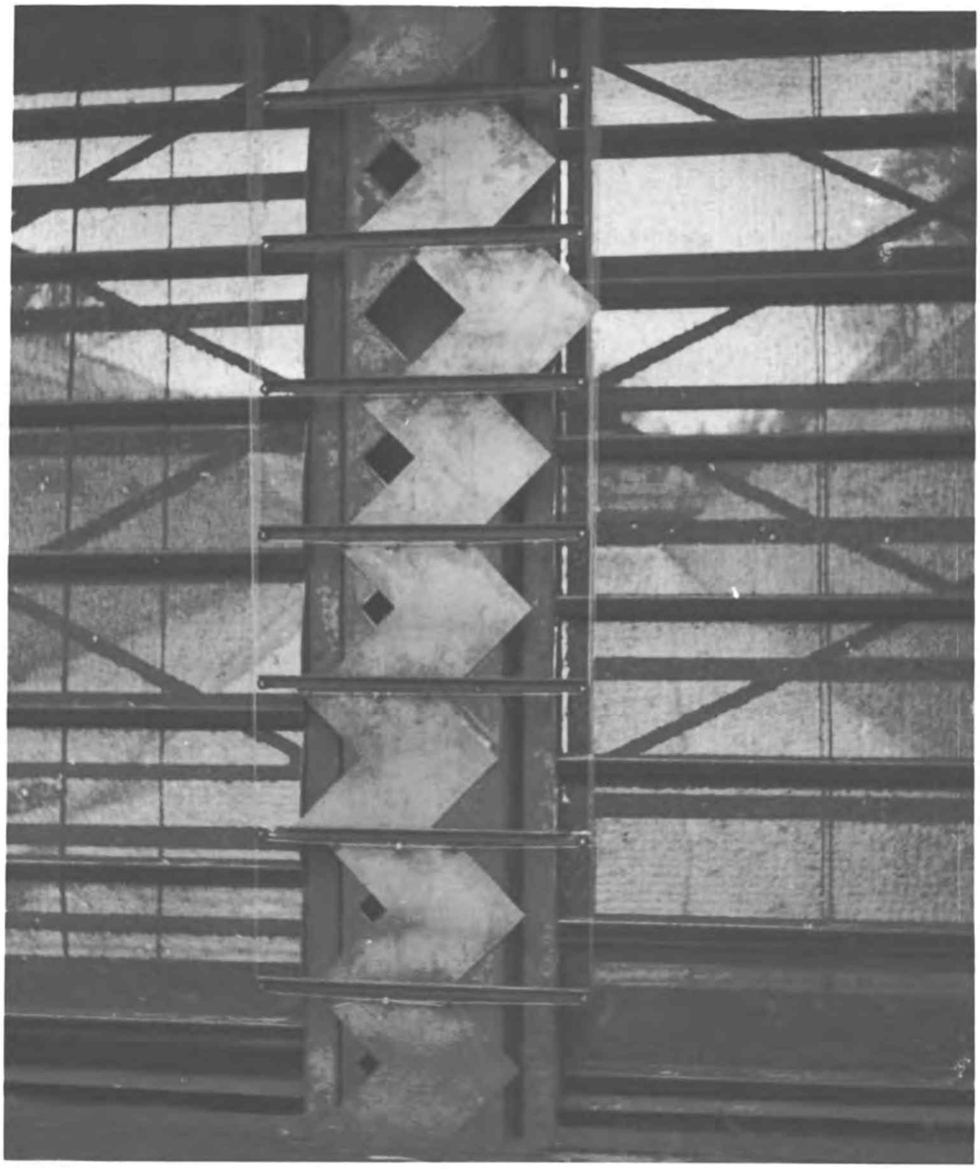

Figure 6. Vertical riser with modified ports
(Photo by Einar Wold)

METHODS AND MATERIALS

Bypass Ports Used Experimentally

All ports were used in the fish bypassing experiments during 1958 with the exception of the large rectangular entrance on the south side of the canal. The 32 ports were divided into groups or sequences which will be described below under experimental testing and results. No further structural modifications of the bypass were made during the present study.

Experimental Fish

Hatchery steelhead trout and coho salmon were utilized exclusively in the 1957 experimental studies. Recovery was extremely poor due to several factors, the foremost of which was the failure of the fish to migrate downstream (3, p. 254). Wild fish of the same species that were physiologically ready for migration and that continued their downstream movement when the proper conditions were present for bypassing were used for experimental purposes in 1958.

Hatchery steelhead trout were again used for comparative purposes. The Oregon State Game Commission Hatchery at Oakridge supplied 4,000 steelhead trout which varied in length from 2.5 to 3.5 inches. They were held until needed in live boxes in a small pond receiving about 2 c.f.s. of stream water.

The wild fish used experimentally were coho salmon, averaging 4.0 inches in length, and two year classes of smolt steelhead trout, averaging 4.0 and 7.0 inches in length. These fish were the predominate downstream migrants available in sufficient numbers for experimental purposes throughout the testing period. Originally, the source of wild test animals was from the scooptrap located in the canal, 300 feet above the screens. The trap proved unsatisfactory; sufficient numbers of fish for experimental purposes were not captured, and there was considerable mortality among those taken.

The only other ready source of wild migrating fish was the bypass trap. In using these fish, it was assumed that bypassing once would not have any conditioning effect on the fish; that is, those which had bypassed once would not be any more likely or unlikely to bypass a second time than those which had not. To test for possible effects of conditioning, fish from the scooptrap, when available in adequate numbers, were compared with the bypass trap fish.

Experimental Procedure

The use of marked fish was necessary in the experiments to determine accurately the number of fish bypassed for a particular port sequence. It was possible for fish, after entering the structure at any one port sequence, to remain in one of the flow regulating chambers until another port sequence was tested before passing into the trapping compartment, thereby giving misleading results which could only be eliminated by marking the fish differently for each treatment period.

Fish collected from the bypass trap and scooptrap, which were to be used in the experiments, were held in three live boxes suspended in the forebay. The maximum holding time was two days for bypass trap fish and four days for scooptrap fish. On the morning of the day of release, the fish were marked by tattooing (1, p. 182-184) after being anesthetized in a solution of 1 part chloretone in 2000 parts water. Various colors, numbers and locations of tattoo dots were used to obtain a series of marks to identify the fish as to date of release and source.

On the afternoon of the day of release, the port sequence specified by the experimental design (described under the experimental testing and results section) was arranged and all fish were removed from the bypass trap. The screen and spray system were operated by the manual control prior to the release of the fish to prevent the system from turning on automatically immediately after the marked fish were introduced into the forebay. This procedure allowed any newly released fish temporarily impinged on the screens time to escape and orient to the water flow. Fish which were dead or weak due to handling and marking were removed from the live boxes before the other fish were released. A known number of marked fish was then introduced into the low velocity water approximately 15 feet upstream from the screens.

The number of fish, experimental and wild,[4] bypassed for each treatment was recorded twice daily in categories of size, species, date of release, and source. Wild fish were recorded as being in one of three size groups, 0 to 5 inches, 5 to 10 inches, and 10 inches and over in length. Both wild and experimental fish were recorded by species, while date of release was applicable only to the recovered experimental fish. Source refers to whether a marked fish was from the bypass trap, scooptrap or hatchery.

A record was made of the number of living and the number of dead marked fish recovered. Dead fish were not considered successfully bypassed for the purpose of

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[4] The term "experimental fish" includes marked wild coho salmon, steelhead trout, and hatchery steelhead trout, while "wild fish" are unmarked coho salmon, steelhead trout, cutthroat trout, and chinook salmon which in their course of downstream migration were bypassed at the screens.

statistical analysis. This eliminated those fish that may have died in the forebay from the effects of marking and were washed into the bypass.

To obtain as complete an accounting as possible of all the fish released, the settling tank was examined carefully for fish which had been flushed from the screens. Most impingement of marked fish against the screens occurred a short time after their release. By manually operating the screens and spray approximately one hour after releasing the fish, and then checking the settling tank, it was possible to recover fish which otherwise ensuing automatic operation of the screens and spray may have flushed from the settling tank into the main bypass pipe to the river.

<u>Volume Measurement and Control</u>

The volume of water flowing through the bypass was measured in cubic feet per second at a gauge on the bypass trap. To calibrate this gauge, a trapezoidal weir was installed at the end of the bypass system in the 1955 study. The gates between the first and second flow regulating chambers were adjusted to maintain the desired rate of flow through the bypass. With all ports closed, the gauge registered 3.5 c.f.s. due to leakage around the port covers and the north side vertical duct.

Studies conducted in 1955 indicated that of the water flows used 10 to 15 c.f.s. were optimum for attracting fish into the escape ports (4, p. 76-81). Flows of this magnitude may also be necessary in the flow regulating chambers to insure the rapid passage of fish through these structures. Most port sequences used in the present investigation permitted a discharge of less than 10 c.f.s. in the bypass chambers. Therefore, additional water was introduced through the rectangular side port to increase flow through the regulating chambers. This port was screened to prevent the entry of fish, and the gate was used to control the flow of water through it. The submerged orifice between the two flow regulating chambers was fully opened throughout all tests, and the upper weir gate was adjusted as required to control flows. There was approximately 7 inches of water spilling over the upper weir when the discharge was 15 c.f.s.

Velocity Measurements

Velocity measurements were taken with a mechanical current meter at all bypass entrances and at various locations in front of the screens. All measurements were based on a 60 second period and were taken three times at each location. A mean water entrance velocity was computed for each port sequence from the measurements taken in the individual escape ports.

The current meter was modified so that it would fit and could be held in the port openings. The tail piece was removed and a handle, which was connected to the hanger screw, extended forward beneath the bucket wheel. The current meter was held by means of this handle and placed into the port so that the bucket wheel was centered in the entrance. The standard suspension with a 10 pound guide was used for measurements in the forebay.

The accuracy of the velocity determinations for port sequences was checked by estimating the discharge of the ports on the basis of their calculated mean velocity and their area and comparing the estimate obtained to the discharge measured at the bypass trap. In most instances, the velocity measurements proved to be fairly accurate.

Underwater Observations

Underwater observations were made to obtain information on fish distribution and movement in the forebay, and on the reactions of the fish as they approached and entered the escape ports. An underwater breathing apparatus was used by the observer for this work.

Daily Observations on Environmental Conditions

Daily observations on weather conditions, water temperature, turbidity and flow were made during the testing period. Water temperatures were recorded morning and afternoon, and data on flow were obtained once daily from the gauging station located at the screens. Only visual observations were made on weather conditions and water turbidity.

It was believed that data collected on these environmental factors might be useful in determining the cause of any changes in fish behavior at the mechanical screens during the experiments.

EXPERIMENTAL TESTING AND RESULTS

In the construction of a bypass, an understanding of where the escape ports should be located is of the utmost importance. The openings should be located where fish will find and enter them with a minimum of delay. The locations required for successful bypassing may vary not only between species but also among the size groups of the same species. The size of escape openings is also important because of its direct effects on the volume and velocity of the water entering the bypass system.

Objectives

Two experiments were designed and tests were conducted from April through June, 1958, to obtain knowledge of the influence of port size and location on fish bypassing. The objectives of the first experiment were to determine the relative efficiencies of (1) ports located on the south side of the canal wall and ports located between the mechanical screens, (2) ports at two depths, and (3) ports of two sizes.

After it became apparent that the side ports were generally more efficient than either the large or small ports of the vertical risers, a second experiment was performed to test the comparative efficiency of the north and south side port arrays in an attempt to determine why the south side ports were more efficient. The two arrays of side ports occupy the same relative location with respect to the screens and risers, but they differ from each other in that on the south side the water continues on a horizontal plane after entering the ports, while on the north side the water turns abruptly downward upon entering the ports. The number of fish available for bypassing in the second series of tests was not large enough to obtain conclusive results, but the indications were that direction of flow was not an important factor.

Experimental Design

The eight ports on the south side of the canal and the 16 ports on the two vertical risers were used in the first experiment. Location as a factor (side vs. riser) was tested between the eight south side ports and the eight ports of the farthest riser from the south side ports. The openings of the ports on the riser were adjusted to form $5\frac{1}{4}$-inch squares, which gave them approximately the same area (28 square inches) as the circular side ports.

Port size as a factor influencing bypassing was tested by using different opening sizes on the two vertical risers. The $5\frac{1}{4}$-inch square ports of the north riser were tested against 14-inch square ports of the south riser.

Depth as a factor was tested by comparing efficiency of the upper four ports (1 to 9 feet deep) to that of the lower four ports (10 to 18 feet deep) of all sequences.

Only the north and south side port arrays were involved in the second experiment, with each array of eight ports utilized as a single sequence. All vertical riser openings were closed.

The experimental design used in the first experiment was an Incomplete Latin Square consisting of six treatments (table 1) and four replications. Treatments were conducted in order from left to right across each of the six rows of the design (table 1). For purpose of analysis, the design was considered a randomized block with a replication consisting of the closest six treatments of "A" through "F" in order of testing. For example, the first replication consisted of "A", "F", "B", and "C" in row one and "D" and "E" of row two. An average of 100 hatchery steelhead trout and 75 each of wild coho salmon and steelhead trout were marked and released for each treatment.

The design used in the second experiment consisted of two treatments, the eight south side ports (G) and the

Table 1

Order of Treatments Used in the First Experiment

Order of Treatments[1]				Treatments	
A	F	B	C	A	Upper four side ports
C	B	D	E	B	Upper four small riser ports
F	E	A	B	C	Upper four large riser ports
D	C	E	F	D	Lower four side ports
E	D	F	A	E	Lower four small riser ports
B	A	C	D	F	Lower four large riser ports

[1] Order of treatments is from left to right across each row.

eight north side ports (H). Five replications of "G" and four replications of "H" were made, two replications being made consecutively for each treatment (except the first time for G) as follows: G,H,H,G,G,H,H,G,G. An average of 29 wild steelhead trout and 67 wild coho salmon were marked and released for each treatment. No hatchery fish were used in this second experiment.

In both experiments, a two day period was used for each treatment to allow experimental fish sufficient time to orient to the screening structure and to pass through the bypass after once entering a port. A preliminary test was conducted to determine the time necessary for fish to reach the bypass trap after entering a port. Several hundred marked fish were introduced directly into the bypass system through a hose inserted into a riser port. Unfortunately the flow of water in the canal was stopped soon after the test began, but there were indications that most of the fish passed through the structure within one day.

Significance of Results

Total numbers of all experimental fish recovered are given in tables 2 and 3. Approximately 60 percent of the fish were recovered. Non-recovery may have been because fish (1) escaped detection after bypassing, (2) were taken by predators, (3) were flushed from the settling tank without being observed, (4) ascended the canal, (5) remained in the forebay at conclusion of experiments, or (6) were not stopped by the screens.

Tables 4 and 5 show the total numbers of wild and experimental fish bypassed in the first experiment for each of the six treatments. Of the wild fish, only the 0 to 5-inch size group was recorded for coho salmon; all three size groups were recorded for steelhead trout; only the 0 to 5-inch and 5 to 10-inch size groups were recorded for cutthroat trout.[5]

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[5] Fish were not present in other size groups in sufficient numbers to warrant consideration.

Table 2

Total Recovery of Experimental Fish in Experiment No. 1, April 23 to June 10, 1958

	Wild Steelhead Trout	Wild Coho Salmon	Hatchery Steelhead Trout
No. Released	1853	1782	1197
No. Bypassed			
Alive	871(47)[1]	805(45)	352(29)
Dead	54(3)	159(9)	16(1)
Total	925(50)	946(54)	368(30)
No. Found in Settling Tank	71(4)	246(14)	59(5)
No. Captured After June 10	12(1)	36(2)	166(14)
Total Recovery	1008(55)	1246(70)	593(49)

[1] Numbers in parentheses are percentages of total number released.

The square roots were taken of the number of wild fish bypassed per treatment to make the variances independent of the mean. Since marked fish were released in relatively constant numbers, the numbers bypassed per treatment, expressed as percentages of the number released for that treatment, were used in the analysis. No analysis was made for hatchery steelhead trout because of low recovery.

The utilization of marked fish made it possible to

Table 3

Total Recovery of Experimental Fish in Experiment No. 2, June 10 to June 28, 1958

	Wild Steelhead Trout	Wild Coho Salmon
No. Released	261	511
No. Bypassed Alive	152(58)[1]	239(47)
Dead	1(0)	70(14)
Total	153(58)	309(61)
No. Found in Settling Tank	2(1)	33(7)
Total Recovery	155(59)	342(68)

[1] Numbers in parentheses are percentages of total number released.

record those bypassed as direct count or as carry-over count. Direct count refers to the percentage of marked fish recovered during a particular treatment from a known quantity released during the same period. It was also possible to obtain a carry-over count of fish released at one treatment which did not bypass until the following treatment. The carry-over data could be used as were the direct count data to provide information on treatment effects. It was determined from inspection, however, that carry-over data would give results similar to those obtained from the direct counts, so no further analyses of

Table 4

Number of Wild Fish Bypassed for Each of the Six Treatments in Experiment No. 1, April 23 to June 10, 1958

Species	Size (inches)	Treatments: Upper Ports: Small Side (A)	Small Riser (B)	Large Riser (C)	Lower Ports: Small Side (D)	Small Riser (E)	Large Riser (F)
Wild Steelhead Trout	0 - 5	92	96	100	50	33	64
	5 - 10	1864	853	1124	3579	631	1469
	10 - over	37	11	64	79	8	93
	Total	1993	960	1288	3708	672	1626
Wild Coho Salmon	0 - 5	4614	1392	1244	4097	1248	2589
	5 - 10	0	0	0	0	0	0
	10 - over	0	0	0	0	0	0
	Total	4614	1392	1244	4097	1248	2589
Wild Cutthroat Trout	0 - 5	16	18	14	14	2	28
	5 - 10	227	58	68	218	87	157
	10 - over	0	0	0	0	0	0
	Total	243	76	82	232	89	185
Totals	0 - 5	4722	1506	1358	4161	1288	2681
	5 - 10	2091	911	1192	3797	719	1626
	10 - over	37	11	64	79	8	93
	Total	6850	2428	2614	8037	2015	4403

Table 5

Numbers of Experimental Fish Released and Bypassed for Each of the Six Treatments in Experiment No. 1, April 23 to June 10, 1958

Species		Treatments					
		Upper Ports			Lower Ports		
		Small Side (A)	Small Riser (B)	Large Riser (C)	Small Side (D)	Small Riser (E)	Large Riser (F)
Wild Steelhead Trout	Released	121	290	356	256	346	324
	Bypassed[1]	40	17	50	89	25	36
	Percent	33	6	14	35	7	11
Wild Coho Salmon	Released	333	276	259	410	309	349
	Bypassed	109	8	19	133	16	29
	Percent	33	3	7	32	5	8
Hatchery Steelhead Trout	Released	200	300	197	100	200	200
	Bypassed	36	7	2	8	4	6
	Percent	18	2	1	8	2	3
Total	Released	654	866	812	766	855	873
	Bypassed	185	32	71	217	45	71
	Percent	28	4	9	28	5	8

1 Figures do not include marked fish which were found dead in the bypass trap.

these data were made (appendix A); and all results discussed were derived from the direct count data.

In the statistical analysis of data, the hypothesis that treatment effects were equal was first tested by the analysis of variance at the five percent significance level. Where the treatment effects were shown to be not equal, the least significant difference (LSD) at the one percent significance level was used to determine which treatments were different. The computation for the analysis of variance is given in appendix A.

No significant differences were shown between any of the treatments in bypassing unmarked, 0 to 5-inch coho salmon and cutthroat trout, nor 5 to 10-inch cutthroat and steelhead trout. Significant differences were found for marked steelhead trout and coho salmon, and unmarked 0 to 5-inch and 10-inch and over steelhead trout.

All possible comparisons of treatment means for each species and size group, where differences were indicated, was next made using the method of least significant difference (table 6). Treatments "A" and "C" (upper side and large riser ports) had significantly higher means than "E" (lower small riser ports) for unmarked steelhead trout 0 to 5 inches in length. Treatments "B", "D" and "F" (upper small riser, lower side and large riser ports) gave results which fell between those of the above two

Table 6

Results of a Test[1] using Least Significant Difference for All Possible Comparisons of Treatment Means for Wild and Experimental Fish

Wild Steelhead Trout	E	F	D	B	A	C
0 to 5-inch Group (LSD.01 = 1.711)	2.775	3.705	3.852	4.198	4.515	4.872
Wild Steelhead Trout	E	B	A	C	D	F
10-inch and over Group (LSD.01 = 3.228)	1.310	1.398	2.395	3.688	3.935	4.740
Marked Steelhead Trout	B	E	F	C	A	D
(LSD.01 = 19.602)	5.272	6.350	12.645	12.758	31.700	36.060
Marked Coho Salmon	B	E	C	F	D	A
(LSD.01 = 23.316)	3.095	4.092	6.068	9.672	27.872	38.632

[1] Groups of means underlined by a continuous single line are not significantly different from each other.

Treatments

A Upper four side ports

B Upper four small riser ports

C Upper four large riser ports

D Lower four side ports

E Lower four small riser ports

F Lower four large riser ports

treatment groups. The relationship among the port sequences for unmarked steelhead trout greater than 10 inches in length is again not clear. The treatment mean for "F" (lower large riser ports) was significantly higher than those for "B" or "E" (upper and lower small riser ports). The means for "A", "D" and "C" (upper and lower side ports and upper large riser ports) are intermediate.

For marked steelhead trout, treatment means "A" and "D" (side ports) were significantly different from "B" and "E" (small riser ports), with "C" and "F" (large riser ports) somewhere between these two groups. The results of the test for the marked coho salmon were similar to those described previously for marked steelhead trout.

After individual comparisons were made, treatment means were combined. Using the mean difference between comparisons of combined treatment means and comparing the difference to a LSD value, it was possible to determine if there were significant differences between any groups of port sequences (tables 7a, b, c, and d). New LSD values were computed for these tests.

In general, the results of group comparisons tended to clarify the data presented in table 6. For unmarked steelhead trout, 0 to 5 inches in length, there was a significant difference between the usage of upper and

Table 7a

Comparison of Combined Treatment Means for Wild Steelhead Trout 0 to 5 Inches in Length

	Treatments						
	Upper Ports			Lower Ports			
	Small Side(A)	Small Riser(B)	Large Riser(C)	Small Side(D)	Small Riser(E)	Large Riser(F)	
Mean	4.515	4.198	4.872	3.852	2.775	3.705	Mean Difference
Comparisons							
Side vs Small Riser	+	-	0	+	-	0	0.697
Upper vs Lower	+	+	0	-	-	0	1.043
Interaction	-	+	0	+	-	0	0.380
Side vs Large Riser	-	0	+	-	0	+	0.105
Upper vs Lower	+	0	+	-	0	-	0.915
Interaction	-	0	+	+	0	-	0.252
Small vs Large Riser	0	-	+	0	-	+	0.802
Upper vs Lower	0	+	+	0	-	-	1.295[1]
Interaction	0	+	-	0	-	+	0.128
All Upper vs All Lower	+	+	+	-	-	-	1.084[1]

LSD = 1.209 (for two means combined for comparison with two other means
LSD = 0.987 (for three means combined for comparison with three other means

[1] Significantly different from zero

Table 7b

Comparison of Combined Treatment Means for Wild Steelhead Trout 10 inches and over in Length

	Treatments						
	Upper Ports			Lower Ports			
	Small Side(A)	Small Riser(B)	Large Riser(C)	Small Side(D)	Small Riser(E)	Large Riser(F)	
Mean	2.395	1.398	3.688	3.935	1.310	4.740	Mean Difference
Comparisons							
Side vs Small Riser	+	-	0	+	-	0	1.811
Upper vs Lower	-	-	0	+	+	0	0.726
Interaction	-	+	0	+	-	0	0.814
Side vs Large Riser	-	0	+	-	0	+	1.049
Upper vs Lower	-	0	-	+	0	+	1.296
Interaction	-	0	+	+	0	-	0.244
Small vs Large Riser	0	-	+	0	-	+	2.860[1]
Upper vs Lower	0	-	-	0	+	+	0.482
Interaction	0	+	-	0	-	+	0.570
All Upper vs All Lower	-	-	-	+	+	+	0.835

LSD = 2.282 (for two means combined for comparison with two other means)
LSD = 1.864 (for three means combined for comparison with three other means)

[1] Significantly different from zero

Table 7c

Comparison of Combined Treatment Means for Marked Steelhead Trout

	Treatments						
	Upper Ports			Lower Ports			
	Small Side(A)	Small Riser(B)	Large Riser(C)	Small Side(D)	Small Riser(E)	Large Riser(F)	
Mean	31.700	5.272	12.758	36.060	6.350	12.645	Mean Difference
Comparisons							
Side vs Small Riser	+	-	0	+	-	0	28.069[1]
Upper vs Lower	-	-	0	+	+	0	2.719
Interaction	-	+	0	+	-	0	1.641
Side vs Large Riser	+	0	-	+	0	-	21.179[1]
Upper vs Lower	-	0	-	+	0	+	2.123
Interaction	-	0	+	+	0	-	2.236
Small vs Large Riser	0	-	+	0	-	+	6.890
Upper vs Lower	0	-	-	0	+	+	0.483
Interaction	0	-	+	0	+	-	0.595
All Upper vs All Lower	-	-	-	+	+	+	1.775

LSD = 13.859 (for two means combined for comparison with two other means)
LSD = 11.3172 (for three means combined for comparison with three other means)

[1] Significantly different from zero

Table 7d

Comparison of Combined Treatment Means for Marked Coho Salmon

	Treatments						
	Upper Ports			Lower Ports			
	Small Side(A)	Small Riser(B)	Large Riser(C)	Small Side(D)	Small Riser(E)	Large Riser(F)	
Mean	38.632	3.095	6.068	27.872	4.092	9.672	Mean Difference
Comparisons							
Side vs Small Riser	+	-	0	+	-	0	29.658[1]
Upper vs Lower	+	+	0	-	-	0	4.881
Interaction	+	-	0	-	+	0	5.878
Side vs Large Riser	+	0	-	+	0	-	25.382[1]
Upper vs Lower	+	0	+	-	0	-	3.578
Interaction	+	0	-	-	0	+	7.182
Small vs Large Riser	0	-	+	0	-	+	4.276
Upper vs Lower	0	-	-	0	+	+	2.300
Interaction	0	+	-	0	-	+	1.303
All Upper vs All Lower	+	+	+	-	-	-	2.053

LSD = 17.898 (for two means combined for comparison with two other means)
LSD = 14.615 (for three means combined for comparison with three other means)

1 Significantly different from zero

lower ports for the vertical risers, with the upper ones being preferred (table 7a). The only significant difference between treatment means for steelhead trout, 10 inches and over in length, was between small and large riser ports, with the larger ports being preferred (table 7b). Results were the same for both marked steelhead trout and coho salmon. The side ports were significantly more efficient than either the small or large riser ports (tables 7c and 7d).

The downstream movement of salmonids declined during the second testing period with the exception of a small migration of spring chinook salmon which peaked in the middle of June. The number of wild fish bypassed and available for marking was therefore limited. Table 8 presents the number of wild fish bypassed per treatment. The number of experimental fish released and the number bypassed per treatment are given in table 9.

Tables of means for the data are given in appendix B. It was determined by inspection of these means that there were no significant differences between south side ports (G) and north side ports (H) for bypassing the 0 to 5-inch size groups of wild coho salmon, chinook salmon, and steelhead trout. Other size groups and species were not present in sufficient numbers to make conclusions possible.

Inspection of the tables of means (appendix B) for

Table 8

Number of Wild Fish Bypassed for Each Treatment in Experiment No. 2, June 10 to June 28, 1958

Treatment	Size	Species			
		Steelhead Trout	Coho Salmon	Cutthroat Trout	Chinook Salmon
South Side (G)	0 - 5	8	150	1	7
	5 - 10	9	0	11	0
	over 10	1	0	0	0
	Total	18	150	12	7
North Side (H)	0 - 5	16	41	0	8
	5 - 10	8	0	3	0
	over 10	1	0	0	0
	Total	25	41	3	8
North Side (H)	0 - 5	31	131	0	24
	5 - 10	3	0	7	0
	over 10	1	0	0	0
	Total	35	131	7	24
South Side (G)	0 - 5	96	213	9	66
	5 - 10	8	0	11	0
	over 10	1	0	0	0
	Total	105	213	20	66
South Side (G)	0 - 5	56	76	7	112
	5 - 10	2	0	6	0
	over 10	0	0	0	0
	Total	58	76	13	112
North Side (H)	0 - 5	27	87	2	105
	5 - 10	4	0	3	0
	over 10	0	0	0	0
	Total	31	87	5	105
North Side (H)	0 - 5	21	46	0	133
	5 - 10	0	0	2	0
	over 10	0	0	0	0
	Total	21	46	2	133
South Side (G)	0 - 5	6	35	0	39
	5 - 10	2	0	0	0
	over 10	1	0	0	0
	Total	9	35	0	39

Table 8 (continued)

Treatment	Size	Species			
		Steelhead Trout	Coho Salmon	Cutthroat Trout	Chinook Salmon
South Side (G)	0 - 5	7	20	1	41
	5 - 10	2	0	0	0
	over 10	1	0	0	0
	Total	10	20	1	41
TOTALS					
South Side (G)[1]		182	344	34	258
North Side (H)		112	305	17	270

[1] First replication for south side (G) excluded from total.

both direct and carry-over counts on experimental fish also showed no significant differences between the two side port sequences in bypassing the smaller fish.

In only one instance do the data show a possible difference and that is with the marked steelhead trout. A mean of 30.36 appears in the carry-over count in "previous ports north" to "present ports south", indicating that a larger number of fish waited to bypass through the south side ports. The mean of 30.36 was due to a single 50 percent carry-over (only 8 fish) which could have been chance. This result, therefore, was not considered significant.

There are indications in the first experiment's data

Table 9

Numbers of Experimental Fish Released and Bypassed for Each Treatment in Experiment No. 2, June 10 to June 28, 1958

Treatment		Species	
		Steelhead Trout	Coho Salmon
South Side (G)	No. Released	30	60
	Direct Count	15(50.00)	35(58.33)
	Carry-over Count	--	--
North Side (H)	No. Released	16	131
	Direct Count	3(18.75)	19(14.50)
	Carry-over Count	3(10.00)	2(3.33)
North Side (H)	No. Released	20	16
	Direct Count	10(50.00)	7(43.75)
	Carry-over Count	4(25.00)	19(14.50)
South Side (G)	No. Released	23	76
	Direct Count	10(43.48)	52(68.42)
	Carry-over Count	3(15.00)	8(50.00)
South Side (G)	No. Released	74	115
	Direct Count	35(47.29)	53(46.09)
	Carry-over Count	0(0.00)	2(2.63)
North Side (H)	No. Released	52	52
	Direct Count	24(46.15)	22(42.31)
	Carry-over Count	0(0.00)	6(5.22)
North Side (H)	No. Released	17	28
	Direct Count	10(58.82)	13(46.43)
	Carry-over Count	1(1.92)	1(1.92)
South Side (G)	No. Released	24	20
	Direct Count	18(75.00)	5(20.00)
	Carry-over Count	1(5.88)	3(10.71)
South Side (G)	No. Released	13	5
	Direct Count	2(15.38)	2(40.00)
	Carry-over Count	2(8.33)	1(5.00)

of preferences by some species for certain port sequences which further testing might show significant. The data in table 4 for wild coho salmon indicate a preference for side ports which was shown in experimental fish to a measurable extent (table 7d). Bypassing of coho salmon in relation to depth is not made clear by the available data. There may be some selection for the upper ports on the south side of the canal, but no consistent pattern was demonstrated with the remaining port sequences.

No preference was indicated by the data for 0 to 5-inch steelhead trout in relation to side, small riser or large riser ports. The steelhead trout 5 to 10 inches in length may have shown a preference for the south side ports (table 4), which would agree with the results obtained with the experimental fish (table 7c). Steelhead trout 10 inches and over in length showed no port preferences other than those presented statistically in table 7b.

Cutthroat trout 0 to 5 inches in length were not abundant enough to make possible the determination of any recognizable bypassing pattern. For the 5 to 10 inch size group, the data in table 4 suggest a preference for side and lower large riser ports.

Complementary Results

The use of hatchery fish was terminated on May 15, 1958, because of their low recovery rate and the poor condition of those remaining in the holding pond. Other than the obvious tendency of hatchery fish to remain in the forebay, nothing can be said concerning the comparison of hatchery and wild fish in relation to the various factors under investigation. Prior to May 17, only 141 hatchery steelhead were bypassed from a total of 1197 released. The rate of recovery of these fish increased during June, until a total of 534 fish had been bypassed by July 1. Some fish had remained in the forebay for over a month before bypassing. This may have been due to the fish not being physiologically ready for downstream migration. The delay in bypassing emphasized the importance of using wild migrants for experimental testing.

Fish obtained from the bypass trap and fish obtained from the scooptrap are compared in tables 10 and 11 in respect to the number bypassed per treatment and to the total number bypassed during the first experiment. It appears from inspection of the data that both groups of fish bypassed equally well. Therefore, the earlier assumption that bypass trap fish were not conditioned to any measurable extent was accepted, and conclusions reached with fish bypassed once would seem to apply in general to

Table 10

Numbers of Bypass Trap Fish and Scooptrap Fish Released and Bypassed for a Two Day Treatment Period

Species	Source	No. Released	No. Bypassed
Coho Salmon	Bypass Trap	623	90(14)[1]
Coho Salmon	Scooptrap	605	71(12)
Steelhead Trout	Bypass Trap	541	75(14)
Steelhead Trout	Scooptrap	166	33(20)

[1] Numbers in parentheses are percentages of total number released.

Table 11

Total Numbers of Bypass Trap Fish and Scooptrap Fish Released and Bypassed from April 23 to June 10, 1958

Species	Source	No. Released	Total Bypassed
Coho Salmon	Bypass Trap	623	315(51)[1]
Coho Salmon	Scooptrap	605	275(46)
Steelhead Trout	Bypass Trap	541	362(67)
Steelhead Trout	Scooptrap	166	95(57)

[1] Numbers in parentheses are percentages of total number released.

all wild fish in the canal.

It might be well to point out that while port size and location were the variables of primary interest, velocity and discharge rate of water entering the various port sequences were important related variables influencing the results to an unknown extent. The measurements for these related variables for the eight port sequences are presented in table 12. The velocity and discharge rate measurements are approximations and useful only for comparisons between port sequences. The discharge rates have been corrected for leakage which would increase each figure in table 12 by 3.5 c.f.s.

Only a few underwater observations of fish movement were made. The appearance of turbid water on May 18 terminated this phase of the study earlier than had been anticipated. Observations showed the majority of the fish during the day to be concentrated in the low velocity water in the middle of the forebay. Only a few fish were seen swimming back and forth in front of the screens. Darkness evidently stimulated movement, as there was a general increase in fish activity throughout the forebay at night. An estimated 70 percent of the fish were bypassed during the night. The increase in activity of fish in the forebay during the hours of darkness corresponded to the increased movement of fish down the canal indicated by the

Table 12

Velocity and Volume Measurements for the Port Sequences

Port Sequence	Mean Velocity	Volume
Upper Side (A)	7.93 f.p.s.	6.00 c.f.s.
Lower Side (D)	7.78 f.p.s.	6.00 c.f.s.
Upper Small Riser (B)	5.19 f.p.s.	3.50 c.f.s.
Lower Small Riser (E)	7.42 f.p.s.[1]	4.00 c.f.s.
Upper Large Riser (C)	1.37 f.p.s.	7.50 c.f.s.
Lower Large Riser (F)	2.41 f.p.s.[1]	9.50 c.f.s.
Eight South Side Ports (G)	6.79 f.p.s.[1]	11.50 c.f.s.
Eight North Side Ports (H)	4.63 f.p.s.[1]	8.50 c.f.s.

[1] Calculations by formula show these velocities slightly higher than expected with corresponding volume.

catch in the scooptrap.

Some fish under 10 inches were observed being swept into the south side and small riser ports, head, tail or side first, apparently having no control over their movements.

Several times during the peak of the migration, for any given treatment, a greater number of fish bypassed after a period of precipitation had increased the river flow. Mean canal discharge rate for the test period was

629 c.f.s. and the rate varied from 488 to 662 c.f.s. (appendix C). Generally, the day to day variation in canal flow was small, and no effects on fish bypassing were noted. As previously mentioned, the water became turbid from suspended volcanic ash on May 18; and, although turbidity varied, the water did not become clear again during the remainder of the tests. Turbidity seemed to have no measurable effects on fish bypassing in the present study.

Water temperature varied from 42° F. to 66° F. during the course of the study. In the middle of May, when the downstream migration was at its peak, the water temperatures averaged approximately 54° F. Water temperature apparently has no effect upon fish bypassing in respect to the factors being investigated.

DISCUSSION AND CONCLUSIONS

Of the many possible factors influencing fish bypassing at the Marmot Dam fish screen, several of those believed most important have been studied. There seems to be substantial proof that escape port location and the volume and velocity of water entering the openings are of great importance in fish bypassing at this installation.

The study made by the Oregon State Game Commission in 1954 and 1955 demonstrated the importance of water volume and velocity entering the bypass system (4, p. 76-81). As the volume and velocity of water increased, a greater number of fish were bypassed. The entrances to the bypass system at that time consisted of 32 circular ports and the rectangular port on the south side of the canal.

The importance of water volume and velocity were also indicated by earlier experience at the mechanical screens. When the bypass system was first put into operation in 1951, it was not efficient, at least for spent steelhead trout. At that time the system consisted of only the 32 circular ports. The side ports were the same as they were in the present investigation, except that the volume and velocity of water flowing through a given port then was less. It seems logical, then, that the increased efficiency of the side ports under present test conditions is due to the greater volume and velocity of water entering these openings. The evidence seems to indicate that, for a given-sized orifice and location, efficiency is greatly dependent upon volume and velocity of the water entering the ports. Any separate effects of water volume and water velocity on fish bypassing are not distinguishable in these studies. It might be expected that fish would enter an escape opening more readily where there was little difference between approach and entrance velocities. This may be true where entrances are located so that fish moving downstream with the current are carried passively into the structure. Under conditions at the screens studied here however, increases in water velocity may be necessary for attraction purposes. Bypass ports with entrance velocities of approximately 7 f.p.s. were readily utilized by fish in this study.

In general, side ports, large riser and then small riser ports were effective in that order for bypassing all sizes and species of wild fish in the present investigation, (tables 4 and 5). Side ports were shown statistically to be significantly better than either large or small riser ports for experimental fish (tables 7c and 7d). The efficiency of the side ports, if explainable on the basis of location, may be due to water currents in the forebay. The poor efficiency of the riser ports may be due to hydraulic conditions present at the screens, the water currents there being away from the risers. It seems likely that fish coming down the canal, or even those present in the forebay, may move into the current at the sides of the canal, where the water direction is downstream, and are thereby brought into position to utilize the side ports more often than the riser ports.

At the close of the first experiment, when it was evident that the south side ports were the most efficient, it was thought that this efficiency could possibly be explained on the basis of direction of water flow entering the openings. That this factor was not significant was indicated when it was tested between north and south side ports in the second experiment. These tests were conducted toward the end of the migration period when the number of fish available for bypassing was reduced. Further testing is needed before the effects of the direction of water flow on fish bypassing can be fully understood.

The effect that the shape of the entrance has on fish bypassing is not known. The greater efficiency of the side ports may be due in part to their circular shape, but this seems doubtful.

The location of the vertical risers may be faulty; a fish searching along the screens for an opening to continue its downstream movement might find and enter a riser port more readily if it were in line with rather than 15 inches upstream from the surface of the screen.

Because of the greater efficiency of the side ports, it seems advisable to continue the discussion and conclusions separately for the south side and riser ports in respect to the remaining factors investigated in the first experiment. Although the riser ports were not as efficient as the side ports in bypassing fish, the data from the riser ports may be useful if this bypass system is to be considered for future installations, or if the present bypass facilities are to be improved.

Limited experiments of the 1957 investigation, in which only the vertical riser ports were involved, indicated that wild and hatchery coho salmon utilized the upper ports in preference to the lower ports. It could not be determined whether that movement of coho salmon through the upper escape ports was a function of lower velocity or migration stratification (3, p. 254). In the present study, depth as a factor in port selection with one exception was not shown to be significant with wild fish (marked and unmarked) regardless of species or size. The only exception was for steelhead trout 0 to 5 inches in length, which showed a significant preference for the upper ports (table 7a). The importance of this result is dubious because of the small number of fish involved. Upper and lower south side ports were equally efficient in bypassing all species and sizes of fish.

Two sizes of ports were tested for comparative efficiency on the vertical risers. Significant differences were shown only for the wild steelhead trout 10 inches and over in length, with the larger ports being selected. Whether or not this result was due to port size as such, or to differences in water velocity and volume cannot be fully determined. The fact that the original bypass was not efficient, especially for spent steelhead trout, until the larger rectangular port at the side was installed indicates the need for larger entrances for fish 10 inches and over in length.

SUMMARY

1. An investigation of factors affecting fish bypassing at the large screened diversion canal at Marmot Dam on the Sandy River, has been continuous since 1952. This study was sponsored by the U. S. Army Corps of Engineers as a part of their Fisheries Engineering Research Program for the lower Columbia River Basin. The program was carried out under contract by the Oregon State Game Commission and the Oregon Cooperative Wildlife Research Unit. The study reported here concerns the comparative efficiency of fish escape ports of various sizes and locations for bypassing downstream migrant salmonids.

2. Three "Rex Traveling Water Screens" of the commercial link belt type are installed in the hydro-electric diversion canal for the purpose of arresting the movement of fish so that they might be returned from the canal to the river. The fish bypass system consists of 16 circular ports (6 inches in diameter), 16 square ports (adjustable in size from 0 to 14 inches square), one rectangular opening 15 inches wide and 50 inches in depth, two flow regulating chambers, a trapping compartment, and a return pipeline to the river. Eight circular ports, spaced two feet on centers, are located on each side of the canal in front of the screens. The 16 square ports are identically spaced on two vertical risers between the

screens. The rectangular port is located on the south side of the canal, 8 feet upstream from the screens. Water entering the risers and north side ports flows vertically downward into a sub-canal horizontal duct which leads to the first flow regulating chamber. Water entering the south side ports and rectangular port flows directly into the first flow regulating chamber. From this chamber the water flows into a second flow regulating chamber, either through a submerged orifice or over a weir. From this second chamber, the water flows into the trapping compartment and then to the river by a subterranean pipeline.

3. Two series of experiments were designed, and tests were conducted in the Spring of 1958. The objectives of the first experiment were to determine the relative efficiencies of (a) ports located on the south side of the canal wall and ports located between the mechanical screens, (b) ports at two depths, and (c) ports of two sizes on the vertical risers.

4. A second experiment was conducted when it became apparent that the south side ports were generally more efficient than either the large or small riser ports. A test of the comparative efficiency of the north side ports, which are similar to the riser ports in that the flow of water entering them is directed downward, and the south side ports, where the flow is horizontal, was made

to determine the effect of direction of water flow on fish bypassing.

5. Water velocity and discharge measurements were taken at all port sequences in an attempt to determine their influence on fish bypassing. Observations were made on weather and water conditions to assist in determining the cause of any changes in fish behavior at the mechanical screens during the experimental testing. Underwater observations were also made on fish distribution and movement in front of the screens, and their reactions as they approached and entered the escape ports.

6. The experimental procedure was to release a known number of marked wild coho salmon and steelhead trout at the screens for a particular port sequence (treatment). The number of marked and unmarked fish bypassed was recorded for the two day test period. Hatchery steelhead trout were also released for comparative purposes but this was discontinued because of low recovery and their poor condition.

7. In the first experiment, no significant differences were shown between any of the treatments in bypassing unmarked, 0 to 5-inch coho salmon and cutthroat trout, and 5 to 10-inch cutthroat and steelhead trout. Significant differences were found for marked steelhead trout and coho salmon, and unmarked 0 to 5-inch and

10-inch and over steelhead trout.

8. Where significant differences were demonstrated, comparisons of treatment means, both singularly and combined, were made using the method of least significant difference. It was found that upper ports on the vertical risers, regardless of size, were more efficient than lower ports in bypassing wild steelhead trout 0 to 5 inches in length. Large riser ports (14 inches square) were significantly better than small riser ports ($5\frac{1}{4}$ inches square) for wild steelhead trout 10 inches and over in length. Marked coho salmon and steelhead trout preferred side ports to those on the vertical risers and showed no depth selection.

9. In the second experiment, direction of water flow in the bypass system was not shown to influence fish bypassing significantly. The number of fish available for bypassing was reduced, and further testing during the peak of the downstream migration may produce different results.

10. Generally, a greater number of fish bypassed after a period of precipitation had increased river flow. Evidently darkness also stimulated movement, as there was a general increase in fish activity throughout the forebay at night. An estimated 70 percent of the fish were bypassed during the hours of darkness. Water temperature apparently has no effect upon fish utilization of the

bypass. Underwater observations showed the majority of the fish during the day to be concentrated in the low velocity water in the middle of the forebay. The fish observed moving into the ports appeared to be swept into them and had no control over their movements.

11. Past experience with the bypass system indicates that, with a given sized orifice and location, port efficiency is greatly dependent upon water volume and velocity.

12. With the water velocity and discharge rate under which the present tests were conducted, the side ports were more efficient than the riser ports. Factors influencing the selection of side ports by fish are probably associated with the water currents at the screens and the bypass design.

13. Depth as a factor influencing port selection was not significant except at the vertical risers for steelhead trout 0 to 5 inches in length.

14. The larger riser ports (196 square inches) were significantly better than small riser ports (28 square inches) for steelhead trout 10 inches and over in length.

BIBLIOGRAPHY

1. Chapman, Donald W. An improved portable tattooing device. Progressive Fish Culturist 19(4):182-184. 1957.

2. Kerr, James E. Studies on fish preservation at the Contra Costa Steam Plant of the Pacific Gas and Electric Company. Sacramento, California Department of Fish and Game, 1953. 66 p. (Fish Bulletin no. 92)

3. Oregon. State Game Commission. Fishery Division. Annual report, 1957. Salem, May 1958. 298 p.

4. U. S. Army. Corps of Engineers. North Pacific Division. Progress report on fisheries engineering research program. Seattle, Wash., Nov. 1956. 179 p.

5. U. S. Dept. of Interior. Bureau of Reclamation, Region 2, and Fish and Wildlife Service, Region 1. Fish protection at the Tracy pumping plant, Central Valley project, California: development of a fish salvage facility. Sacramento, Feb. 1957. 96 p.

APPENDIXES

APPENDIX A

Table 1

The Number of Wild Coho Salmon (0 to 5-inch group) Bypassed for Individual Treatments in Experiment No. 1

Replication Treatment	1	2	3	4
A	179	1405	833	2200
B	61	180	785	376
C	71	113	877	182
D	601	1824	1648	71
E	112	97	328	711
F	58	638	1447	446

Table 2

Analysis of Variance Calculations for Wild Coho Salmon (0 to 5-inch group) Bypassed in Experiment No. 1

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F
Total	3498.1421	23		
Replications	1042.1107	3	347.3702	3.50
Treatments	966.8469	5	193.3694	1.95
Error	1489.1845	15	99.2790	

Table 3

The Number of Wild Steelhead Trout (0 to 5-inch group) Bypassed for Individual Treatments in Experiment No. 1

Replication Treatment	1	2	3	4
A	32	26	3	31
B	30	27	12	7
C	45	23	14	18
D	22	19	5	17
E	16	6	4	7
F	31	23	4	6

Table 4

Analysis of Variance Calculations for Wild Steelhead Trout (0 to 5-inch group) Bypassed in Experiment No. 1

Variation Due to:	Sum of Squares	Degrees of Freedom	Mean Square	F
Total	46.8828	23		
Replication	26.0734	3	8.6911	12.89
Treatments	10.6951	5	2.1390	3.17[1]
Error	10.1143	15	.6743	

[1] Significant at the five percent level.

Table 5

The Number of Wild Steelhead Trout (5 to 10-inch group) Bypassed for Individual Treatments in Experiment No. 1

Replication Treatment	1	2	3	4
A	211	1439	105	109
B	155	308	374	16
C	345	366	401	12
D	1688	1298	590	22
E	148	153	169	159
F	77	667	652	74

Table 6

Analysis of Variance Calculations for Wild Steelhead Trout (5 to 10-inch group) Bypassed in Experiment No. 1

Variation Due to:	Sum of Squares	Degrees of Freedom	Mean Square	F
Total	2440.7483	23		
Replications	951.7105	3	317.2368	4.87
Treatments	512.6591	5	102.5318	1.58
Error	976.3787	15	65.0919	

Table 7

The Number of Wild Steelhead Trout (over-10-inch group) Bypassed for Individual Treatments in Experiment No. 1

Replication Treatment	1	2	3	4
A	0	27	7	3
B	3	6	0	2
C	19	34	8	3
D	37	32	9	1
E	1	14	4	5
F	13	19	30	15

Table 8

Analysis of Variance Calculations for Wild Steelhead Trout (over-10-inch group) Bypassed in Experiment No. 1

Variation Due to:	Sum of Squares	Degrees of Freedom	Mean Square	F
Total	91.7474	23		
Replications	15.2875	3	5.0958	2.12
Treatments	40.4676	5	8.0935	3.37[1]
Error	35.9923	15	2.3995	

[1] Significant at the five percent level.

Table 9

The Number of Wild Cutthroat Trout (0 to 5-inch group) Bypassed for Individual Treatments in Experiment No. 1

Replication Treatment	1	2	3	4
A	11	5	0	0
B	6	10	2	0
C	7	5	0	2
D	6	5	3	1
E	0	0	0	2
F	3	5	19	1

Table 10

Analysis of Variance Calculations for Wild Cutthroat Trout (0 to 5-inch group) Bypassed in Experiment No. 1

Variation Due to:	Sum of Squares	Degrees of Freedom	Mean Square	F
Total	35.9005	23		
Replication	7.0244	3	2.3415	1.75
Treatment	8.8293	5	1.7659	1.32
Error	20.0468	15	1.3365	

Table 11

The Number of Wild Cutthroat Trout (5 to 10-inch group) Bypassed for Individual Treatments in Experiment No. 1

Replication Treatment	1	2	3	4
A	5	53	70	99
B	12	21	14	10
C	17	25	23	2
D	36	44	130	13
E	5	6	17	58
F	0	38	83	36

Table 12

Analysis of Variance Calculations for Wild Cutthroat Trout (5 to 10-inch group) Bypassed in Experiment No. 1

Variation Due to:	Sum of Squares	Degrees of Freedom	Mean Square	F
Total	181.9488	23		
Replication	46.7054	3	15.5685	2.59
Treatments	44.9055	5	8.9811	1.49
Error	90.3379	15	6.0225	

Table 13

The Direct Count (percentage) of Marked Steelhead Trout Bypassed for Individual Treatments in Experiment No. 1

Replication Treatment	1	2	3	4
A	16.67	32.00	53.13	25.00
B	6.00	3.00	0.00	12.09
C	3.51	3.00	8.25	36.27
D	28.00	33.04	39.71	43.49
E	3.75	4.00	7.27	10.38
F	2.00	12.00	26.32	10.26

Table 14

The Carry-over Count (percentage) of Marked Steelhead Trout Bypassed for Individual Treatments in Experiment No. 1

Replication Treatment	1	2	3	4
A	---	20.00	44.44	51.65
B	1.00	6.00	2.00	9.38
C	14.00	10.53	6.96	18.82
D	55.00	14.29	37.74	7.84
E	10.00	2.00	2.06	7.02
F	8.33	10.00	25.45	17.65

Table 15

Analysis of Variance Calculations for Marked Steelhead Trout (Direct Count) Bypassed in Experiment No. 1

Variation Due to:	Sum of Squares	Degrees of Freedom	Mean Square	F
Total	5506.4842	23		
Replication	715.0307	3	238.3436	2.69
Treatment	3464.0100	5	692.8020	7.83[1]
Error	1327.3535	15	88.4902	

[1] Significant at the five percent level.

Table 16

The Direct Count (percentage) of Marked Coho Salmon Bypassed for Individual Treatments in Experiment No. 1

Replication Treatment	1	2	3	4
A	68.75	24.00	15.75	46.21
B	2.00	0	8.00	2.38
C	0	0	8.99	15.28
D	16.00	26.95	25.58	42.96
E	4.00	0	6.49	5.88
F	6.00	2.00	23.38	6.81

Table 17

The Carry-over Count (percentage) of Marked Coho Salmon Bypassed for Individual Treatments in Experiment No. 1

Replication Treatment	1	2	3	4
A	---	23.08	25.00	35.71
B	0	12.77	18.00	3.28
C	0	0	3.37	0
D	26.00	42.00	6.72	1.39
E	2.00	4.00	8.99	4.48
F	0	4.00	10.38	6.98

Table 18

Analysis of Variance Calculations for Marked Coho Salmon (Direct Count) Bypassed in Experiment No. 1

Variation Due to:	Sum of Squares	Degrees of Freedom	Mean Square	F
Total	6967.7252	23		
Replication	381.7712	3	127.257	.86
Treatment	4372.0681	5	874.414	5.92[1]
Error	2213.8859	15	147.592	

[1] Significant at the five percent level.

APPENDIX B

Table 1

Table of Means for Wild Steelhead Trout (0 to 5-inch group)
Bypassed in Experiment No. 2

Previous Ports Present Ports	South (G)	North (H)	Mean
South (G)	32	57	42
North (H)	22	26	24
Mean	27	38	33

Table 2

Table of Means for Wild Coho Salmon (0 to 5-inch group)
Bypassed in Experiment No. 2

Previous Ports Present Ports	South (G)	North (H)	Mean
South (G)	48	124	86
North (H)	64	89	77
Mean	56	107	81

Table 3

Table of Means for Wild Chinook Salmon (0 to 5-inch group) Bypassed in Experiment No. 2

Previous Ports Present Ports	South (G)	North (H)	Mean
South (G)	77	53	65
North (H)	57	79	68
Mean	67	66	67

Table 4

Table of Means for Marked Steelhead Trout (Direct Count) Bypassed in Experiment No. 2

Previous Ports Present Ports	South (G)	North (H)	Mean
South (G)	31.34	59.24	42.29
North (H)	32.45	54.41	43.43
Mean	31.90	56.83	44.36

Table 5

Table of Means for Marked Steelhead Trout (Carry-over Count) Bypassed in Experiment No. 2

Previous Ports Present Ports	South (G)	North (H)	Mean
South (G)	4.17	10.44	7.31
North (H)	5.00	13.46	9.23
Mean	4.59	11.95	8.27

Table 6

Table of Means for Marked Coho Salmon (Direct Count) Bypassed in Experiment No. 2

Previous Ports Present Ports	South (G)	North (H)	Mean
South (G)	43.05	44.21	43.63
North (H)	28.41	45.09	36.75
Mean	35.73	44.65	40.19

Table 7

Table of Means for Marked Coho Salmon (Carry-over Count) Bypassed in Experiment No. 2

Previous Ports Present Ports	South (G)	North (H)	Mean
South (G)	3.82	30.36	17.09
North (H)	4.28	8.21	6.25
Mean	4.05	19.29	11.67

APPENDIX C

Daily Canal Discharge from April 23 to June 28, 1958

April	c.f.s.	May	c.f.s.	June	c.f.s.
23	488	14	650	4	648
24	560	15	638	5	662
25	526	16	631	6	657
26	610	17	650	7	633
27	631	18	641	8	629
28	624	19	645	9	650
29	624	20	629	10	638
30	637	21	639	11	641
		22	660	12	629
May		23	659	13	629
		24	644	14	631
1	637	25	647	15	637
2	637	26	651	16	633
3	634	27	660	17	636
4	633	28	648	18	647
5	634	29	638	19	629
6	629	30	645	20	603
7	631	31	657	21	612
8	642			22	600
9	639	June		23	575
10	651			24	591
11	629	1	639	25	633
12	638	2	633	26	583
13	641	3	642	27	590
				28	647