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PROGRAM OF RESEARCH ON FINGERLING PASSAGE PROBLEMS  
ASSOCIATED WITH KAPLAN TURBINES, 1962 - 64

by

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## INTRODUCTION

Provisions for safe passage of fingerling salmonids at low-head dams on the Columbia and Snake Rivers may be required in the future, as higher percentages of the fish population are forced to pass through the Kaplan turbines of more and more river-run-projects. In 1961, the Bureau of Commercial Fisheries initiated a program of research leading to the development and application of methods for protecting these fish.

The status of research on the problem of fish passage through turbines has been reviewed by Lucas (1962) who points out that most of the research to date has been designed to assess the mortality rates occurring at various installations. Research by the U. S. Army Corps of Engineers has provided the most comprehensive examination of this problem (Cramer and Oligher, 1964). Their work has shown a correlation between fish mortality and general turbine design and operational characteristics. Maximum survival of fish in prototype Francis runners was associated with (a) relatively low runner speed, (b) high efficiency of the turbine, (c) relatively deep setting of the turbine below tailwater to minimize negative pressures, and (d) maximum clearances. Fish mortalities in model studies were similar for both Francis and Kaplan runners of 12-inch diameter when operated at similar net heads and normal speeds and at turbine settings as related to tailwater.

A majority of the low-head dams on the Columbia and Snake Rivers, however, are already constructed, and economic considerations preclude major design changes that involve runner speed or turbine settings in relation to tailwater. The adjustment of turbine operation to achieve maximum runner efficiencies and minimum fingerling mortalities will be increasingly difficult as greater demands for power require higher turbine loads. It is possible that positive steps to minimize fish mortalities beyond the adjustment of turbine operation will be necessary in order to safeguard future fish runs at these dams.

General approaches to the problem of providing fingerling salmonids with suitable protection at existing dams include (a) guiding fish into safe areas and (b) eliminating or nullifying lethal agents within turbines. Factors that can influence the economic feasibility of applying these protective methods include (1) the distribution and behavior of the fish within the massive water passages of the Kaplan turbines, (2) the relationship of fish distribution to lethal agents which fall in the general categories of mechanical clearances and pressure phenomena, and (3) the relative importance of each agent in terms of the mortality rates. These finite fish-turbine relationships exist only within each prototype installation involved in the problem and cannot be measured elsewhere.

To conduct research in prototype turbines, special equipment has been developed. These research tools and techniques are being used to determine

how, where, and to what extent fingerling salmonid mortalities occur within Kaplan turbines. The most economical and practical approach for protecting the young migrants will depend upon the answers to these and other basic questions. The nature of the equipment developed for this research program and the general characteristics of the Kaplan turbines are described in this report.

## KAPLAN TURBINES

The concept of the research program considers (1) the size and design of the turbines, (2) potentially dangerous areas, (3) the pattern of hydraulic flows through the water passages, and (4) fish behavior in relation to the structures.

### Design

Kaplan turbines and related water passages in low-head dams on the Columbia and Snake Rivers are similar in general design and conformation. Figure 1 is a schematic drawing that illustrates the major features of a Kaplan unit in plan view. Each turbine has three turbine intakes and two draft tubes. The intakes merge into a single scroll case which distributes the water around a 360° ring of wicket gates. Water flows through the scroll case, generally in a right-handed (clockwise) direction, although in some dams, such as The Dalles, they are left handed. The wicket gates, essentially butterfly valves that pivot on a vertical shaft located in the center of each gate, are used to regulate the amount of water passed by the turbine. These gates can be completely closed. The width of the opening between the gates determines the angle at which the water strikes the turbine blades. Stay vanes (fig. 1) are structural supports only.

Kaplan turbines have variable pitch propellers that are automatically synchronized to the opening of the wicket gates. In low-head dams on the Columbia and Snake Rivers, the Kaplan runners, or turbines, exceed 20 feet in diameter and are capable of passing a maximum of 12,000 c. f. s. or higher, depending upon the design of the turbine and the river conditions at the time.

A transverse cross section of a main unit of Ice Harbor Dam (fig. 2) illustrates the general size of the structures involved. Although the dimensions of each unit vary from dam to dam, all are equipped with trash racks that span the entire mouth of each intake. Intake gatewells are included in the design of each turbine intake. Large gates are lowered through these wells to close and seal the intakes so that the turbines can be unwatered for maintenance. Some dams have an ice and trash sluice that spans the entire length of the powerhouse at the surface of the forebay. These open flumes are designed to carry debris through the dam to the tailrace.

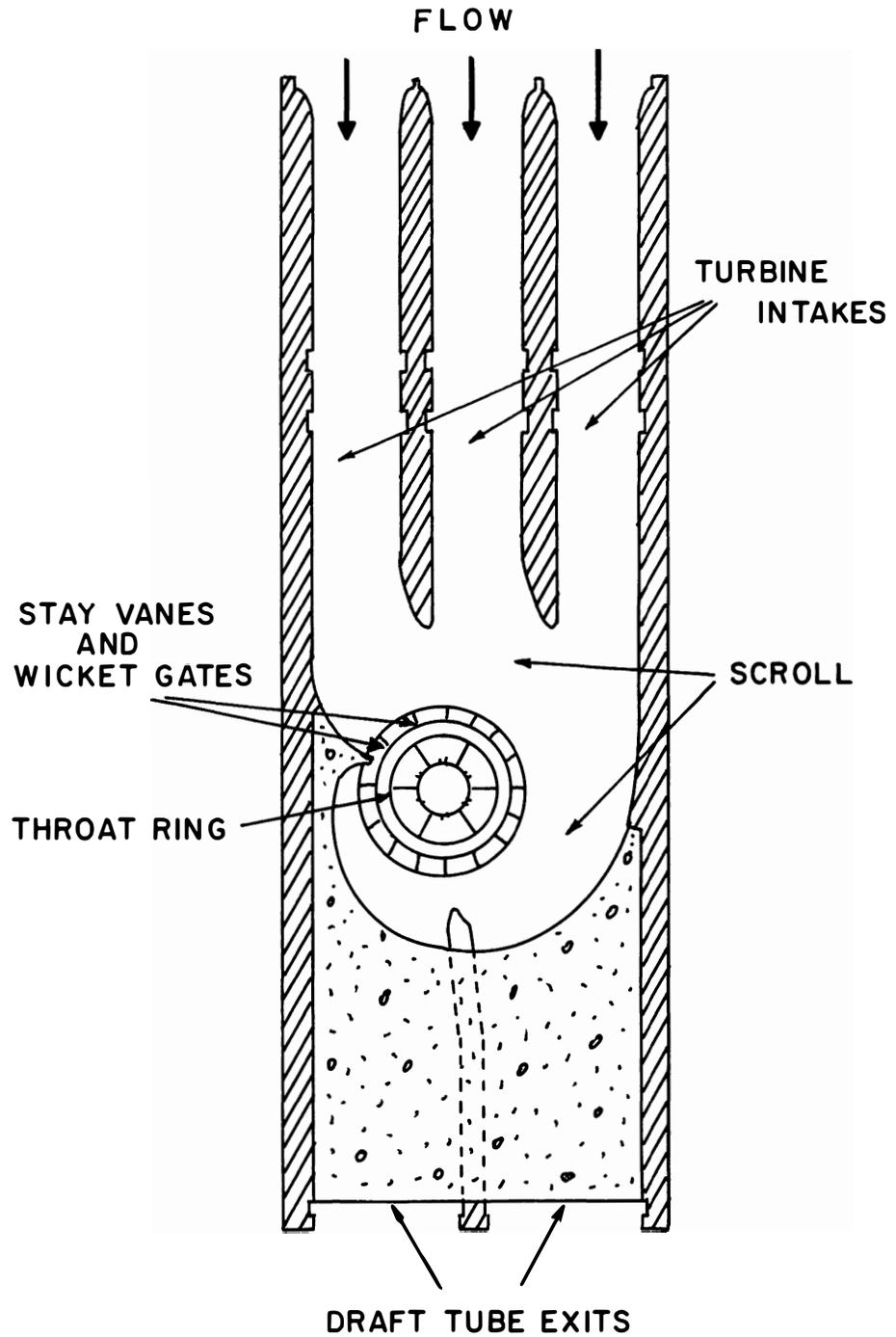


Figure 1.--Main unit of Ice Harbor Dam in plan view showing general conformation and major features.

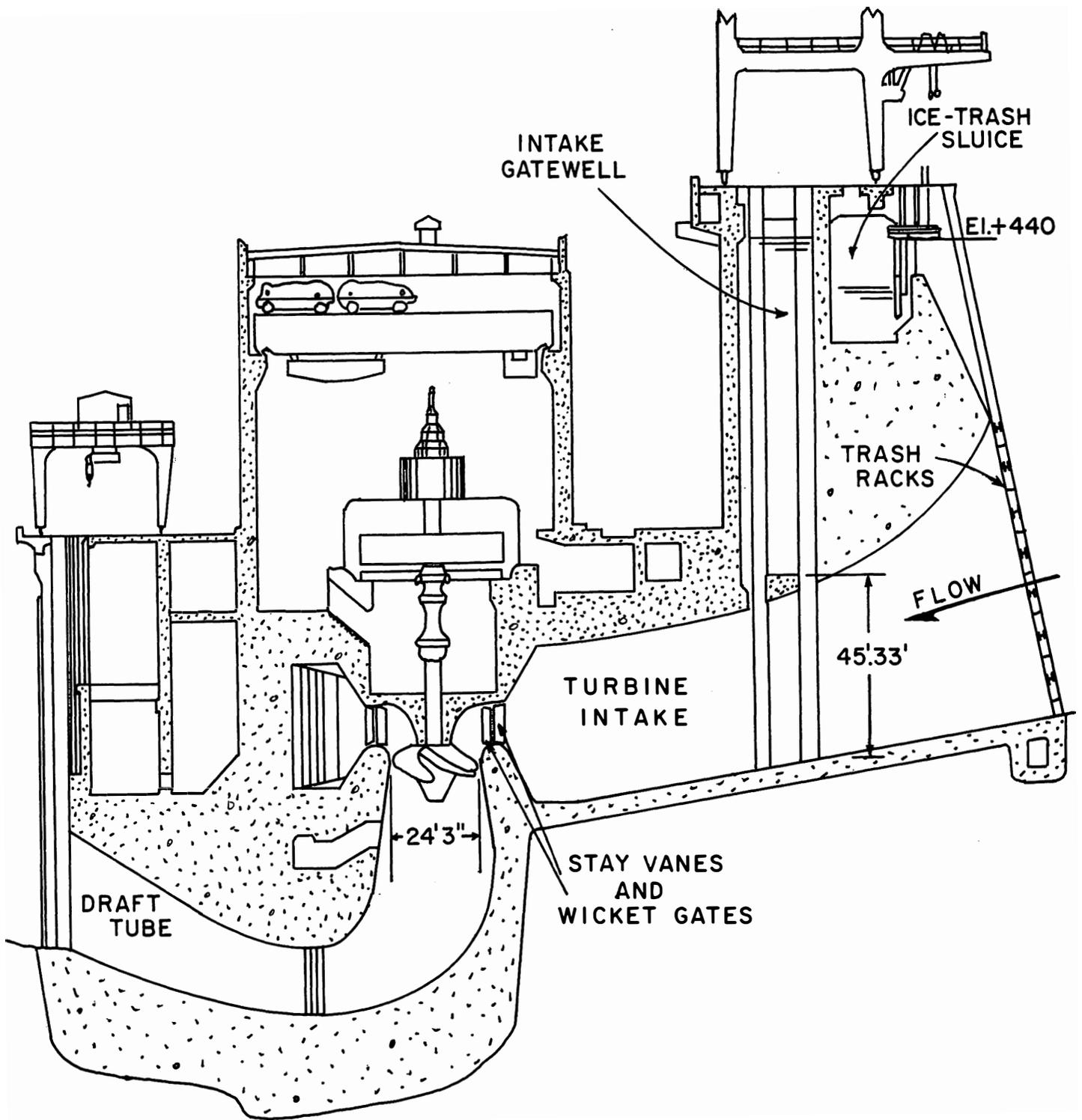


Figure 2.--Turbine at Ice Harbor Dam (elevation) showing general conformation and dimensions.

## Potentially Dangerous Areas

Mechanical injuries to fish passing through Kaplan turbines may be caused directly by turbine blades or by zones of minimal clearance. Injuries also may result from non-mechanical causes such as pressure changes, cavitation, and shear planes of water (turbulence). Knowledge of the location, operation, and design of mechanical features and of the location of nonmechanical phenomena, which may produce mortalities within turbines is important to the design of research experiments.

The leading edge of each blade is the most obvious mechanical feature within turbines that may cause injury to fish. The chance of a collision between a fish and the leading edge depends, among other things, upon the speed of the blade in relation to that of the water and the distance between the blades at the point of fish passage. The speed of the blade increases from the hub to the blade tips, as does the distance between the blades. The speed and the distance are influenced by the load or power output of the turbine. As the turbine discharge increases, the speed of the water in relation to that of the blade and the distance between the blades increase. The chance of a collision is influenced, therefore, by the operating load of the turbine, and by the location of the fish between the hub and blade tips.

A potential lethal area is in zones of minimal clearance. One zone is between the leading edge of the wicket gates and the trailing edge of the stationary or fixed stay vanes (fig. 3). However, this clearance is minimal only at discrete wicket-gate openings. Another zone of minimal clearance exists between the base of the blades and the hub of the runner (fig. 4). Such a zone occurs on both sides of a blade shaft that rotates to adjust the pitch of the blade. A similar area is formed between the blade tips and the throat ring (fig. 5). Dimensions of these clearances vary with the blade pitch and differ between dams.

The characteristics of design may determine the type of injury produced. For example, the Kaplan blades (fig. 6) designed for turbines at Bonneville Dam are approximately 1-3/4 inches thick on the leading edge and rounded. Injuries produced by this blade would not include cuts and sharply defined lacerations, but might cause bruises, abrasions, or possibly macerations. The blunt hydrofoil shape of the wicket gates may cause similar types of mechanical injuries. On the other hand, the zones of minimal clearance between the base of the blade and the hub and between the blade tips and the throat ring are characterized by sharp edges (fig. 4). At least some of the injuries produced at these points might be cuts and sharply defined lacerations. Injuries produced by each of these features may be similar, but each is associated with flows that are broadly separated.

Migrating fingerlings will experience a sharply defined pressure drop in Kaplan units, as in Francis turbines, as they pass through the runner. The degree of pressure change and its effect on fish mortalities depend upon the



Figure 3.--Zone of minimal clearance between stay vane (A) and wicket gate (B) at Bonneville Dam. Width depends upon wicket-gate setting or turbine load.

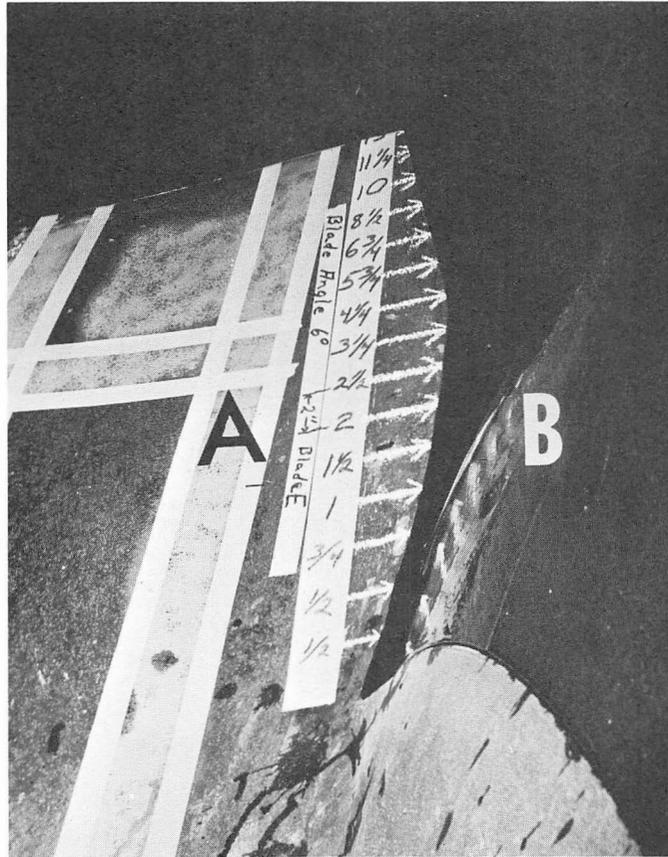


Figure 4.--Zone of minimal clearance at base of Kaplan blade (A) and hub (B) at Bonneville Dam showing clearance (in inches) at a blade angle of 6°.

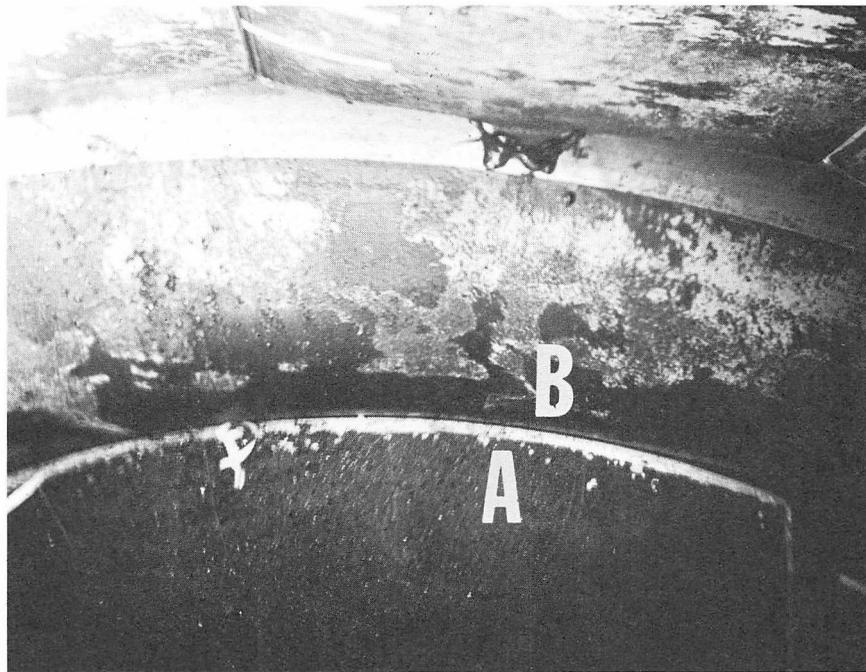


Figure 5.--Clearance between tip of Kaplan blade (A) and throat ring (B) at Ice Harbor.



Figure 6.--Kaplan blade designed for use in turbines of Bonneville Dam shows rounded conformation and thick leading edge.

operation of the turbine and the river conditions, but may be unusually severe in zones of minimal clearance.

Fingerling migrants may also experience mortalities from cavitation, a phenomenon that is related to pressure. Sharp (1940) discusses the production of cavitation in Kaplan runners and emphasizes the importance of design for improving efficiency of operation by reducing the production of cavitation. He points out that cavitation occurs at the hub and at the periphery of the blades before it occurs elsewhere, but this may vary depending upon design of the runner.

Turbulence at the runner varies with efficiency of turbine operation. The violence of shear planes required to produce injuries in fish, however, may be associated with specific areas, such as zones of minimal clearance or the trailing edge of turbine blades.

### Flows

Model studies have shown that flows in the turbine intakes, although somewhat turbulent, are generally predictable. Water near the ceiling of the intakes passes through the top of the wicket-gate openings, while flows near the bottom of the intakes pass through the bottom of the wicket-gate openings (fig. 7). This information suggests that flows near the ceiling of the intake may pass in the vicinity of the hub of the runner, while flows near the bottom may pass by the tips of the blades.

Flows at the draft-tube exits, however, are unbalanced. At Bonneville Dam, for example, the south draft tube of each pair passes more water than does the north. In addition, velocities measured in each exit vary with location, ranging from a high of 12.3 to a low of 1.7 feet per second at a turbine discharge of about 13,000 cubic feet per second (fig. 8).

### Fish Behavior

Present knowledge of fish distribution indicates that a majority of salmonid fingerlings 1 year of age or older and about 50 percent of the fish of the year are concentrated within 15 feet of the intake ceiling over a 24-hour period. These fish may associate with intake water flows and travel predictable paths through the turbine. If this occurs, the relative importance of lethal zones and the segments of fish populations that pass through them can be determined. Once defined, it may be possible to divert the endangered segment of the fish run away from hazardous areas more economically than to protect the entire population.

Data on fish passage indicate that most fingerlings over a year old migrate through turbines between 7 p. m. and 7 a. m. (85 to 95 percent). Passage of 0-year salmonids is more evenly distributed between these two time periods (66 percent at night and 34 percent during the day). The timing of fish passage in relation to the power demand schedule is important if consideration is given to controlling turbine operations to reduce mortalities.

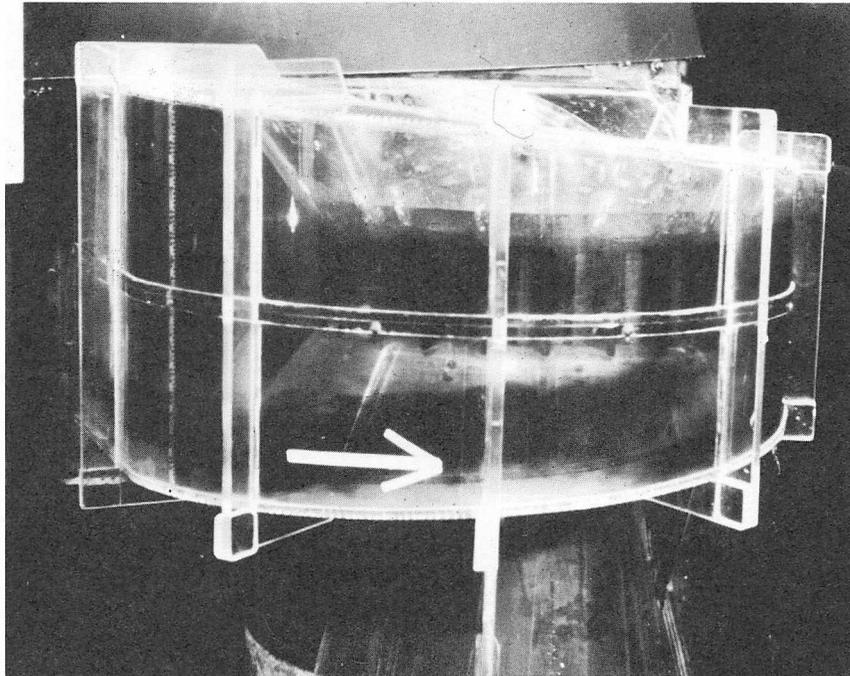


Figure 7.--Predictability of flow patterns shown by dye studies in model of Dalles Dam scroll case. Dye introduced near bottom followed the floor and passed near bottom of wicket gates (simulated flow, 16,000 c.f.s.).

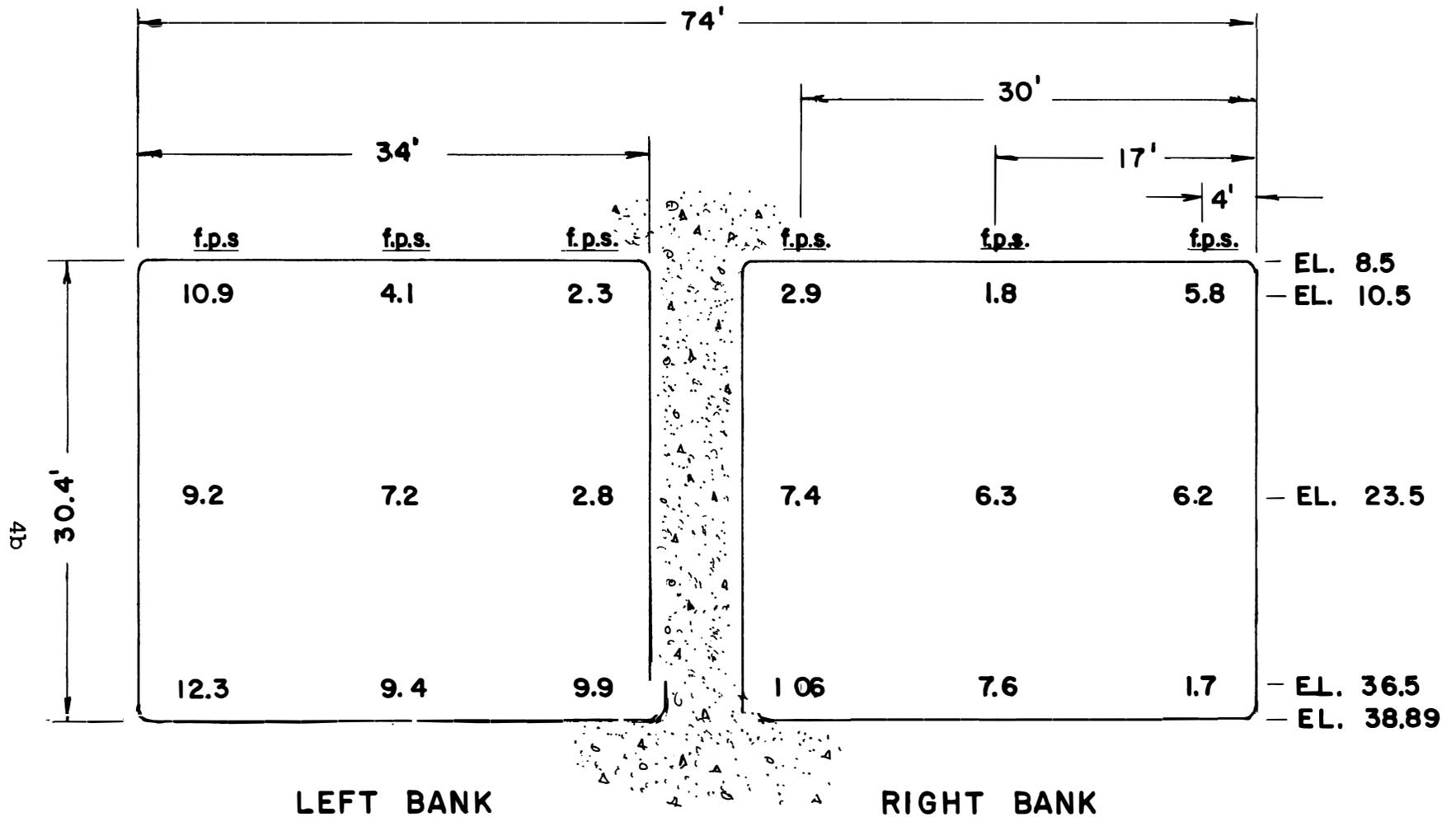


Figure 8.--Velocity profile at exit of divided draft tube (looking downstream) at Bonneville Dam--turbine discharge of about 13,000 c.f.s.

## RESEARCH EQUIPMENT AND TECHNIQUES

Equipment developed for research in prototype Kaplan turbines was designed to (1) measure the distribution of fingerling salmonids within the turbine intakes; (2) release marked fish at specific locations upstream and downstream of the turbines; (3) recover, in the tailrace, fish that pass through the turbines; (4) measure the production of phenomena, such as cavitation, occurring within the turbines; and (5) separate and transfer large groups of fish quickly with a minimum stress. These tools and techniques are briefly described in this section.

### Intake Frame

The intake frame is a basic tool that can be used to install a variety of research equipment into the turbine intakes (fig. 9). This frame was used at The Dalles and McNary Dams to measure the vertical distribution of native fingerlings as they entered and passed through the turbine intakes.

### Fish-Release Capsules

Fish-release capsules (fig. 10) provide a means for releasing several groups of fish simultaneously at specific locations within turbine intakes or draft tubes. Figure 11 illustrates how several capsules might be deployed from an intake frame to release groups of fish at different depths in a turbine intake. This tool is designed to hold 100 or more yearling salmonids and is opened by remote control by activating a solenoid release mechanism.

### Fish Recovery Equipment

A funnel net and sanctuary barge (fig. 12) were developed to strain the entire discharge of a draft tube to collect fish passing through a turbine. The recovery of injured and uninjured fish provides data for interpreting the effect of turbines on migrating fingerlings. The net guides fish from the draft-tube exit, through the cod end, into a sanctuary downstream where they are diverted into a trap over an inclined-plane screen.

### Cavitation Monitoring Equipment

Electronic and acoustic equipment has been installed in turbine number 9 at Bonneville Dam to detect and analyze noise produced within the turbine. Information gathered with this equipment during fingerling mortality studies will be carefully analyzed to determine if cavitation production is correlated with fish mortality.

### Fish Handling Techniques

Special methods were developed for quickly and efficiently separating and transferring fish with a minimum of stress. These include a siphon system



Figure 9.--Intake frame used to examine fish distribution and for suspending research equipment in turbine intake. Frame here is being lowered through gateway into intake.

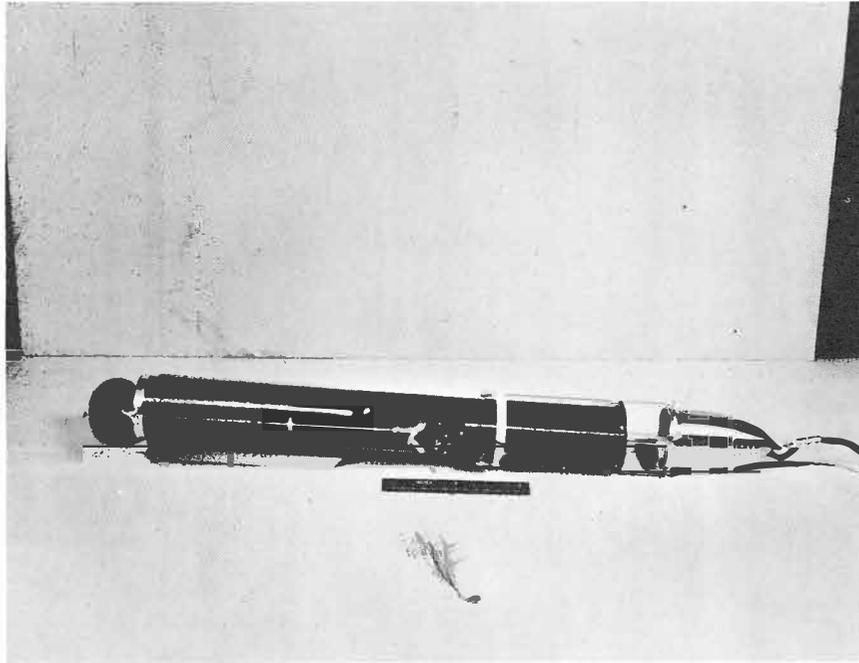


Figure 10.--Fish-release capsule designed to hold 100 or more yearling salmonid fingerlings. Capsules can be placed at discrete depths upstream or downstream of turbines and fish released by remote control.

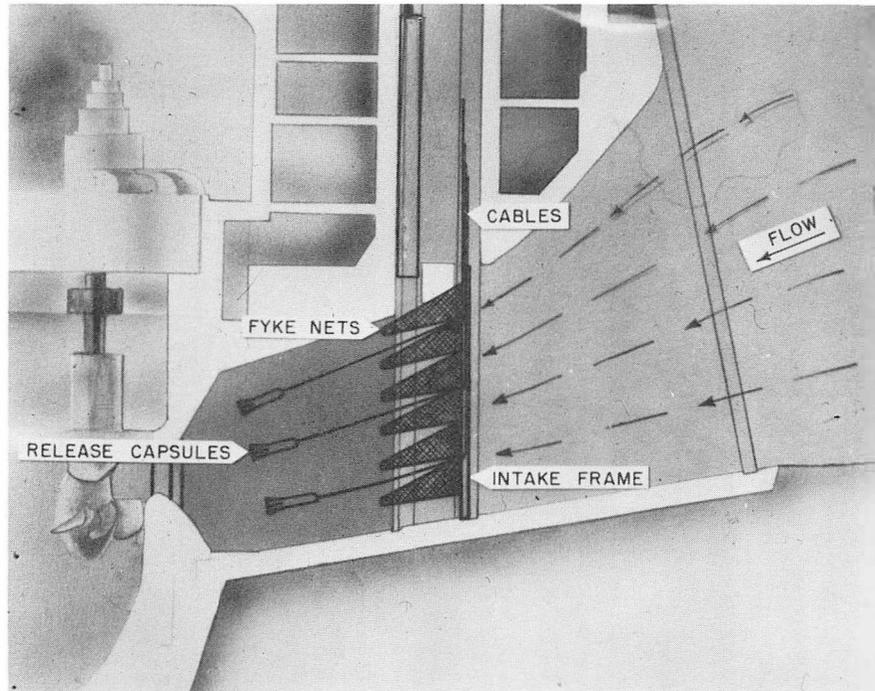


Figure 11.--Fish-release capsules (schematic) deployed from intake frame upstream of turbine to release fish at specific depths.

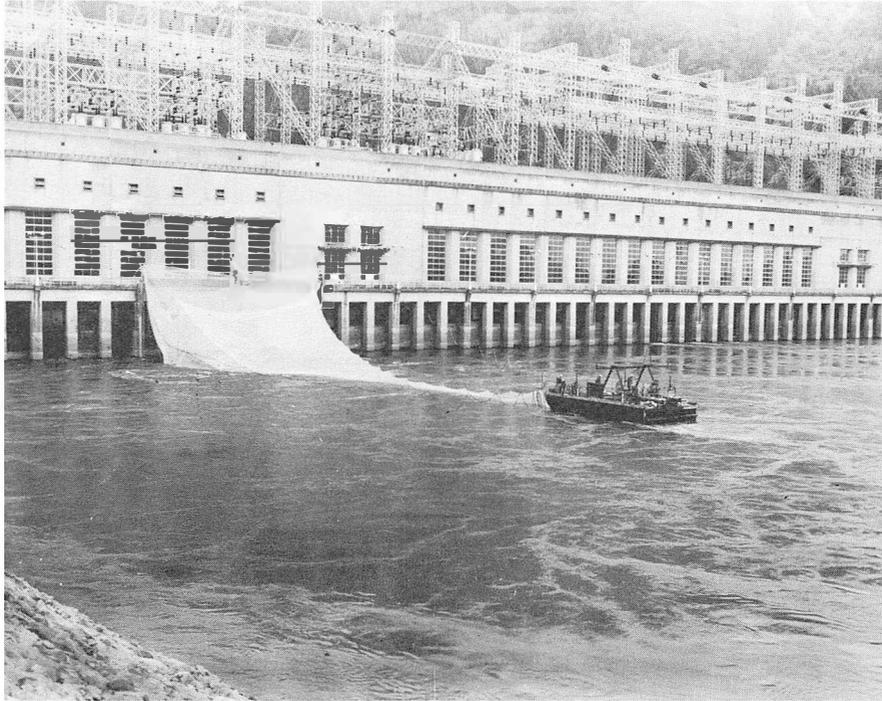


Figure 12.--Recovery net and sanctuary barge used to recover fish passed through a turbine.

(fig. 13) to separate fish into small groups and specially designed holding pens (fig. 14) for transporting fish. Each pen, when removed from the water, retains both fish and a small amount of water, which are released by removing a rubber stopper from a funnel-shaped bottom. With this handling technique, individual fish are removed from the water only for marking or inspection.

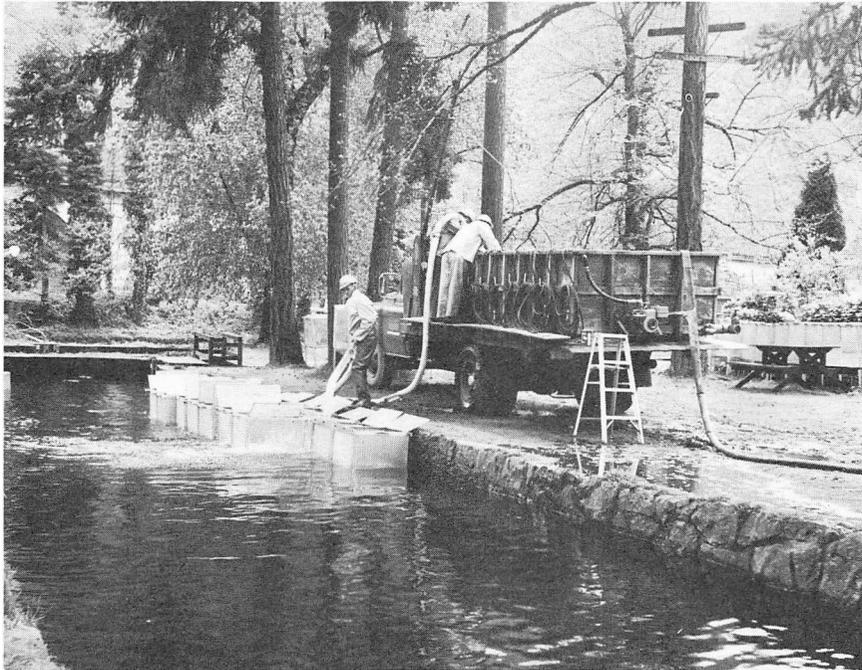


Figure 13.--Siphon system used to randomly separate fish at a controlled rate for turbine experiments.

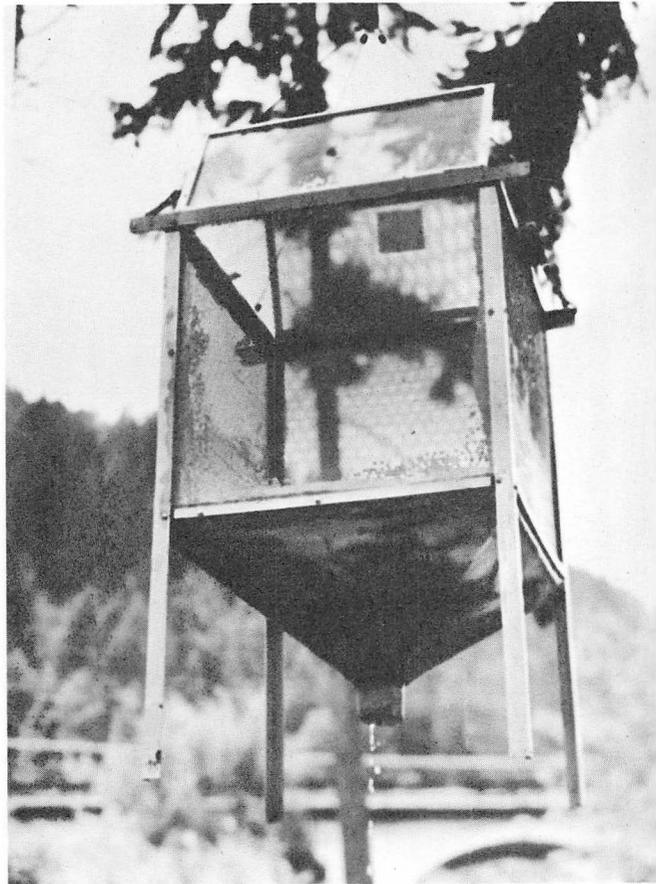


Figure 14.--Transport and holding pens are constructed of perforated aluminum plate with a nonperforated funnel bottom that retains water and fish when pen is removed from pond.

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