VELOCITY MEASUREMENTS AT SIX FISH SCREENING FACILITIES IN THE YAKIMA RIVER BASIN

SUMMER 1988

Annual Report

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PREFACE

The Bonneville Power Administration (BPA), the United States Bureau of Reclamation (USBR), and the Washington State Department of Ecology (WDOE) are funding the construction and evaluation of fish passage facilities and fish protection facilities at irrigation and hydroelectric diversions in the Yakima River Basin, Washington State. This construction implements Section 803 (d) of the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program (NPPC 1987). The program provides offsite enhancement to compensate for fish and wildlife losses caused by hydroelectric development throughout the Columbia River Basin, and addresses natural propagation of salmon to help mitigate the impact of irrigation in the Yakima River Basin.

The Columbia, Richland, Westside Ditch, Sunnyside, Wapato, and Roza Screens are six of the juvenile screening facilities. This report evaluates the flow characteristics of the screening facilities. Studies consisted of velocity measurements taken in front of the rotary drum screens and within the fish bypass systems during peak flows. Measurements of approach velocity and sweep velocity were emphasized in these studies; however, vertical velocity was also measured. Results indicate that velocity patterns within the screening facilities often exceed design specifications, but are generally conducive to effective fish bypass.

ACKNOWLEDGMENTS

The involvement and cooperation of many people during these studies were greatly appreciated. Thomas J. Clune of the Bonneville Power Administration was the Project Manager. Robert Pearce of the National Marine Fisheries Service (NMFS) and Ken Bates of the Washington Department of Fisheries reviewed the plans for measuring velocities. Chuck Keller of the Bureau of Reclamation and his operations and maintenance staffs provided critical support and assistance during site preparation and data collection. Alvin L. Jensen (NMFS) provided the instrumentation used in our studies. The manuscript was reviewed by Susan A. Kreml, Wallace H. Walters, and Dennis D. Dauble.

ABSTRACT

We measured the velocity conditions at six fish screening facilities in the Yakima River Basin: the Columbia, Richland, Westside Ditch, Sunnyside, Wapato, and Roza screens. Approach, sweep, and vertical velocity measurements were taken in front of the rotary drum screens using bidirectional electromagnetic instruments. Velocities were also measured at the entrance of fish bypasses, in front of traveling belt screens in separation chambers, and in the entrance to the fish return.

Approach velocities at the Columbia Screens exceeded design specifications under peak canal flow conditions. Discharge through each of the drum screens was comparable. Stoplog configuration did not adversely affect approach velocity at the face of the drum screens.

Approach velocities at the Richland Screens generally met design specifications; however, low sweep-to-approach velocity ratios occurred at the first drum screen. The canal was not operating at peak canal flow. Velocities under the curvature of the drum screens were similar to velocities in front of the drum screens. Discharge through the drum screens appeared to be equal; however, fish return discharge was greater than described in the design specifications.

Velocities at the Westside Ditch Screens met design criteria, except in front of the most upstream screen. Discharge through the drum screens was not identical. The close proximity of the outer wall to the last drum screen did not adversely affect performance at that screen. Fish return discharge was low because of a

stoplogging error; however, adequate fish return discharge is easily achievable.

Approach velocities at the Sunnyside Screens exceeded design specifications during peak canal flow. The intermediate wing wall disrupted the sweep velocity. Sweep velocities in the head end of the intermediate and terminal bypasses indicated that discharges were not identical. Velocities were not uniform in the separation chamber, and approach velocity exceeded design specifications in some areas on the face of traveling screens.

Approach velocity at the Wapato Screens exceeded design specifications in front of the rotary drum screens during peak canal flow. Flow through the three fish bypasses were not equal, with more flow passing through the terminal bypass. Reverse sweep velocities occurred in the upstream end of the fish separation chamber. Unequal discharge through the two traveling belt screens caused excessive approach velocities at the face of one of the screens. Total discharge in the fish return was adequate; however, most of the water entered the fish return from the bottom.

Approach velocity at the Roza Screens during peak canal flow often exceeded design specifications. Additionally, low sweep velocities in the screen forebay resulted in a sweep-to-approach ratio that was less than desirable. Approach velocity exceeded design specifications in front of the traveling belt screens in the separation chamber. Discharge in the fish return was adequate, with water entering equally from the surface and the bottom.

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INTRODUCTION

The Pacific Northwest Electric Power Planning and Conservation Act (Public Law 96-501) was passed to enable preparation and implementation of a regional Conservation and Electric Power Plan. The Northwest Power Planning Council administers the plan, and is charged with developing a program to protect and enhance fish and wildlife populations and to mitigate adverse effects from development, operation, and management of hydroelectric facilities.

The Yakima River Basin was selected as one site for enhancement of salmon (Oncorhynchus spp.) and steelhead (Salmo gairdneri) runs. Under the Plan, the Bonneville Power Administration (BPA), the Bureau of Reclamation (USBR), and the Washington State Department of Ecology (WDOE) are funding the construction of fish passage and protection facilities at irrigation and hydroelectric diversions in the Yakima River Basin (Figure 1).

The improvement of fish screening facilities in irrigation canals is a major component in the overall fisheries enhancement program. Hydrologists and biologists from various agencies, including the National Marine Fisheries Service (NMFS), the Washington Department of Fisheries (WDF), and the Yakima Indian Nation (YIN), provided input for the design of the new facilities. The angled rotary drum screen design was chosen as the best alternative for fish screening in irrigation canals.

The BR and NMFS built scale models (1:10) of some of the proposed facilities to evaluate velocity parameters before the actual construction of the facilities began. The Sunnyside Fish Screening Facility, the first of the new fish screening facilities in the Yakima Basin, began operation in 1985.

Pacific Northwest Laboratory (PNL) conducted fisheries evaluations at five of the new fish screening facilities from 1985 through 1988 (Neitzel et al. 1985, 1986, 1987). The scope of the studies included the quantification of injury and mortality, predation, and passage effectiveness for emigrating salmonids; however, it did not include evaluation of hydraulic characteristics within the screening facilities. The hydraulic conditions in front of the drum screens as well as within components of the fish guidance system (fish bypasses, separation chamber, and fish return slot) are critical in providing optimal conditions for safe fish bypass. The screens were designed to provide an approach velocity (perpendicular to the screens) of 0.5 feet per second (fps) or less to minimize impingement of fish, and a sweep velocity (parallel to the screen face) of at least twice the magnitude of the approach velocity to guide fish into the bypass system (Easterbrooks 1984).

Inadequate sweep velocities, excessive approach velocities, or unequal discharges through the drum screens and fish bypass system have been observed at several of the screening facilities during our fisheries evaluations. These flow pattern anomalies can affect the overall efficiency of a facility. The objective of these hydraulic studies was to monitor the actual velocity characteristics at selected facilities during normal operation, as defined by the operating criteria for each facility.

This report describes the measurement studies conducted by PNL staff at the Columbia, Richland, Westside Ditch, Sunnyside, Wapato, and Roza screens in 1988. The report describes the equipment and methods used to measure the hydraulic characteristics and the operating conditions at each facility during data collection, and summarizes the results. The similarities and differences among sites are discussed.

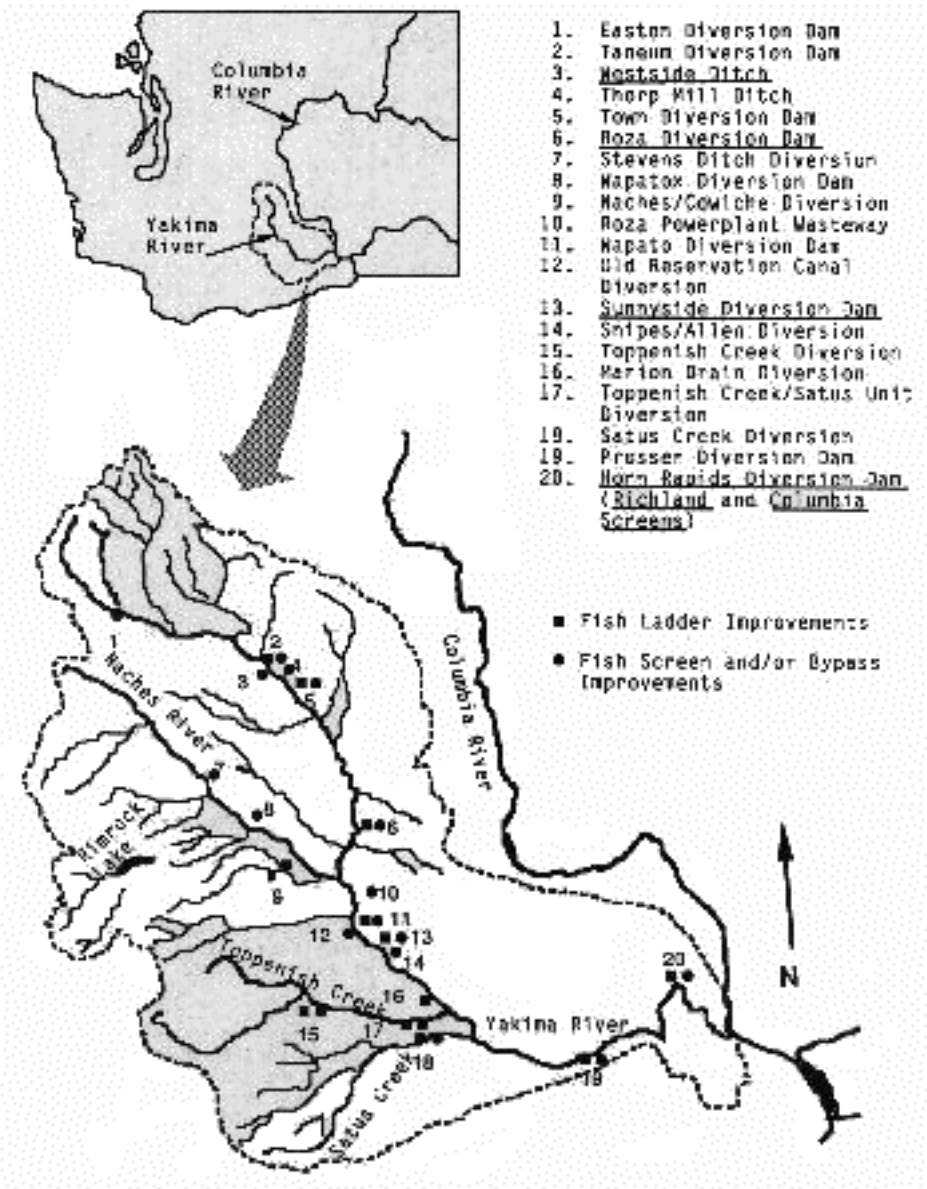

Figure 1. Yakima River Basin Fish Screening Facilities and Other Fish Protection and Passage Facilities

METHODS

Two monitoring protocols were used in our data collection. Partial surveys, in which measurements were taken only at 0.2 and 0.8 of the water depth [Z; hereinafter referred to as "of water depth" or 0.2 (e.g.) depth], were conducted at the Columbia, Westside Ditch, Sunnyside, and Roza screens. Additional measurements were taken to address specific concerns at these four sites. Complete surveys, which included additional measurements at 0.05, 0.5, 0.8, and 0.9 of the water depth (Figure 2), were conducted at the Richland and Wapato screens. Velocity measurements were taken in front of the rotary drum screens, in the separation chamber (if applicable), and in the fish return. Velocity parameters were simultaneously measured in the X (approach), Y (sweep), and Z (vertical) axes.

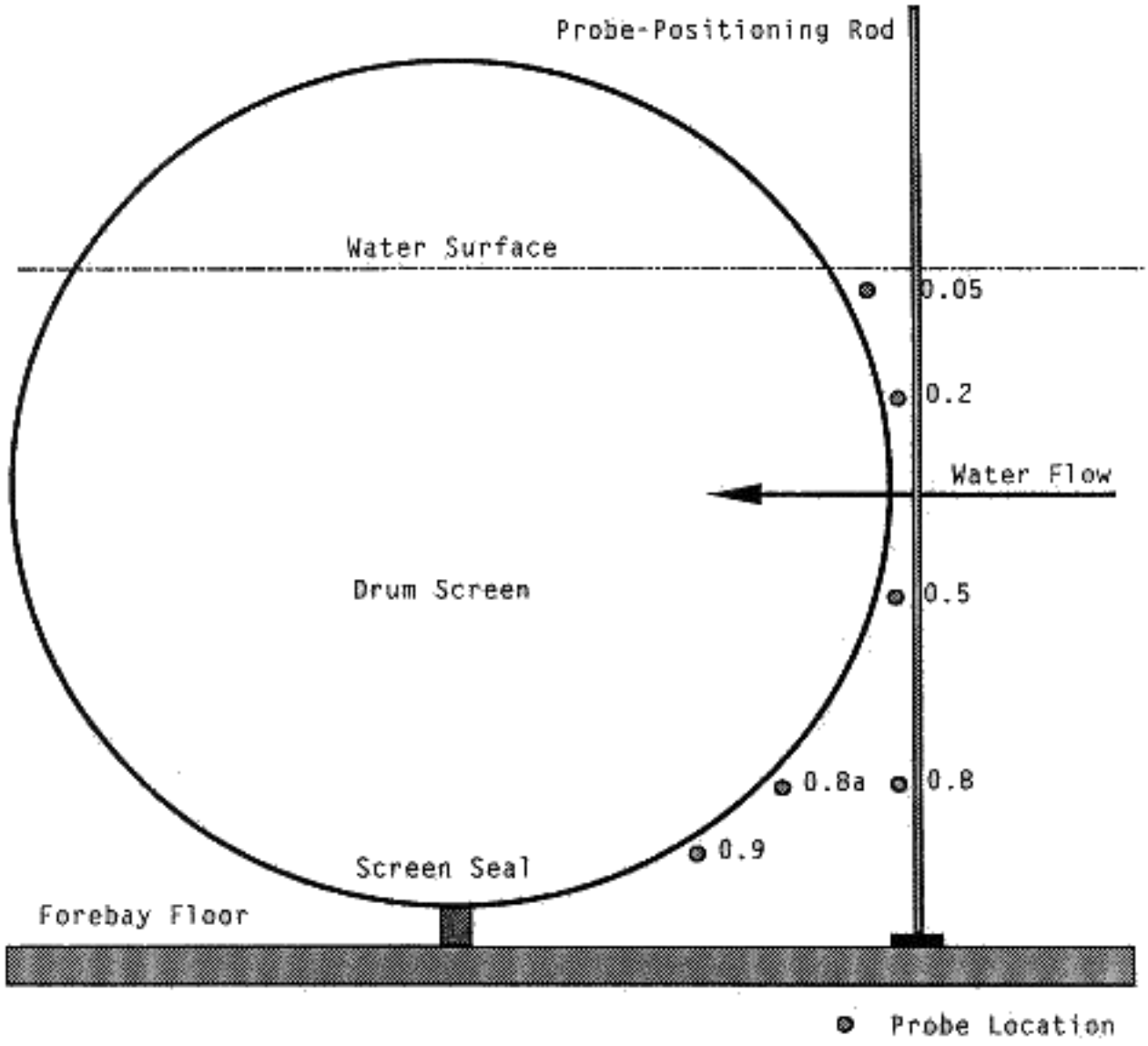

Figure 2. Measurement Depths and Probe Positioning Relative to the Front Face of Rotary Drum Screens in Complete Surveys

EQUIPMENT

Four electromagnetic water current meters were used to monitor water velocities. Each meter utilized a bidirectional probe (Figure 3). Probes were mounted in pairs so that one measured the X and Y and the other measured the Y and Z velocity components at a given depth. Measurements were made at two depths simultaneously. Outputs were read visually from the panel gauges.

The meter probes were securely fastened to a horizontal arm that extended from a movable sleeve secured to a vertical pole. The length of the horizontal arm and the position of the sleeve on the vertical pole were adjustable. The probe support assembly was positioned at least 18 in. downstream or outside of the sensors so that the vertical pole and horizontal bracket arm would not disrupt velocity readings at the probes (Figure 4).

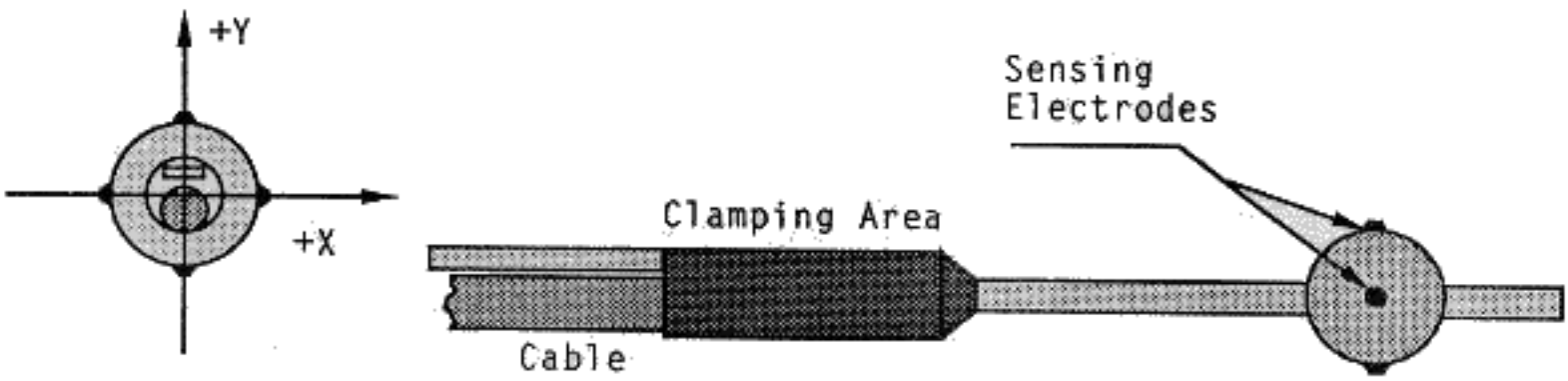

Figure 3. Bidirectional Electromagnetic Probes Used in Velocity Measurements

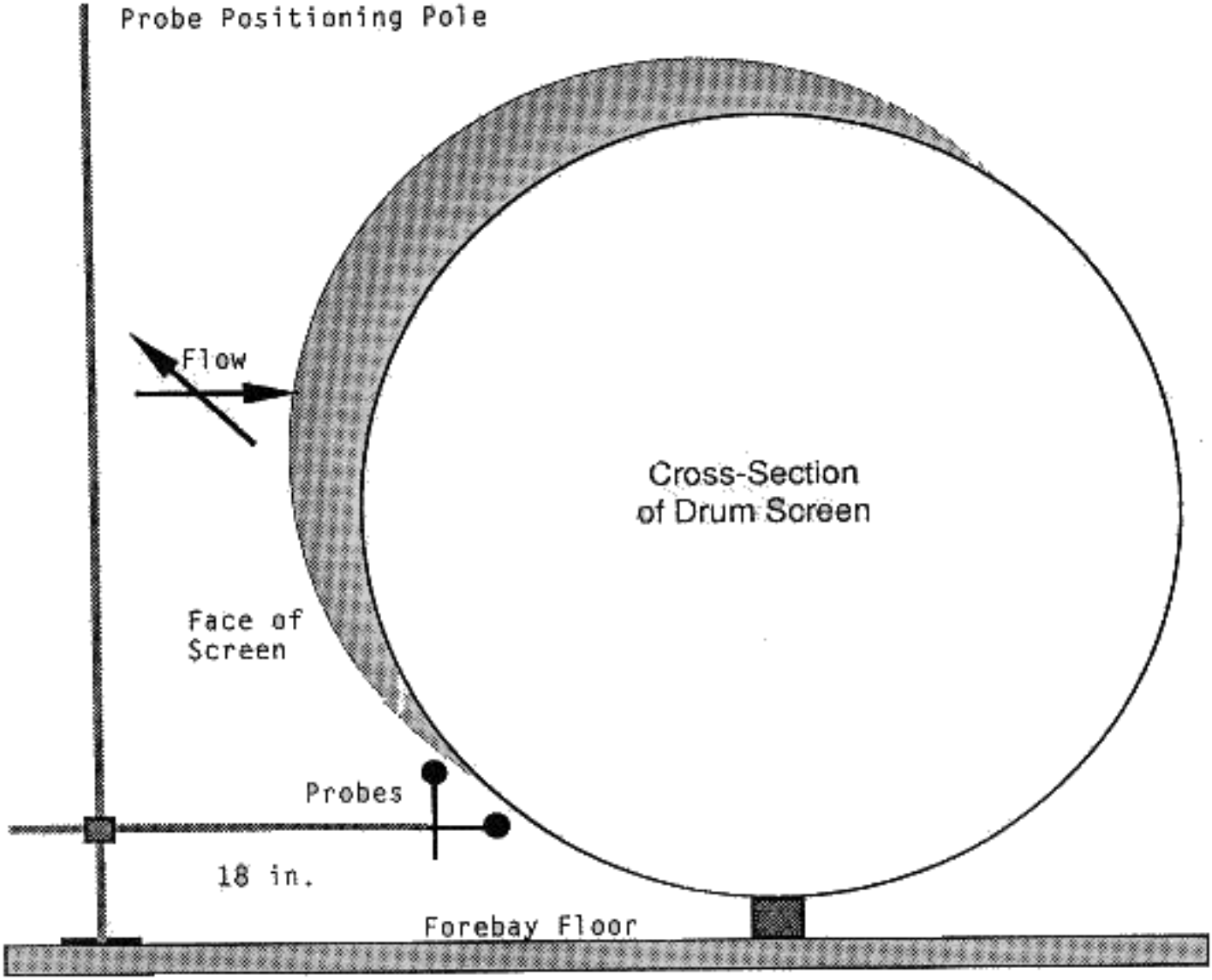

Figure 4. Relationship of Probe Support Assembly to Probes During Velocity Measurements

PROBE POSITIONING

Drum Screens

The vertical pole was positioned close to the perimeter of the screen; however, none of the components of the probe assembly was in contact with the screen face. The bottom of the pole rested on the forebay floor, and the top end of the pole was clamped to a fixed object such as the gantry frame or a girder. Measurements at 0.2, 0.5, and 0.8 of water depth were taken by mounting the probes on a horizontal arm pointing upstream, and measurements near the screen face at 0.05, 0.8, and 0.9 of water depth were taken by mounting the probes on a horizontal arm pointed inward toward the face of the screen. The length of the horizontal arm required to position the probes close to the screen face was calculated based on screen diameter, water depth, and the position of the vertical pole relative to the perimeter of the screen. The set of probes was generally within 4 to 6 in. of the screen face for the near-screen measurements. The drum screens are constructed at an angle to the canal flow; therefore, all measurements were taken with the probe orientation parallel and perpendicular to the screen face, not to the canal flow. Most of the velocity measurements were taken at the centerline of the screen. Measurements were also taken in the upper and lower quadrant (halfway between the upper or lower edge of the screen and the centerline) in complete surveys.

Fish Bypasses

Measurements were taken at 0.2 and 0.8 of water depth at the centerline of the 24-in.-wide fish bypasses. All bypasses had submerged ramps to guide fish and water up from the bottom of the screen structure and over an adjustable weir at the back of the ramp. The probes were positioned about 18 in. upstream of the ramp. This positioning generally placed the probes within the concrete structure of the bypass. Additionally, at the request of the Washington Department of Fisheries (WDF), velocity measurements were taken at 0.1, 0.3, 0.5, 0.7, and 0.9 of water depth at the Sunnyside Screens, instead of the normal 0.2 and 0.8 depth.

Separation Chamber

Measurements were taken at 0.2 and 0.8 of water depth in transects across the width of the separation chamber. Transects were made upstream of the vertical traveling screens and at the centerline of selected traveling screens. The traveling screens were constructed perpendicular to the separation chamber flow, with the outer wall (distal to the traveling screens) angling toward the screens. The probes were positioned parallel to the traveling screens, pointing upstream. Turbulent areas where bypass flows mix at the head of the separation chamber were not evaluated.

Vertical Traveling Screens

Measurements were taken at 0.2 and 0.8 of water depth at the face of the traveling screens. The probes were positioned parallel to the screen face at 1-ft intervals at the Sunnyside Screens, and at the centerline and in the upper and lower quadrants at the Wapato and Roza screens. The measurements along the screen face and the transects across the separation chamber merged to form a T pattern of velocity measurements.

Fish Return

Velocity in the fish returns of the smaller facilities (Columbia, Richland, and Westside Ditch screens) was measured in the "window" of water passing over the flow-regulating dam boards. Velocity in the larger facilities (Sunnyside, Wapato, and Roza screens) was measured near the upstream end of the fish return slot. The vertical pole was positioned upstream of the submerged approach ramp. A second set of measurements was taken in the middle of the Wapato Screens fish return.

DATA COLLECTION AND ANALYSIS

Ten sets of velocity measurements were recorded in a 3- to 5-min interval. Each set of readings provided a "snapshot" of all velocity measurements. Beginning and ending times were recorded for each series of data. Abnormal operating or canal flow conditions were recorded as "Notes" on the data sheets. Analyses and comparisons were performed using the means of the data.

DESCRIPTION OF CONDITIONS AT EACH SITE

Our data were collected at the time of the year when maximum canal flow was most likely to occur, and under normal operating conditions, as described in the operating criteria for each site. However, because of projected water shortages in 1988, some canals were not operating at maximum capacity. Surface elevation and/or forebay depth were determined from staff gauges at each site. Canal flows were also provided by BR for most sites; however, canal flow at the Richland Canal was not available. Abnormal flow or operating conditions were recorded at each site.

COLUMBIA CANAL

The Columbia Screens are located in the Columbia Canal on the right bank of the Horn Rapids Diversion Dam at river mile (RM) 18.0 on the Yakima River. The facility consists of 10 rotary drum screens (8 ft in diameter, 10 ft in length) and a fish return. The water depth in the screen forebay is about 4.2 ft when the canal is at the maximum flow of 150 cubic feet per second (cfs). Flow through the fish return is maintained at about 25 cfs by placing dam boards in the fish return.

A partial survey was conducted at the Columbia,,Screens on August 3, 1988, under full canal flow conditions, estimated at 148 cfs by Columbia Canal maintenance personnel. Canal elevation was 4.2 ft on the staff gauge behind the screens. Only 47 in. (49%) of the 96-in.-diameter drum screens was submerged. Water depth in front of the screens was 53 in. We assumed the difference in water depth and submerged screen depth to be the height of the bottom screen seal.

All operating conditions were normal during our measurements with the following exceptions:

- Screen 8 was not turning and was completely plugged with debris.
- Screens 2 and 3 were not turning when we arrived and were reset before our measurement series.
- Porosity boards were in use in all screen bays behind the screens. The upper half of each screen bay was completely closed off, and 2 ft of board were positioned 6 to 10 in. from the bottom in the lower half of each screen bay to prevent silt buildup near the screens.
- The fish return had dam boards in slot A (narrow slot at the front end of the fish return) instead of slot C (wide slot in the middle of the fish return).

Velocity measurements were taken at 0.2 and 0.8 of water depth. Measurements were made at the centerline of most screens; however, measurements were taken in the upper and lower quadrants on selected screens to determine if the porosity board configuration behind the screens affected approach velocities at different points on the face of the screens (Figure 5). Measurements in the fish return were made in the center of the water column at middepth of the water flowing over dam boards in the narrow slot. The series of measurements was completed in 3 hr. No changes in canal flow or operating conditions occurred during our measurements.

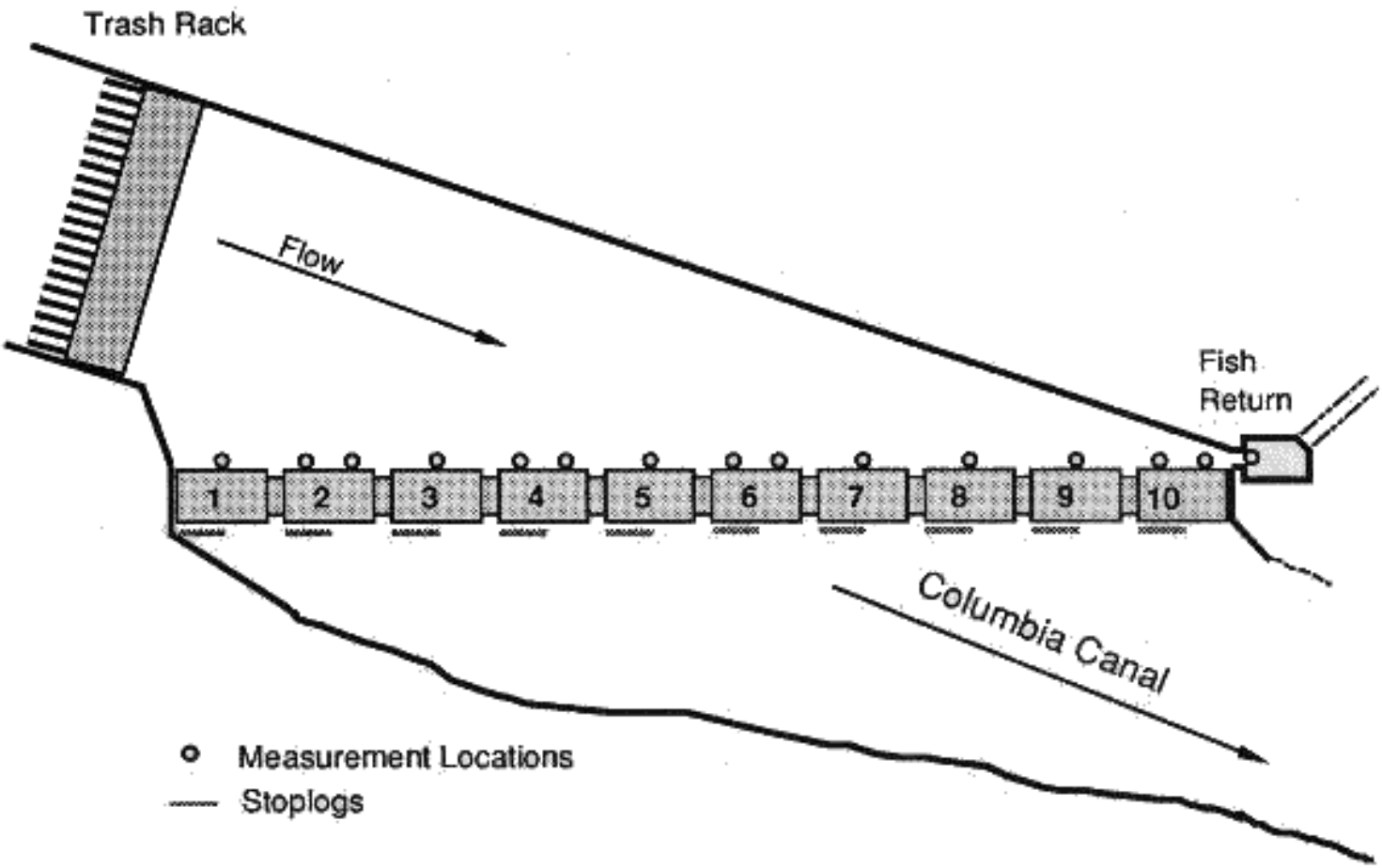

Figure 5. Probe Location Map for Partial Velocity Measurement Survey at the Columbia Screens, Summer 1988

RICHLAND CANAL

The Richland Screens are Located in the Richland Canal on the left bank of the Horn Rapids Diversion Dam at RM 18.0 on the Yakima River. The facility consists of four rotary drum screens (6 ft in diameter, 10 ft in length), a wastewater channel, and a fish return. Maximum canal flow is 80 cfs. The canal surface elevation at maximum canal flow is 413.85 ft. This forebay elevation represents the maximum canal level with no spill over the sill of the wastewater channel.

A complete survey was conducted at the Richland Screens on August 4 and 8, 1988. The forebay elevation was 413.8 to 413.85 ft, and canal level was 5.7 ft on the staff gauge behind the screens. Total canal flow was unknown. The water in front of the screens was 69 in. deep. Of the 72-in. drum screen diameter, 55 in. (76%) was submerged. The screens at the Richland Canal are set on top of a 12.in. sill. We used the submerged screen depth (55 in.) as the basis for our measurements so that the probe positioning at 0.8a and 0.9 depths would be relative to the screen and not to the solid sill.

All operating conditions were normal during our measurements with the following exceptions:

Flow through the fish return was excessive. Stoplogs may not have been all the way to the bottom in

slot C, allowing water to go under as well as over the stoplogs. Porosity boards were in use behind the screens to reduce silt buildup in the screen bays. Two 12 in. boards were positioned about 10 in.from the bottom in each bay. Siltation was excessive behind the screens; however, silt deposition in the screen forebay was minimal.

Velocity measurements were taken at six locations at five depths (0.05, 0.2, 0.5, 0.8, 0.8a, and 0.9 of water depth) in three transects (centerline and upper and lower quadrants) at each screen (Figure 6). Measurements in the fish return were made in the center of the water column at 0.2 and 0.8 of water depth in Slot A. Survey measurements required a total of 10 h during 2 days. Change in canal elevation during the 2 days of sampling was negligible.

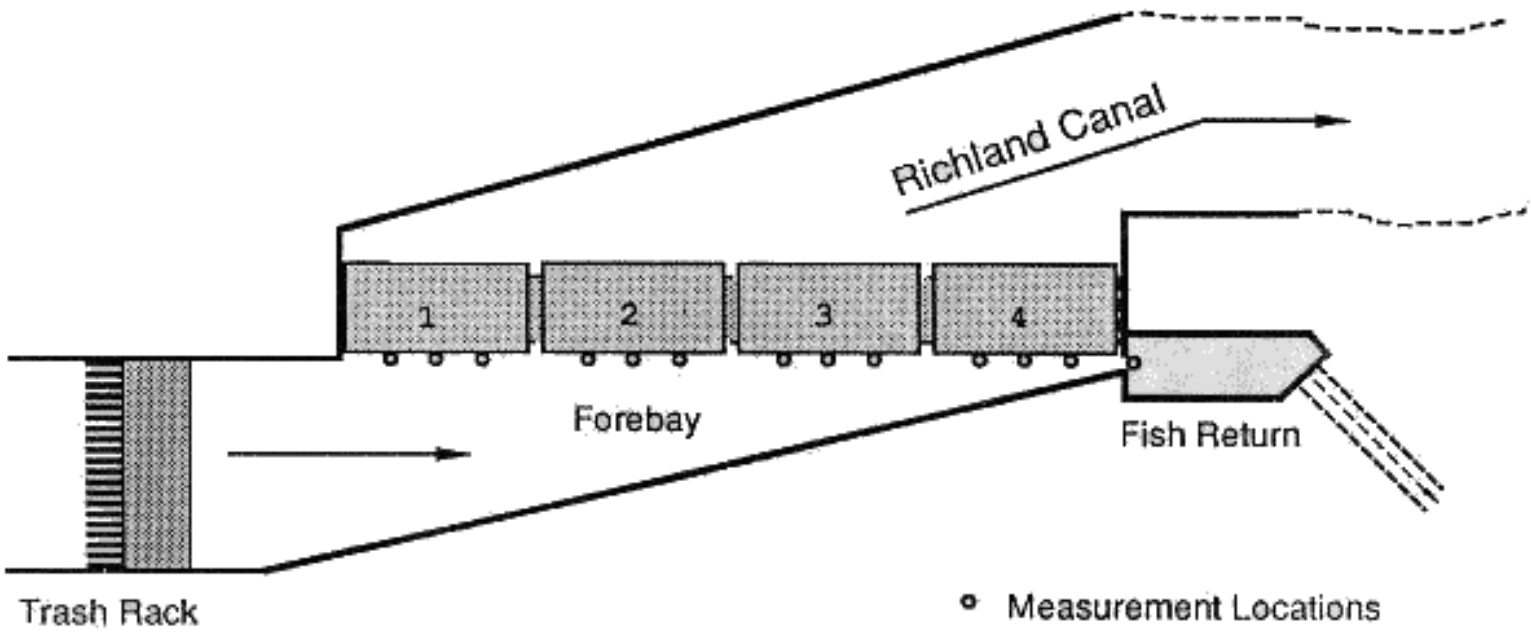

Figure 6. Probe Location Map for Complete Velocity Measurement Survey at the Richland Screens, Summer 1988

WESTSIDE DITCH

The Westside Ditch Screens are located in the Westside Ditch on the right bank of the Yakima River at RM 166.2. The facility consists of four rotary drum screens (6 ft in diameter, 12 ft in length), a wastewater channel, and a fish return, Maximum canal flow is 120 cfs. The maximum forebay level is about 1682.1 ft on the staff gauge in the screen forebay.

A partial survey was conducted at Westside Ditch on August 9, 1988. The canal was operating at an excessively high level when we arrived at the site. About 6 in. (8%) of the drum screen diameter was above the surface, and 6 to 8 in. of water was spilling over the wastewater channel sill. About 6 in. of water was spilling over the weir on a wastewater channel at the old head gate structure in the bay behind the screens.

The head gates were closed until the canal level stabilized at 1682.0 ft on the staff gauge. At this level, 14 in. of the drum screens was exposed and 58 in. (81%) was submerged, and no water spilled over the sill of the wastewater channel. About 6 in. of water was flowing through the wastewater channel slot. Water flow ceased in the old wastewater channel behind the screens. The dam board height in the fish return was not changed. Canal flow was 96 cfs.

The water depth of 64 in. in front of the drum screens was used to calculate depths for probe positioning. Velocity measurements were taken at 0.2 and 0.8 of the depth (Figure 7). Measurements in the fish return were made in the center of the water column at middepth of the water flowing over the dam boards in the fish return slot. The fish return flow was 19 in. of head instead of the 24 to 27 in. suggested in the operating criteria.

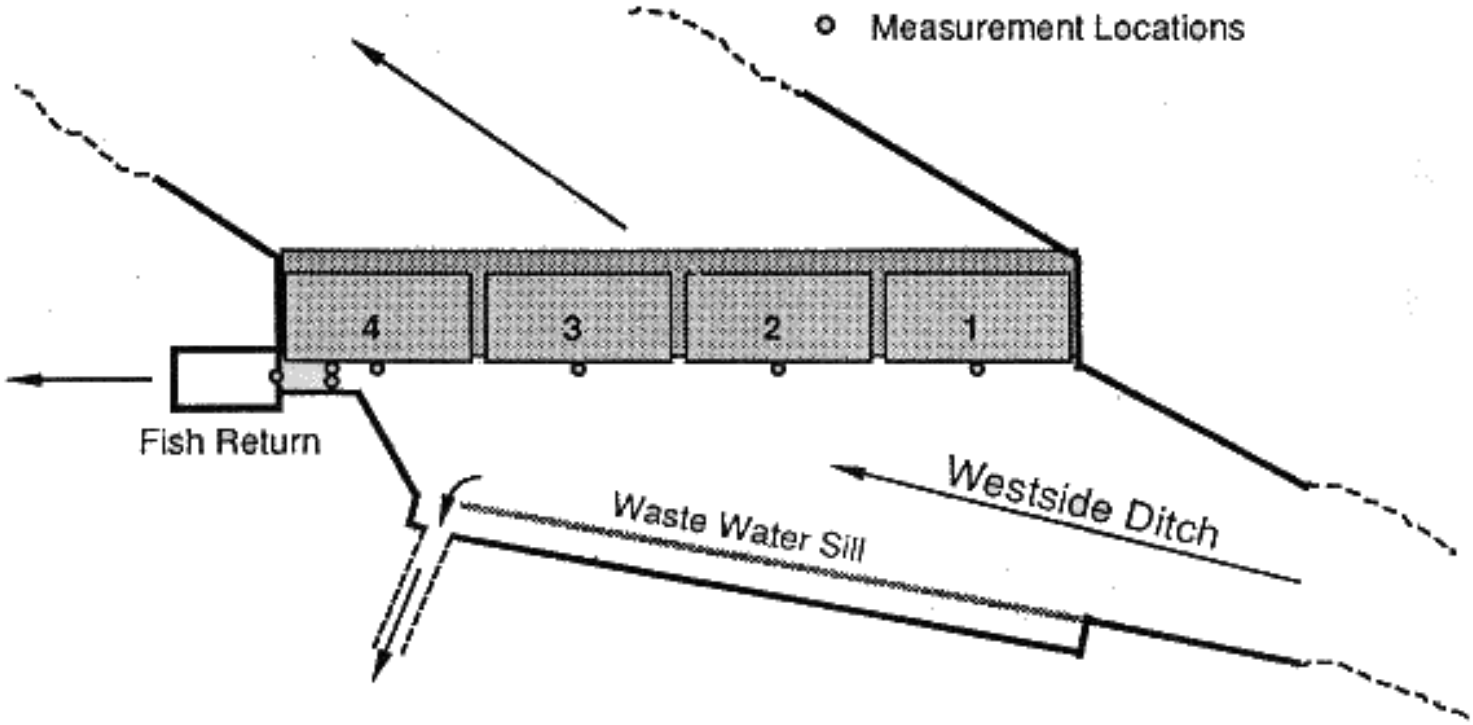

Figure 7. Probe Location Map for Partial Velocity Measurement Survey at the Westside Ditch Screens, Summer 1988

SUNNYSIDE CANAL

The Sunnyside Screens are located in the Sunnyside Canal on the left bank of the Yakima River at RM 103.8. The facility consists of 17 rotary drum screens (16 ft in diameter, 12 ft in length) and a fish bypass system that includes intermediate and terminal fish bypasses, a separation chamber with two bypass water recovery pumps located behind vertical traveling screens, and primary and secondary fish return pipes. The maximum canal flow is about 1550 cfs, and the maximum forebay elevation is 897.0 ft. Flow through the bypass system is controlled by adjusting weir gates in the fish bypasses and fish returns. Of the 100 cfs of water entering the separation chamber (50 cfs from each fish bypass), 80 cfs are pumped back to the canal when both pumps are operating, leaving 20 cfs to flow through the primary fish return. Porosity boards are used behind screens 8 and 10 through 14 to help balance discharge through the screens. Screens 1 and 2 are completely blocked off.

A partial survey was conducted at the Sunnyside Screens on August 10 and 11, 1988 (Figures 8 and 9). The canal forebay elevation was 897.0 and canal flow was about 1275 cfs. Both pumpback systems were in operation, and the weirs in the intermediate bypass, the terminal bypass, and the fish return were adjusted according to the operating criteria. Water depth in front of the screens was 168 in.; 150 in. (83%) of the 180-in. drum screen diameter was submerged. We used the submerged screen depth (150 in.) for our calculations so that probe

positioning would be relative to the drum screens.

All operating conditions were normal during our measurements except that screens 1 and 2 were stoplogged and out of service. The operating criteria call for only screen 1 to be stoplogged although screen 2 has not been in operation since 1985.

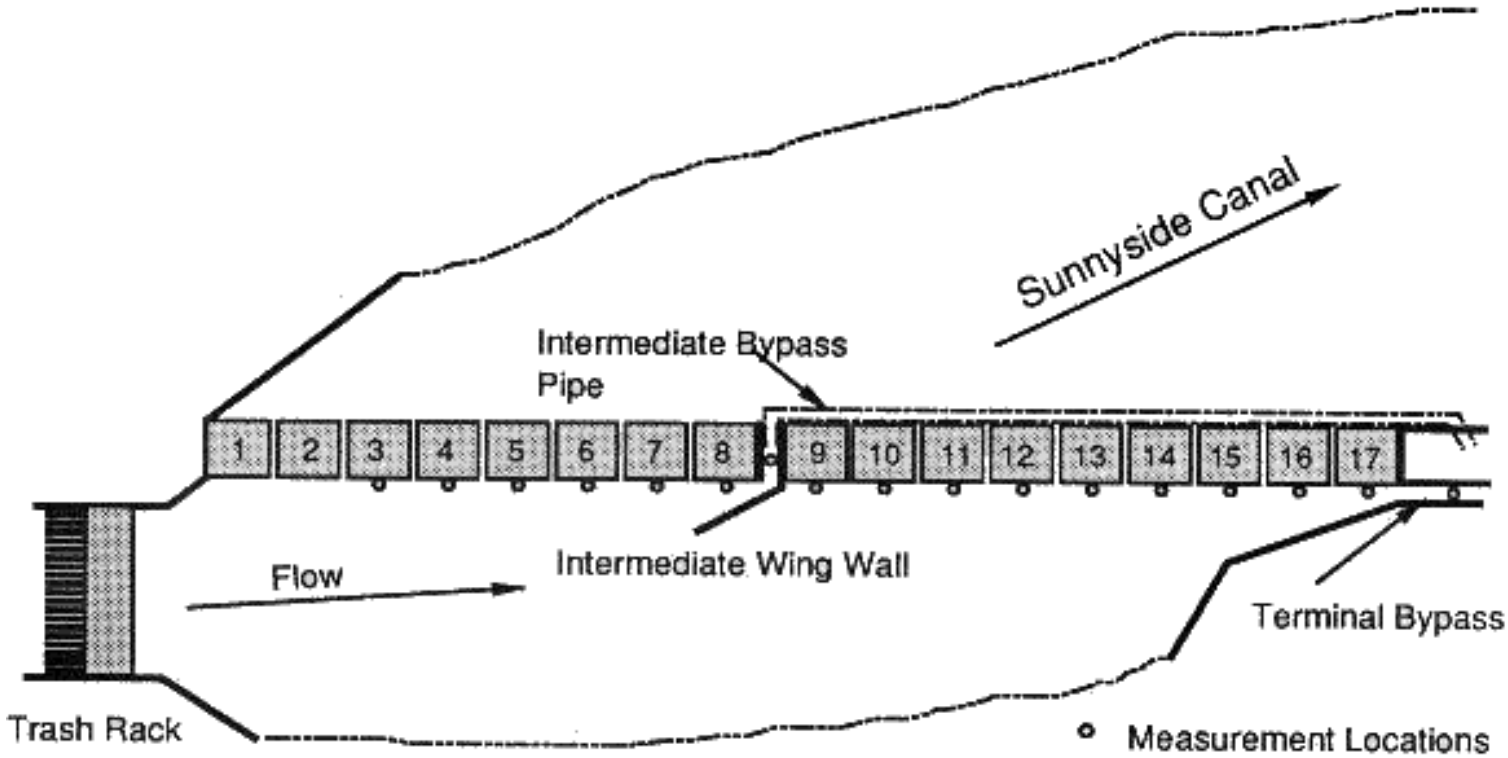

Figure 8. Probe Location Map for Partial Velocity Measurement Survey in Front of the Screens at the Sunnyside Screens, Summer 1988

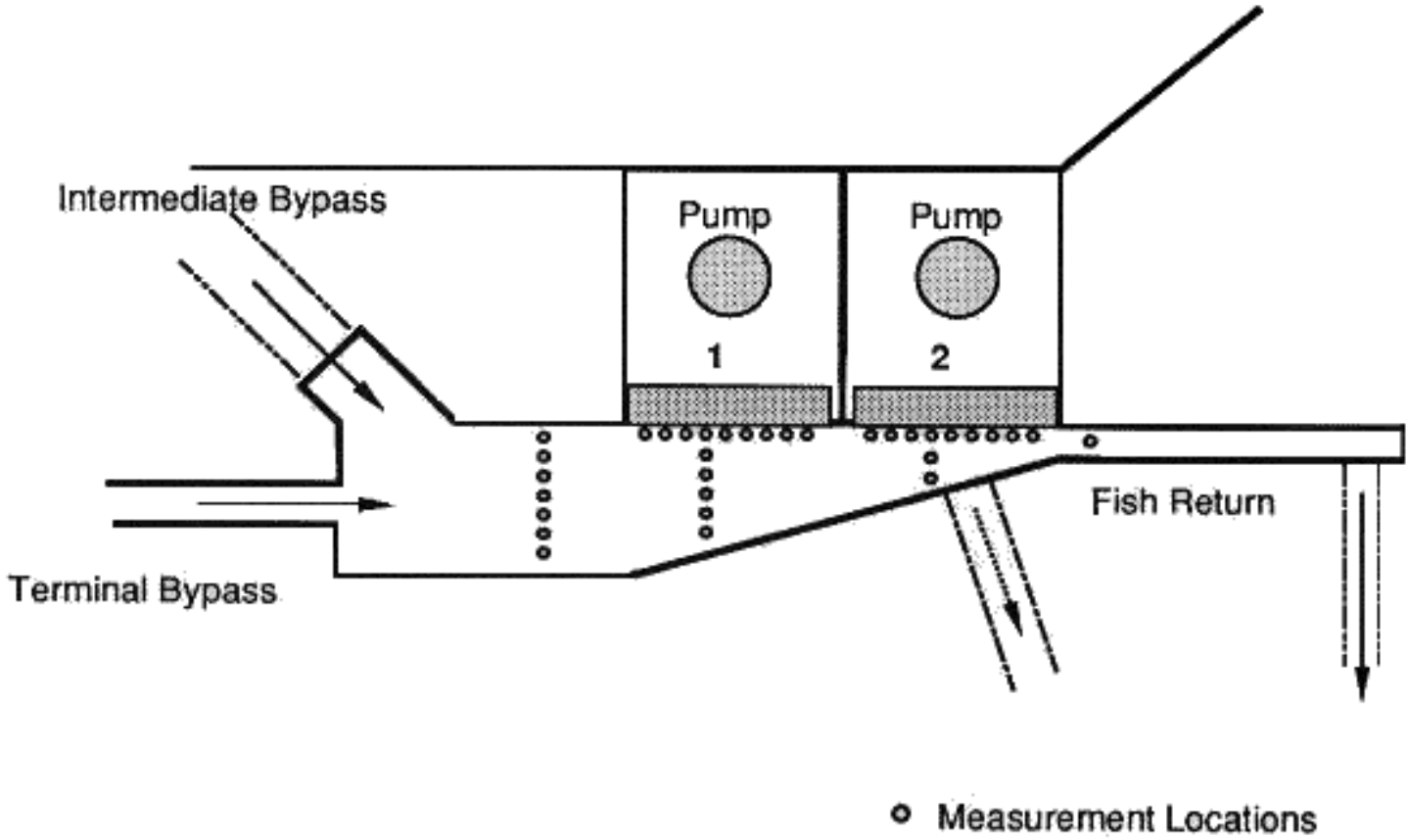

Figure 9. Probe Location Map for Partial Velocity Measurement Survey in the Separation Chamber at the Sunnyside Screens, Summer 1988

WAPATO CANAL

The Wapato Screens are located in the Wapato Canal on the right bank of the Yakima River at RM 106.7. The facility consists of 15 rotary drum screens (14 ft in diameter and 24 ft in length) and a fish bypass system that includes three fish bypasses (two intermediate and a terminal), a separation chamber with two bypass water recovery pumps located behind vertical traveling screens, and a fish return. The forebay elevation is about 935 ft at the maximum canal flow of 1800 cfs. Flow through the fish bypass system is controlled by adjusting weir gates in each fish bypass, the fish return, and the recovery pump bays behind the traveling screens. The two recovery pumps are not used during normal operation. Of the 150 cfs of water entering the separation chamber (50 cfs from each fish bypass), about 30 to 35 cfs flows through the fish return and the remainder is wasted over the weirs behind the traveling screens.

A complete survey was conducted at the Wapato Canal on August 16 through 18, 1988. Canal elevation was 934.6 ft, and the canal flow was 1750 cfs. Weir heights in the three fish bypasses and the fish return were set according to the operating criteria. Water depth in front of the screens was 135 in. Of the 168-in. drum screen diameter, 130 in. (77%) was submerged. We used the submerged screen depth as the basis for calculating probe positioning.

All operating conditions were normal with the following exceptions:

- The vertical traveling screens in the separation chamber were not fully functional. The screens were cleaned and lowered into operating position when we took our measurements in the separation chamber; however, the spray pumps were not operating, and only one traveling screen was rotating. When our measurements were completed, the screens were removed.
- Discharge through the two traveling belt screens was not equal. Most of the wastewater was discharged through screen 2 (the screen closer to the fish return slot).
- Rotary drum screens 1 and 9 were not operational. The screens were not stoplogged; however, they appeared to be totally plugged with debris. No measurements were taken in front of these screens.
- Three YIN salmon rearing pens were floating in the canal forebay.
- All drum screens were stoplogged according to previous modeling data; however, stoplog configurations were not included in the operating criteria.

Velocity measurements were taken at six locations at five depths (0.05, 0.2, 0.5, 0.8, 0.8a, and 0.9 of water depth) in three transects (centerline and upper and lower quadrants) at screens immediately upstream and downstream of each fish bypass (screens 5, 6, 10, 11, and 15). Measurements were taken at 0.2 and 0.8 depths at the centerline of the remaining screens, in the entrance to fish bypasses, in front of the traveling belt screens in the separation chamber, and in the fish return (Figure 10).

We also conducted velocity measurements on September 8, 1988, after the YIN salmon pens were removed from the canal forebay. The purpose of these measurements was to determine if the floating pens affected velocity measurements in front of the drum screens or in the fish bypasses. However, the surface elevation in the canal had dropped from 934.6 to 933.3 ft, and the canal flow was down to 1150 cfs because of reduced irrigation demands. Additionally, bypass flows described in the operating criteria were not achievable at a canal elevation of 933.3 ft.

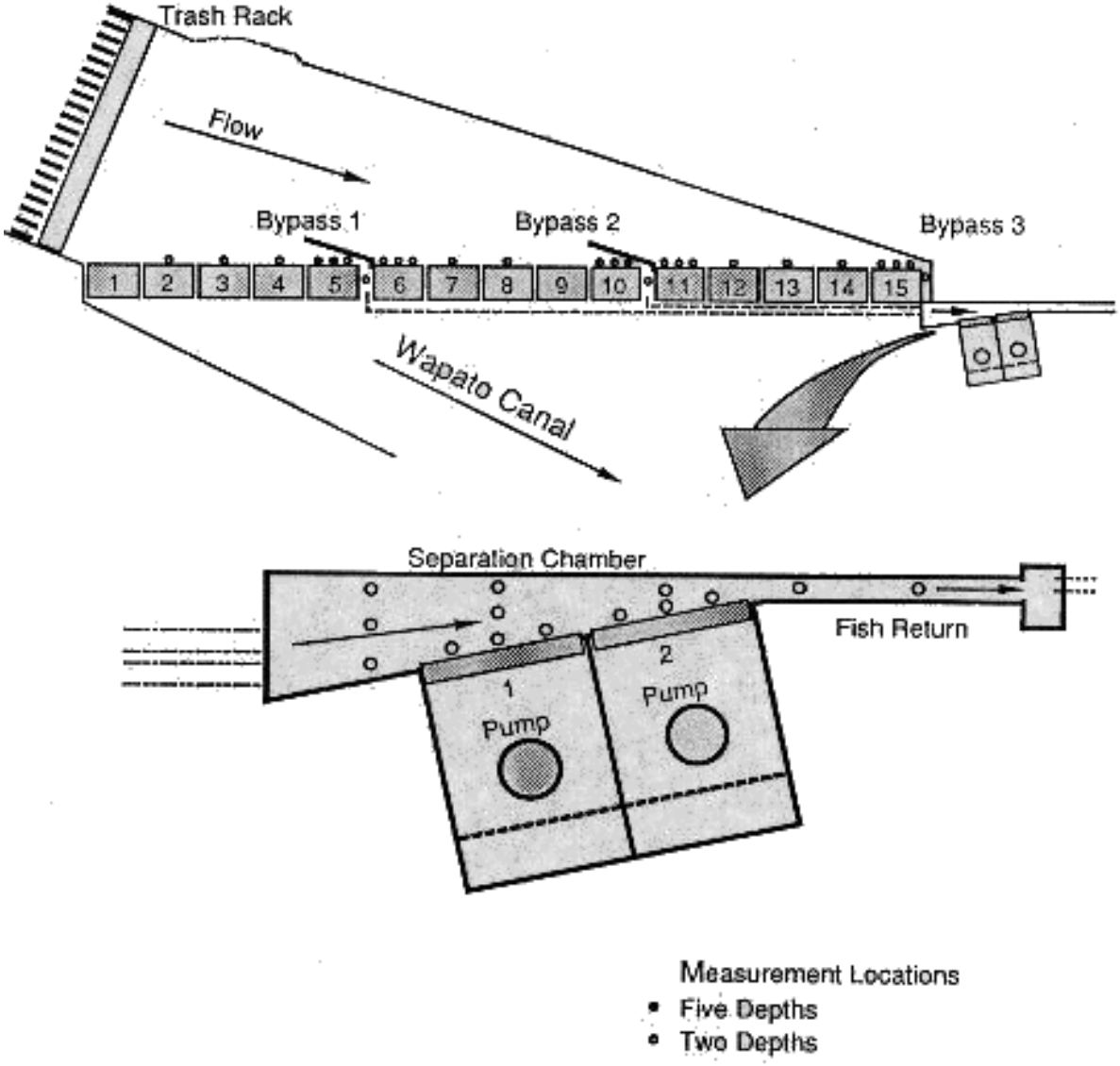

Figure 10. Probe Location Map for Complete Velocity Measurement Survey at the Wapato Screens, Summer 1988

ROZA CANAL

The Roza Screens are located in the Roza Canal on the right bank of the Yakima River at RM 127.9. The facility consists of 27 rotary drum screens (17 ft in diameter and 12 ft in length) in five screen bays (7 screens in the upstream bay and 5 in each of the other four bays), a fish bypass system that includes five fish bypasses, a separation chamber with four bypass water recovery pumps located behind vertical traveling screens, and a fish return. At the maximum canal flow of 2000 cfs, the forebay elevation is about 1220.8 ft. Flow through the fish bypass system is controlled by adjusting weir gates in each of the fish bypasses and the fish return. Of the 250 cfs of fish bypass flow (50 cfs through each fish bypass) during normal operation, 20 cfs flows through the fish return and 230 cfs (57.5 cfs for each of the four pumps) is pumped back to the canal.

A partial survey was conducted at the Roza Screens on August 22 and 23, 1988. Canal elevation was 1220.3 ft behind the screens, and total canal flow was 1950 cfs. Velocity measurements were taken in the first bay. Water depth in front of the screens was 160 in. Of the 204-in. drum screen diameter, 151 in. (74%) was submerged. We used the submerged screen depth (151 in.) as our depth so that probe positioning would be relative to the drum screens. Measurements were taken at 0.2 and 0.8 of water depth at the centerline of screens 1, 2, 4, and 5. No measurements were taken in front of screen 3 because the boom truck used to position our probe assembly would not reach the screen. Measurements were taken at 0.05, 0.2, 0.5, 0.8, 0.8a, and 0.9 depths at the centerline of screens 6 and 7 (Figure 11). Velocity measurements were taken in front of the first and third vertical traveling screens in the separation chamber (Figure 12). All operating conditions were normal.

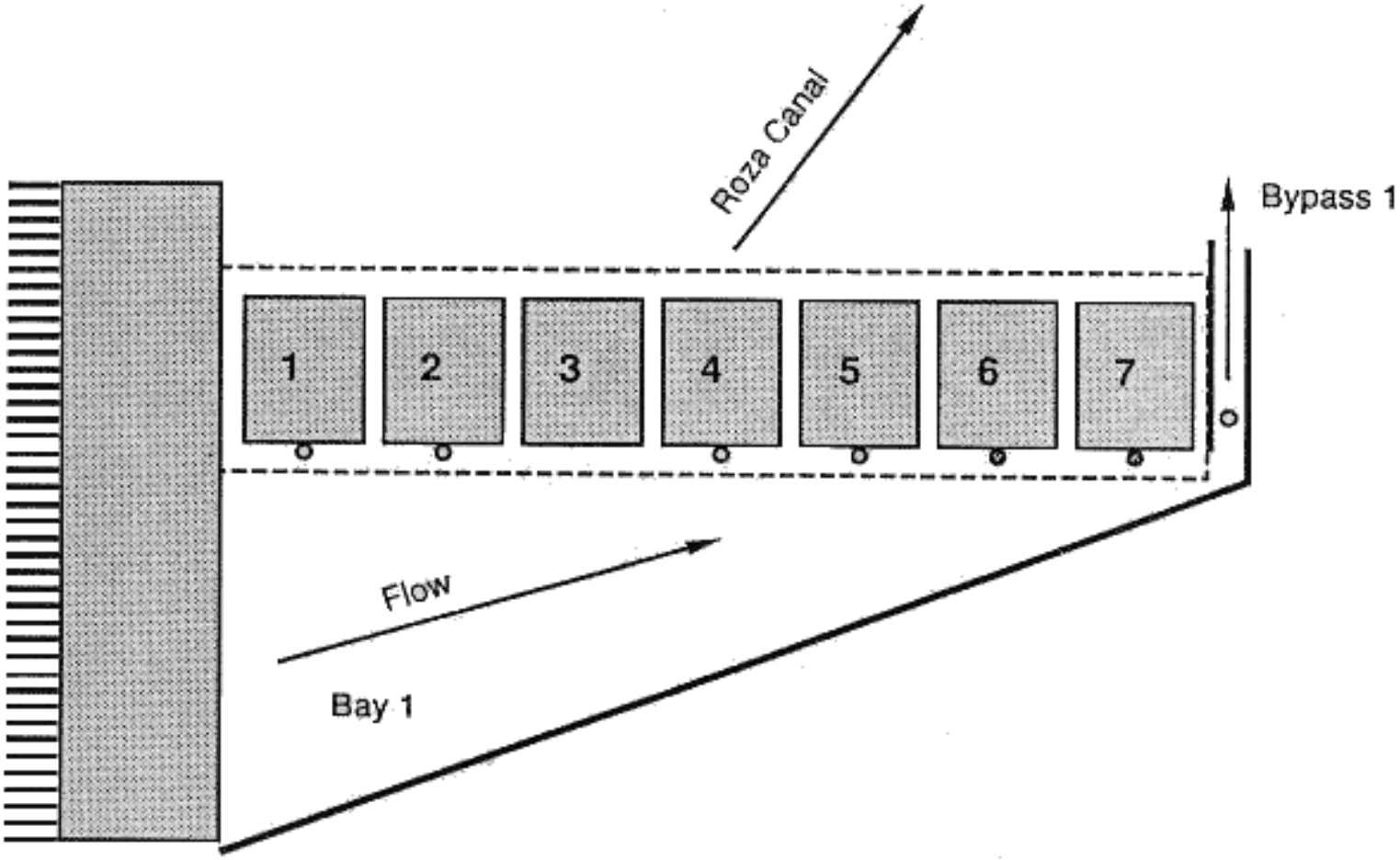

Figure 11. Probe Location Map for Partial Velocity Measurement Survey at the Roza Screens, Bay 1, Summer 1988

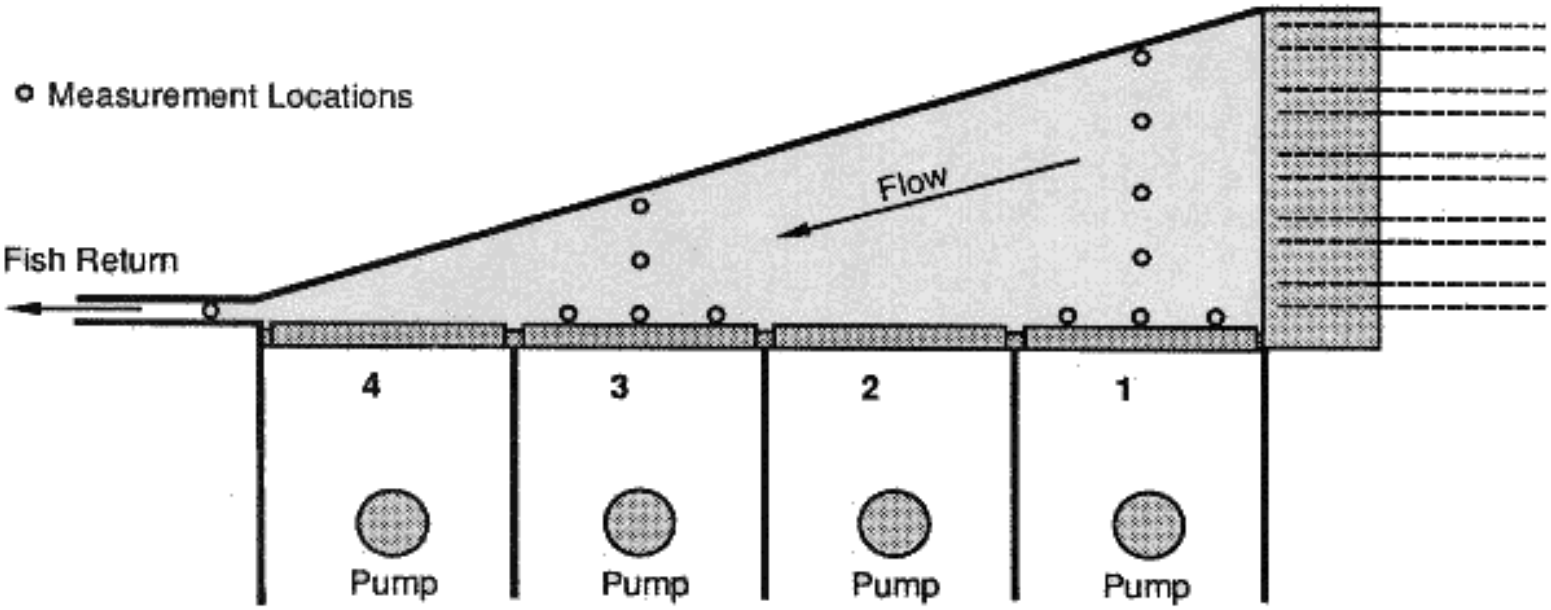

Figure 12. Probe Location Map for Partial Velocity Measurement Survey in the Separation Chamber at the Roza Screens, Summer 1988

RESULTS

Current velocities were measured at six screening facilities during 1988. The facilities are Columbia, Richland, Sunnyside, Wapato, Roza, and Westside Ditch. Velocities measured in all the canals were near the design specification and generally conducive to an effective fish bypass. Approach velocities sometimes exceeded 0.5 fps, however, they usually were at least twofold less than sweep velocities. Vertical velocities were usually less than 0.5 fps. Some velocity anomalies related to facility design were observed. For example, negative flow velocities were measured near walls and at some bypass entrances. The velocity characteristics are presented on a site-by-site basis. The raw data for each site are included in Appendices B through G.

COLUMBIA SCREENS

Velocity measurements for the Columbia Screens are summarized in Table 1. Approach velocity exceeded 0.5 fps by more than 10% at all operating screens. The excess occurred more often at 0.8 depth. Even though approach velocities exceeded 0.5 fps, the sweep-to-approach ratio of 2:1 was maintained at eight of nine operating screens for 0.2 depth and seven of nine operating screens at 0.8 depth. Vertical velocity was less than 0.2 fps at seven of the nine operating screens. Vertical velocities were consistently greater at 0.2 depth than for 0.8 depth. There was no consistent variation in the difference between approach measurements at the upper and lower quadrants of Screens 2, 4, 6, and 10. Flow through the fish return was adequate to prevent diverted fish from swimming into the screen facility from downstream of the fish return slot. The stoplog configuration being used during our measurements was not the same as prescribed by the operating guides.

TABLE 1. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity Measurements (fps) at Peak Canal Flow at the Columbia Screens, Summer 1988

Screen		0.2 Depth			0.8 Depth		
Number	Quadrant	X	Y	Z	X	Y	Z
1[a]	Center	0.61[b]	1.15	0.16	0.84[b]	1.41[c]	0.06
2	Upper	0.51	1.78	0.26	0.88[b]	2.10	0.17
2	Lower	0.44	1.60	0.36	0.65[b]	1.93	0.28
3	Center	0.36	1.56	0.29	0.55[b]	1.63	0.09
4	Upper	0.49	1.62	0.17	0.63[b]	1.68	0.06
4	Lower	0.61[b]	0.98[c]	0.11	0.67[b]	1.42	0.00
5	Center	0.57[b]	1.56	0.13	0.69[b]	1.54	0.05
6	Upper	0.56[b]	1.66	0.16	0.71[b]	1.71	0.08
6	Lower	0.57[b]	1.49	0.17	0.52	1.33	0.05
7	Center	0.52	1.45	0.13	0.62[b]	1.24	0.04
8[d]	Center	0.38	0.93	0.16	0.26	1.17	0.00
9	Center	0.60[b]	1.28	0.19	0.62[b]	1.01[c]	0.06
10	Upper	0.60[b]	1.38	0.11	0.78[b]	1.34	0.01
10	Lower	0.58[b]	1.41	0.11	0.62[b]	1.29	0.00
Fish Return[e]	Center	0.43	8.0	0.41			

a Screen 1 is at the upstream end of the screening facility; Screen 10 is at the downstream end nearest the fish return.

b Approach velocity exceeds design specification (≤0.5 fps) by >10%.

c Sweep-to-approach velocity ratio is less than design specification of ≥2:1 by >10%.

d Screen 8 was not operating and was plugged with debris.

e Fish return flow cross-sectional area of 4.17 ft^2; velocities were measured in the center of the fish return overflow.

RICHLAND SCREENS

Velocity measurements for the Richland Screens are summarized in Table 2. Approach velocities did not exceed 0.5 fps by more than 10% at 0.05, 0.5, and 0.8 depth near the screen. Approach velocity exceeded 0.5 fps by more than 10% for three of 12 measurement locations at 0.2 depth, 1 of 12 measurement locations at 0.8 depth near the screen, and 1 of 12 measurement locations at 0.9 depth. Sweep-to-approach velocities exceeded a 2:1 ratio at all depths measured on Screen 1 except for 0.5 depth. For Screen 2, the sweep-to-approach ratio was greater than 2:1 at 0.2 and 0.8 depth. For Screens 3 and 4, the sweep-to-approach ratios were 2:1 or greater at all measurement locations.

Approach velocities were consistently higher in the upstream quadrant of each screen compared to the centerline and lower quadrant measurements, indicating that screen bay walls affected flow patterns. Flow through the fish return resulted in average approach velocities of less than 0.2 fps for the lower quadrant of Screen 4. Approach velocity at 0.9 depth for the lower quadrant of Screen 4 was reversed. Flow through the fish return was adequate to prevent diverted fish from swimming into the screen facility from downstream of the fish return slot.

Table 2 (246 k)

TABLE 2. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity (fps) Measurements at the Richland Screens, Summer 1988

WESTSIDE DITCH SCREENS

Velocity measurements for the Westside Ditch Screens are summarized in Table 3. Approach velocities were less than 0.5 fps at 0.2 depth and exceeded 0.5 fps by more than 10% at 0.8 depth for Screens 1 and 4. The sweep-to-approach ratios were greater than 2:1 at all measurement locations except at 0.8 depth on Screen 1. One additional velocity measurement location was added in the lower quadrant of Screen 4 because of the location of the fish return slot. Measurements indicated the approach velocities were not affected by the close proximity of the wing wall to Screen 4. The fish return flow was less than required to prevent fish from swimming into the screen facility from downstream of the fish return slot. The stoplog configuration used during the measurements was not the same as prescribed by the operating guides.

TABLE 3. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity (fps) Measurements at Peak Canal Flow at the Westside Ditch Screens, Summer 1988

Screen Number	Quadrant	0.2 Depth X	0.2 Depth Y	0.2 Depth Z	0.8 Depth X	0.8 Depth Y	0.8 Depth Z
1[a]	Center	0.30	0.74	-0.19	0.66[b]	0.63[c]	-0.08
2	Center	0.33	1.08	-0.30	0.37	0.90	0.10
3	Center	0.23	1.27	-0.16	0.51	1.20	0.09
4	Center	0.42	1.39	0.09	0.65	1.23	0.22
4	Lower[d]	0.15	1.39	-0.14	0.09	0.96	0.21
Fish Return[e]	Center	-0.93	3.95	0.47	-	-	-

a Screen 1 is at the upstream end of the facility; Screen 4 is nearest the fish return.
b Approach velocity exceeds the design specification (≤0.5 fps) by >10%.
c Sweep-to-approach ratio is less than design specifications by >10%.
d Additional transect was added because of close proximity of outer wall to the lower end of Screen 4.
e Fish return velocities were measured in the center of the fish return overflow. Cross-sectional area was 2.38 ft^2; fish return was not stoplogged properly during our measurements.

SUNNYSIDE SCREENS

Approach velocities in front of the drum screens exceeded 0.5 fps in most instances (Table 4). Sweep velocity was generally high, resulting in sweep-to-approach velocity ratios greater than 2:1. Sweep-to-approach velocities were less than 2:1 only where velocities were disrupted by the intermediate bypass wing wall. An eddy in front of Screen 9 (immediately downstream of the wing wall) resulted in a negative sweep velocity at the 0.2 depth.

TABLE 4. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity (fps) Measurements in Front of the Rotary Drum Screens During Peak Canal Flow at the Sunnyside Screens, Summer 1988

Screen Number	Quadrant	0.2 Depth X	0.2 Depth Y	0.2 Depth Z	0.8 Depth X	0.8 Depth Y	0.8 Depth Z
3[a]	Center	0.53	2.19	0.02	0.51	3.84	-0.54
4	Center	0.53	2.27	-0.34	0.86[b]	3.11	-0.36
5	Center	0.61[b]	1.47	-0.41	0.46	2.20	-0.21
6	Center	0.53	2.30	-0.17	0.50	2.37	-0.37
7	Center	0.68[b]	1.90	-0.41	0.39	2.43	0.00
8	Center	0.73[b]	1.29	-0.36	0.41	1.58	-0.10
9	Center	0.64[b]	-0.61[c]	0.06	0.63[b]	1.42	0.16
10	Center	0.68[b]	0.85[c]	-0.21	0.75[b]	2.06	-0.37
11	Center	0.76[b]	1.51	-0.11	0.67[b]	2.52	-0.33
12	Center	0.66[b]	1.75	-0.26	0.58[b]	3.40	-0.20
13	Center	0.52	1.75	-0.32	0.41	3.17	-0.28
14	Center	0.68[b]	1.98	-0.15	0.65[b]	2.71	-0.05
15	Center	0.65[b]	1.92	-0.23	0.46	3.26	-0.25
16	Center	0.64[b]	1.82	-0.21	0.72[b]	2.22	-0.11
17	Center	0.70[b]	1.97	-0.20	0.74[b]	3.10	-0.07

a Screen 3 is the first operational screen at the upstream end of the facility; Screen 8 is upstream and inside of the intermediate wing wall; Screen 17 is nearest the terminal fish bypass.

b Approach velocity exceeds design specification (≤0.5 fps) by >10%.

c Sweep-to-approach ratio is less than design criteria by >10%.

A low sweep velocity in front of Screen 8 indicated that flow may be restricted by the intermediate wing wall and/or intermediate bypass. Velocity measurements within the intermediate and terminal bypasses (Table 5) indicated that the terminal bypass (oriented parallel to the screens) had a greater sweep velocity than the intermediate bypass (oriented perpendicular to the screens).

TABLE 5. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity (fps) Measurements in the Intermediate and Terminal Fish Bypasses During Peak Canal Flow at the Sunnyside Screens, Summer 1988

	Intermediate Bypass[a]			Terminal Bypass[b]		
Depth	X	Y	Z	X	Y	Z
0.1	0.38	0.99	0.02	0.25	4.28	0.12
0.3	0.17	2.45	-0.03	0.21	3.74	0.71
0.5	0.19	2.10	-0.01	0.18	6.25	1.19
0.7	0.07	3.27	-0.03	0.05	5.75	1.42
0.9	0.21	3.03	-0.04	0.00	5.75	1.42

a Intermediate bypass measured 14.0 ft deep; therefore, cross-sectional area is 28 ft^2.

b Depth at measurement point was 10.5 ft because of approach ramp on the bottom. Cross-sectional area of terminal bypass is 21 ft^2.

Sweep velocity in the separation chamber upstream of and in front of the traveling screens was not uniform (Table 6). Flow patterns within the separation chamber were affected by the bypass design and unbalanced bypass flows (Figure 13; Table 7). The intermediate bypass pipe enters below the surface and is oriented at approximately a 45¡ angle away from the traveling screens. The terminal bypass discharge, which dominated the flow pattern in the separation chamber, enters at the surface and is oriented parallel to to traveling screens. Discharge from the terminal bypass is directed toward the face of the traveling screens and resulted in a very high sweep velocity immediately in front of the traveling screens, whereas sweep velocity near the wing wall opposite the traveling screens was lower. The flow patterns persisted throughout the length of the separation chamber.

TABLE 6. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity (fps) Measurements in the Separation Chamber at the Sunnyside Screens, Summer 1988

Transect	Position	0.2 Depth			0.8 Depth		
		X	Y	Z	X	Y	Z
Upper[a]	1[b]	0.73	2.37	-0.61	-0.52	2.60	1.40
	2	0.59	1.26	-0.12	-0.37	3.12	0.85
	3	0.80	1.51	-0.32	-0.54	2.28	0.07
	4	0.88	3.72	-0.65	-0.77	1.88	-0.25
	5	0.55	6.10	-0.59	-0.14	1.72	-0.45
	6	0.69	7.15	-0.62	0.33	4.77	-1.21
	7	0.76	7.60	-0.44	0.37	4.70	-1.16
Screen 1	1	0.98	2.12	-0.61	-0.56	0.10	0.69
	2	0.83	2.06	-0.38	-0.88	0.27	0.13
	3	0.77	2.76	-0.40	-0.72	0.27	-0.02
	4	0.94	4.15	-0.23	-0.44	1.78	-0.70
	5	0.78	3.96	-0.61	-0.16	1.73	-0.65
Screen 2	1	0.85	3.09	-0.44	0.40	0.54	-0.13
	2	0.98	3.82	0.07	0.44	1.43	-0.48

a Upper transect is 3 ft upstream of the upstream edge of traveling screen 1. Screen transects are at the centerline of the designated screen.

b Position is distance (feet) from the wall opposite the traveling screens. Last position of each screen transect merges with the centerline measurement (Position 5) at the traveling screen face in Table 7.

Table 7 (202 k)

TABLE 7. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity (fps) Measurements at the Face of the Traveling Belt Screens and in the Fish Return at the Sunnyside Screens, Summer 1988

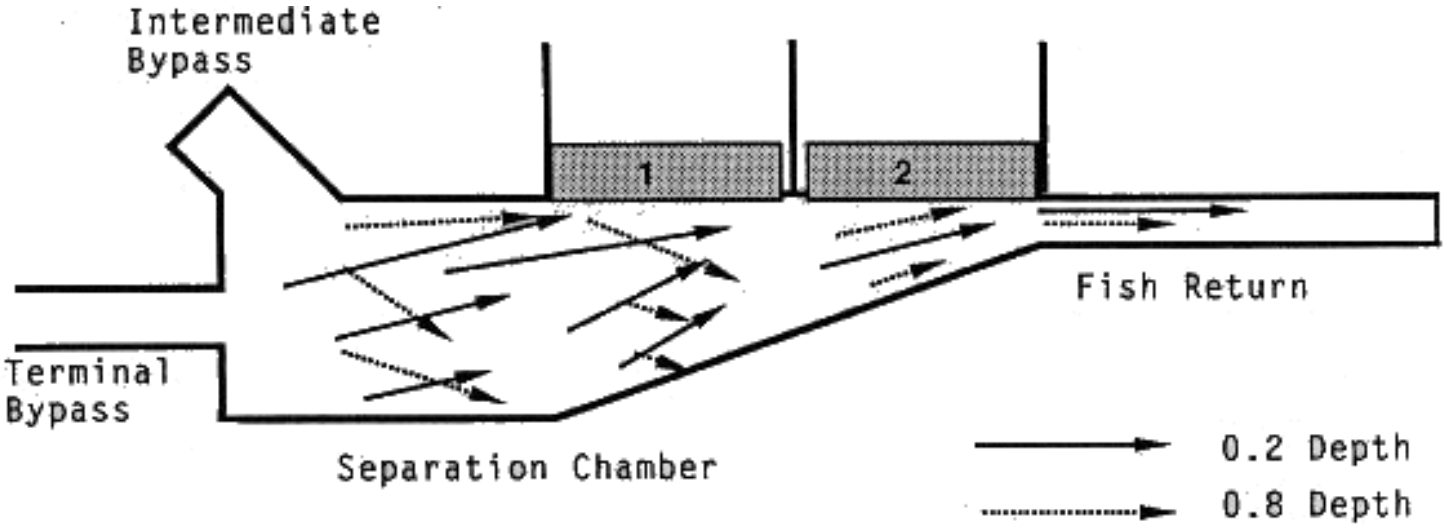

Figure 13. Flow Patterns in the Sunnyside Screens Separation Chamber as Described by Velocity Data and Visual Observations of the Water Surface

Approach velocities at the face of the traveling belt screens exceeded 0.5 fps by more than 10% (Table 7). Approach velocities at traveling screen 1 were uniform at 0.2 of the depth but not at 0.8 of the depth, where approach velocities were negative at the upstream end but exceeded 1.5 fps at the downstream end of the traveling screen face (Figure 14). Additionally, sweep velocities were consistently lower at the 0.8 depth. Sweep and approach velocities were more consistent in front of traveling screen 2; however, approach velocity was excessive at the 0.2 depth and sweep velocity was greater at the 0.2 depth than at 0.8 depth. Flow in the fish return was adequate, but the sweep velocity was greater at the 0.2 depth than at 0.8 depth, the same pattern as was observed in the separation chamber.

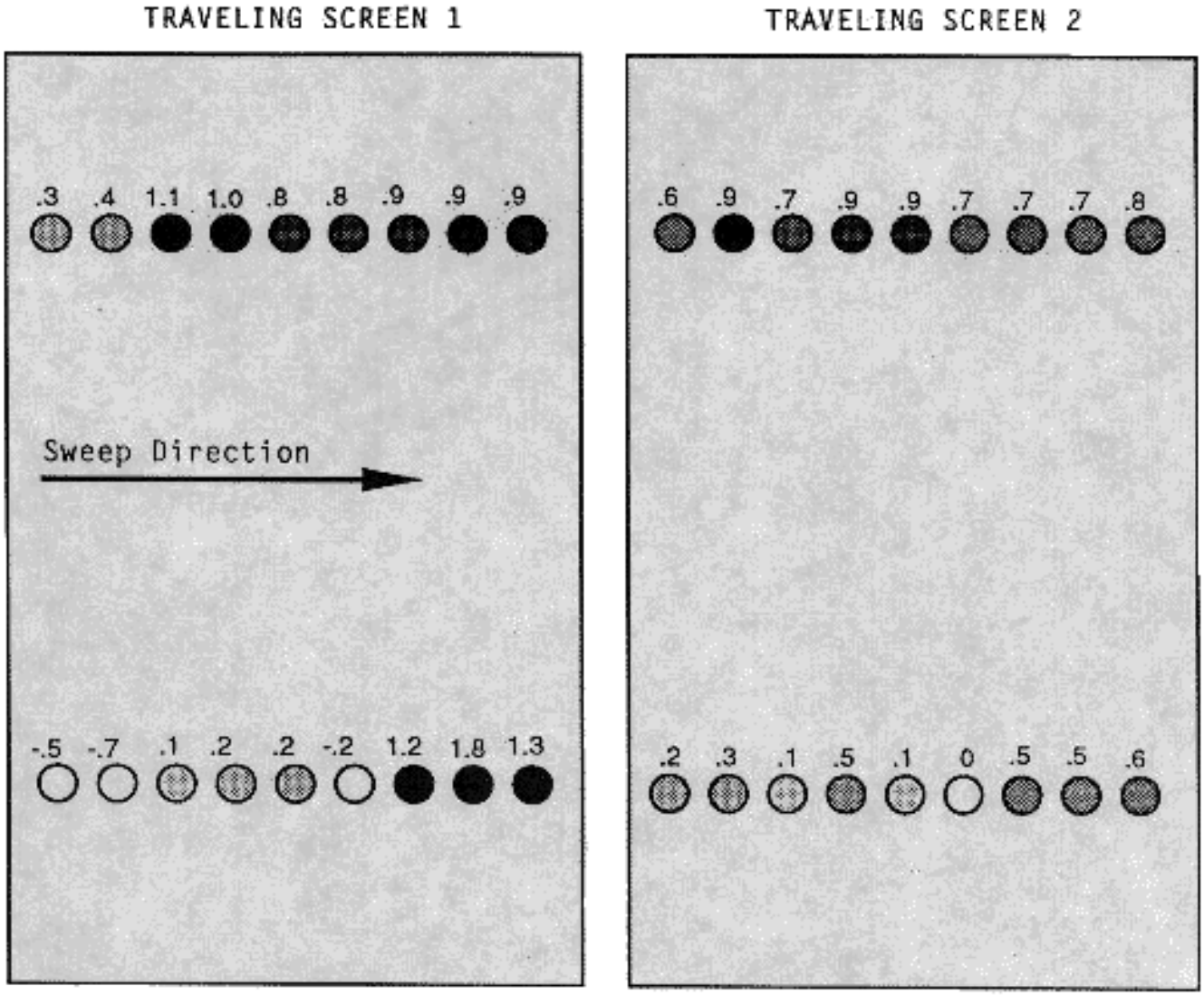

Figure 14. Approach (Impingement) Velocity at the Face of the Traveling Belt Screens in the Sunnyside Screens Separation Chamber

WAPATO SCREENS

Approach velocities slightly exceeded 0.5 fps by more than 10% at over 60% (64 of 105) of the measurement locations during peak canal flow (Table 8). Approach velocities were uniform; except at Screens 6 and 11 where wing walls seemed to affect approach velocity, especially at the 0.8, 0.8a, and 0.9 depths. Measurements in the upper, center, and lower quadrants of these screens showed that the approach velocity returned to normal within one screen length (24 ft).

Table 8 (181 k)

TABLE 8. Summary of Approach (X), Sweep(Y), and Vertical (Z) Velocity (fps) Measurements in Front of the Drum Screens During Peak Canal Flow at the Wapato Screens, Summer 1988

Sweep velocities were generally twice as great as approach velocities, but steadily declined with depth and proximity to the terminal bypass.

Approach velocities met design specifications at most measurement locations during 65% canal flow (Table 9). Approach velocities tended to be less at the 0.2 depth than during peak canal flow; however, the approach velocity at the 0.8 depth was similar at both canal flows. Sweep-to-approach ratio was greater than 2:1 at most

measurement locations. Sweep velocities were lower in the downstream end of the facility. No measurements were taken in the fish bypass system during 65% canal flow.

TABLE 9. Summary of Approach (X) and Sweep (Y) Velocity (fps) Measurements in Front of the Rotary Drum Screens During Moderate Canal Flow at the Wapato Screens, Summer 1988

Screen	Quadrant	0.2 Depth X	0.2 Depth Y	0.8 Depth X	0.8 Depth Y
2[a]	Center	0.42	1.34	0.60[b]	1.45
3	Center	0.84[b]	1.64	1.15[b]	1.86[c]
4	Center	0.41	1.61	0.50	1.50
5	Center	0.45	1.61	0.47	1.70
6	Center	0.45	1.27	0.68[b]	1.13[c]
7	Center	0.44	1.36	0.58[b]	1.47
8	Center	0.41	1.41	0.50	1.40
9					
10	Center	0.37	1.55	0.47	1.26
11	Center	0.27	1.22	0.54	1.00
12	Center	0.32	1.38	0.43	1.15
13	Center	0.35	1.16	0.47	1.05
14	Center	0.30	1.19	0.52	1.02
15	Center	0.43	1.03	0.58[b]	0.92[c]

a Screens 1 and 9 were not operating. Screen 2 is at the upstream end of the facility.
b Approach velocity exceeds design specifications (0.5 fps) by >10%.
c Sweep-to-approach ratio is less than design specifications by >10%.

Discharge through the three bypasses was not balanced (Table 10). Sweep velocities indicated that almost half of the bypass flow may enter the separation chamber via the terminal bypass. Sweep velocities were similar between the two intermediate bypasses (bypass 1 and 2).

TABLE 10. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity (fps) Measurements at the Entrance to the Fish Bypasses at the Wapato Screens, Summer 1988

Fish Bypass	0.2 Depth X	0.2 Depth Y	0.2 Depth Z	0.8 Depth X	0.8 Depth Y	0.8 Depth Z
Intermediate Bypass 1[a]	0.16	1.61	0.14	-0.79	1.68	0.04
Intermediate Bypass 2	0.17	1.74	-0.13	0.77	0.95	0.03
Terminal Bypass 3	0.77	3.59	-0.26	0.27	2.17	-0.34

a Cross-sectional area of each fish bypass at the entrance was 21.67 ft^2.

Sweep velocities were not uniform in the upstream end of the separation chamber (Table 11). Negative sweep velocity occurred at the 0.2 depth (Figure 15), causing an accumulation of floating debris in the head of the separation chamber. High vertical velocities were also observed in the transect upstream of the traveling belt screens. Sweep velocity was more uniform in front of the traveling screens, however.

TABLE 11. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity (fps) Measurements in the Separation Chamber and Fish Return at the Wapato Screens, Summer 1988

		0.2 Depth			0.8 Depth		
Transect	Position	X	Y	Z	X	Y	Z
Upper[a]	Outer[b]	0.57	-1.23	1.37	0.01	0.86	-[c]
	Center	0.56	-1.66	1.13	-0.19	1.57	-
	Inner	0.66	1.51	0.67	-0.59	1.51	-
Screen 1	Outer	-0.66	1.48	0.48	-0.35	2.26	-0.25
	Center	-0.45	0.75	-0.57	-0.26	2.30	-0.10
Screen 2	Center	0.22	1.55	-0.21	0.42	6.38	-
Fish Return	1[c]	0.06	2.02	-0.14	-0.13	6.61	0.01
	2	0.28	2.31	-0.11	0.00	2.33	0.01

a Upper transect was 9.75 ft downstream of the head end of the separation chamber. Screen transects were at the centerline of the respective screens.

b Outer position was 2 ft from the outer wall. Center position was midway between the outer wall and the face of the traveling screens. Inner position was 2 ft from the wall adjacent to and upstream of the traveling screens.

c Position 1 and 2 were 6 and 27 ft, respectively, downstream of the entrance to the fish return. Cross-sectional area of fish return was 16.67 ft^2.

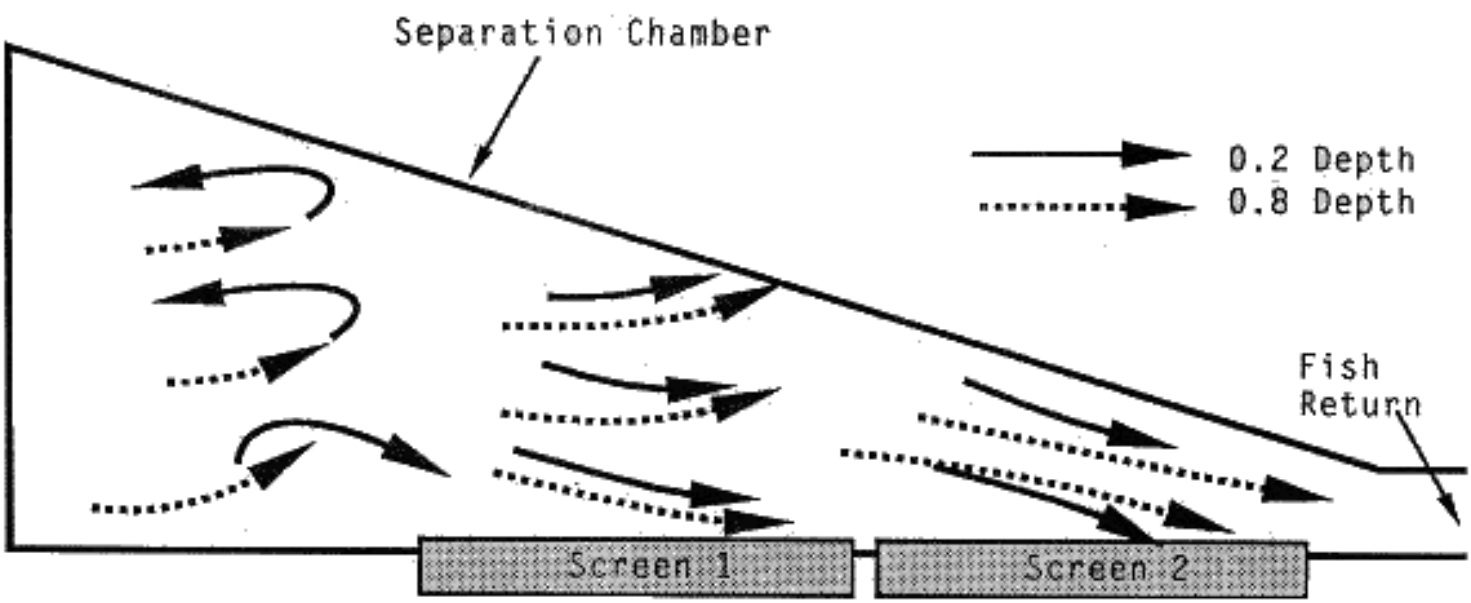

Figure 15. Flow Patterns in the Wapato Screens Separation Chamber as Described by Velocity Data and Visual Observations of the Water Surface

Approach velocities taken in front of each of the traveling screens indicated that most of the water discharged through traveling screen 2, and approach velocity exceeded 0.5 fps by more than 10% at the 0.8 depth (Table 12; Figure 16). After we completed our measurement series, we visually inspected the spill gates (gates 5 and 6) behind the two traveling screens and found that most of the spill was over Gate 6, the gate controlling discharge through traveling screen 2. Additionally, abnormal sweep velocities (>6 fps) occurred at the 0.8 depth in front of traveling screen 2 that continued into the head end of the fish return (Table 12). A second set of measurements taken about 28 ft from the head end of the fish return showed that sweep velocities were nearly equal at 0.2 and 0.8 depths.

TABLE 12. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity Measurements (fps) at the Face of the Traveling Belt Screens at the Wapato Screens, Summer 1988

		0.2 Depth			0.8 Depth		
Screen[a]	Position[b]	X	Y	Z	X	Y	Z
1	Upper	0.35	2.27	-0.11	0.32	2.04	-0.42
	Center	0.30	2.12	0.79	0.39	2.29	-0.39
	Lower	-0.03	1.86	0.35	0.25	1.25	-0.43
2	Upper	0.71[c]	1.82	0.26	1.22[c]	5.83	0.02
	Center	0.60[c]	1.67	0.23	0.92[c]	6.27	-[d]
	Lower	0.53	1.31	-[d]	0.64[c]	6.27	-[d]

a Screen 1 is the upstream screen. Screen 2 is nearer the fish return.
b Upper position is 2 ft from the upstream edge of the traveling screen; center is at the screen centerline; lower is 2 ft from the lower edge of the screen.
c Approach velocity exceeds design specification by >10%.
d Instrument/probe failure. No data.

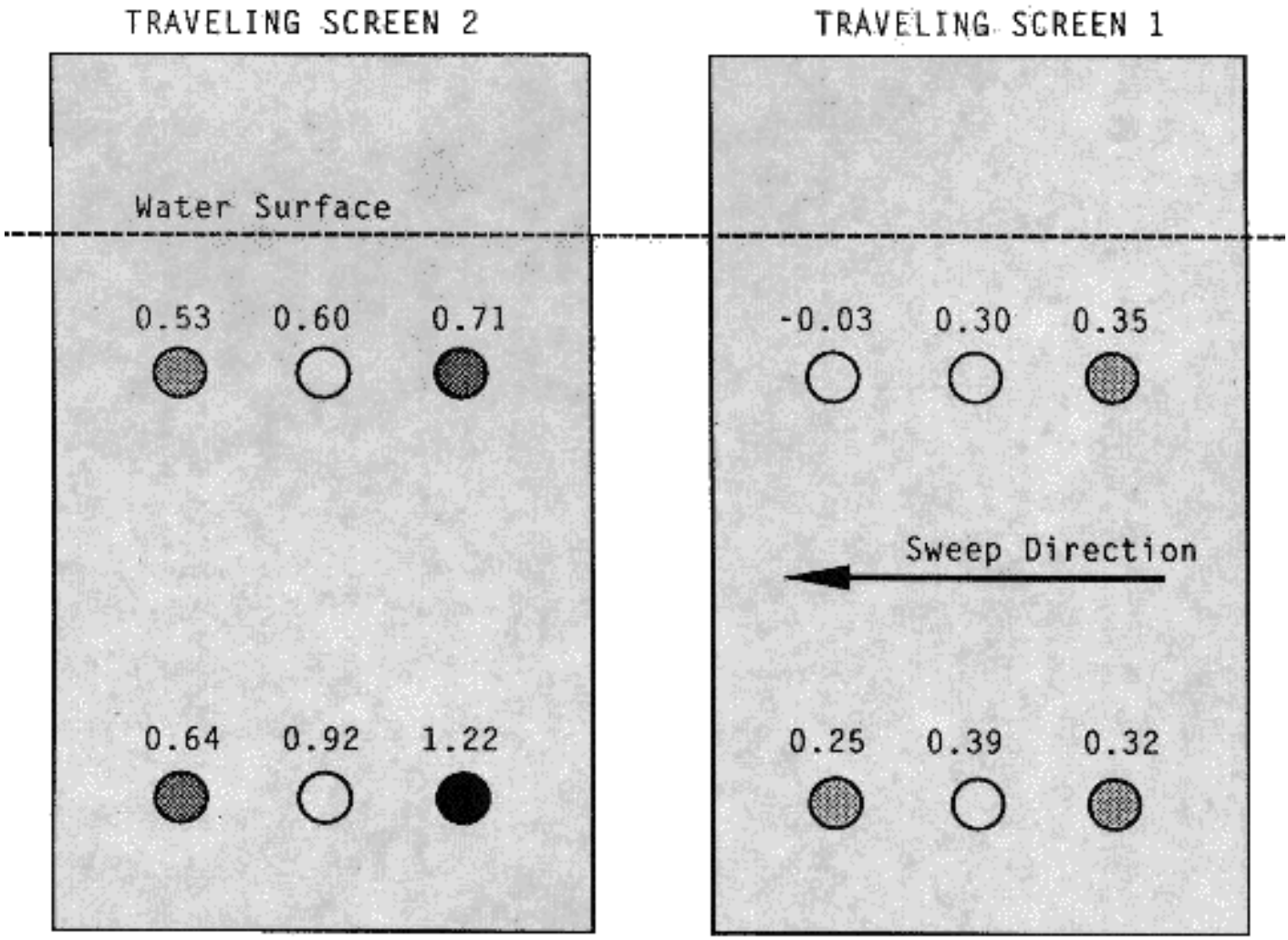

Figure 16. Approach (Impingement) Velocity at the Face of the Traveling Belt Screens in the Wapato Screens Separation Chamber

ROZA SCREENS

Approach velocities at the Roza Screens exceeded 0.5 fps by more than 10% at 5 of 6 screens measured in the first bay (Table 13). Sweep velocities varied with measurement locations and depth. Sweep velocities gradually decreased from the upstream to the downstream end of the screen forebay; however, the approach velocity remained relatively constant. The sweep-to-approach ratio was less than 2:1 throughout most of the screen bay, especially at the 0.8, 0.8a, and 0.9 depths.

Table 13 (311 k)

TABLE 13. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity Measurements (fps) During Peak Canal Flow in Front of the Drum Screens and in the Fish Bypass in the First Bay at the Roza Screens, Summer 1988

Bypass flow appeared to be well balanced, drawing water equally from 0.2 and 0.8 depths. Instrument failure occurred during the course of our measurements in front of screens 6 and 7 and in the fish bypass, resulting in the loss of some data. Apparent increases in vertical velocity in the lower end of the screen bay may have been caused by instrument failure.

Data collection in the separation chamber was limited to sweep and approach velocity measurements because of time constraints and instrument problems. Sweep velocities were not uniform across the upstream end of the separation chamber (Table 14; Figure 17). Sweep velocity as low as 0.3 fps occurred at the 0.2 depth near the

center of the separation chamber, and sweep velocities at the 0.8 depth were about twice that at the 0.2 depth.

Approach velocities through traveling screens 1 and 3 was generally greater than 0.5 fps, and the sweep-to-approach ratio was often less than 2:1 (Table 15). Discharge through the traveling screens appeared to be well balanced, based on average approach velocities for the two measured screens (Figure 18). Flow in the fish return was balanced with equal sweep velocity at the 0.2 and 0.8 depths (Table 14).

TABLE 14 Summary of Approach (X), Sweep (Y), and Vertical (Z) velocity Measurements (fps) in the Separation Chamber and Fish Return at the Roza Screens, Summer 1988

		0.2 Depth			0.8 Depth		
Transect	Position	X	Y	Z	X	Y	Z
Screen 1[a]	1[b]	0.66	1.05	-[c]	0.31	2.11	-[c]
	2	0.39	0.30	-	0.30	1.66	-
	3	0.44	0.27	-	0.34	3.10	-
	4	0.37	0.61	-	0.24	2.61	-
Screen 3	1	0.43	1.14	-	0.54	1.39	-
	3	0.54	1.39	-	0.50	1.72	-
Return[d]	Center	0.06	3.44	-	0.11	3.51	-

a Screen 1 and Screen 3 transects were at the centerline of the corresponding traveling screens.
b Position 1 was 1 ft from outer wall. Position 3 was the centerline of the separation chamber. Positions 2 and 4 in the Screen 1 transect were 4.3 and 11 ft from the outer wall, respectively.
c Instrument failure; no data collected.
d Measurements taken 6 ft downstream of entrance to fish return. Cross-sectional area of fish return was 12 ft^2.

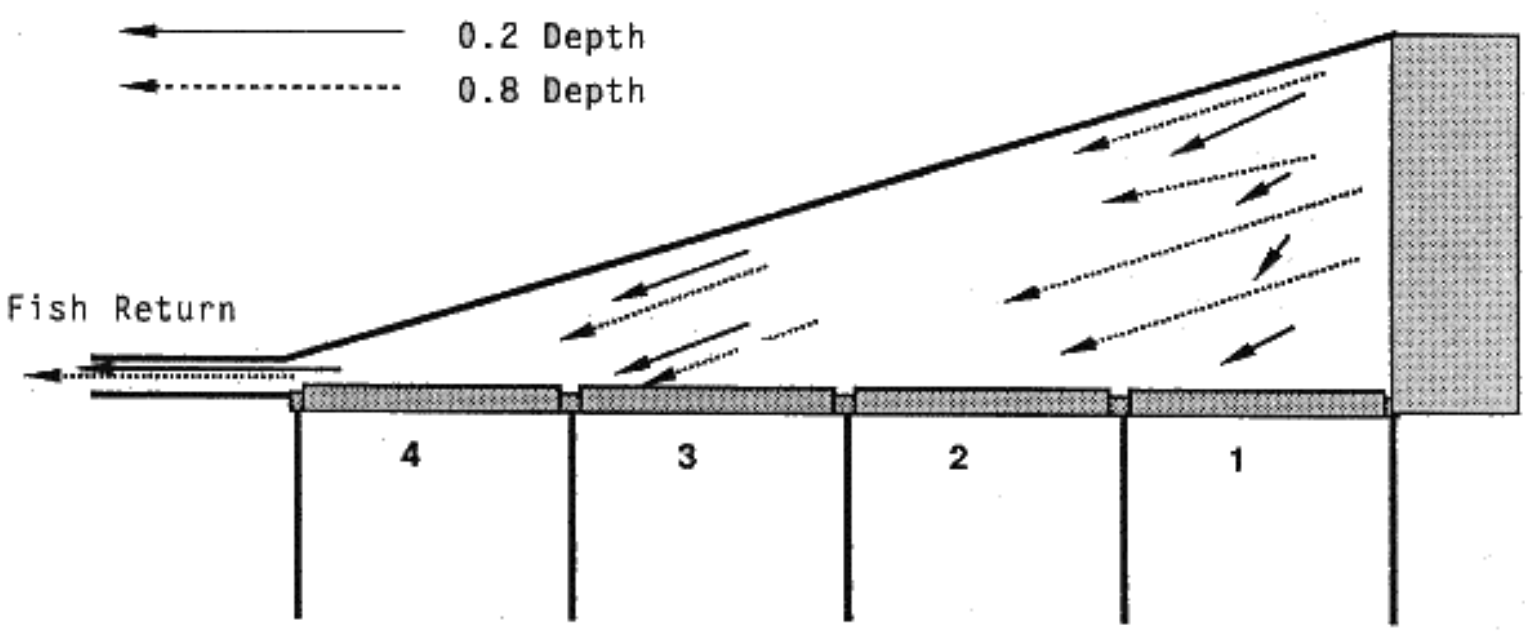

Figure 17. Flow Patterns in the Roza Screens Separation Chamber as Described by Velocity Data and Visual Observations of the Water Surface

TABLE 15. Summary of Approach (X), Sweep (Y), and Vertical (Z) Velocity Measurements (fps) at the Face of the Traveling Belt Screens at the Roza Screens, Summer 1988

		0.2 Depth			0.8 Depth		
Screen[a]	Position[b]	X	Y	Z	X	Y	Z
1	Upper	0.62[c]	1.41	-[e]	0.48	3.56	-[e]
	Center	0.76[c]	0.96[d]	-	0.58[c]	3.42	-
	Lower	0.63[c]	1.04[d]	-	0.78[c]	2.42	-
3	Upper	0.66[c]	1.27	-	0.30	2.06	-
	Center	0.67[c]	1.47	-	0.69[c]	1.96	-
	Lower	0.76[c]	1.25[d]	-	0.47	1.87	-

a Screen 1 is the upstream screen; Screen 3 is nearer the fish return.
b Upper position is 3 ft from the upstream edge of the traveling screen; center is at the screen centerline; lower is 3 ft from the lower edge of the screen.
c Approach velocity exceeds design specification (0.5 fps) by >10%.
d Sweep-to-approach ratio is less than design specifications by >10%.
e Instrument failure. No data.

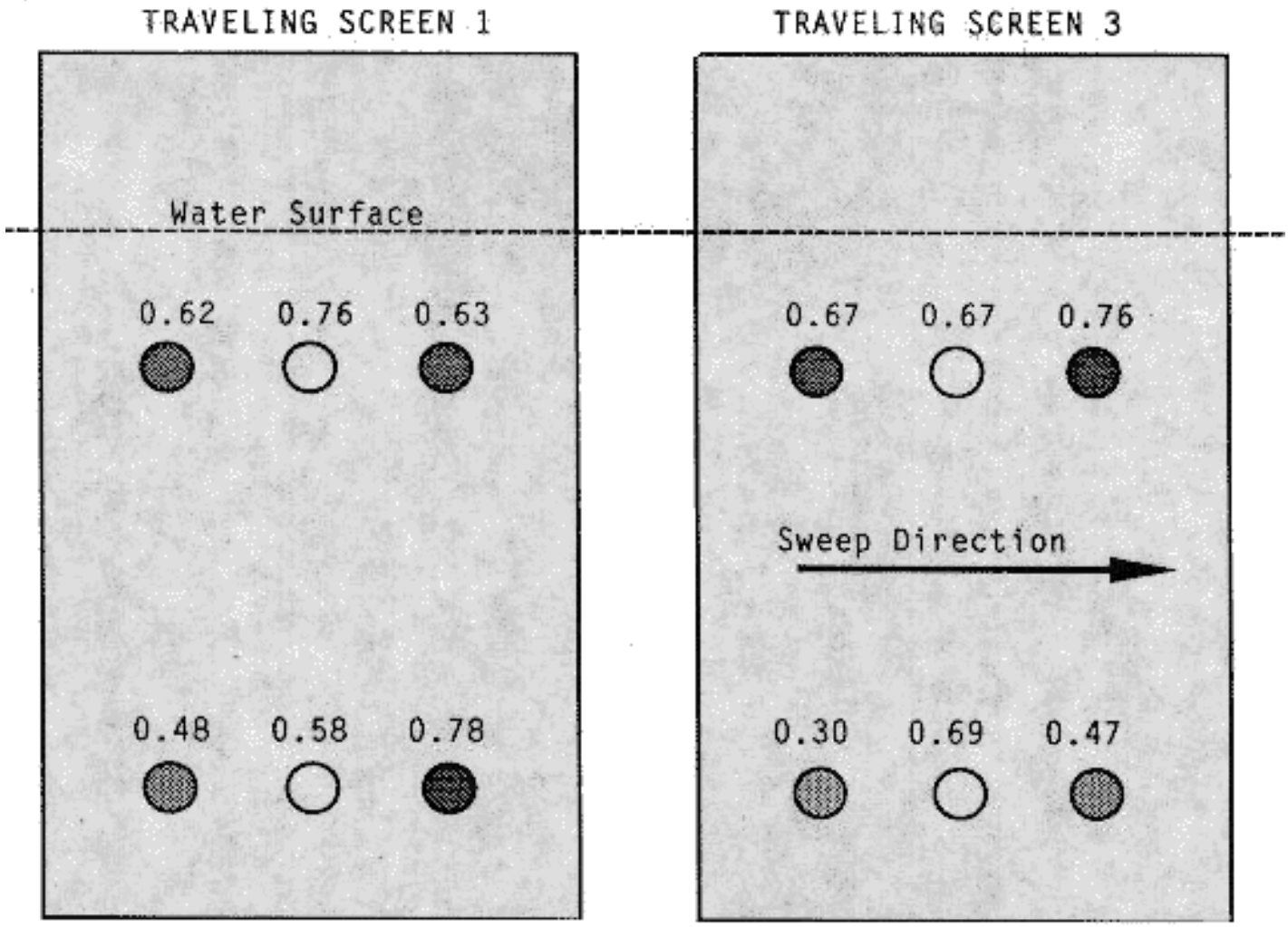

Figure 18. Approach (Impingement) velocity at the Face of the Traveling Belt Screens in the Roza Screens Separation Chamber

DISCUSSION

This study was conducted to determine if water velocities and patterns within fish screening facilities met design specifications and were conducive to effective fish bypass. Measurements were taken to determine if: 1) approach (impingement) velocities were less than or equal to 0.5 fps in front of the drum screens and vertical traveling screens; 2) sweep velocities were adequate to guide fish toward the fish return and maintain a sweep-to-approach velocity ratio of 2:1; 3) discharges through components of fish bypass systems were adequate and balanced when set to operating criteria specifications; and 4) site-specific structures and/or operations altered flow patterns that could affect bypass efficiency. Velocity studies were conducted at six screening facilities, ranging from small canals with simple fish return pipes and flows as low as 50 cfs to large canals with flows up to 2000 cfs and complex bypass systems that include guidance walls, fish bypass pipes, vertical traveling screens, and pumpback systems.

SWEEP AND APPROACH VELOCITY IN FRONT OF THE ROTARY DRUM SCREENS

Sweep velocities indicate downstream movement, or movement parallel to the screen face and in the direction of the fish return. Several structural features of the screen forebays appear to affect sweep velocity. Inadequate or unbalanced sweep velocity can affect the sweep-to-approach ratio and provide habitats where either downstream migrant salmonids or their predators could congregate.

Approach velocities indicate lateral movement, or movement that is perpendicular to the screen face (impingement). Structural features that decrease sweep velocity usually cause an increase in approach velocity as well, which can result in a poor sweep-to-approach velocity ratio.

Fisheries evaluations at existing screen sites in the Yakima River Basin have demonstrated that fish are effectively bypassed without significant injuries or delays (Neitzel et al. 1985, 1986, 1987). However, approach velocity measurements offer the best source of data for identifying potential trouble spots at screening facilities and evaluating whether a screening facility meets the specified velocity criteria. Attempts to improve sweep and approach velocity conditions in identified problem areas should be considered in the design of future screen facilities.

Forebay Configuration

In all the screening facilities we evaluated, except the Roza Screens, the new screen sites have been installed in an existing canal channel. Generally, the screen forebays are wider than the canal to accommodate the large number of screens used in the angled screen design. The new screening facilities link up to the existing canal behind the screens, forming a dogleg in the canal with the screens on the inside of the bend. Sweep velocities are consistently lower in front of the screen at the head end of each facility (Screen 1), resulting in a lower sweep-to-approach ratio. At the Roza Screens, five bays of screens with five to seven screens per bay are constructed in a saw-tooth arrangement, with the front of the screens facing upstream. The sweep velocity is higher in front of Screen 1 than subsequent screens, because the screens are located on the outer bend of the dogleg. After the canal flow is "bent" to run parallel to the screen faces, sweep velocity becomes more stable.

Approach velocities are generally slightly higher in front of the screen at the head end of a facility (Screen 1), again as a result of canal flows that have not fully stabilized. However, an abnormally low approach velocity is possible, as in the case of the Sunnyside Screens, where screens 1 and 2 have been stoplogged shut because negative approach velocities were observed in 1985. The combination of low sweep velocity and high approach velocity car result in poor sweep-to-approach ratios. At Westside Ditch and Richland Canal, approach velocity can equal or exceed sweep velocity in front of Screen 1. At Columbia Canal and Roza Canal, the convergence of sweep and approach velocity is slight. No measurements were taken in front of the first screen at Wapato Canal because it was not in operation.

Drum Screens

The standard hydraulic measurements for evaluating velocity in a channel are taken at 0.2 and 0.8 of the water depth. The curved surface of a drum screen dictates how close the sensors can be positioned relative to the screen face. Because screens are not fully submerged during normal operation, the 0.2 depth is just above the centerline of the screen, and consequently the probe can be positioned close to the screen face. However, the 0.8 depth is well below the centerline of the drum screen, and the probe can be as far as 30 in. from the screen face at facilities with large screen diameters, such as the Roza Screens.

Based on comparisons of measurements at each site, sweep and approach velocities at the 0.2 depth are often similar, although not identical, to those at the 0.8 depth. Sweep velocity at the 0.8 depth is higher than at the 0.2 depth at the Sunnyside and Wapato screens and lower at the Westside Screens, and approach velocity at the 0.8 depth is higher than at the 0.2 depth at the Westside and Columbia screens and lower at the Richland Screens.

Additional measurements were taken at 0.05, 0.5, 0.8, and 0.9 depths (probes positioned near the screen face) at the Richland, Wapato, and Roza screens to evaluate if values obtained from the standard hydraulic measurements at 0.2 and 0.8 depths accurately describe conditions near the screen face and to verify velocity conditions under the curvature of the screens. Values at 0.05 and 0.5 depths are similar to and thus represented by the standard measurements; however, data collected near the screen face under the curvature of the screen (0.8a and 0.9 depth measurements) shows that velocity values may differ significantly from values obtained at 0.8 depth.

Sweep and approach velocity values may be affected by the position of the screen in relation to the forebay floor. The screens in the Richland Canal are set on top of a 12-in.-high sill. Sweep velocities are similar at 0.8 and 0.8a depths. but are higher at 0.9 depth. The higher sweep velocity at 0.9 depth may be the result of the open channel below the screens where friction along the screen face and the forebay floor and screen wall foundations does not hinder sweep velocity. Approach velocity under the curvature of the screens is similar to the 0.8 depth value, except at the upper end of Screen 1. However, approach velocity is higher in the upper quadrant of each screen than at the center or lower quadrant, indicating that the concrete walls between screen bays affect approach velocity.

The screens at Wapato Canal are mounted on a 6-in.-high bottom seal, or nearly flush with the forebay floor. Sweep velocities at 0.8a and 0.9 depths are generally lower than at 0.8 depth. The lower sweep velocity under the curvature of the drum may be the result of friction on the screen face and forebay floor or may be a function of screen bay wall foundations in the narrow channel under the screens. Approach velocity at 0.8 and 0.9 depths is greater than at 0.8 depth and usually exceeds design specifications. However, the additional measurements at 0.8a and 0.9 depths were taken only on screens near wing walls and fish bypasses and not along the entire length of the screening facility.

The screens at Roza Canal are set 2 ft below the level of the forebay floor, which is contoured to the shape of the screen, sloping downward at the perimeter of the screens, then leveling off under the screens. Sweep velocity at 0.8 and 0.8a depths are nearly equal, and values at 0.9 depth are somewhat higher. However, approach velocity under the curvature of the drum screen is greater than at 0.8 depth and exceeds design criteria. Measurements at 0.8a and 0.9 depths were taken only at screens 6 and 7 (near the fish bypass) and not along the entire length of the screening facility.

Fish Bypass Entrance and Wing Walls

Larger screening facilities, such as the Sunnyside and Wapato screens, incorporate intermediate bypasses and wing walls to prevent fish from contacting the entire array of screens during guidance to the fish bypass. Our measurements show that wing walls dramatically disrupt sweep velocity, especially in front of the screen immediately downstream of the wing wall. At the Sunnyside Screens, sweep velocity is reversed or reduced in front of Screen 9, depending on the depth; however, approach velocities are not affected. Additionally, flow appears to be bottlenecked because of the wing wall and intermediate bypass, as demonstrated by reduced sweep velocities in front of Screen 8 (above and inside the wing wall). At the Wapato Screens, sweep and approach velocity are altered below each of the intermediate bypasses, resulting in poor sweep-to-approach

ratios and approach velocities that exceed design specifications. However, flows do not appear to bottleneck inside the wing walls at the Wapato Screens as was observed at the Sunnyside Screens.

The angle and/or length of the wing wall may be a factor affecting wing wall performance. The wing walls at Wapato are longer than at the Sunnyside Screens. Disruption of the sweep velocity is only momentary at both sites; sweep velocity returns to normal within one screen length.

SWEEP AND APPROACH VELOCITY IN THE FISH BYPASS SYSTEM

Adequate bypass flows are essential to guide fish into and through the fish bypass system. Balanced flow through various components of the bypass system ensures favorable bypass conditions for fish. In facilities with multiple fish bypasses, more flow is required to achieve adequate sweep velocity through each fish bypass than is necessary to provide effective bypass through the fish return pipe. Excess bypass flow can be utilized for irrigation by the use of pumpback systems that withdraw water through traveling screens in the separation chamber.

Approach and sweep velocity parameters are just as important in front of traveling belt screens as in front of rotary drum screens. An approach velocity of >0.5 fps at the face of the traveling screens can result in impingement. Sweep velocities are important for maintaining an adequate sweep-to-approach ratio for guiding fish to the fish return pipe. Areas within the separation chamber with low sweep velocities can provide habitat for predators.

Fish Bypasses

Based on sweep velocity measurements taken at the upstream end of fish bypasses, discharge through intermediate bypasses is less than discharge through the terminal bypass at the Sunnyside and Wapato screens, although flow control gates were set to the operating criteria specifications at both sites during our studies. The unbalanced discharge may be the result of greater resistance in intermediate bypass pipes than was observed in models used in facility design. Unbalanced bypass discharges may affect flow patterns and fish passage efficiency in the separation chamber. An adjustment to the flow control gate settings listed in the operating criteria may correct the problem. However, no apparent problem exists with respect to passage through bypass pipes. No injuries or other adverse effects were observed to be caused by passage through intermediate or terminal bypasses during fisheries evaluations at the Sunnyside and Wapato screens (Neitzel et al. 1985, 1987).

Separation Chamber

Measurements across the width of the separation chamber indicate that sweep velocity is not uniform and may be dependent on the location and orientation of, and volume of discharge through, components of the fish bypass system. Extreme variations in sweep velocity occur (from -1.6 to >7.0 fps). This suggests that areas exist within the separation chamber where fish, either predators or prey, could reside. Sweep velocity also varies in relation to depth. Sweep velocity is consistently lower at 0.8 of water depth in the Sunnyside Screens separation chamber, and at 0.2 of water depth in the Wapato and Roza screens separation chambers. The sweep velocity patterns observed in the separation chamber are related to the depth and orientation of the fish bypasses, and can persist through the entire length of the separation chamber.

The highest sweep velocities in the separation chamber are generally near the face of the traveling screens, resulting in a high sweep-to-approach ratio. Fish that followed the dominant flow pattern during transit through the separation chamber would likely be directed near the face of the traveling screens. A uniform sweep velocity throughout the separation chamber would result in fewer fish passing directly in front of the traveling screens, and areas where potential predators could reside would be diminished.

The variation in approach velocity at the face of traveling screens suggests that water is not drawn equally through all portions of the screen, especially in front of traveling screens at the Sunnyside Screens. Turbulent flow conditions in the upstream end of the separation chamber may adversely affect approach velocity in front

of the traveling screens. Unequal velocities also occur at the face of the traveling screens at the Wapato Screens, where wastewater passes over flow control gates and the pumps are not operated. The flow patterns in the separation chamber at the Roza Screens are less turbulent, and approach velocity at the face of the traveling screens is more uniform.

Fish Return

Sweep velocity in the fish return is dependent on sweep velocity parameters in the separation chamber just upstream of the entrance to the fish return. In order for the fish return to draw water equally from all depths, sweep velocities in the separation chamber must also be equal from the surface to the bottom.

SUMMARY

Velocity measurements were conducted at six fish screening facilities in the Yakima Basin: the Columbia, Richland, Westside Ditch, Sunnyside, Wapato, and Roza screens. Our objective was to determine if velocity parameters in front of the rotary drum screens and within components of the fish bypass system were consistent with design specifications necessary to promote effective fish bypass. The objective was addressed by evaluating if: 1) the approach (impingement) velocity was less than or equal to 0.5 fps at the face of rotary drum screens and traveling belt screens; 2) the sweep velocity in front of the screens was sufficient to provide a 2:1 sweep-to-approach velocity ratio; 3) fish bypass flows were balanced and sufficient to direct fish toward the fish return pipe; and 4) operating criteria were successful in providing effective fish passage conditions.

COLUMBIA SCREENS

Velocity measurements taken during full canal flow conditions indicated that the approach velocity slightly exceeds design specifications. Sweep-to-approach velocity ratio in front of the drum screens is adequate. Approach velocity in front of each drum screen is uniform, and stoplog configuration behind the drum screens (upper half of screen bay closed off) do not significantly alter approach velocity at the face of the drum screens. Fish return flows were adequate at peak canal flow.

RICHLAND SCREENS

The canal flow at the Richland Screens could not be determined, but appeared to be much less than the full canal flow. The approach velocity at the face of the drum screens was generally within design specifications; however, approach velocities would undoubtedly be higher at peak canal flow. Approach velocities were higher under the curvature of the drum screens at the upper end of each screen. Comparable approach velocity in front of each screen indicated canal discharge was equally distributed among the four screens. Sweep-to-approach velocity was acceptable throughout most of the facility. Excessive fish return discharge may have resulted in higher sweep velocities than could be expected when fish return discharge is set in accordance to the operating criteria. Mounting drum screens on top of a 12-in. sill may improve sweep-to-approach velocity ratios under the curvature of the drum screen.

WESTSIDE DITCH SCREENS

Velocity measurements taken during full canal flow conditions indicated that the approach velocity and sweep-to-approach velocity ratio in front of the drum screens met design specifications. Approach velocity in front of the four screens is not uniform, indicating that stoplogging behind the screens may be necessary to balance discharge through the screens. The close proximity of the guidance wall did not affect approach velocity at the last drum screen. The low fish return flow was the result of improper stoplogging during velocity measurement preparation; however, adequate fish return flows appear to be achievable.

SUNNYSIDE SCREENS

Velocity measurements taken under nearly full canal flow conditions indicated that approach velocity slightly exceeded the design specifications. Sweep-to-approach velocity was acceptable except where disrupted by the intermediate wing wall. Approach velocity in front of each drum screen indicated that the present stoplog configuration distributes discharge evenly among the 15 operational screens. Total bypass flow was adequate; however, the flow was not equally distributed between the two fish bypasses, with less discharge through the intermediate bypass.

Sweep velocity in the separation chamber was dominated by the terminal fish bypass discharge that enters at the surface of the separation chamber. High sweep velocity occurred at the surface and near the traveling screens, and low sweep velocity occurred near the bottom and along the outer wall of the separation chamber. Approach velocity was not uniform on the face of the traveling screens with areas of each screen exceeding

design specifications. Fish return flow was adequate, although more water enters the fish return from the surface than from the bottom of the separation chamber.

WAPATO SCREENS

Velocity measurements taken under full canal flow conditions indicated that approach velocity equaled or slightly exceeded the design specifications. Excessive approach velocity occurred under the curvature of the drum screens. The sweep-to-approach velocity ratio was adequate in front of most screens, but was poor at the downstream end of the facility (in front of screens 14 and 15) and under the curvature of screens immediately downstream of wing walls (screens 6 and 11). The low ratio was a result of both high approach and low sweep velocities.

At 65% of peak canal flow, approach velocities still slightly exceeded design specifications at the 0.8 depth; however, approach velocity at the 0.2 depth was proportionally lower than during peak canal flow. Sweep velocity was also proportionally lower at both depths. Stoplog configuration behind the drum screens may affect flow patterns during lower canal flow because of the accompanying lower canal surface elevation. The effect of floating net pens on velocity patterns within the screen forebay could not be determined because of the substantial difference in canal flow during our two sampling sessions.

Flow through the fish bypasses was adequate but not balanced. The sweep velocity in bypass 3 (terminal bypass) was higher than in the two intermediate bypasses. Sweep velocity in the separation chamber was not uniform. A negative sweep velocity (eddy) in the upstream end of the separation chamber provides a habitat where potential predators or downstream migrant salmonids could reside. Sweep velocity was lower at the surface than at the bottom of the separation chamber, and velocities near the bottom increased in the downstream end of the separation chamber.

Discharge through the traveling screens was not balanced. The pumps behind the traveling screens are not operated under normal conditions, and balanced discharge is achieved by visually adjusting overflow gates. Approach velocity was low in front of traveling screen 1 and high in front of traveling screen 2, although a high sweep velocity provided an adequate sweep-to-approach ratio in front of the screens. Fish return flow was adequate, although most of the water entered the fish return near the bottom.

ROZA SCREENS

Velocity measurements taken under full canal flow conditions in the first screen bay indicated that approach velocity in front of the drum screens slightly exceeded the design specifications, and was highest in front of Screen 1. Sweep velocity throughout the forebay was low and contributed to a low sweep-to-approach ratio in front of all screens. Sweep velocity in the fish bypass indicated an adequate flow, with water drawn equally from the surface and the bottom.

Sweep velocity in the separation chamber was greater near the bottom than at the surface; however, the flow was much more uniform than we had observed in separation chambers at the other sites. Approach velocity at the face of the traveling screens was uniform, but slightly exceeded design specifications. Additionally, the sweep-to-approach ratio was lower than design specifications near the surface. Fish return flow was adequate, and water was drawn equally from the surface and the bottom.

RECOMMENDATIONS

Although fisheries evaluations conducted by PNL at four of the six sites have not identified any major design problems resulting in mortality, injury, or delay to migrating fish, these hydraulic studies indicate that velocity conditions could be improved at some of the sites through modification of operating criteria or adjustment of the existing facilities. Furthermore, these studies suggest that additional flow modeling might be required to address and resolve common velocity condition problems to provide information for the design of similar facilities in the future.

The shape and configuration of the forebay structure can result in poor velocity conditions in front of the first (upstream) screen. Canal flow should be stable and parallel to the screen structure before reaching the first screen. Sweep and approach velocity anomalies at the head end of the screen structure could be reduced if flow were more parallel and the straight-sided wall immediately upstream of the first screen were contoured similar to the walls between the screen bays. However, it would be very expensive to retrofit existing screen facilities to control flow parameters this precisely, and the potential benefit to fish is small. Reduced discharge through one screen may not be a significant problem at larger facilities; however, at smaller facilities with few screens, a reduced discharge through the first screen could result in a significant increase in discharge through other screens, affecting approach velocities and performance of other screens.

Stoplogging behind individual screens appears to be an effective method of balancing discharge among screens and reducing silt buildup in the screen bays. However, optimum stoplog configurations may be different during periods of reduced canal flow when canal surface elevations are lower. Our studies indicate that stoplogging might be necessary to balance discharge through the screens at Westside Ditch and to reduce the discharge through the first screen in the first bay at the Roza Screens. Although only one of the five bays was evaluated at Roza Screens, stoplogging may be necessary elsewhere at the facility. When stoplogs are used, a 12-in. gap is usually left at the bottom to prevent silt buildup. Increased approach velocity under the curvature of the drum screens may be the product of a high volume of water passing through the lower portions of the drum screen. Reducing the stoplog gap to the minimum required to prevent siltation might reduce the approach velocity under the curvature of the drum screens, especially during periods when canal surface elevations are low.

The most dominant structural feature affecting velocity conditions in front of the screens is the intermediate wing wall. The purpose of a wing wall, from a fisheries standpoint, is to prevent migrating fish from coming into contact with all the drum screens at a large screening facility by directing fish into an intermediate bypass. No signs of mortality, descaling, or other injury attributable to screen contact have been observed in previous fisheries evaluations. However, hydraulic studies show that wing walls can dramatically affect sweep and approach velocity in front of the drum screens, especially on the screen just downstream of the wing wall. Additionally, our data show that discharge through intermediate bypasses is less than discharge through the terminal bypass. Flow gate adjustments and modification of operating criteria are required. Hydraulic forces, such as resistance in bypass pipes or head level in the separation chamber, may make discharge balance difficult to achieve. If wing walls and intermediate bypasses do not significantly improve fish passage, fish bypass systems could be simplified, reducing the construction and operating costs of screening facilities designed in the future.

Our studies indicate that the least desirable velocity conditions at a fish screening facility occur in the separation chamber. High approach (impingement) velocity can occur at the face of the traveling screens, and nonuniform sweep velocity can provide habitat for predators. Flow adjustment to achieve balanced discharge through intermediate and terminal bypasses may improve sweep and approach velocity parameters in the separation chamber; however, dominant flow patterns may also be altered. Velocity measurements should be repeated in separation chambers at the Sunnyside and Wapato screens if bypass discharges are significantly changed, to determine how bypass discharges affect conditions in the separation chamber. Additionally, discharge should be balanced through the two traveling screens at the Wapato Screens. Gauges should be installed on flow gates 5 and 6 (behind the traveling screens) to aid operations personnel in maintaining a balanced discharge between the two traveling belt screens.

Our measurements in the first bay at the Roza Screens indicate that stoplogging may be required at the first screen in that bay; however, the other four bays were not evaluated. If stoplogging is under consideration at the Roza Screens, measurements should be taken in the other bays to determine where stoplogs are needed.

Additionally, all five fish bypasses should be measured to check for balanced discharges.

Velocity measurements made during complete surveys indicate that many of the measurements taken were not necessary. Vertical velocity measurements had little utility except during measurements in the separation chamber. Measurements in front of the drum screens at 0.05 and 0.5 depths did not provide any unique information, and should be dropped in future velocity monitoring studies. Velocity measurements under the curvature of the drum screen are often different from velocity measurements obtained using the standard 0.8 depth measurement that is not near the drum screen face, and provide a more accurate estimate of impingement velocity at the screen face. In most instances, velocity measurements at the 0.9 water depth were comparable to measurements at the 0.8a water location. Therefore, the 0.9 depth measurement could also be abandoned in future monitoring programs. However, velocity measurements at the 0.8a location provide valuable information and should be considered as a replacement for or supplement to the standard 0.8 depth readings at rotary drum screening facilities.

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