passive intake screen workshop

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PASSIVE INTAKE SCREEN WORKSHOP

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PREFACE

Section 316b of the Federal Clean Air and Water Act, Public Law 92-500, (1972) requires the use of "Best Available Technology" to protect marine life at surface water intakes. For most surface water users, complying with the requirement has been difficult as conventional water screen equipment was designed primarily for pump and plant protection, not fish protection.

In an effort to solve the problem, Johnson Division, UOP Inc. developed the concept of Passive Screening. This new techology is based on the principle of controlling the approach velocity field at the screen face in order to minimize impingement and entrainment of mobile and non-mobile aquatic life.

The programs reported in these proceedings cover an assortment of applications, system designs and field tests summarizing the state of the art of Passive Screen Technology as of this date.

FIELD EVALUATION OF PASSIVE BAR SCREENS FOR GUIDING JUVENILE SALMONIDS OUT OF TURBINE INTAKES OF HYDROELECTRIC DAMS

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Abstract.--Laboratory and field studies have led to the development of a passive bar screen capable of successfully guiding oceanbound juvenile salmonids out of turbine intakes of dams on the Columbia and Snake Rivers. Because it contains fewer moving parts, this new fish-guiding device would be less costly to maintain than the submersible traveling screen presently in use. Field studies measured fish-guiding efficiency, percent of the fish descaled, and swimming performance of fish guided by passive bar screens or submersible traveling screens. Back flushing proved satisfactory as a means of cleaning the bar screens. However, implementing this method of cleaning is considered costly. Alternative cleaning methods are under consideration.

INTRODUCTION

Since 1975, the National Marine Fisheries Service (NMFS), under contract to the U.S. Army Corps of Engineers, (CofE) has been conducting research to develop an improved fish protection system for use at Bonneville Dam, McNary Dam, and other CofE dams on the main stem of the Columbia and Snake Rivers. Part of the research objectives called for developing a less expensive (passive) screening system (bar screen) that could be substituted for the submersible traveling screen (STS) presently used to guide fish (mainly Pacific salmon, *Oncorhynchus spp*., and steelhead, *Salmo gairdneri*), out of turbine intakes at hydroelectric dams (Fig. 1) (Long and Krcma 1969; Farr 1974).

To reduce the losses of oceanbound fingerling salmonids a system for collecting the fish at upstream dams, transporting them around intermediate dams, and releasing them back into the Columbia River at a safe site below Bonneville Dam has been introduced on the Snake and Columbia Rivers (Fig. 2). By bypassing dams, losses due to turbine activity, predation, nitrogen supersaturation, pollution, and delays in passing through large reservoirs are avoided. Screening of the turbine intakes is an important part of the collection system.

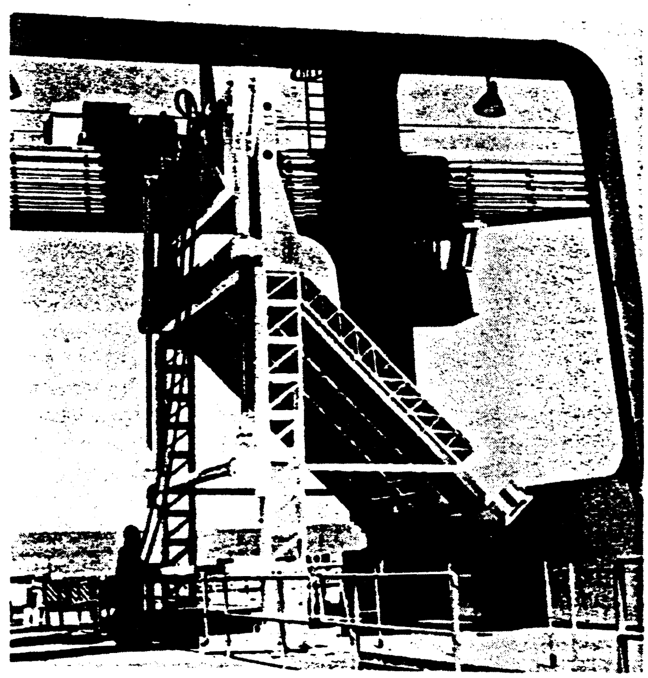

Figure 1.--The submersible traveling screen now in general use to guide oceanbound juvenile salmonids out of turbine intakes of dams on Columbia and Snake Rivers.

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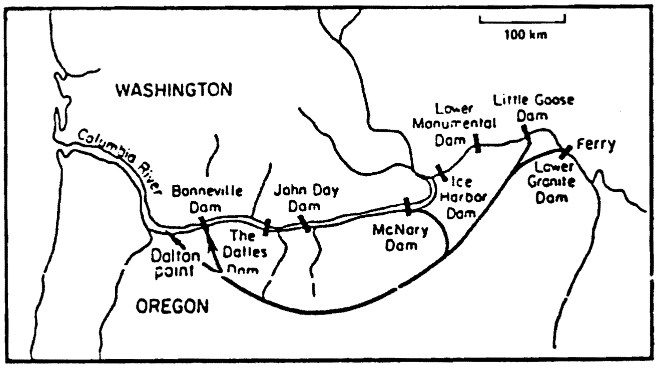


Figure 2.--Transportation routes and release locations of chinook salmon and steelhead collected at Little Goose, Lower Granite, and McNary Dams.

The first phase of the study to develop the bar screen was conducted under controlled laboratory conditions. The second phase utilized the findings of the laboratory tests to design prototype screens for testing at dams on the Columbia River. Initial prototype studies were conducted at Bonneville Dam in 1977 and 1978. Favorable results led to more extensive testing at McNary Dam in 1978 and 1979.

LABORATORY STUDIES

The laboratory studies were conducted in an oval flume--0.91 m (3.0 feet) wide, 2.1 m (7.0 feet) deep, and 4.88 m (16.0 feet) long (Ruehle et al. 1978). Three 50 hp pumps provided the capability of circulating water through the flume at velocities up to 2.44 ms (8.0 feet/s).

Various types of screen materials were tested in the flume. They included flat bar screens designed by NMFS; commercially manufactured wedge bar screens of various porosites (hereafter termed Johnson Screen[3]); and a standard screen of crosswoven mesh (similar to that used on the STS). Fish of various lengths were subjected to each type of screen and examined for injuries such as descaling. In addition, tests were conducted with various types of debris to determine the self-cleaning tendencies of each type of screen and how readily each could be cleaned by backflushing or other methods.

From the results of these tests, the flat bar screen and the Johnson screen materials were chosen for testing in the turbine intakes at Bonneville and McNary Dams.

FIELD STUDIES

The economic and practical feasibility of guiding downstream migrant salmonids out of a hydroelectric turbine intake using a passive fish screening system depends upon a number of factors:

1. The water velocity and guiding angle of the screen must be compatible with the size and swimming capabilities of the fish as computed using vector analysis (Kemeny et al. 1959).

2. The fish should be concentrated near the turbine intake ceiling so only a small amount of the total flow needs to be intercepted with the guiding device to guide a large percentage of the fish (75 to 85%).

3. The debris load in the river should allow a reasonable amount of operating time before the screen requires cleaning.

4. In addition, specific design considerations are necessary so the screening system will not endanger or seriously obstruct the operations of the dam.

Based on the results of the laboratory studies, we believed that fish could be guided safely out of the turbine intakes at both Bonneville and McNary Dams. Vertical distribution curves (Appendix A) established from previous research studies (Long 1968;1975) indicated that fish-guiding devices that would intercept the upper 3.05 to 4.57 m (10.0 to 15.0 feet) of water at the intake gatewell could guide 80 to 90% of the salmon and steelhead at Bonneville Dam and 75 to 80% of these fish at McNary Dam.

Description of Experimental Equipment

Figure 3 is a transverse section through a turbine intake in a typical hydroelectric dam in the Columbia River. Each turbine has three such intakes. Each of the intakes is constructed with a gatewell that allows a bulkhead gate to be lowered into the intakes so

[3] Reference to trade names does not imply endorsement by the National Marine Fish. Service, NOAA.

the turbine can be unwatered for maintenance or repair. Fish guiding devices are installed within the intakes via these gatewells. The dimensions of the intakes at the gatewell are about 6.5 m (21.0 feet) wide and 15.5 m (51.0 feet) high.

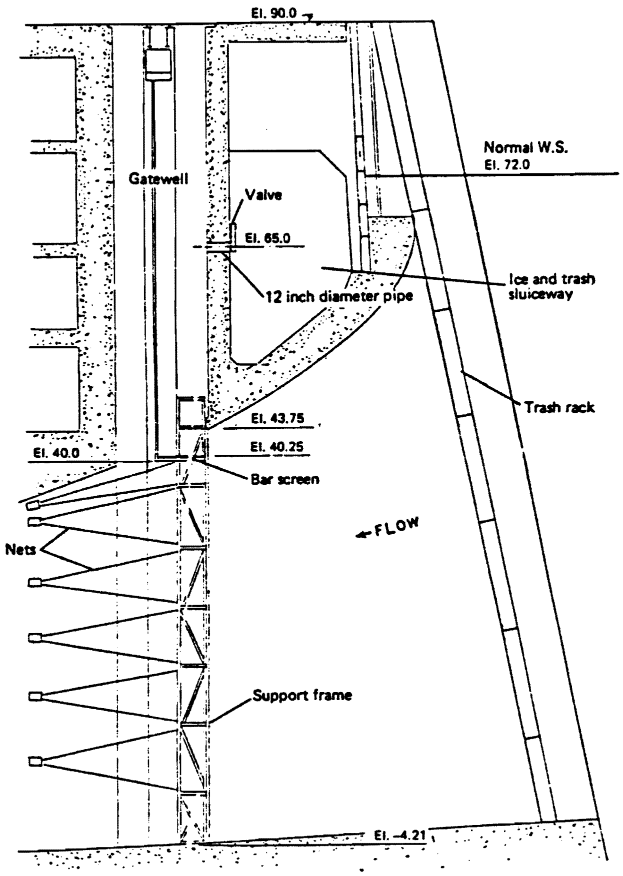


Figure 3.--Typical turbine intake at Bonneville Dam showing first prototype bar screen in position to guide fish out of intake and into gatewell.

The water velocities in each of the three intakes of a turbine unit are dissimilar depending upon the design of the turbine. In addition, the intake velocities vary between dams due to the size and shape of the intakes and the hydraulic head on the project. Maximum water velocities in the intakes at Bonneville and McNary dams are 1.28 m/s (4.2 feet/s), and 1.83 m/s (6.0 feet/s), respectively.

The first bar screen tested was installed in Bonneville Dam by NMFS in 1977. Figure 3 shows the placement of the screen in the intake. The face of the bar screen was constructed of 0.32 cm (1/8 inch) x 2.54 cm (1.0 inch) steel bars placed on edge with a 0.48 cm (3/16 inch) space between them allowing a 60% open area (Fig. 4). The bar screen was slightly narrower than the width of the intake, 6.5 m (21.0 feet) and was 1.5 m (5.0 feet) long. In operation, the face of the bar screen intercepted the upper 1.07 m (3.5 feet) of flow within the intake or only 7.8% of the total area.

Figure 4.--Bar screen tested in a turbine intake at Bonneville Dam in 1977-78.

Based on the favorable results of the 1977 tests at Bonneville Dam, a more advanced bar screen design was tested at McNary Dam.

Because fingerlings are not as concentrated in the upper flows of the intakes (see Appendix A) of McNary Dam as they are at Bonneville Dam, a two-part bar screen system was designed. One section was attached to a trash rack [trash rack deflector (TD)] and the other was installed in the gate slot [gatewell deflector(GD)]. Figure 5 shows the placement of the GD in the gate slot and the TD on the trash rack.

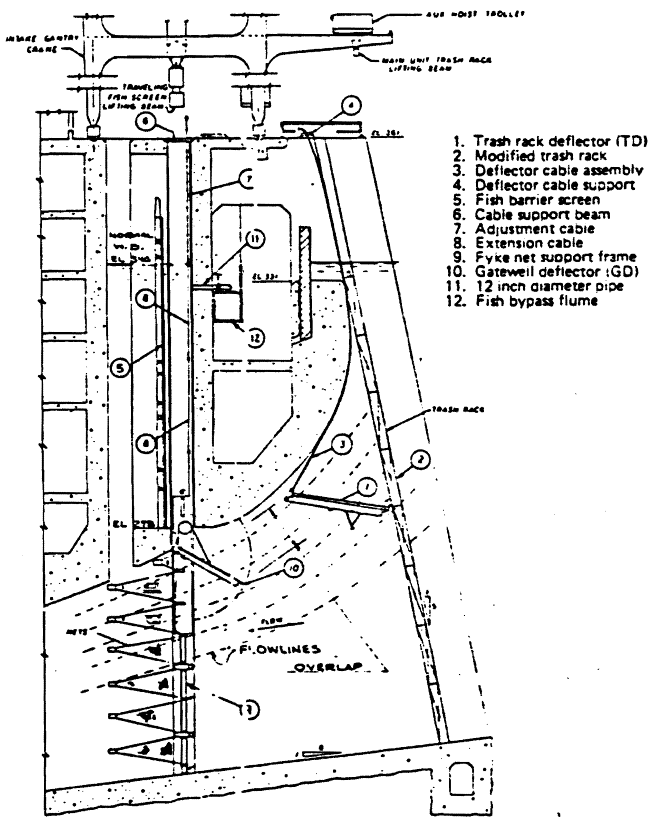


Figure 5.--Typical turbine intake at McNary Dam showing deployment of gatewell deflector and trash track deflector bar screens.

The screen material on the GD and TD was Johnson Screen wire (No. 93 profile) made of 304 stainless steel with a 0.127 cm (0.05 inch) space between the wires. This configuration provides a 36% open area (porosity). The GD was 5.94 m (19.5 feet) wide (slightly less than the width of the intake) and 3.04 m (10.0 feet) long.

For experimental purposes, the GD (Model I) was designed so the panels at the downstream end could be placed at a different angle-to-flow than the panels at the upstream end (Fig. 6). After the GD was placed in position in the intake, the upstream panels could be operated, at 10° angle increments, through a range from a plus 20° to a minus 30° from horizontal.

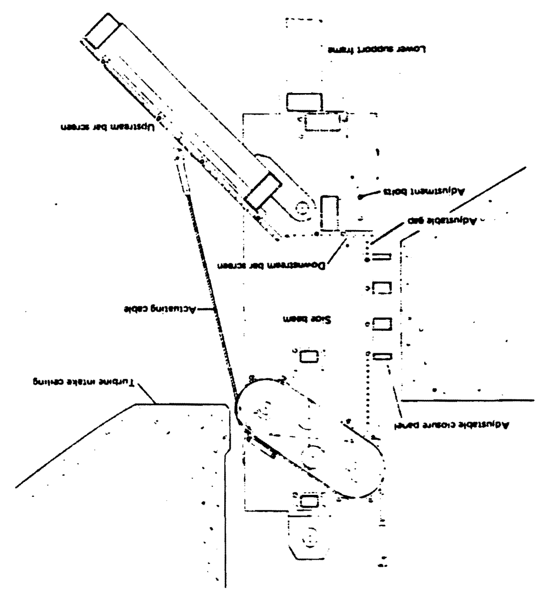


Figure 6.--Model I gatewell deflector tested at McNary Dam in 1978.

The TD, 5.52 m (18.0 feet) wide by 6.10 m (20.0 feet) long, was attached to the downstream side of a trash rack section by means of a special hinged bracket. The downstream end of the TD could be raised until it touched the ceiling of the intake or be lowered until the face of the screen was parallel to the flow entering the intake. This was accomplished with an existing 100-ton gantry crane.

Following the tests at McNary Dam in 1978, the CofE redesigned the GD (renamed Model II) so that the upstream and downsteam panels were joined together by a single frame (Fig. 7). The overall length of the GD was increased to 4.88 m (16.0 feet) so that a greater percentage of the flow could be intercepted without increasing the angle-to-flow. The dimension of the TD remained the same. The bar screens were moved into fish-guiding position by use of cables actuated from the intake deck. In 1979, the construction costs of one prototype GD and TD assembly were $73,500 and $39,300, respectively, for a total of $112,800. The 1979 price for one STS was $112,000; however, costs based on life expectancy, routine maintenance, and repair would be much greater than for a passive screening system.

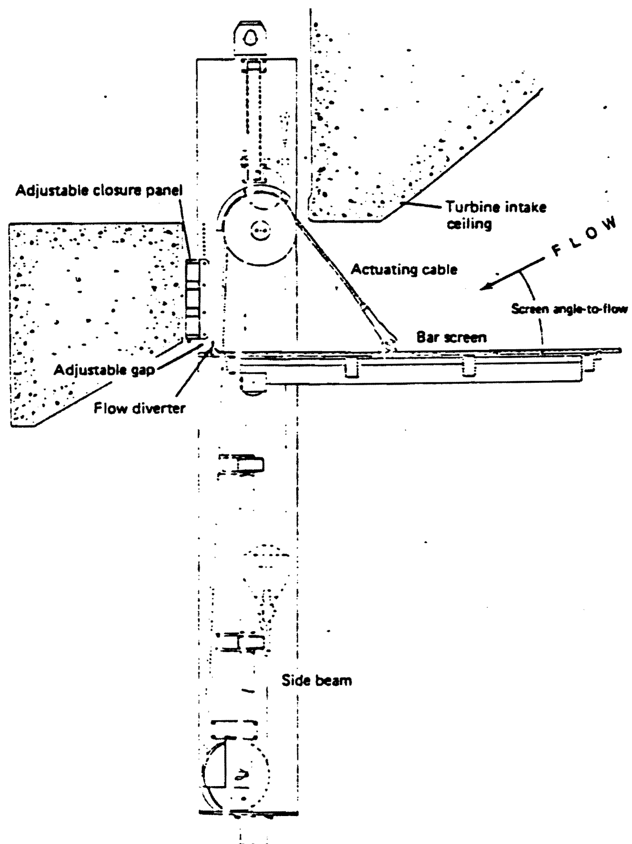
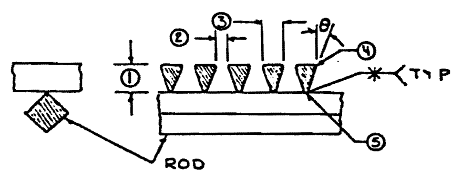


Figure 7.--Model II gatewell deflector tested at McNary Dam in 1979 shown in position 2/1 m (7 feet) below the intake ceiling. The device also could be set at 1.5 m (5 feet) below the intake ceiling.

Figure 5 shows the equipment used in 1979. Three sets of bar screens (one GD and one TD=a set) were used so that all three intakes serving a single turbine could be screened. Each of the sets of bar screens utilized panels constructed of Johnson screen wire to create different interspaces and porosities so that optimum interspace and porosities could be determined through field testing (Table 1). The support frames shown below the GD would not normally be required in an operational situation because they were only needed to support the fyke nets used for estimating the number of unguided fish. The Model II GD was designed to be operated at two elevations, 1.5 m (5.0 feet) and 2.1 m (7.0 feet) below the intake ceiling measured at the upstream side of the gatewell slot (Fig. 7).

Table 1.--Pertinent dimensions and porosites (percent open area) of bar screens tested at McNary Dam in 1979.



BAR SCREEN DETAIL

Screen panels	Dimensions mm (inches) 1	2	3	4	5	θ	IOD	% open area (porosity)
A	3.556 (0.140)	1.270 (0.050)	2.286 (0.090)	0.025 (0.010)	0.508 (0.020)	13°	12 7 ϕ (.50 ϕ)	35
B	4.623 (0.182)	2.108 (0.083)	1.905 (0.075)	0.025 (0.010)	0.508 (0.020)	7°	9.52x9.52 (.375x.375)	52
C	4.623 (0.182)	3.175 (0.125)	1.905 (0.075)	0.025 (0.010)	0.508 (0.020	7°	9.52x9.52 (.375x.375)	62

Experience indicated that some debris would wash off the screen rather than accumulate on the screen. Accordingly, we provided an opening or gap at the terminal end of the screen to allow the debris to pass. This, of course, also provided an escape route for fish.

To monitor the passage of fish and debris through the gap, we attached a "gap" net that strained the entire flow passing through the gap. A vertical adjustable panel was installed at the downstream end of the GD to vary the gap from 0 to 15.2 cm (0.5 foot). For some tests, we attached a small flow diverter just upstream from the opening. The purpose of the flow diverter was to reduce the escapement of fish without interfering with the passage of debris.

Methods and Procedures

To evaluate the fish-guiding device for use in turbine intakes, four basic factors were considered:

1. What percent of the fish passing through the turbine intake can the guiding device be expected to intercept (vertical distribution data)?

2. What percent of the intercepted fish are being guided [fish guiding efficiency (FGE)]?

3. Is the device capable of guiding the fish without causing serious injury or stress?

4. Can the device operate effectively with the expected debris loads?

The methods used for evaluating the bar screens at Bonneville and McNary Dams were similar. Because STS's were in use at McNary Dam, we were also able to obtain data for this fish-guiding method. Vertical distribution data (Appendix A) were used to determine the number of fish that could be expected to be intercepted by the bar screens and STS.

FGE for a particular test condition was computed with the formula: $N = \frac{100\ G}{n}$

N = FGE expressed as the percentage of the fish committed to the turbine intake that were intercepted and guided up into the gatewell.

n = The estimated number of fish committed to the turbine intake (the total of guided and unguided fish).

G = The number of fish guided into the gatewells.

To determine n, it was necessary to estimate the number of unguided fish. The fyke nets (Fig. 5) provided an estimate of the number of fish passing under the GD and the STS. Gap nets caught all of the fish escaping through the opening at the terminal end of the GD and the STS. The total number of unguided fish included the fyke net catches x 3 plus the gap net catch.

The guided fish were removed from the gatewell with a specially designed dipnet for enumeration and assessment of quality (Swan et al. 1979).

Procedures for conducting a typical fish-guiding efficiency test were as follows:

1. The turbine was shut down to stop the passage of water and fish through the intake.

2. The gatewell deflector frame with the fyke nets attached was installed in the intake.

3. All fish in the gatewell were removed with the dipnet and released.

4. The turbine was brought back into operation to begin a test.

5. The turbine was shut down to terminate a test.

6. The guided fish were removed from the gatewell by dipnetting and counted by species.

7. The GD and net frame were removed.

8. Fish were removed from all fyke nets and counted by species.

9. Fish were removed from the gap net and counted by species.

Test durations ranged from 6 to 24 h, some exclusively during the day and some exclusively during the night. Both the design and deployment of the bar screen were important in evaluating the principle for guiding fish. Some of the parameters that were examined included various guiding angles for the GD and TD; water velocities approaching the screens; screen porosity; wire interspace dimensions (between bars); a two-part system versus a one-part system (GD only); and the amount of intake flow intercepted [GD positioned 1.5 m (5.0 feet) or 2.1 m (7.0 feet) below intake ceiling].

In addition to determining FGE, we examined guided fish for signs of descaling and, at McNary Dam, measured swimming performance to determine if the fish were significantly fatigued. Fish guided by the bar screens and STS and fish that entered adjacent gatewells of their own volition (no guiding devices were present in the associated intake) were examined for descaling and swimming performance. A fish was classified as descaled if more than 10% of their scales were missing. The swimming performance tests were conducted with the use of a swimming stamina chamber (Thomas et al. 1964).

During tests conducted to assess the efficiency of backflushing as a method of cleaning the bar screens, debris was allowed to accumulate on the GD for a few hours to 7 days. To assess the extent of accumulated debris, the turbine was shut down, the GD removed, and either a picture was taken or a visual estimate was made of the accumulated debris. The GD was then lowered, backflushed for a few minutes, and removed again for comparative photographs or observations. Backflushing was accomplished by raising the leading edge of the GD to about a 40° to 50° angle above horizontal (approaching contact with the intake ceiling). A reverse flow through the bar screen occurred when the GD was in this position.

Results

Bonneville Dam

During the initial phase of the testing at Bonneville Dam, FGE's for the bar screen approached maximum expected values for some species. The FGE's for spring chinook and coho salmon fingerlings were as high as 70%. This indicated that nearly 100% of the intercepted fish were being successfully guided from the turbine intake (based upon vertical distribution data curves - Appendix A). It was also noted that the condition of these fish was not adversely affected. The descaling rate for fingerlings collected with the GD was not significantly greater than that for fish that entered gatewells volitionally.

Screen porosity tests conducted during this first phase of testing indicated that FGE was related to screen porosity. Test results showed that the FGE for spring chinook and coho salmon fingerlings dropped 28 and 22%, respectively, when the porosity of the GD was reduced from 35 to 0% (total occlusion). However, when the porosity was reduced from 65 to 35%, a reduction of similar magnitude did not occur. This implied that a screen porosity of something less than 35% was unacceptable. On the other hand, the 65% porosity screen could theoretically tolerate a 50% debris plugging before reduced FGE would occur.

The results of the tests at Bonneville Dam provided the basis for improving the design of the passive screening system and justified testing the improved system at McNary Dam.

McNary Dam

The tests at McNary Dam were directed toward evaluating the two-part bar screen by determining those parameters that would maximize FGE while maintaining low levels of stress or injury.

Bar Screen Porosity and Interspace.--Tests in 1978 with a 35% porous GD and TD showed that overlapping the devices by only 1.2 m (4.0 feet) (overlap defined in Fig. 6) caused a significant reduction in FGE indicating a severe disruption of flow. Tests in 1979 showed that screens having 52 and 62% porosity had consistently higher FGE's than those having a 35% porosity. In addition, the higher porosity GD and TD could be overlapped by as much as 1.5 m (5.0 feet) without a reduction in FGE.

Screens having an interspace of 3.2 mm (0.125 inch) gilled excessive numbers of lamprey ammocoetes. However, an interspace of 2.1 mm (0.083 inch) only caused gilling in intakes having the highest water velocities, and then primarily only at the terminal 0.6 m (2.0 feet) of the GD. An interspace of 1.3 mm (0.05 inch) (35% porosity) showed little evidence of gilling. We speculate that reducing the interspace of the 52% screen from 2.1 mm (0.083 inch) to 1.8 mm (0.07 inch) may eliminate gilling. By using the same wire size, porosity will be reduced only 4%; i.e., from 52 to 48%, and FGE will probably not be affected.

Bar Screen Deployment.--The size of fish to be guided influenced the deployment of the bar screen. For the purpose of discussion, we can divide the fish into two groups--those > 70 mm in length and those <70 mm in length.

For fish >70 mm in length, the following observations can be made:

1. Where the angle of the screen-face to flow (angle-to-flow) exceeded 45°, excessive impingement (at least 2%) was noted. At shallower angles-to-flow, the percentage of fish intercepted by the GD alone is significantly fewer than desired. Therefore, both the GD and TD are required to obtain FGE's equivalent to the STS at McNary Dam.

2. Escapement of fish through the 15.2 cm (0.5 feet) gap at the terminal end of the scoop was reduced to 3% or less (all species considered) by employing the flow diverter and by raising the GD to the upper elevation. Even closing the gap completely to eliminate escapement proved feasible in that FGE was not impaired, and the rate of accumulation of debris on the GD was not increased.

3. A significantly higher FGE occurred during daylight hours, as shown in Figure 8. Because the bar screen is located in an area of constant darkness, a visual response is unlikely. Apparently, however, the fingerling salmonids enter the turbine intake more surface oriented during daylight hours; and, therefore, a higher percentage are intercepted by the bar screen. In the biological evaluation of this type of system, it is important that the diel behavior of the fish be considered to obtain accurate and meaningful data.

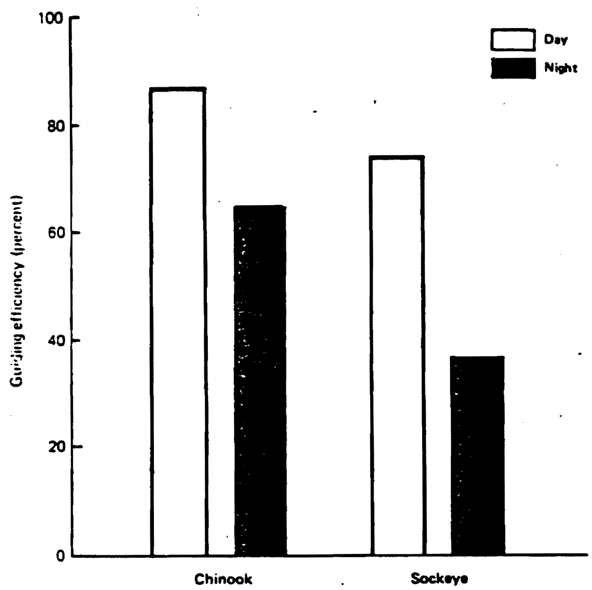


Figure 8.--A comparison of day and night fish guiding efficiencies for chinook and sockeye salmon fingerlings obtained with a passive screening system in a turbine intake at McNary Dam in 1978.

4. Best FGE was obtained when the GD (52% porosity) and TD (62% porosity) were used together with a 0.6 m (2.0 feet) overlap. At this setting, the angle-to-flow of both screens was estimated to be 30°. With this deployment, the FGE's for chinook salmon and steelhead were equal to that obtained with the STS. However, bar screens guided significantly fewer sockeye salmon than the STS (Fig. 9).

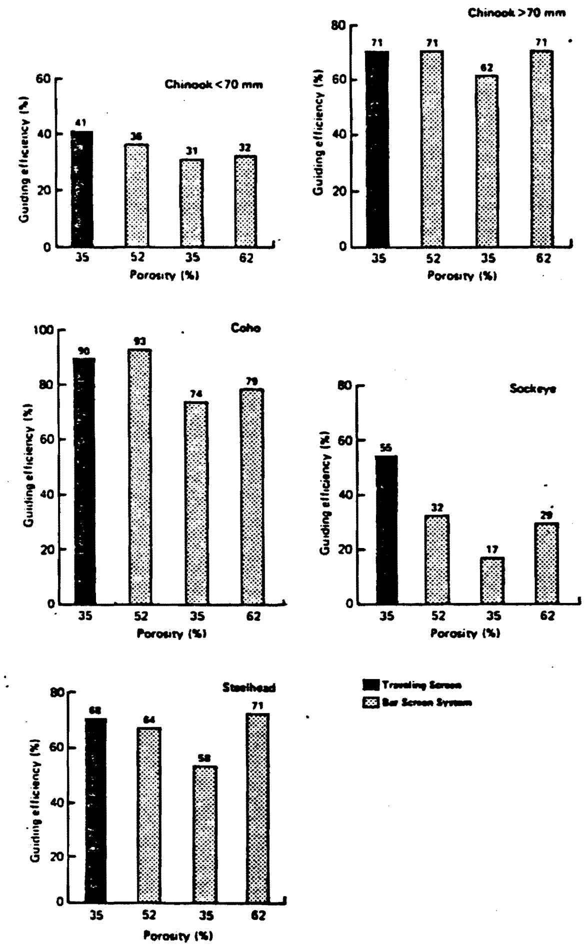


Figure 9--Comparison of fish-guiding efficiency obtained with the submersible traveling screen and the passive bar screens (McNary Dam, 1979).

5. Percent of descaled fish (all species) was low for both the bar screen and the STS, and it was not significantly higher than the percent of descaled fish entering gatewells volitionally.

6. Chinook salmon guided by either the bar screen or the STS were not significantly fatigued by comparison with chinook salmon entering gatewells volitionally.

For Fish <70 mm in length, impinging was a problem. Small chinook salmon fingerlings ranging from 35 to 70 mm in length were impinging on the GD in significant numbers during routine tests. The combination of guiding angle-to-flow and aproach velocities apparently required swimming speeds in excess of the capabilities of these small fish.

According to Greenland and Thomas (1972), fall chinook salmon ranging from 34 to 40 mm in length are capable of swimming 0.18 m/s (0.6 feet/s) for 9 minutes. In general, the wild fish entering the turbine intakes were about this size in early May, but as the season progressed, the average size of the fish increased.

A series of tests were initiated on June 5 with the objective to reduce or eliminate impingement by reducing the screen angle-to-flow and reducing approach veolcities (Table 2). Vector analysis was used to predict the required swimming speed for any combination of screen angle's and water velocities. As shown in Table 2, impingement was reduced or eliminated when required swimming speeds did not exceed 0.37 m/s (1.2 feet/s). Guiding angles of 30° and approach velocities as high as 0.7 m/s (2.3 feet/s) were successfully negotiated by the fish. Under this test condition, calculations show that the GD and TD together were straining about 19.82 m^3/s (700.0 $feet^3/s$) of water.

Table 2.--Observed impingement of fish <70 mm in length for various combinations of estimated water velocities and guiding angles for the McNary gatewell deflector - 1979.

Table 2. —Observed impingement of fish <70 mm in length for various combinations of estimated water velocities and guiding angles for the McNary gatewell deflector - 1979.

Test Series[A]	Date	Water Velocity Approaching the GD[B]		Guiding angle	Required swimming velocity[C]		Observed impingement
		(m/s)	(feet/s)	(degrees)	(m/s)	(feet/s)	(%)
1	5/5 to 6/10	0.94	3.1	30	0.49	1.6	19.0
2	6/5 to 6/10	0.61	2.0	30	0.30	1.0	6.0
3	6/5 to 6/10	0.67	2.2	30	0.34	1.1	1.0
4	6/13 to 6/16	0.94	3.1	30	0.49	1.6	5.0
5	6/13 to 6/16	0.61	2.0	20	0.21	0.7	0.0
6	6/13 to 6/16	0.67	2.2	30	0.34	1.1	1.0
7	6/19 to 6/20	0.70	2.3	30	0.37	1.2	0.0
8	6/19 to 6/20	0.46	1.5	30	0.21	0.7	0.0
9	6/19 to 6/20	0.52	1.7	30	0.27	0.9	0.0

A Each test in a series was replicated two to five times.

B Computed approach velocities based on ambient intake velocity and bar screen porosity.

C Swimming velocities given are calculated minimums required if fish are to avoid impingement.

<u>Backflushing of Bar Screens</u>.--For experimental purposes, the CofE gantry crane was used to backflush the GD's and TD's. We have been advised that implementing the backflush method of cleaning would be very expensive where numerous sets of bar screens are employed. For example, McNary Dam, with 14 turbines, would require 42 separate sets of screens.

During fish-guiding tests, debris accumulation on the face of the screen was negligible due to the relatively short duration of a test (24 h or less). Consequently, special long-term tests were conducted. These debris studies were designed to determine: (1) the length of time of continuous operation required to cause a serious accumulation of debris on the screens, and (2) the effectiveness of backflushing in eliminating the debris.

Figures 10 and 11 show the typical amount of debris accumulation after a 7-day period of operation and the amount of debris retained by the screen following a 10-min period of backflushing. Several 7-day tests were conducted; all yielded similar results.

Figure 10.--Accumulation of debris on bar screen after 7 days of continuous operation in turbine intake at McNary Dam. The bar screen was subsequently lowered into position and backflushed for 10 min (see Fig. 11).

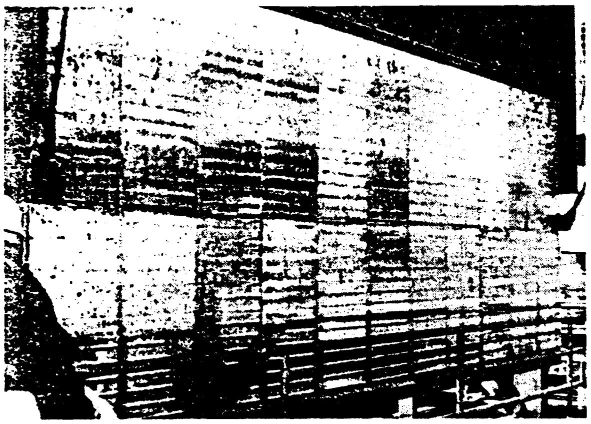


Figure 11.--A 10-minute period of backflushing removed virtually all of the 7-day accumulation of debris from the bar screen (see Fig. 10).

Obviously the rate of accumulation of debris on the screen depends upon the debris load in the river at the time. However, we estimate that a conservative backflush rate would be once every 24 h. Such a rate would maintain the bar screens in a nearly clean condition most of the time.

CONCLUSIONS AND RECOMMENDATIONS

The passive bar screen appears to be a viable method for guiding fish. With proper design and deployment, this method can be used to guide salmonids as small as 35 mm in length.

However, it is more limited in application than the STS. Whether the bar screen is suitable for use at a dam will depend upon: (1) the vertical distribution of the fish, (2) the minimum size of fish encountered, and (3) the ambient water velocities in the intake.

A method for intermittent cleaning of accumulated debris is a necessary component of a passive fish-guiding device. Because implementing the backflushing method is presently considered too costly, alternative methods should be considered, and the more promising of these evaluated under field conditions.

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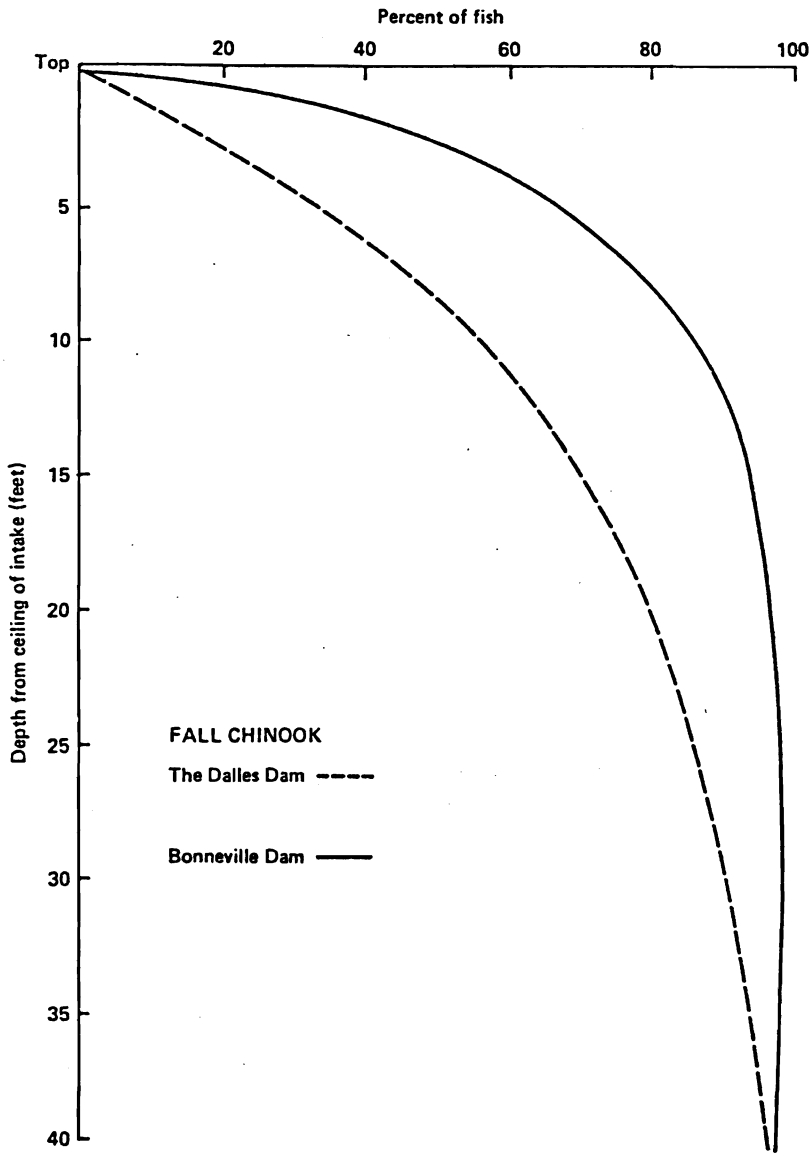
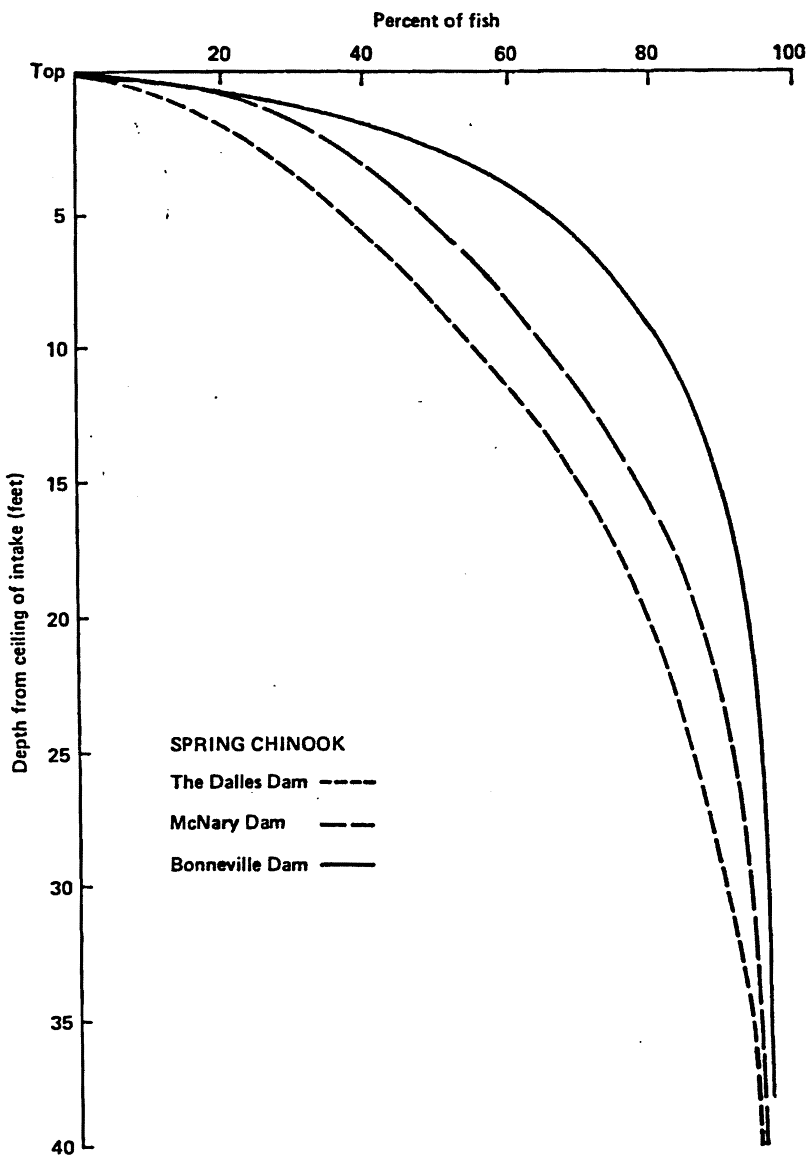
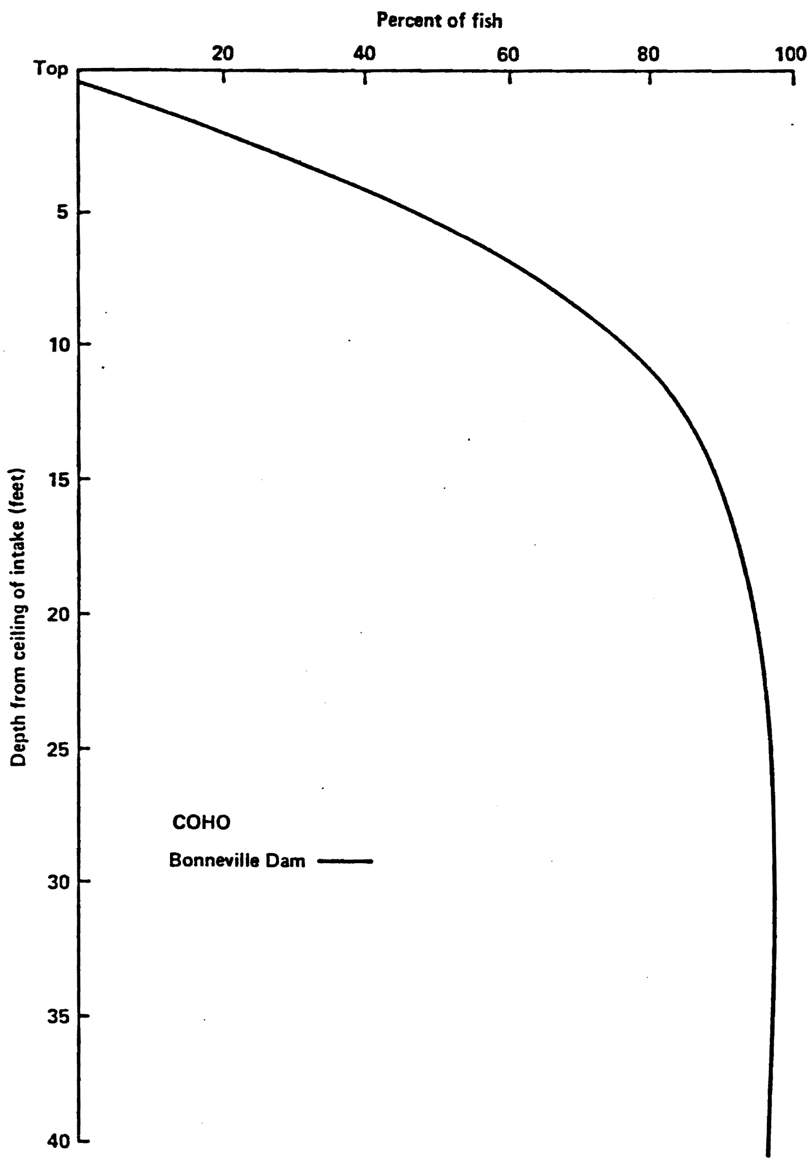
APPENDIX A



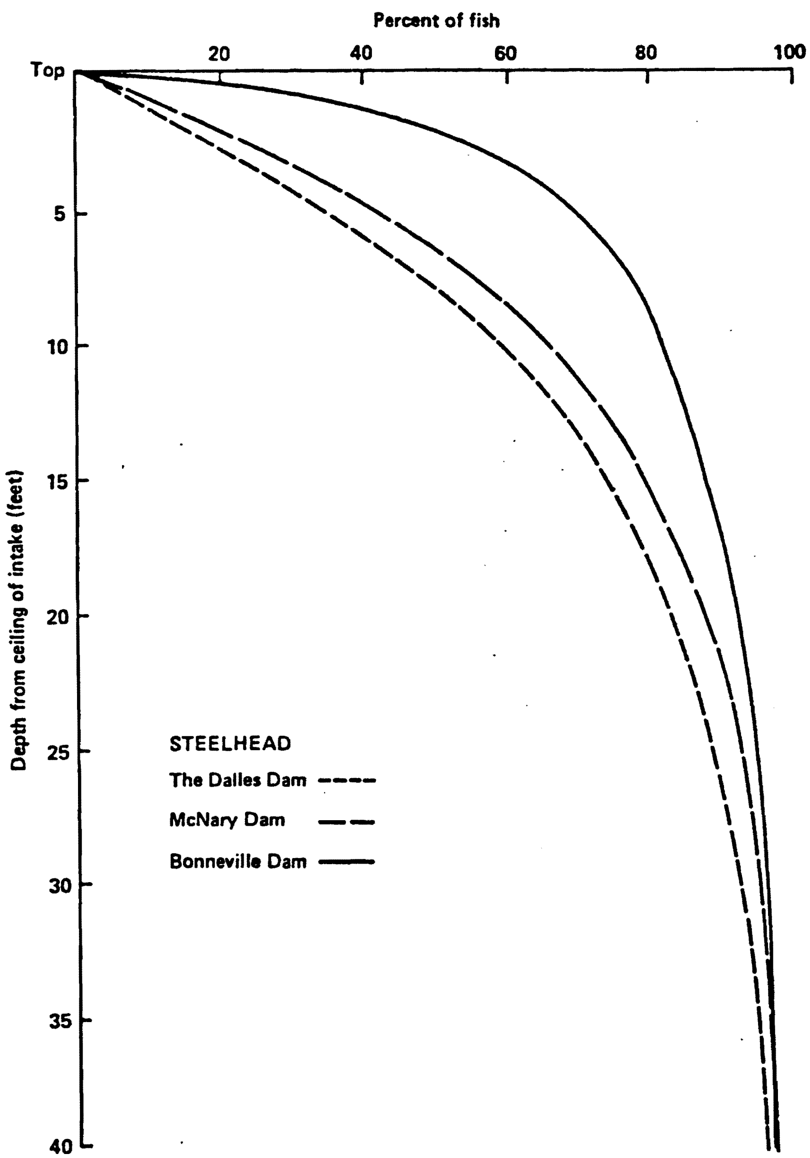
Vertical distribution of fall chinook salmon fingerlings in turbine intakes of Bonneville Dam (1975) and The Dalles Dam (1960).



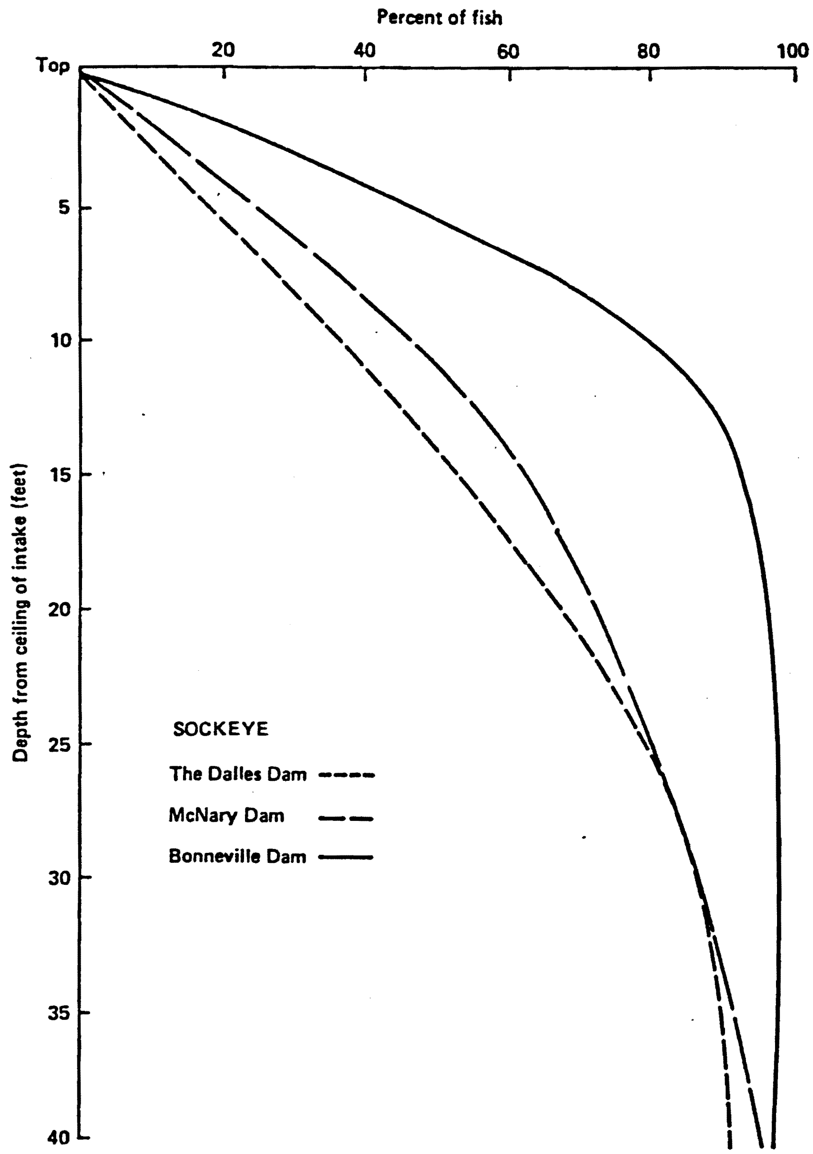
Vertical distribution of spring chinook salmon fingerlings in turbine intakes at Bonneville Dam (1975), The Dalles Dam (1960) and McNary Dam (1961).



Vertical distribution of coho salmon fingerlings in turbine intakes of Bonneville Dam (1975).



Vertical distribution of steelhead trout fingerlings in turbine intakes of Bonneville Dam (1975), The Dalles Dam (1960) and McNary Dam (1961).



Vertical distribution of sockeye salmon fingerlings in turbine intakes of Bonneville Dam (1975), The Dalles Dam (1960) and McNary Dam (1961).