EVALUATION OF JUVENILE SALMONID BYPASS FACILITIES AND PASSAGE AT WATER DIVERSIONS ON THE LOWER UMATILLA RIVER

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ABSTRACT

Outdated juvenile and adult fish passage facilities were recently reconstructed at the five major irrigation dams on the lower Umatilla River, Oregon to meet National Marine Fisheries Service (NMFS) design standards. Changes in design at juvenile fish bypass facilities included reduced mesh size on the rotating drum screens, larger screening area, a more oblique orientation of the drum screens to canal flow, improved screen seals, replacement of bypass portals with vertical slot bypass channels, and increased bypass pipe diameters. Weir-and-pool adult fish ladders and jump pools were replaced with vertical-slot ladders. From 1991-1995, we investigated injury and travel rate of juvenile fish moving through the facilities, and efficiency of screens in preventing fish entry into the canals. Uater velocities in front of canal screens, at bypass channel entrances, and at ladder diffusers were measured to assess adherence to NHFS criteria and identify hydraulic patterns. Biological evaluations were conducted by releasing and recapturing marked yearling summer steelhead (Oncorhynchus mykiss), yearling spring chinook salmon (0. tshawytscha), and subyearling fall chinook salmon (0. tshawytscha) in varying locations within the fish passage facilities. Most test fish passing through bypass facilities and fish ladders incurred insignificant or negligible injury ($P > 0.10$). Significant injury at West Extension Canal ($P = 0.006$) and Feed Canal (P - 0.01) bypasses was probably a result of sampling error and handling injury, respectively. Subyearling fall chinook salmon were injured in the passage section of the east-bank fish ladder at Three Hile Falls Dam ($P = 0.04$) and in the auxiliary water system of the fish ladder at Uestland Dam ($P = 0.05$). Respective descaling and mortality rates for subyearling fall chinook salmon were 19.2% and 3.2% at the Three Mile Falls Dam ladder, and 1.4% and 0% at the Uestland Dam ladder. Hidchannel diffusers probably caused most of the descaling at both sites; the slot-and-pool segment of the passage section caused most of the mortality at Three Mile Falls Dam. Movement of subyearling fall chinook salmon was slower near drum screens (62 m/h) than in the headworks canal (485 m/h) at Furnish Canal. Short delays were associated with the headgates and outfall at West Extension Canal and the bypass pipe at Uestland Canal. Extensive delay was associated with the uppermost midchannel diffuser in the passage section of the east-bank fish ladder at Three Mile Falls Dam. Screening efficiencies of drum and vertical belt screens were greater than 99.7% and 99.4%, respectively. Impingement of test fish on the vertical belt screen at West Extension Canal was less than 0.7%. Approach velocities in front of drum screens are expected to meet criteria for smolt protection (I 0.24 m/s) and exceed criteria for fry protection (I 0.12 m/s) at maximum canal flow expected from March through May. Highest approach velocities were usually measured at screens near the bypass channel. Sweep to approach velocity criteria (> 2:l) was met at all sites except Haxwell Canal, where sweep velocities were low (0.08-0.16 m/s) at the screen furthest from the bypass channel. Water velocities at bypass channel entrances ranging from 0.58-0.82 m/s met criteria. Water velocity in front of the vertical belt screen at West Extension Canal met criteria when both 0.28 m /s-pumps were on or the pumpback bay drain pipe was 20% open. Direction and magnitude of flow approaching ladder diffuser panels was variable. In general, current designs of bypass and ladder facilities on the lower Umatilla River safely and quickly pass juvenile salmonids. However, some facility components pose passage problems for juvenile fish. Regular maintenance and proper operation of facilities, and minor modification of facility structures are recomnnded.

Designs for adult fish ladders should include consideration of juvenile fish passage.

INTRODUCTION

Large runs of salmon (Oncorhyncus spp.) and steelhead (0. mykiss) once supported productive fisheries in the Umatilla River, Oregon. By the 1920s, dams with inadequate adult fish passage facilities, unscreened canals, diversion of river flow for irrigation, and habitat degradation had extirpated the salmon runs and drastically reduced the steelhead run (ODFW and CTUIR 1989). However, a comprehensive fisheries rehabilitation program was initiated in the mid-19803 under the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program (1987). The rehabilitation plan included improved fish passage facilities, enhanced river flow, rehabilitation of fish habitat, and increased hatchery production (Boyce 1986). Salmon runs in the Umatilla River are presently sufficient to provide a fishery in most years, but they are still below long-range production goals (ODFW and CTUIR 1990).

Five major irrigation dams in the lower river had outdated fish passage facilities. Rotating drum screens at the fish bypass facilities had a high potential for fish leakage and impingement due to their small size, perpendicular orientation to canal flow, and large mesh openings. Also, small bypass portals (0.15 m diameter) and vertical slots (0.15-0.20 m wide) were conducive to passage delay and fish injury when occluded-with debris. Adult passage facilities at the dams were also ineffective. The tallest and lowermost dam (Three Mile Falls) was the most significant barrier to adult migrations. Poor attraction to an overflow-weir ladder on the east bank and a vertical-slot ladder on the west bank presented passage problems at all river flows (Boyce 1986). Silt and debris accumulation and lack of self-regulating flow were additional problems for the overflow-weir ladder. Smaller dams upriver were barriers to adult fish migration at low and moderate river flows due to shallow pool depths below the dams.

Juvenile and adult fish passage facilities were reconstructed at the five irrigation dams between 1988 and 1994. The state-of-the-art facilities were intended to correct potential fish leakage, impingement, delay, and injury problems. Rotating drum screens were enlarged and re-orientated at an oblique angle to canal flow, and screen mesh openings were reduced. Bypass systems were replaced with larger, vertical slot channels coupled with a weir for flow regulation and larger diameter pipes for returning fish to the river. Vertical-slot adult fish ladders were constructed at most dams to improve adult fish passage.

Bypass facility designs have improved incrementally over the years in response to information gained from facility evaluations, operational experience, hydraulic modeling, and laboratory experiments (Easterbrooks 1984, Rainey 1985, Taft 1986, Bates 1988, Pearce and Lee 1991). Evaluations of rotating drum screen systems are largely reported in technical literature. Taft (1986) sumnarized operational experiences and unpublished evaluations of twenty-two facilities that utilize rotating drum screens. More recently, evaluations have been conducted at rotating drum screen systems at irrigation diversions on the Yakima River, Washington (Neitzel et al. 1985, 1987, 1988, 1990a, 1990b, 1991; and Hosey and Associates 1988a, 1988b, 1989, 1990; Abernethy et al. 1989a, 1989b) and Sacramento River, California (Cramer 1992). These studies found that rotating drum screen systems designed according to current criteria are usually highly effective at quickly returning migrating juvenile salmonids to the river unharmed. However, intermittent natural events such as floods or freezes can reduce facility effectiveness. Maintenance of key facility components was also essential for proper operation. This information has allowed the National Marine Fisheries Service (NMFS) in conjunction with state fisheries agencies to update and fine-tune criteria for the design and operation of fish bypass facilities (NMFS 1989, 1990).

Design criteria for fish ladders has almost exclusively been based on requirements for upstream-passage of adult fish (Clay 1961, 1995; Bell 1986; Orsborn 1985). However, fish ladders also provide juvenile salmonids an alternate downstream passage route at dams. Nevertheless, few studies have been conducted on downstream passage of juvenile salmonids through adult fish ladders. Studies were conducted at dams on the North Fork Clackamas River, Oregon (Gunsolus and Either 1970). and South Cow Creek,.California (Moock and Steitz 1985) where fish ladders are used as the primary bypass system. These studies documented percent recapture of juvenile salmonids passing through the fish ladders but did not determine whether fish were injured.

from 1991 to 1995, we conducted studies to evaluate whether juvenile salmonids are able to safely and quickly pass through reconstructed juvenile fish bypass and adult fish ladder facilities associated with major irrigation dams on the lower Umatilla River, Oregon. Using mark-recapture methodologies, we assessed I) facility-caused injury, 2) rate of travel and recapture, and 3) screen efficiency (leakage) and impingement (rollover). We also measured water velocities at key facility locations to determine whether velocities were within NMFS criteria. Our studies were modeled after evaluations conducted in the Yakima River basin to provide a comparable data base.

STUDY SITES

Studies were conducted at juvenile fish bypass facilities and adult fish ladders associated with the five major irrigation canals and dams on the lower Umatilla River (Figure 1). Fish bypass facilities are constructed within West Extension Canal at Three Mile Falls Dam, Haxwell Canal at Haxwell Dam, Uestland Canal at Uestland Dam, Feed Canal at Feed Canal Dam, and Furnish Canal at Stanfield Dam. All dams are approximately 1 m in height, except Three Hile Falls Dam which is 7.3-m high. Maximum canal withdrawals range from 2-9 m^3/s at the study sites (Table 1). Most canals deliver water to irrigators from mid-March to early October, with peak demand in May, June, and July. Feed Canal is operated near maximum capacity from November to May to fill a storage reservoir.

Fish bypass facilities are built into irrigation canals to quickly return fish to the river unharmed. They are usually located near the point of water diversion to minimize the time fish spend in the canal. However, topographic constraints at Maxwell and Furnish canals resulted in construction of bypass facilities 2,425 m and 985 m from the point of diversion, respectively (Table 1). The basic components of fish bypass systems include 1) screens to exclude

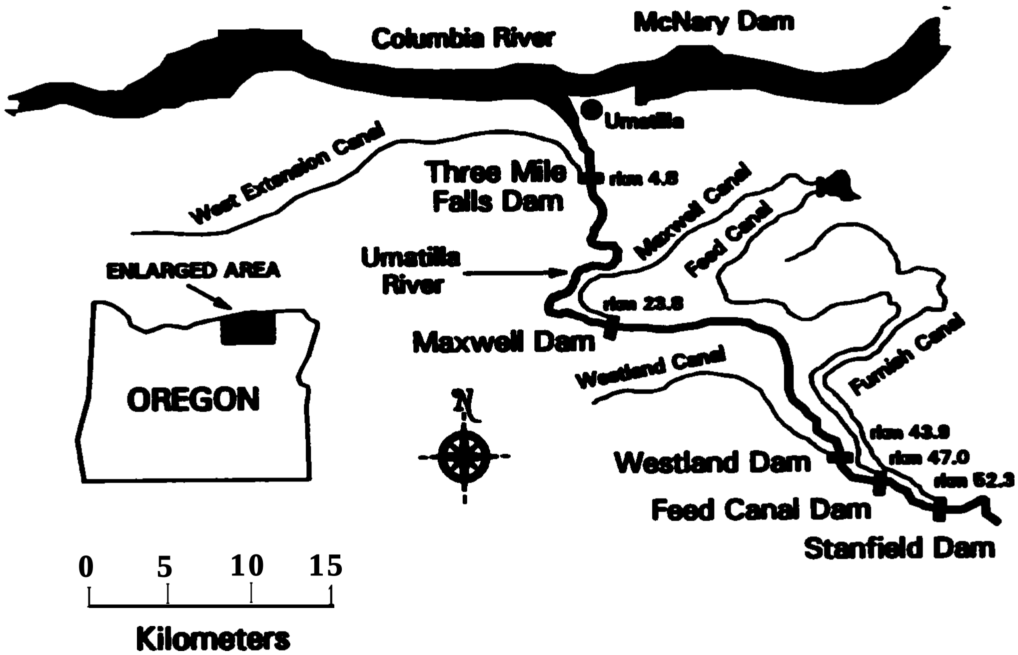


Figure 1. Location of irrigation dams and canals on the lower Umatilla River, Oregon.

fish from the canal, 2) a bypass channel at the downstream end of the screens that provides fish an exit mute from the screen forebay, 3) a weir and stilling chamber (downwell) in the bypass channel to regulate bypass flow, 4) a bypass pipe at the downwell for returning fish to the river, and 5) an outfall or submerged outlet structure at the terminus of the bypass pipe (Figure 2).

Rotating drum screens are utilized at fish bypass facilities on the lower lhatilla River because they perform well in waters with high debris loads and temperatures above freezing. The bypass facilitieswere designed with varying numbers and sizes of screens to provide enough surface area when screens are 80% submerged to prevent approach velocities from exceeding 0.15 m/s at maximum canal withdrawal. The screens are constructed of-stainless steel wire cloth, with 3.2-a^{2} openings, riveted to a spoke-and-wheel frame (Figure 3). They are mounted on metal frames and deployed into guides in concrete support structures. Gaps between the screen and frame are sealed with 6.4-mm-thick strips of rubber (89-102 A wide) extending from the sides and bottom of the frame (flat seal). At West Extension Canal, solid-bulb seals (9.5 mm thick) are used to seal the sides of large diameter screens. Gaps between the bottom of the screen frame and canal bottom are sealed with a hollow-bulb or flat seal. At Furnish Canal, plastic wedges were installed in the frame guides to facilitate gap closure between the frame and guide.

Table 1. Specifications of fish bypass facilities at irrigation canals on the lower Umatilla River. Oreaon.

Canal	Maximum[a] canal flow (m^3/s)	Distance from headgates to bypass (m)	Drum screens Number	Length (m)	Diameter (m)	Angle to flow (°)	Byoass flow Normal (m^3/s)	Low (m^3/s)	Bypass pipe Length (m)	Terminus
West Extension	5.1	39	4	3.7	2.4	15	0.71	0.14	73	outfall
Haxwell	1.7	2,425	3	3.7	1.2	25	0.25	0.06	69	outfall
Uestland	9.3	100	10	3.8	1.8	16	0.74	0	213	outlet
Feed	6.9	212	10	3.7	1.7	16	0.51	0.16	a9	outlet
Furnish	4.3	985	7	3.8	1.5	24	0.57	0.42	140	outlet

a *Maximum canal flows reported in fish passage facility predesign memorandums.*

Drum screens are orientated at a 15-25° angle to canal flow to guide fish toward the entrance of the bypass channel (Table 1). Bypass channels at the sites are 0.61 m wide, vary from 0.9-1.8 m in depth, and are open at top to provide natural lighting. Bypass flow is regulated by a weir at the terminus of the bypass channel. Bypass flows are reduced at most sites when river flow is low (Table 1). Spill over the bypass weir plunges into a 0.6-1.2-m-deep pool of water in the downwell (Figure 2). Downwells are rectangular in shape at all sites except Feed Canal, which has an L-shaped downwell to direct the bypass pipe toward the river. Bypass pipes are 0.61 m in diameter at all sites except Feed Canal (0.76 m diameter). Bypass pipe slopes are fairly uniform (0.6-0.8x). At Uestland Canal, a 0.69~m-diameter drain pipe from the pumpback bay and juvenile fish trap ties into the bypass pipe 44 m from the downwell. Host sites have submerged outlets with simple concrete structures that anchor the terminus of the bypass pipe. The outfall at West Extension Canal has a 7.6~m-long sloped channel at the terminus of the bypass pipe to slow water velocity, followed by a ramp that directs fish through a notched weir. Fish passing over the weir drop approximately 3.2 m into a river plunge pool.

Fish trapping facilities were incorporated into the fish bypass facilities at Uestland and West Extension canals (Figure 2). The trap at Uestland Canal is used to collect juvenile and adult fish migrating downstream during periods of low river flow. Fish are subsequently transported to the river mouth. The trap at West Extension Canal is used to sample migrating juvenile fish (Knapp and Ward 1990). During trapping operations at both

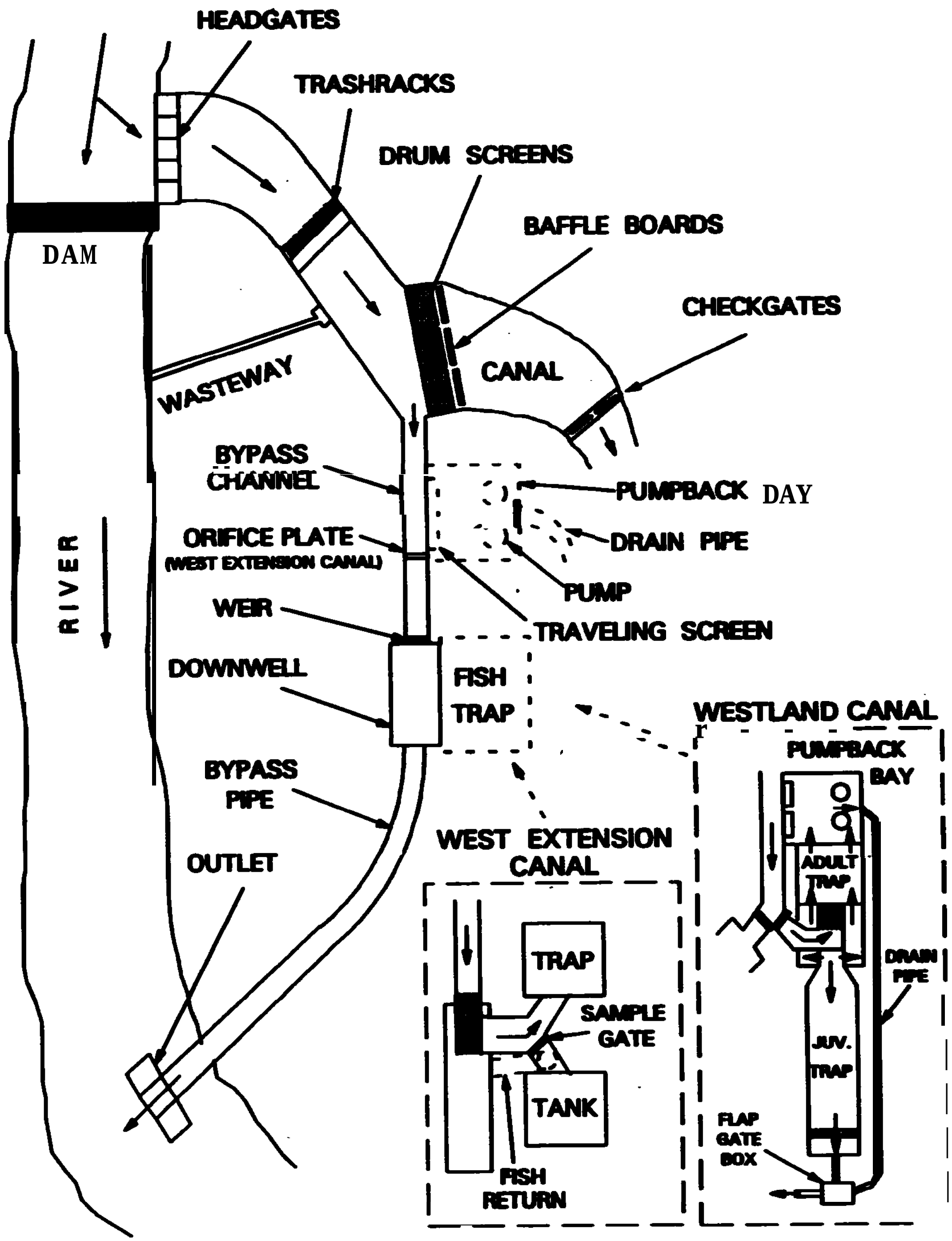


Figure 2. Generalized schematic of fish bypass facilities at irrigation canals on the lower Umatilla River, Oregon.

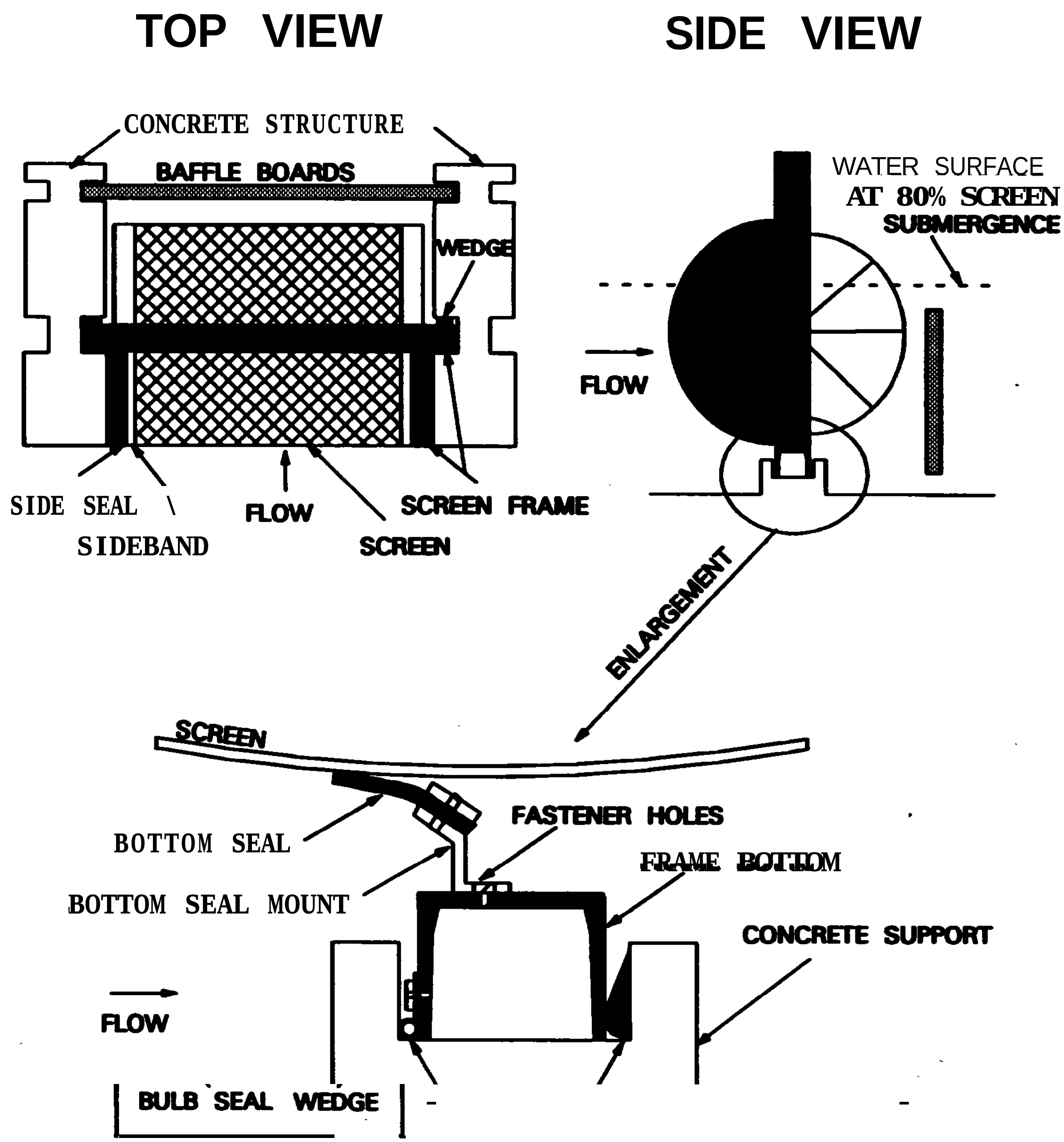


Figure 3. Generalized schematic of a drum screen used in fish bypass facilities at irrigation canals on the lower Umatilla River, Oregon.

sites, bypass flows are reduced by 80% to achieve proper water balance in the traps. Reduction of bypass flow decreases water velocity at the bypass channel entrance. Pumpback systems draw water through vertical belt screens during trapping operations to reestablish the 0.6-m/s water velocity at the bypass channel entrance that oscurs during normal bypass operations (Figure 2). At Westland Canal, 0.09 m /s of flow is drawn passively through 75-m x 762-mm orifice slots behind each of the two belt screens. The submerged portion of the belt screens are 1.2~m-wide x 1.4~m-high. Vertical belt screens are sealed with 6.4-mm-thick rubber strips along the sides and bottom. Excess water entering the pumpback bay is removed by a drain pipe or two variable flow pumps. At West Extension Canal, flow through the 2.3~m-wide x 1.9~m-high vertical belt screen is adjusted by varying pumpback operations. Normal pumpback operations include two 0.28 m^3/s-pumps operated singularly or in tandem or opening the 0.5~m-diameter pumpback bay drain pipe 20% (0.4 m^3/s), 30% (0.5 m^3/s), or 40% (0.8 m /s).

Several key structures are primarily associated with canal operations. Canal flow and elevation is regulated by adjusting the openings of canal headgates and checkgates (Figure 2). Large debris is intercepted by rounded trashrack bars, with 140-11~ openings, located upstream of the drum screens or headgates. Silt accumulation at the base of drum screens is minimized by baffle boards set 152 mm downstream of the drum screens that increase water velocity near the bottom of the screens. Baffle boards usually block about 80% of the water column.

Vertical slot fish ladders were constructed at the diversion dams on the lower Umatilla River because they maintain uniform flow through the fishway over a wide range of river flows. The larger fish ladders at Westland and Three Mile Falls dams incorporate both passage and auxiliary water components to the total ladder design (Table 2; Figure 4). The passage section provides a route for fish migration; the auxiliary water section increases flow through the fish entrances for fish attraction. The original design for the fish ladder at Stanfield Dam included an auxiliary water system, but was subsequently changed to a double fishway to simplify operation.

Fish ladders on the Umatilla River have standard designs for their primary flow stabilizing structures. They are 2.4~m-wide x 3.0-m-long pools with 38-cm-wide vertical slots and a maximum hydraulic drop of 0.3 m per slot. Water depth is approximately 1.5 m in the slot and pool section. The standard 36 orientation of the slot jet centerline was used at all sites except-Three Mile Falls Dam where the slot jet is orientated at a-46 angle. Flow through the fish ladders is primarily determined by whether their high or low flow fish entrance gate (outflow) is open. All the fish ladders have high and low flow entrance gates for flow regulation, except the fish ladder at Feed Canal Dam where orifice plates are inserted at the vertical slots to reduce flow. Flow through the auxiliary water systems at Three Mile Falls and Westland dams is regulated with a weir.

Fish ladders at Three Mile Falls and Westland dams use diffuser panels and flow baffles to reduce fish attraction to the auxiliary water system (D-2 at Three Mile Falls Dam; Figure 4). Diffusers at the upper end of the passage section of the Three Mile Falls Dam fish ladder guide adult fish past a viewing window (D-3) and into a steeppass (D-l) that leads to a fish trap. Trashracks at the inflow of the auxiliary water system at both dams have the

Table 2. Specifications of fish ladders at irrigation dams on the lower Umatilla River, Oregon

Dam[a]	Ladder Length (m)	Ladder Width (m)	Pool to tail-race head differential (m)	Passage flow[b] Low (m^3/s)	Passage flow[b] High (m^3/s)	Auxiliary water flow (m^3/s)
Three Mile Falls	41.1	9.4	3.0	1.1	I.4	0.0-4.0
Uestland	32.8	5.2	1.2	1.1	1.4	0.0-4.0
Feed	9.1	2.4	0.8	NA	1.0	--
Stanfield	29.3	4.9	1.1	2.3	3.1	--

[a] No fish ladders are present at Maxwell Dam.
[b] Maximum design flow.

same design as diffusers. Trashracks at the fishway inflow consist of 76-mm-diameter bars spaced with 203-mm openings.

METHODS

Our investigations began at Three Mile Falls Dam and proceeded upriver as reconstruction of fish passage facilities was completed (Table 3). Ye conducted tests to evaluate injury, rate of travel and recapture, and screen efficiency, and measured screen and bypass channel velocities. Screen efficiency tests were not performed at Maxwell Canal. An additional test was conducted at Uest Extension Canal to ascertain fish impingement on the belt screen at varying pumpback bay operations. Injury to juvenile salmonids passing through fish ladders was also evaluated at Three Mile Falls, Uestland, Feed Canal, and Stanfield dams. Improvements in test methodology were progressively adopted throughout the five-year study.

Test Fish

Yearling spring chinook salmon, yearling summer steelhead, and subyearling fall chinook salmon were selected for injury tests because they are present in the Lhnatilla River. Mean fork lengths of fish used in injury tests ranged from 144-195 MM for summer steelhead, 124-168 mm for spring chinook salmon, and 79-91 mm for fall chinook salmon. Subyearling fall chinook salmon were used for screen efficiency and impingement tests inwediately after hatchery marking. Mean fork lengths of fall chinook salmon ranged from 57-67 mm for drum screen efficiency tests, 63-64 mm for belt screen efficiency tests, and 61-71 mm for belt screen impingement tests.

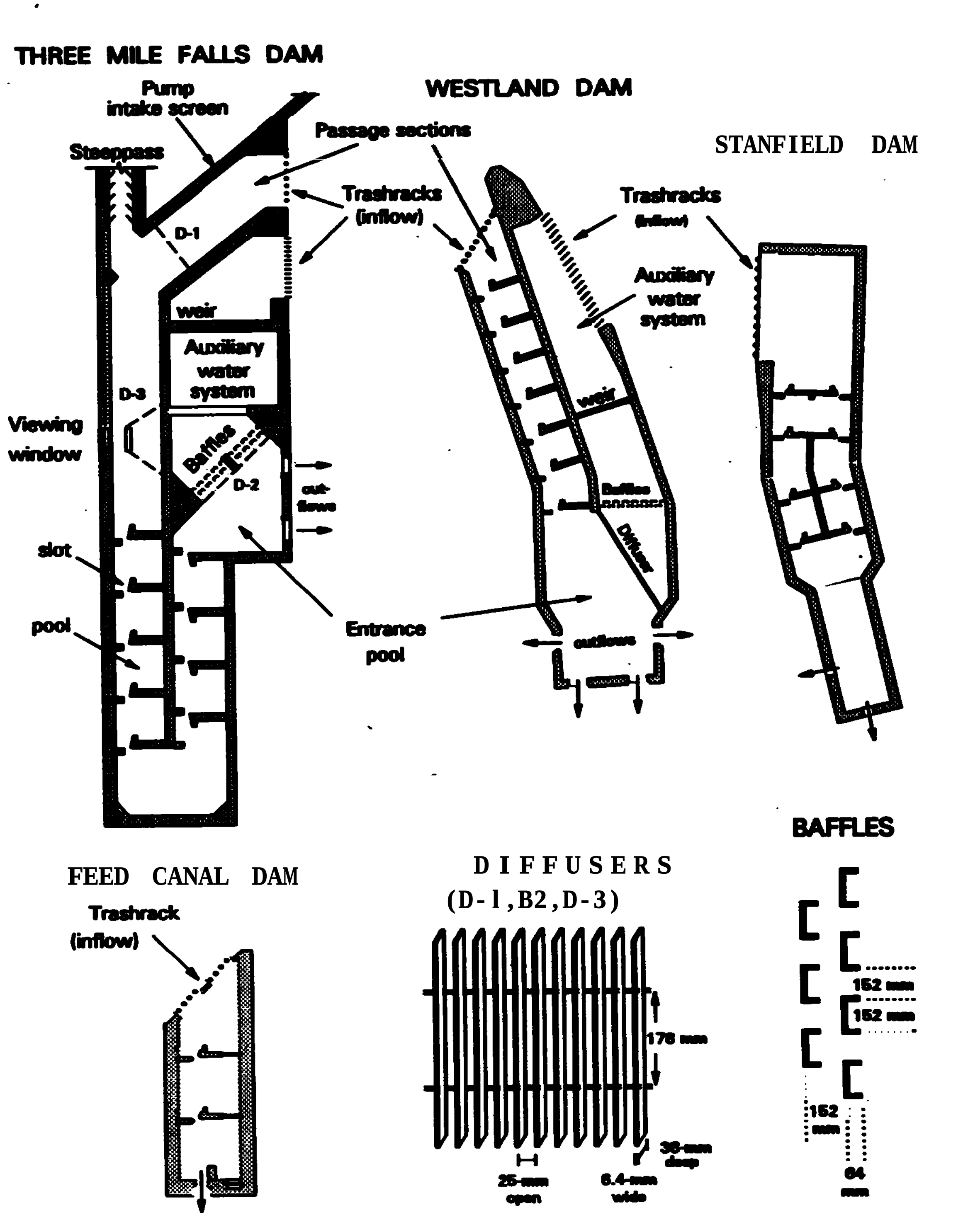


Figure 4. Schematic of fish ladders at irrigation dams on the lower Umatilla River, Oregon.

Table 3. Schedule of study activities conducted'at fish bypasses and ladders associated with irrigation dams on the lower Umatilla River, Oregon, 1991-1995.

Site	Year	Activity	Fish[a] species
Three Mile Falls Dam and West Extension Canal	1991	screen injury tests	CHS, CHF
	1991	outfall injury tests	STS, CHS
	1991	drum screen efficiency test	CHF
	1992	headgate injury tests	STS, CHS, CHF
	1992	screen injury test	STS
	1992	downwell injury test	CHS
	1992	outfall injury test	CHF
	1993	belt screen efficiency and impingement tests	CHF
	1993	ladder injury tests	CHS, CHF
	1994	ladder injury test	CHS
	1994	velocity measurements	
	1995	velocity measurements.	
Maxwell Canal	1993	canal injury test	CHF
	1994	velocity measurements	
Yestland Dam and Canal	1993	headgate injury tests	CHS, CHF
	1993	screen injury tests	CHS, CHF
	1993	outfall injury test	CHS
	1993	drum screen efficiency test	CHF
	1993	belt screen efficiency test	CHF
	1994	ladder injury test	CHF
	1994	velocity measurements	
Feed Canal Dam and Canal	1994	facility injury test	CHS
	1994	ladder injury test	CHS
	1994	drum screen efficiency test	CHF
	1994	velocity measurements	
Stanfield Dam and Furnish Canal	1994	canal injury-test	CHF
	1994	screen injury test	CHF
	1994	outfall injury test	CHF
	1994	drum screen efficiency test	CHF
	1994	ladder injury test	CHF
	1994	velocity measurements	

a STS = surer steelhead, CHS – spring chinook salmon, CHF.= subyearling fall chinook salmon

Fish were transported from hatcheries to study sites in a 1.0-m^3 or 1.5-m^3 oxygenated transport tank. Transport times ranged from 0.5-3.0 hours. Injury test fish were held in two to six, 2.3-m circular tanks supplied with 0.2-0.3 m^3/s of canal water inflow or in 1.2-m x 2.4-m x 1.2-m net pens submerged in the canal. Holding densities were kept below 32 kg/m^3. Fish were held on site from 1-24 days prior to their release in tests.

Traps

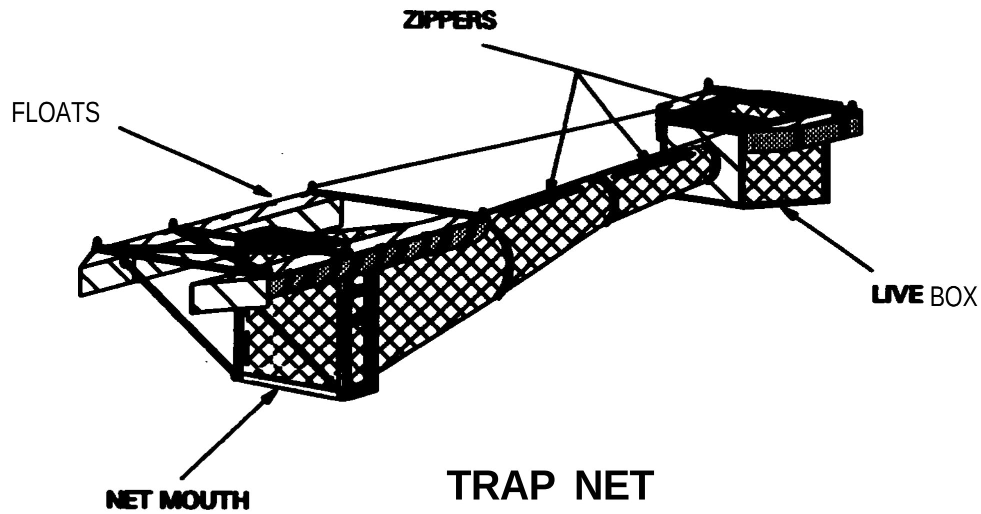
Ye installed traps in the bypass facilities to collect fish at the bypass weir and bypass outlet/outfall structures. At most sites, we installed inclined plane traps at the bypass weir (Knapp 1992; Figure 5) to recapture test fish released in the upper bypass during injury, screen efficiency, and impingement tests. Inclined plane traps were constructed of aluminum and included a hinged mouth, perforated plate floor (40% open) with 3.2-w diameter holes, and a terminal live box. Traps were sized to maximum bypass . flow, providing 4.9 m^2 of perforated floor per 1 m^3/s of bypass flow. Live box capacities ranged from 0.08-0.12 m^3.

A permanent sampling facility was used at West Extension Canal to collect fish released in the upper bypass (Knapp and Ward 1990; Figure 2). An inclined screen in the bypass channel guided fish over the bypass weir where a separator passed fish (< 400 mm) into a Y-shaped transfer flume. A sample gate at the flume fork diverted fish to either a trap or a 0.15-m-diameter pipe that terminated in the downwell. Fish were removed from the trap using an internal crowder and lift basket.

A floating net pen was used to collect fish beneath the bypass outfall at West Extension Canal (Knapp and Ward 1990). The net mouth was attached to a 1.8 m floating frame; net depth was 3.4 m flaring to a width of 3.1 m at the lead-weighted bottom. Trap netting consisted of an inner 4.8-mm mesh reinforced by an outer 7.9-m mesh of knotless nylon. At other bypass outlets, we used a floating trap net to capture test fish (Cameron et al. 1994; Figure 5). The 6.1-m-long net tapered from a 1.5-m^2 mouth to a circular 0.4-m-diameter end. A 0.9-m live box was attached to the terminal end of the net. The net was attached to a wooden frame made buoyant with Styrofoam blocks.

Fish leaking through or rolling over drum screens were captured using fyke nets deployed behind each screen in guides normally used for baffle boards (Knapp 1992; Cameron and Knapp 1993; Cameron et al. 1994, 1995). Normal canal operations were simulated by fixing baffle boards to the net frames. Fyke nets were sized to screen dimensions and canal flow. Nets made of 4.8-mm knotless nylon netting ranged in size from 1.2-7.6-m long, and tapered to a 0.3-0.6-m cod end. Net shapes were-angled to conform to localized flow patterns behind each screen.

Fyke nets were also used to capture fish behind belt screens at West Extension and Uestland canals. At West Extension Canal, the net was attached to the outlet of the pumpback bay drain pipe (Knapp 1992). The 3.7-meter-long net tapered from a 0.6-m x 0.8-m mouth to a 0.15-m cod end. At Uestland Canal, the opening in an orifice plate located behind each screen was utilized for net attachment. These nets consisted of a submerged portion that tapered



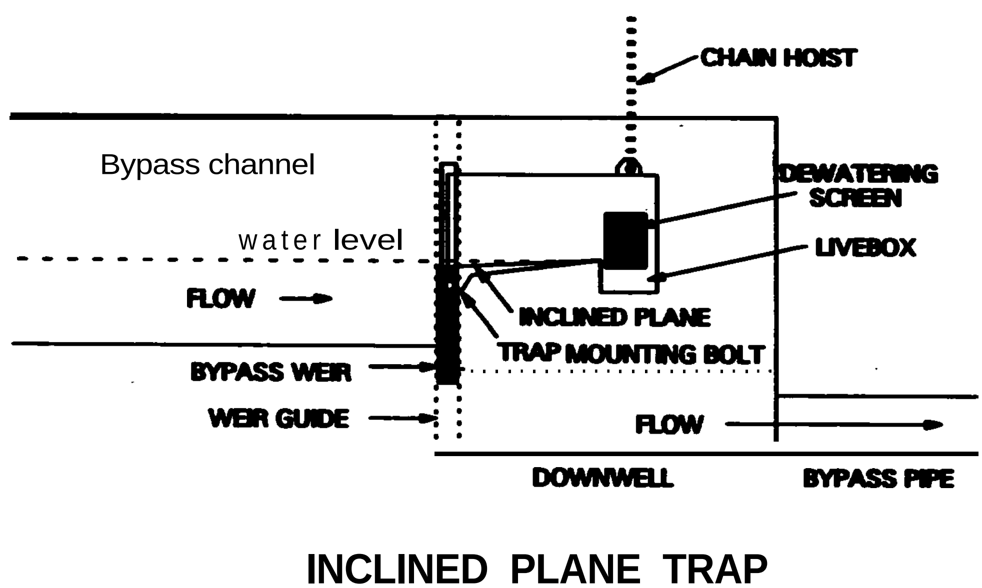


Figure 5. Floating trap net and inclined plane trap used for fish collection at bypass facilities and fish ladders on the lower Umatilla River, Oregon.

from a diameter of 0.6 m to 0.3 m, and a neck portion that bridged the gap between the mouth and submerged portions of the net (Cameron and Knapp 1993).

Ye collected test fish at fish ladders using the floating net trap at Three Mile Falls, Feed Canal, and Stanfield dams. We modified a drum screen fyke net used at Feed Canal to collect test fish at the Uestland Dam fish ladder.

Injury

Injury tests consisted of releases of one to three groups of uniquely marked treatment and control fish on two to three consecutive dates (Table 3). Treatment fish were released upstream of the facility structure being evaluated; control fish were released either immediately downstream from the structure or in a recovery trap to assess trap and handling-caused injury. Injury was evaluated on all or a subsample of fish from each replicate group prior to release to establish pre-release condition. If subsampled, examined fish were not returned to the release group. Injury rates of recaptured treatment and control fish were compared to determine facility-caused injury.

In 1991 and 1992, we determined fish condition (injury) using descaling criteria developed by the Army Corps of Engineers (Basham 1982). Fish condition was based on the percentage of scale loss in each of five designated sections per fish side. Fish were classified as "healthy" (scale loss ≤ 3% in each section), "partly descaled" (scale loss > 3%, but < the equivalent of 40% of two sections), or 'descaled" (scale loss ≥ the equivalent of 40% of two sections). Other types of injuries recorded included body and head injuries, torn operculums, bird marks, mammalian predator marks, parasites, and fungal infections. In 1993 and 1994, we modified the criteria by subdividing the partly descaled category into low partially descaled (> 3% scale loss and ≤ the equivalent of 20% of two sections) and moderate partially descaled (> 20% and < the equivalent of 40% of two sections).

Facility-caused injury was ditermined for each test by comparing the amount and severity of injury incurred by treatment and control fish after release. Net-weighted injury units were used as a quantitative measure. They were computed by first calculating the percentage of uninjured, low partially descaled, moderate partially descaled, otherwise injured, descaled, and dead fish for each pre- and post-release replicate. These percentages were multiplied by weighting factors that reflected the severity of each category uninjured (0.0), low partially descaled (0.167), moderate partially descaled (0-33), otherwise injured (0-33), descaled (0.67), and dead (1.0). (A weighting factor of 0.33 was used for the single partly descaled category used in tests at West Extension Canal in 1991 and 1992). Weighted percentages of each injury category were summed for each replicate. These sums were averaged for each pre- and post-test treatment and control group to calculate weighted injury. Net-weighted injury was calculated for treatments and controls by subtracting weighted pre-test injury from weighted post-test injury. Facility-caused injury was calculated as the mean difference between treatment and control net-weighted injury rates.

Some changes in methodology were adopted over the course of the study to improve the accuracy of injury tests. These changes included increased sample sizes, increased subsampling rates for pre-test injury, expanded descaling criteria, and improved marking and holding logistics. In 1992, sample sizes of treatment and control groups were increased from 100 fish to 150 fish and subsampling rates were increased from 10% to 30%. In 1993, we subdivided the partially descaled category to improve detection of low levels of descaling. In 1994, new marking techniques allowed 100% of the test fish to be evaluated for pre-test injury and released a couple hours after marking.

Several techniques were used to mark and hold individual release groups. Between 1991 and 1993, freeze branding was used to mark treatment and control fish. In 1991 and 1992, marked fish were segregated by brand into net pens or perforated plastic containers submerged in circular tanks and held 48-72 hours to allow brands to darken. In 1993, we attempted to reduce the variability in pre-test injury among segregated groups of test fish by holding groups with common release dates and locations in a single net pen. Four hours prior to release, fish were sorted into separate release containers and a 30% subsample of fish was evaluated for pre-test condition. Brand retention and readability was checked during pre-test subsampling. In 1994, test fish were marked by injecting approximately 0.1 ml of acrylic paint onto the ventral body surface using either-a syringe with 26-gauge intradermal needle or Panjet needleless injector (Hart and Pitcher 1969; Thedinga and Johnson 1995). This allowed evaluation of pre-test injury on all test fish during the marking process. After marking, groups of test fish were held in separate containers for approximately two hours prior to release.

Bypass

Separate injury tests were conducted in the upper and lower segments of most fish bypass facilities. For our evaluations, we defined the upper bypass as that segment upstream of the bypass weir which contained the headgates, headworks canal, screen forebay, drum screens and bypass channel. Upper bypass tests included headgate injury, canal injury, and screen injury tests. The lower bypass was that segment downstream of the bypass weir which contained the bypass downwell, pipe, and outlet. Lower bypass tests included downwell injury and outlet/outfall injury tests. During upper bypass tests, traps at the bypass weir were operated on a continuous basis for at least 96 hours after test fish were released. In lower bypass tests, trapping at bypass outlets was conducted during daylight for approximately two to six hours after test fish releases.

Most injury tests were conducted under normal operating conditions.- At West Extension Canal, downwell and outfall jnjury tests were conducted at design bypass flows of 0.14 m^3/s and 0.71 m^3/s. We also tested a non-standard operating procedure by increasing pool depth in the downwell to 3.1 M to test whether turbulence and (potential) fish injury could be reduced. Normal downwell pool depths were 0.6 m and 1.2 m at 0.14-m^3/s and 0.71-m^3/s bypass flows, respectively. Downwell pool depth was increased for the 0.71-m^3/s high-pool tests by reducing the gate opening at the bypass pipe terminus. During the 0.14-m^3/s high-pool test, we closed the bypass pipe gate completely to back up water in the downwell. When pool depth reached 3.1 m, we simultaneously released test fish and raised the gate at the bypass pipe terminus. Approximately 40 seconds elapsed until the downwell pool returned to a depth of 0.6 m.

Test fish were transported to release sites in 20-gallon or 5-gallon containers. Fish were released by either carefully pouring out the container contents or netting small groups of fish from the containers. Ye released fish in the upper bypass approximately one meter upstream of the headgates for headgate injury treatments, 20 m downstream of the headgates for canal injury treatments, 32-78 m upstream of the drum screens for screen injury treatments, and at the mouth of the trap for screen injury controls. At Maxwell Canal, canal injury controls were released at the trap mouth. Screen injury treatment groups were released from the bank on the screened side of the canal at most sites. At West Extension Canal, one replicate group of screen injury treatments was released into each of three flow control flumes upstream of the screens.

Ye released fish at the bypass weir for downwell and outlet/outfall injury treatments, at the start of the bypass pipe for downwell injury controls, and into the trap mouth for outlet/outfall controls. Downwell injury control fish were released into the bypass pipe entrance using a hopper with a 51-m-diameter hose. Releases of treatment and control groups were paired in downwell and outlet/outfall injury tests at 0.5 hour to 1 hour intervals.

After capture, test fish were separated from collected river-run fish and either processed immediately or held momentarily in net pens. Collected fish were anesthetized using a 50-ppm to 100-ppm solution of tricaine methanosulfonate. Examinations were completed within one hour of sorting. Collection time, scale. loss, injuries, and test marks were recorded on all recaptured test fish.

Ladder

Ladder injury tests followed the same sampling protocol described above for bypass injury tests. We released fish in fish ladders 0.5 m upstream of the vertical slot closest to the fish exit for passage treatments, at the crest of the auxiliary water weir for auxiliary water treatments, and approximately one meter in front of the trap-mouth for controls. At the Stanfield Dam fish ladder, approximately equal numbers of fish were released in each half of the dual-passage ladder. Two treatment groups were released in the passage section of the fish ladder at Three Mile Falls Dam to assess injury associated with midchannel diffuser panels. Release locations for the treatments were 7 m upstream of Diffuser 1 (Treatment UD) and 5 m downstream of Diffuser 3 (Treatment DD).

Travel Rate and Recapture

Bypass

Ye recorded release and recapture times of fish during injury tests conducted in fish bypass facilities to determine the time for the fish to travel from a release location to recapture site. For tests conducted in the upper bypasses,-rate of fish movement was quantified by calculating the average time to recapture 50% (median travel time) and 95% of the test fish released. For tests conducted in the lower bypasses, fish movements were quantified by plotting average cumulative percent recapture of test fish against average time after release. Cumulative percent recapture was corrected for trap efficiency. We also used median travel speed to quantify fish movement in the upper and lower bypass. Median travel speed (m/s) was based on median travel time. It was calculated by dividing distance traveled by median travel time. Percent recapture was calculated for tests conducted in the upper bypass as the percentage of fish recaptured at the end of the test, and was not corrected for trap efficiency.

Ladder

We recorded release and recapture times of fish during injury tests at fish ladders to determine the average time for fish to pass through the ladder. Fish movements were quantified by plotting average cumulative percent recapture of test fish against average time after release. Cumulative percent recapture was corrected for trap efficiency.

Screen Efficiency and Impingement

Dru Screens

Screen efficiency of (leakage) and impingement at (roll-over) drum screens was evaluated by releasing unmarked subyearling fall chinook salmon upstream of the screens and recapturing them in fyke nets deployed behind the screens and at the bypass downwell trap. Harked fish were released in the mouth of fyke nets and at the bypass channel entrance to determine trap capture efficiencies. Trap efficiency fish were marked by immersion in a 24-mg/l solution of Bismark brown dye. The dye imparted an orange stain on the body surface and gills of test fish that was detectable for at least 48 hours after release.

Drum screen efficiency tests were replicated three times at each site: Test intervals of 48 hours were selected to allow-adequate time for test fish to clear the system before releasing the next group of fish. At Uest Extension Canal, each test consisted of midmorning releases of 300 unmarked fish upstream of the screens, 300 marked fish at the bypass channel entrance,' and a total of 300 marked fish in the fyke nets. At Uestland, Feed, and Furnish canals, sample sizes of-test fish released upstream of-the screens and at the bypass channel entrance were proportional to the total number of fish released in the fyke nets (100 fish per screen); fish released upstream of the screens were equal to the total number of fish released in the fyke nets and half as many fish were released at the bypass channel entrance. Test fish released upstream of the screens and at the bypass channel entrance were split equally among a midmorning and late afternoon release. Trap efficiency fish were only released into the fyke nets in midmorning. We checked traps at the downwell at least once per hour and fyke nets 2-4 times per day. At all sites, we periodically monitored the drum screens for fish impingement after each release and recorded number, date, time, and location of impinged fish.

Screen efficiencies were estimated as the percentage of fish guided safely past drum screens. Estimates were based on the number of fish captured behind the screens in fyke nets and the number of fish captured in the bypass-trap. Number of fish captured in the fyke nets and bypass trap were corrected for trap capture efficiency. We calculated efficiencies for individual screens and an overall screen efficiency for each test period. Overall efficiencies for the three tests were then averaged to calculate a mean screen efficiency for the fish bypass facility. We assumed fish caught in the fyke nets were retained. The formula for calculating fyke net capture efficiency (EFFfn) behind each screen was

$$EFFfn = \frac{nfn}{Nfn}$$

where nfn was the number of control fish released at the fyke net mouth and captured in the fyke net, and Nfn was the number of control fish released at the fyke net mouth.

The formula for calculating bypass collection efficiency (EFF_{bc}) was

$$EFF_{bc} = \frac{nbc}{Nbc}$$

where nbc was the number of control fish released at the bypass channel entrance and captured in the bypass trap, and Nbc was the number of control fish released in the bypass channel entrance.

The formula for calculating both efficiency of individual screens and an overall screen efficiency (EFF_{sc}) for all screens combined was

$$EFF_{ds} = \left[1 - \frac{(Xfn)}{(EFF_{fn})\ (N)} \right] (100)$$

where Xfn was the number of treatment fish released upstream of the screens and recaptured behind the screens, and N was an estimate of the total number of fish encountering the screens.

$$N = \frac{Xfn}{EFFfn} + \frac{X_{bc}}{EFF_{bc}}$$

where Xb_c was the number of treatment fish released upstream of the screens and caught in the bypass trap.

The formula for calculating overall screen efficiencies at Uestland Canal was modified because we were unable to collect fish in the downwell trap and, thus, could not estimate the number of fish encountering the screens. Screen efficiency estimates (EFF_{sc}) were modified by assuming the number of fish encountering the screens (N) was equal to the number of fish released upstream of the screens within each test period.

Bolt Screens

Belt screen efficiency tests at Uestland Canal required non-standard facility operations. Normally, the belt screens are only in use when the fish bypass facility is operated in a trapping mode. However, fish bypassing was a priority when belt screen efficiency tests were conducted. We simulated fish trapping operations by fully opening the orifice slots behind each screen and throttling back one pumpback pump to maintain a constant water level in the pumpback bay. A bypass flow of 0.57 m^3/s was used instead of the 0.11-m^3/s flow that normally enters the trap.

At Uestland Canal, treatment releases consisted of 600-800 subyearling fall chinook salmon, released hourly in groups of 200 at the bypass channel entrance. Fyke nets attached to each orifice slot were used to collect fish that leaked through the belt screen (Cameron and Knapp 1993). Trap efficiency fish were marked with Bismark brown dye. We released one group of 150 marked fish at the mouth of each fyke net to estimate capture efficiencies of the nets at the start of the test. We released groups of 100 marked fish downstream of the belt screen after each release of treatment fish to estimate capture efficiency of the bypass trap. We checked the bypass trap and fyke nets at least once per hour. We periodically monitored the belt screens for fish impingement after each release. Number, date, time, and location of impinged fish were recorded.

At West Extension Canal, we conducted separate belt screen efficiency tests when the pumpback bay drain pipe was 20%, 30%, and 40% open. Belt screen efficiency during pump operations was not determined because of the inability to capture fish at the pump outflow. We released a total of 400 unmarked subyearling fall chinook salmon hourly in groups of 100 upstream of the screens at the bypass channel entrance. A fyke net attached to the terminus of the pumpback bay drain pipe collected fish that passed through the belt screen (Knapp 1992). Capture efficiency of the fyke net was determined by releasing 100 Bismark brown-dyed fish into the pumpback bay at the start of each test. We did not determine collection efficiency of the bypass trap. Ye checked the bypass trap and fyke net at least once per hour.

We calculated belt screen efficiency following the same formula used for drum screen efficiency with the following exception. At West Extension Canal, we assumed the bypass trap was 100% efficient, therefore $EFF_{bc} = 1$.

Belt screen impingement tests were conducted at West Extension Canal when the pumpback bay drain pipe was 20%, 30%, and 40% open and both 0.28-m^3/s canal pumps were off, and when the canal pumps were operated singularly and in tandem with the drain pipe closed. A total of 400 unmarked subyearling fall chinook salmon were released hourly in groups of 100 at the bypass channel entrance. We released 100 Bismark-brown dyed fish downstream of the belt screen at the start of each test to determine capture efficiency of the bypass trap. We continually monitored the screen until most of the unmarked fish were recaptured. Fish were counted as impinged if they were lifted out of the water while pressed against the screen. The screen spray wash was turned off to provide an unobstructed view of the above-water portion of the screen.

Calculation of belt screen impingement followed a formula analogous to the one used for drum screen efficiency. The formula for percent belt screen impingement (IMP_{sc}) was

$$IMP_{sc} = \frac{(X_{imp})(100)}{N}$$

where X_{imp} was the number of fish impinged on the belt screen, and N was an estimate of the total number of fish encountering the screen.

$$N = \frac{(X_{bt})(N_{bt})}{(n_{bt})}$$

where X_{bt} was the number of treatment fish released upstream of the belt screen and caught in the bypass trap, N_{bt} was the number of control fish released upstream of the bypass trap, and n_{bt} was the number of control fish released upstream of the bypass trap and captured in the bypass trap.

Water Velocity

Bypass

We measured water velocity in front of drum and belt screens and at bypass channel entrances to assess compliance with velocity criteria developed by the National Warine Fisheries Service (NMFS 1989, 1990). The criteria specifies the required velocity for flow perpendicular (approach velocity) and flow parallel (sweep velocity) to the screen face. Maximum allowable approach velocity is 0.12 m/s for protection of salmonid fry (fish < 60 mm); and 0.24 m/s for protection of salmonid smolts (fish > 60 mm). Sweep velocity should be at least twice the magnitude of approach velocity (sweep : approach ratio ≥ 2). At the bypass channel entrance, approach velocity must equal or exceed the maximum velocity of canal flow in front of the screens.

We used a Harsh McBirney (Model 2000) electromagnetic flowmeter to collect velocity measurements during normal facility operations. The meter displayed velocity readings as fixed point averages or instantaneous readings. Fixed point averaging provided a mean of 150 velocity readings collected over a period of five seconds. We used fixed point averaging to measure water velocity.

At drum screens, velocity measurements were taken 76-152 cm upstream of the screens at three vertical transects located at 25%, 50%, and 75% of the screen length. Sampling depths at each transect were 20%, 50%, and 80% of screen submergence depth. At each sampling location, we pointed the meter's sensor probe into the vector of maximum water velocity. We used a thin rod with flagging to determine the maximum velocity vector if water clarity was good. If water clarity was poor, we set the meter to instantaneous readings and slowly rotated the probe to determine the vector of maximum velocity. To measure the angle of the maximum velocity vector relative to the drum screen, we incorporated a modified protractor onto the meter pole (Figure 6).

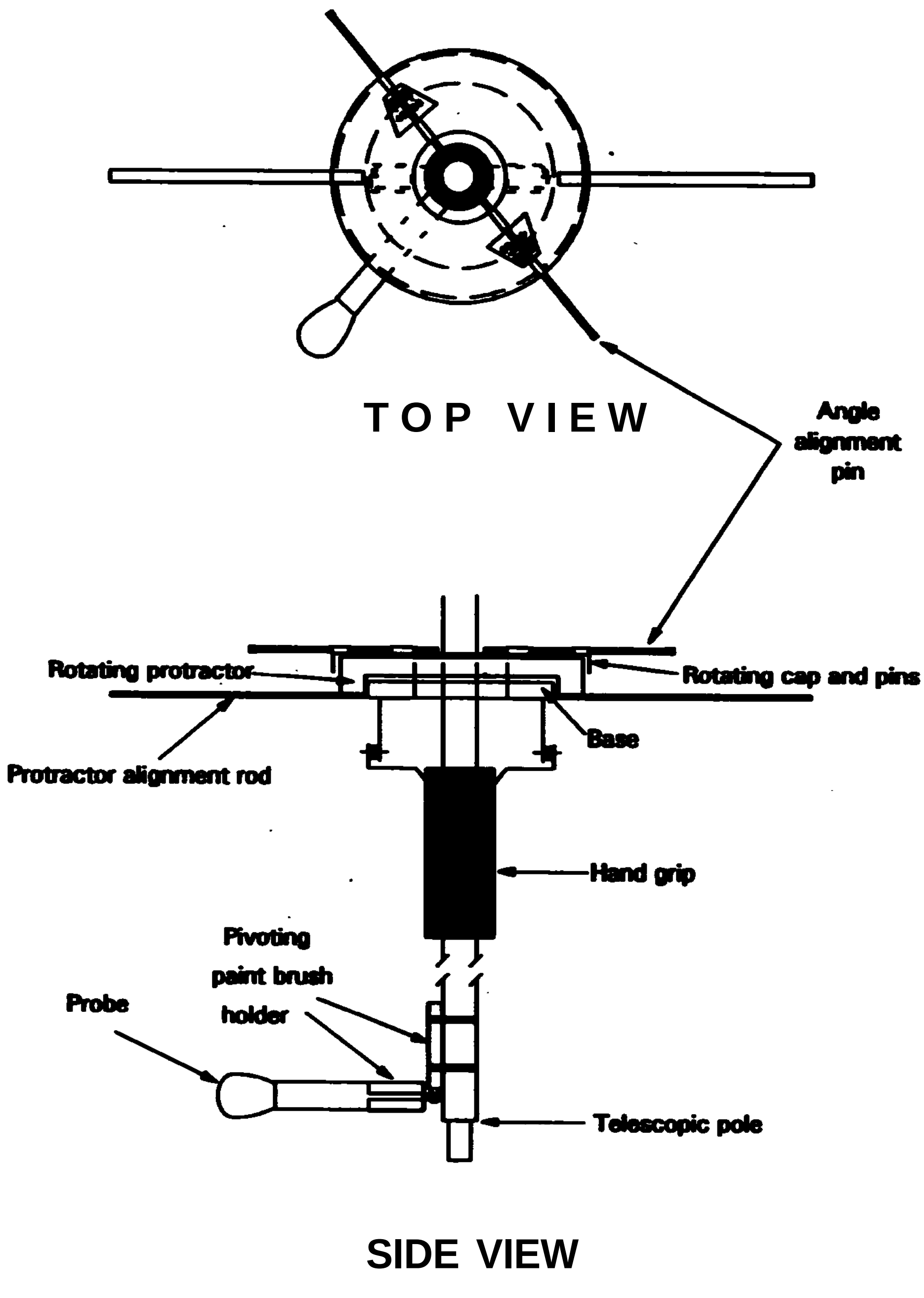


Figure 6. Device used with an electromagnetic water velocity meter -to measure the angle of the maximum velocity vector in front of screens and diffusers at fish passage facilities on the lower Umatilla River, Oregon.

Measurements at the bypass channel entrance were taken midchannel at 20%, 50%, and 80% of water depth, The probe was pointed into the maximum velocity vector which was usually 90 to the bypass entrance.

We measured water velocity in front of the belt screen at West Extension Canal during varying pumpback operations including operation of Pump 1, Pump 2, both pumps, and 20%, 30%, and 40% openings of the pumpback bay drain pipe. Measurements were collected at 20%, 50%, and 80% of the water depth along three vertical transects. Transects were located at the middle of the screen and 0.3 m from the upstream-and downstream edges of the screen. We used the rod with flagging to determine the vector of maximum velocity at 20% of water depth. Turbulence at 50% and 80% of water depth prevented us from finding the maximum velocity vector using instantaneous meter readings. As an alternative, we rotated the-probe until the force of the water current on the probe assembly was minimized.

Ye used trigonometric functions to calculate water velocity perpendicular (approach) and parallel (sweep) to screens. Resultant approach and sweep velocities were calculated from the measured velocity and angle of maximum velocity converted to radians such that

$$\text{approach velocity} = \text{SIN}\left[\frac{\pi}{180}(\Theta)\right](V)$$

and,

$$\text{sweep velocity} = \text{COS}\left[\frac{\pi}{180}(\Theta)\right](V)$$

where COS was the Cosine function, SIN was the Sine function, π was the constant pi (3.14), Θ was the angle of maximum flow to the screen face (in degrees), and V was the water velocity measured.

Accuracy of drum screen velocity measurements was checked by comparing canal flow estimated from the velocity data to flow data recorded at Oregon Water Resource Department (OURD) gauging stations. Flow through each screen was calculated as the product of mean screen approach velocity, effective screen length, and submerged screen depth.

Velocity measurements collected at low canal flow did not adequately assess adherence to approach velocity criteria. Therefore, approach velocity measurements were expanded to estimate approach velocity at the highest canal flows expected when salmon fry are present (March - Hay). We reviewed flow data from 1992 to 1996 to estimate the highest canal flows expected in March through Hay at West Extension (3.4 m^3/s), Maxwell (1.1 m^3/s), Uestland (7.1 m^3/s), Feed (6.9 m^3/s) and Furnish (3.4 m^3/s) canals. The formula for expanding approach velocity measurements (AV_m) to estimate approach velocity at the highest canal flow expected from March through May (AV_e) was

$$AV_e = \frac{(AV_m)\ (F_{max})\ (CF)}{F_{act}}$$

where Fmax was the highest expected canal flow from March through May, Fact was the actual canal flow at the time velocity measurements were collected (OWRD gauge reading), and CF was a correction factor that compensated for inaccuracy of velocity measurements.

The formula for calculating CF was

$$CF = \frac{F_{act}}{F_e}$$

where Fe was the canal flow estimated from velocity data.

Ladder

We measured water velocity in front of Diffusers 1 and 2 inside the fish ladder at Three Mile Falls Dam to supplement information on fish injury and travel rate associated with these structures. Collection of velocity measurements at diffusers followed the sampling protocol used at bypasses with the following exceptions. At Diffuser 1, measurements were taken approximately 150 cm in front of the diffuser along vertical transects located at 16.7%, 33.3%, 50.0%, 66.7%, and 83.3% of the diffuser length. At Diffuser 2, measurements were taken downstream of the baffles, approximately 150-230 cm in front of the diffuser. Vertical transects were located at 25%, 50%; and 75% of the length of the east and west panels. Transect sampling depths at Diffusers 1 and 2 were 20%, 50%, and 80% of water depth. Location of the maximum velocity vector at Diffusers 1 and 2 followed methods described for velocity measurements in front of drum and belt screens, respectively. Fish exit gates (inflow) were 55% open when we measured water velocity in front of Diffuser 1.

We calculated water velocity perpendicular (approach) and parallel (sweep) to the diffusers using the velocity measurements and angle of maximum velocity vector. Computation of approach and sweep water velocity followed the formula used for water velocity measurements collected in front of drum and belt screens.

Statistical Analysis

Injury

Parametric paired t-tests were used to test the null hypothesis that mean net-weighted injury for treatment minus control was significantly greater than zero. Pairing of replicate treatment and control groups was based on common release times. For tests with more than one treatment (upper bypasses and passage section of Three Mile Falls Dam fish ladder), downstream treatment releases were used as the control for upstream treatment releases. We used a significance level (a) of ≤ 0.10 (one-tailed) for all tests.

Travel Rate and Recapture

Statistical comparisons were conducted on groups of fish releases that shared common test times. Parametric independent t-tests were used for statistical analysis of single comparisons of 50% travel time, median travel speed, and percent recapture. We used analysis of variance for more than one comparison. We tested the null hypothesis that differences in mean 50% travel time, median travel speed, or percent recapture of fish released at two or more than two locations were not significantly different. Ye used a significance level (a) of ≤ 0.05 (two-tailed) for most tests. Ye used a one-tailed test of significance for comparisons of 50% travel time and percent recapture of fish released upstream and downstream of the headgates because we assumed the headgates would interrupt fish passage into the canal.

RESULTS

Injury

Bypass

Fish bypass facilities at irrigation canals on the lower Umatilla River were highly effective at returning juvenile salmonids back to the river unharmed. The difference in injury rates between treatment and control fish was not significantly greater than zero in 26 of 28 injury tests (Figures 7 and 8). Significant injury was detected in the nighttime screen injury test conducted at Uest Extension Canal with subyearling fall chinook salmon (P = 0.006) and the facility injury test conducted at Feed Canal with yearling spring chinook salmon (P = 0.01). Fall chinook salmon that passed the screens at West Extension Canal at night had an 8.2% higher rate of partial descaling than control fish. However, 59% of the difference in injury between treatment and control fish was a result of biased pre-test subsampling of control injury. Subsampling bias was evidenced by the negative value for net-weighted injury (NUI) calculated for controls. Spring chinook salmon that passed by the screens and through the downwell, bypass pipe, and outlet at Feed Canal had a 12.3% higher rate of low partial descaling and a 3% higher rate of full descaling than control fish.

Outfall and downwell injury tests at West Extension Canal were less precise than tests conducted in upper bypasses (Figures 7 and 8). The mean minimum difference in treatment and control injury required for significance (a - 0.10) in outfall and downwell injury tests was 8.1 NWI units compared with a mean of 3.0 NWI units for tests conducted in upper bypasses. Even with this constraint, results were nearly significant in outfall injury tests conducted with subyearling fall chinook salmon at a bypass flow of 0.14 m^3/s (*P* - 0.16) and 0.71 m /s (*P* = 0.12), in outfall injury tests conducted with spring chinook salmon at a bypass flow of 0.14 m^3/s (P = 0.19), and in the high-pool downwell injury test conducted with spring chinook salmon at a bypass flow of 0.14 m /s (P = 0.14). Probabilities (P) were greater than 0.62 in all other outfall and downwell injury tests. Injuries were most severe to fall chinook salmon in outfall injury tests; treatment injury was greater than control injury by 1.3% in full descal-ing and 12.0% in mortality at a 0.71-m^3/s bypass flow and by 9.4% in full descaling and 2.6% in mortality at a 0.14-m^3/s bypass flow. For spring chinook salmon, treatment injury was greater than

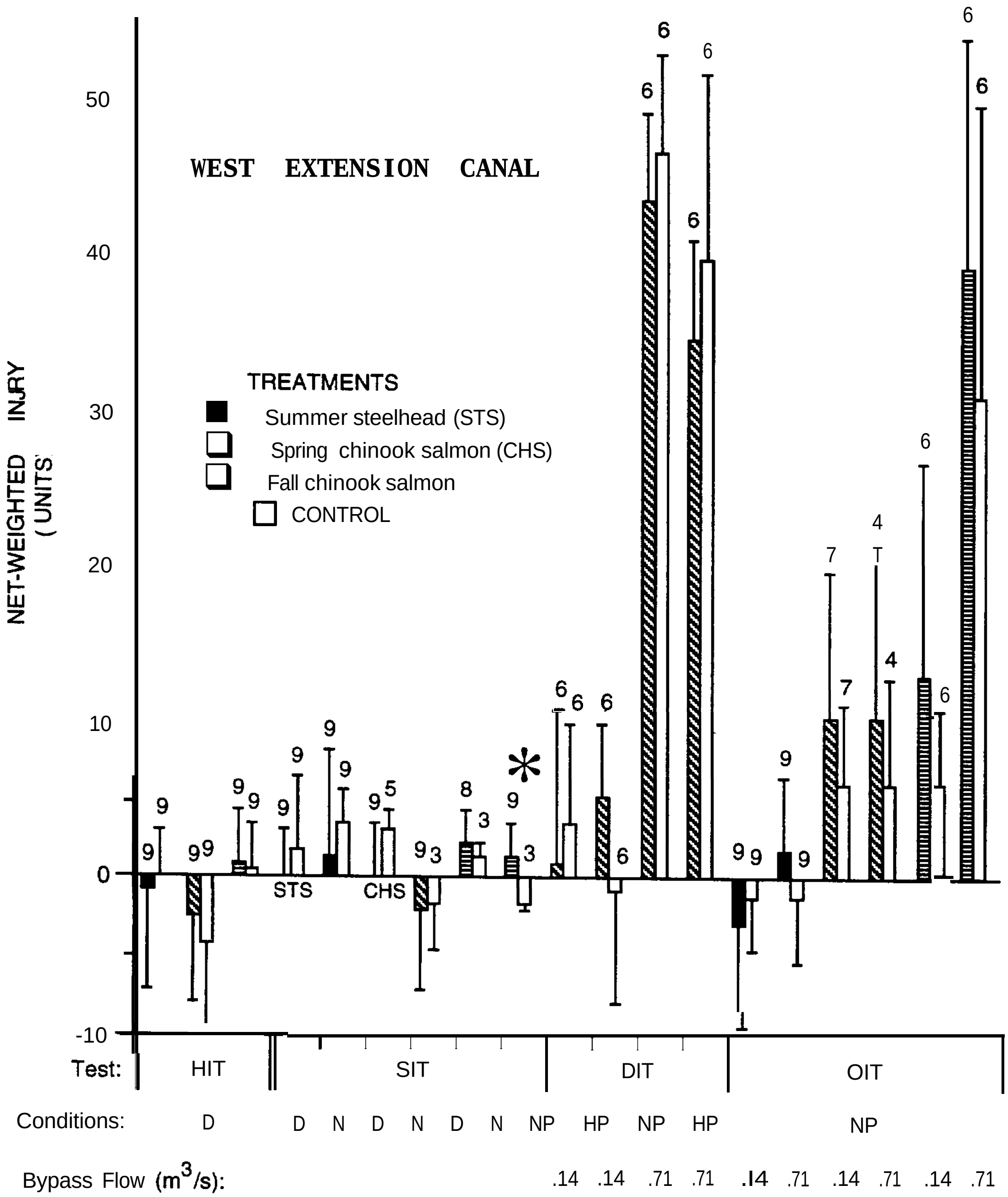


Figure 7. Mean net-weighted injury incurred by treatment (filled bars) and control (open bars) fish in varying segments of the bypass facility at West Extension Canal, Umatilla River, Oregon. Sample sizes and significant comparisons (*) are shown above SD error bars. Tests, relevant test conditions, and bypass flows are shown below the graph (HIT = headgate injury test, SIT = screen injury test, DIT = downwell injury test, OIT = outfall injury test, D = day release, N = night release, NP = normal downwell pool depth, HP = high downwell pool depth).

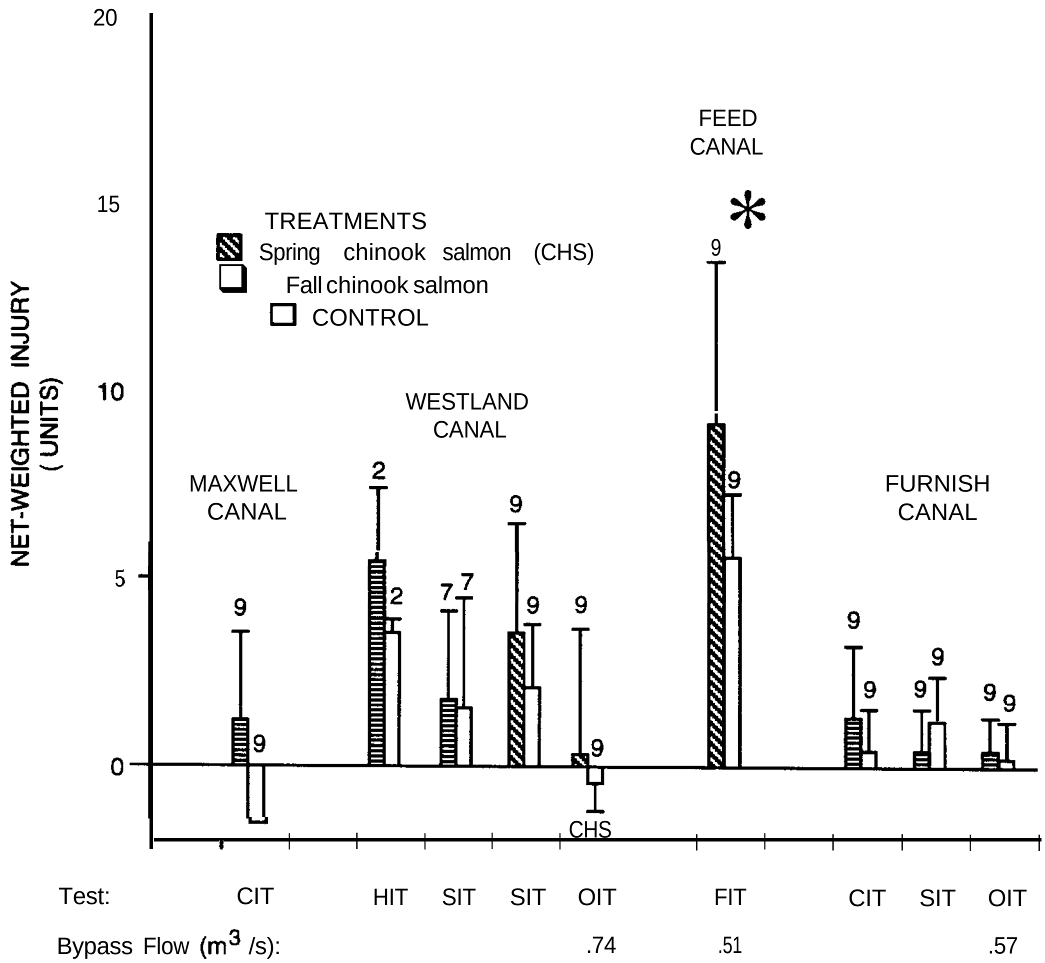


Figure 8. Mean net-weighted injury incurred by treatment (filled bars) and control (open bars) fish in varying segments of the bypass facilities at Maxwell, Westland, Feed, and Furnish canals, Umatilla River, Oregon. Sample sizes and significant comparisons (*) are shown above SD error bars. Tests, relevant test conditions, and bypass flows are shown below the graph (CIT = canal injury test, HIT = headgate injury test, SIT = screen injury test, OIT = outfall injury test, FIT = facility injury test).

control injury by 9.0% partial descaling and 0.4% full descaling in the outfall injury test at a 0.14-m^3/s bypass flow and 16.3% partial descaling in the high-pool downwell injury test at a 0.14-m3/s bypass flow.

Accuracy of injury tests improved when subsampling rates for pre-test condition were increased. Negative values for net-weighted injury occurred in 40% of the tests conducted at West Extension and Westland canals when subsampling rates were 10% and 30%. When 100% of the test fish were evaluated for pre-test injury, negative injury rates decreased to 12%. In latter tests, negative injury rates occurred only when post-test injury was low.

Scale loss was the predominant injury recorded during bypass injury tests. "Other" injuries recorded during tests were attributed to preexisting injuries. Mortality associated with fish bypass facilities was 0.0-0.4% in all tests except the outfall injury test with subyearling fall chinook salmon at West Extension Canal (0-12%).

Ladder

Juvenile salmonids passed safely through smaller adult fish ladders on the lower Umatilla River, but not at larger ladders. Subyearling fall chinook salmon incurred significant injury in the passage section of the fish ladder at Three Mile Falls Dam during low flow operations and in the auxiliary water section of the fish ladder at Westland Dam during high flow operations (Figure 9).

Injury to subyearling fall chinook salmon was significant in the passage section of the fish ladder at Three Mile Falls Dam in segments with and without diffuser panels ($P = 0.04$ and $P = 0.001$, respectively; Figure 9). Total injury to fall chinook salmon in the entire passage section of the ladder was 2.5% moderate partial descaling, 19.2% full descaling, and 3.2% mortality. The section with diffusers accounted for 66% of the total descaling injury, whereas 78% of total mortality was attributable to the segment of the ladder downstream of the diffusers. In contrast, yearling spring chinook did not incur significant injury in the passage section of the fish ladder ($P = 0.32$). Injury to treatment fish passing through the auxiliary water system of the fish ladder at Three Mile Falls Dam was not significant for fall chinook salmon ($P = 0.81$) and spring chinook salmon ($P > 0.50$) relative to control injury.

Subyearling fall chinook salmon passing through the auxiliary water system of the fish ladder at Westland Dam received significant injury ($P = 0.05$), whereas fish moving through the passage section did not ($P = 0.50$; Figure 9). Treatment fish in the auxiliary water system incurred greater low partial descaling (7.6%), moderate partial descaling (3.1%), and full descaling (1.4%) than control fish.

Injury was not significant for test fish passing through fish ladders at Feed Canal Dam ($P = 0.13$) or Stanfield Dam ($P = 0.40$; Figure 9). Treatment injury was greater than control injury at Feed Canal Dam by 4.0% in moderate partial descaling and 0.5% in full descaling. At Stanfield Dam, treatment injury was greater than control injury by 0.4% low partial descaling, 1.7% moderate partial descaling, and 0.6% full descaling.

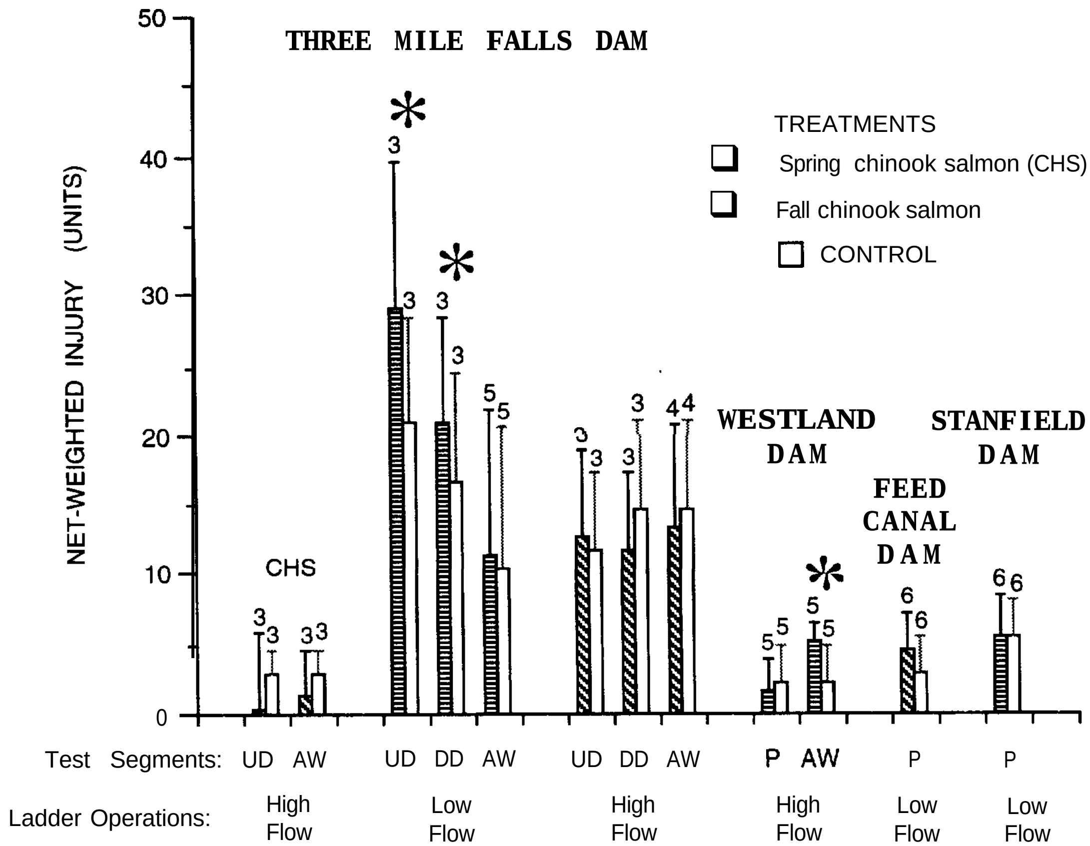


Figure 9. Mean net-weighted injury incurred by treatment (filled bars) and control (open bars) fish in varying segments of fish ladders at Three Mile Falls, Westland, Feed Canal, and Stanfield dams, Umatilla River, Oregon. Sample sizes and significant comparisons (*) are shown above SD error bars. Tests segments and ladder operations are shown below the graph (UD = upstream of diffusers, AW = auxiliary water system, DD = downstream of diffusers, P = passage section).

Scale loss was the predominant injury recorded during ladder injury tests. "Other" injuries were rarely observed. Only at Three Mile Falls Dam was mortality associated with passage through fish ladders.

Travel Rate and Recapture

Bypass

Test fish released in the upper portion of fish bypass facilities traveled distances of 32-2,410 m under varying physical conditions (Table 4). Fish were released in the day, evening, or night, and at canal withdrawals of 17-94% of maximum canal flow.

Median travel time and travel speed of subyearling fall chinook salmon released upstream of the drum screens at Furnish Canal (0.6 h, 62 m/h) was significantly different from those released downstream of the headgates (2.0 h, 485 m/h; $P < 0.05$) when canal withdrawals averaged 54% of maximum flow. At Maxwell Canal, median travel speed for fall chinook salmon passing through the headworks canal was 831 m/h when canal flow was 23-48% of maximum flow. Fall chinook salmon released short distances upstream of screening facilities at West Extension and Westland canals traveled only 5-65 m/h when canal withdrawals averaged 68% and 71% of maximum flow, respectively.

At West Extension Canal, median (50%) travel times for treatment fish released upstream of the headgates were significantly slower compared with controls released upstream of the drum screens for summer steelhead ($P < 0.01$) and subyearling fall chinook salmon ($P < 0.01$), but not spring chinook salmon ($P > 0.10$; Table 4). Percent recapture of summer steelhead, spring chinook, and fall chinook salmon released upstream of the headgates was significantly lower ($P < 0.05$) compared with controls (Table 4). Mean 50% travel time and percent recapture for all species of test fish released upstream of the headgates was 26.3 hours and 57.4% compared with 6.8 hours and 66.0% for fish released upstream of the drum screens, respectively.

Travel time and speed did not appear to be associated with canal flow when fish were released downstream of the headgates. Median travel speed for subyearling fall chinook salmon was slower at Furnish Canal (485 m/h) than Maxwell canal (831 m/h), even though canal flow was slightly higher at Furnish Canal. Median (50%) travel times for subyearling fall chinook and yearling spring chinook salmon released upstream of the drum screens at Westland Canal were nearly equal, even though canal flow was more than three times higher during tests with fall chinook salmon (Table 4).

Median travel time for fall chinook salmon released downstream of the headgates at Maxwell Canal was not significantly different among day, evening, or nighttime release groups ($P > 0.19$). However, percent recapture of the day released group was significantly lower than the evening and night released groups ($P < 0.05$). In tests conducted at West Extension Canal in 1991, median travel time of treatment fish released upstream of the drum screens was significantly faster at night compared with their daytime movement for fall chinook salmon ($P < 0.05$), but not for spring chinook salmon or summer steelhead ($P > 0.05$; Hayes et al. 1992).

Table 4. Travel time (mean hours to recapture 50 percent and 95 percent of test fish released) and percent of fish recaptured by the end of testing at the five major irrigation canals on the lower Umatilla River, Oregon.

Median test date	Species[a]	Release time	Release site[b]	Travel distance (m)	Canal flow (m^3/s)	Percent maximum canal flow	Bypass flow (m^3/s)	N	50% travel[c] time (hours) Mean	50% travel[c] time (hours) SD	95% travel[c] time (hours) Mean	95% travel[c] time (hours) SD	Percent recapture Mean	Percent recapture SD
West Extension Canal fish bypass facility														
4/8/92	STS	day	U-HG	39	1.2-1.4	23-27	0.1	9	33.5(4)	25.7			42.5	16.1
4/8/92	STS	day	U-DS	32	1.2-1.4	23-27	0.1	9	10.3(4)	10.3			47.1	23.4
5/5/92	CHS	day	U-HG	39	1.0-1.1	19-22	0.1	9	13.1	8.3			74.3	10.1
5/5/92	CHS	day	U-DS	39	1.0-1.1	19-22	0.1	9	11.1	12.4			81.1	11.2
5/19/92	CHF	day	U-HG	32	1.7-1.8	34-36	0.1	9	32.3(4)	22.8			55.3	25.7
5/19/92	CHF	day	U-DS		1.7-1.8	34-36	0.1	9	9.0(4)	8.3			69.7	12.4
Maxwell Canal fish bypass facility														
5/13/93	CHF	day	D-HG	2,410	0.4-0.8	23-48	0.3	3	3.6	0.8			70.3	4.7
5/13/93	CHF	evening	D-HG	2,410	0.4-0.8	23-48	0.3	3	2.6	0.6			85.7	2.1
5/13/93	CHF	night	D-HG	2,410	0.4-0.8	23-48	0.3	3	2.6	0.7			80.3	5.5
Westland Canal fish bypass facility														
4/16/93	CHS	day	U-HG	91	1.6-2.1	17-22	0.6	9					0.2	0.4
4/16/93	CHS	day	U-DS	78	1.6-2.1	17-22	0.6	9	T.3	0.9	16.0(7)	17.0	95.8	5.1
5/20/93	CHF	day	U-HG	91	6.6-6.8	70-72	0.6	5	0.5(2)	0.1	7.8(5)	6.2	96.3 28.2	35.0
5/20/93	CHF	day	U-DS	78	6.6-6.8	70-72	0.6	7	1.2	1.0				3.5
Feed Canal fish bypass facility														
3/24/94	CHS	day	U-DS	200[d]	6.3-6.5	91-94	0.5	9					26.9	8.3
Furnish Canal fish bypass facility														
5/20/94	CHF	day	D-HG	970	2.2-2.3	53-54	0.6	9	2.0	0.5	8.2(5)	2.8	94.0	5.1
5/20/94	CHF	day	U-DS	37	2.2-2.3	53-54	0.6	9	0.6	0.3	8.2	2.6	98.8	1.9

a STS = summer steelhead CHS = spring chinook salmon, CHF = subyearling fall chinook salmon.
b U-HG = upstream of headgates, U-DS = upstream of drum screens, D-HG = downstream of headgates.
c (N) given in parentheses, designates the number of test replicates that reached 50% or 95% recapture.
d Test fish were recaptured at the bypass outlet instead of the downwell.

The single bypass pipe design of the lower bypass at Furnish Canal passed subyearling fall chinook salmon quickly (0.57-m^3/s bypass flow; Figure 10). Fifty-two percent of the fish released at the bypass weir were recaptured at the outlet within 0.05 hours; 97% were recaptured within 1.2 hours, afterwards no additional fish were recaptured. Median travel speed through the lower bypass at Furnish Canal (2,800 m/h) was more than three times faster than travel rates through headworks canals at Furnish (485 m/h) and Maxwell (831 m/h) canals.

The coupled bypass-drain pipe design of the lower bypass at Westland Canal appeared to delay movement of yearling spring chinook salmon even though bypass flow was 0.74 m /s. Approximately half (47%) of the test fish traveled through the lower bypass at a speed of 533 m/h and were recaptured within 0.4 hours (Figure 10). Further collection of fish was protracted and continued for more than three hours after release. Only 76% of the test fish were recaptured at the conclusion of testing.

At West Extension Canal, the bypass pipe and energy-dissipating design of the lower bypass channel quickly passed only subyearling fall chinook salmon when bypass flow was 0.71 m /s (Figure 10). Ninety-two percent were recaptured in 0.5 hours. This was similar to the rapid travel of fall chinook salmon through the lower bypass at Furnish Canal. Recapture decreased for larger-sized fish and at lower bypass flows. Recapture for fall chinook salmon, spring chinook salmon, and summer steelhead after 0.5 hours was 92%, 16%, and 14% at a 0.71-m^3/s bypass flow and 17%, 13%, and 0.5% at a 0.14-m^3/s bypass flow, respectively.

Ladder

Test fish traveled quickly through the fish ladders at Stanfield and Feed Canal dams and the passage section of the fish ladder at Westland Dam. At these locations, greater than 90% recapture was reached in less than one hour; additional recaptures were not recorded after 1.5 hours (Figure 11). Travel was slower through the auxiliary water section of the fish ladders at Three Mile Falls and Westland dams. Approximately 50-65% of the fish released in the auxiliary water systems were recaptured after one hour; additional recapture was protracted (Figure 11). Final cumulative recapture of treatment fish passing through auxiliary water systems at the conclusion of testing was 82% for subyearling fall chinook salmon and 54% for spring chinook salmon at Three Mile Falls Dam, and 66% for fall chinook salmon at Westland Dam. Recapture was protracted for fish released upstream of Diffuser 1 in the passage section of the fish ladder at Three Mile Falls Dam. Recapture of spring chinook and fall chinook salmon released upstream of Diffuser 1 was 18% and 25% at the end of the testing.

Screen Efficiency and Impingement

Drum Screens

Mean drum screen efficiency exceeded 99.7% at West Extension, Westland, Feed, and Furnish canals (Table 5). Canal withdrawals during testing were approaching maximum design flow at Feed and Furnish canals and were less than

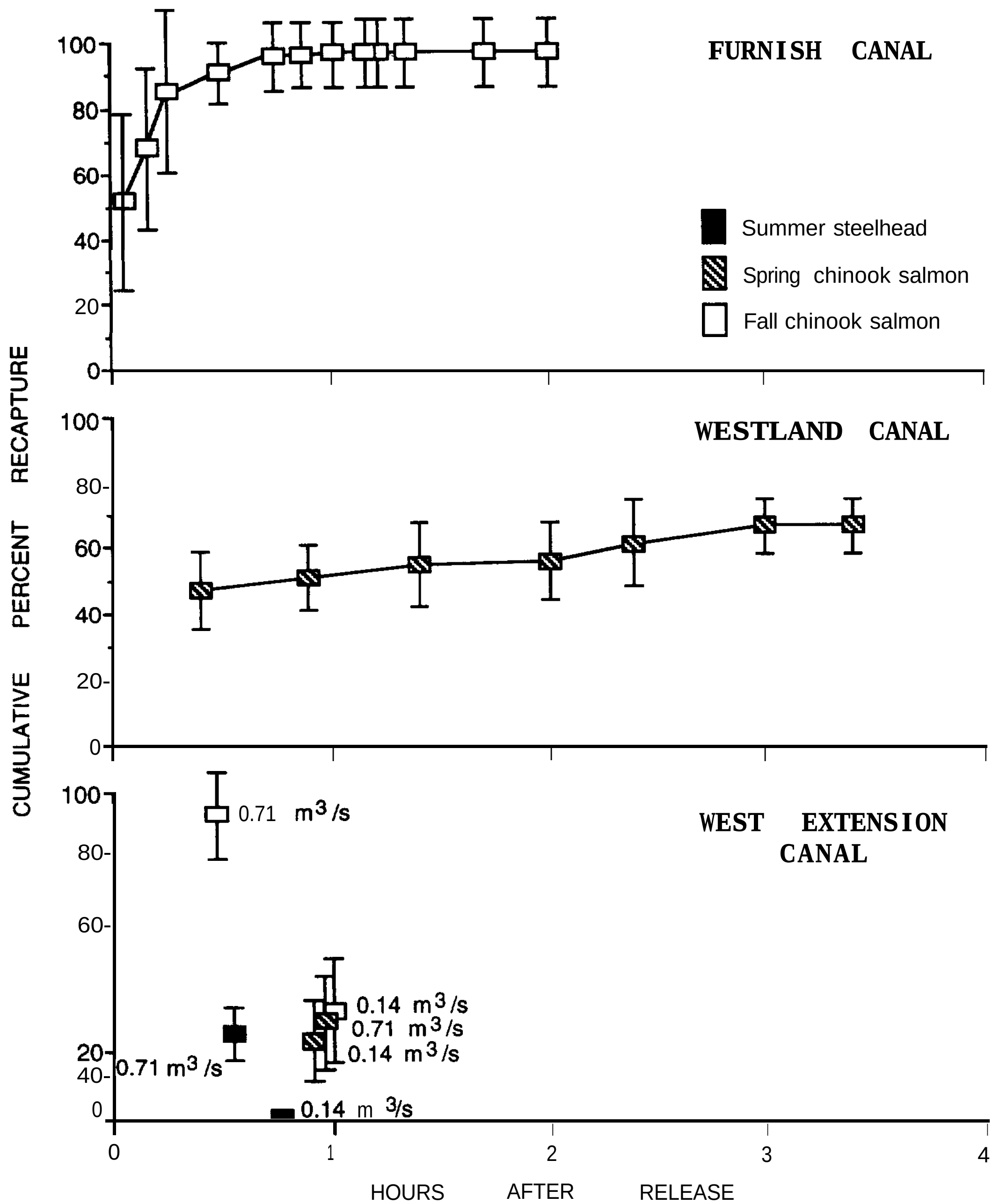


Figure 10. Cumulative percent recapture (mean and SD) of treatment fish released during injury tests conducted in the lower portion of fish bypass facilities at Furnish, Westland, and West Extension canals, Umatilla River, Oregon. Bypass flow (m^3/s) is shown for tests conducted at West Extension Canal.

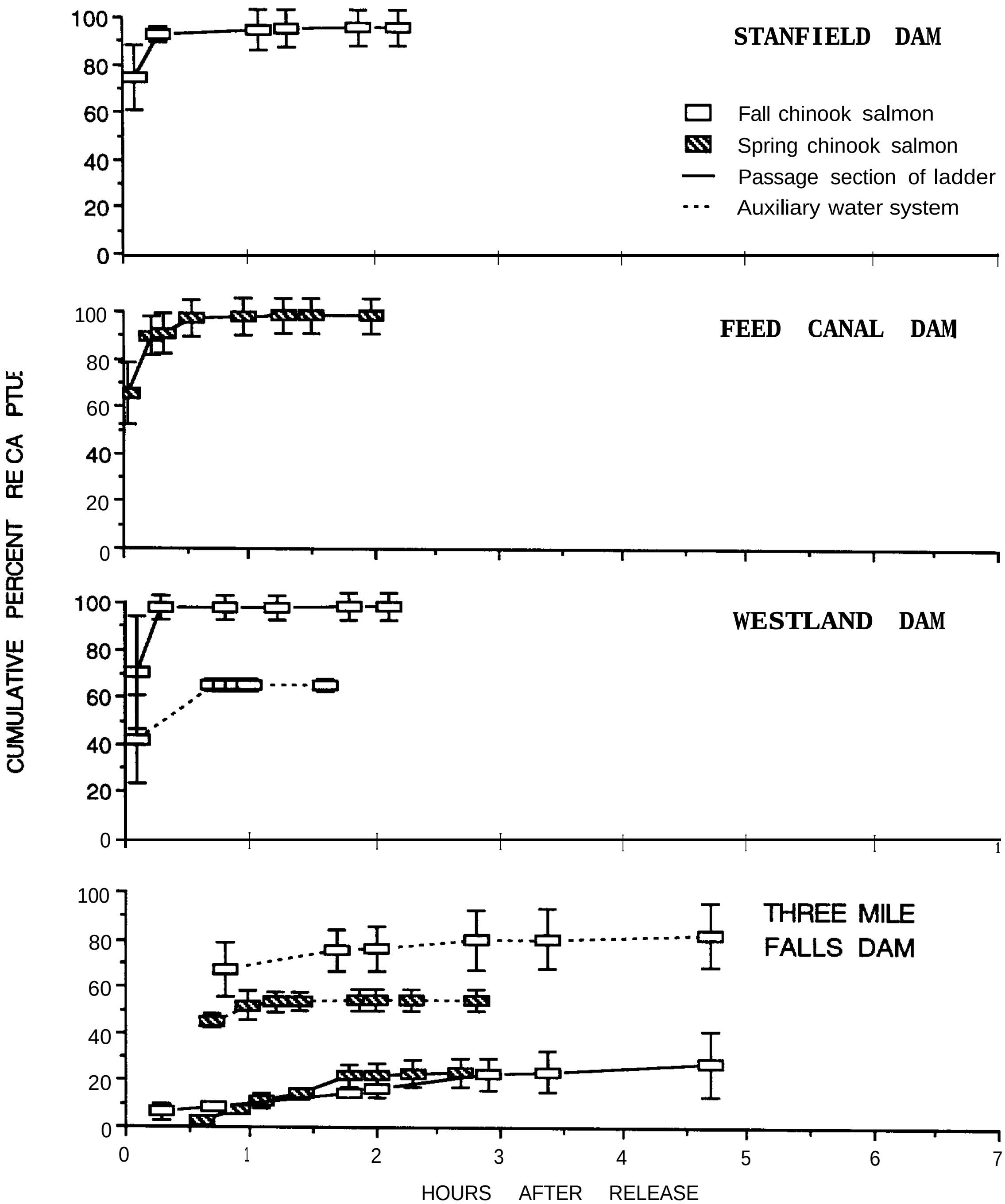


Figure 11. Cumulative percent recapture (mean and SD) of treatment fish released during injury tests conducted in the passage and auxiliary water sections of fish ladders at Stanfield, Feed Canal, Westland, and Three Mile Falls dams, Umatilla River, Oregon.

Table 5. Test fish release and recapture data, fish leakage through drum screens, and screening efficiency of drum screens at four irrigation canals on the lower Umatilla River, Oregon.

Canal	Number of screens	Percent maximum canal flow	Fish released upstream of screens: Fork length (mm)	Fish released upstream of screens: Number	Fish released upstream of screens: Recaptured (%)	Fish released at bypass channel entrance: Number	Fish released at bypass channel entrance: Recaptured (%)	Fish released in fyke nets: Number	Fish released in fyke nets: Recaptured (%)	Fish leakage through screens: Screens with leakage[a]	Fish leakage through screens: Mean fork length[b] (mm)	Mean screen efficiency (%)
West Extension	4	37-42	60.6	900	68.9	900	77.0	900	82.3	1(3), 2(1) 3(1), 4(1)	64.2(5)	99.78
Westland	10	12-16	56.6	3,000	0	0	0	3,000	83.5	1(5), 4(1) 5(2), 9(1) 10(5)	53.5(13)	99.95
Feed	10	85-88	64.1	3,000	88.3	1,440	98.3	3,000	84.5	1(1), 3(4) 4(1), 5(2) 7(2), 8(2) 9(1)	63.0(4)	99.95
Furnish	7	71-78	67.1	2,100	49.9	1,028	96.8	2,100	75.0	7(2)	60.0(1)	99.90

[a] Estimated number of fish that leaked through a screen is given in parentheses next to the screen number where leakage occurred.
[b] Numbers of fish in which fork lengths were measured is given in parentheses.

50% of maximum design flow at West Extension and Westland canals. Although screening efficiency was high, 50-100% of the screens at each site had some leakage except at Furnish Canal where only one fish was recaptured behind Screen 7. Fish leakage was highest at screens on the upstream and downstream ends of the screening facilities at Westland (Screens 1 and 10), West Extension (Screen 1), and Feed (Screen 3) canals. Mean fork lengths of fall chinook salmon were smaller for fish that leaked or rolled over the screens (53.5-63.0 mm) compared with fish released upstream of the screens (56.6-67.1 mm). Numbers of fish captured behind the screens were too low for statistical analyses. Capture efficiency for individual fyke nets ranged from 48-100%, and overall fyke net efficiency for each site ranged from 75.0-84.5%.

We rarely observed test fish impinged on drum screens during drum screen efficiency tests. Total number of impinged test fish was less than 0.01% of the total number released. Impingement of test fish was observed at Screen 4 at West Extension Canal, Screen 10 at Westland Canal, and Screen 5 at Feed Canal. Only one of these impinged test fish rolled over the screen (Screen 4 at West Extension Canal).

Belt Screens

Both belt screens at Westland Canal were 100% efficient at preventing test fish from entering the pumpback bay during simulated trapping operations. Most treatment fish were recaptured during testing (2 98%) and fyke net efficiencies were high (≥ 74-99%). Impingement of test fish on the screens was not observed.

The belt screen at West Extension Canal was greater than 99.4% efficient at preventing test fish from entering the pumpback bay when the pumpback bay drain pipe was 20%, 30%, or 40% open. Screening efficiency was slightly lower when the drain pipe was 20% open (99.5%) than when the drain pipe was 30% or 40% open (≥ 99.9%). More than 83% of treatment fish were recaptured at the end of testing and fyke net efficiency was high (≥ 97%).

Impingement of test fish on the belt screen at West Extension Canal was observed only when the drain pipe was 40% open (0.6%) or when both canal pumps were on (0.1%). Impingement occurred at the downstream end of the screen where turbulence was created by backflow off the orifice plate. Two of three fry impinged when the drain pipe was 40% open died from being caught between the screen and side seal. Other impinged fish did not appear injured.

Water Velocity

Bypass

Accuracy of the drum screen velocity measurements varied from 17% underestimation to 42% overestimation based on comparison of canal flow estimated from velocity measurements to canal flow measured at OWRD gauging stations (Table 6). Most approach velocities measured in front of drum screens at the five canals met screening criteria for protection of smolts (I 0.24 m/s) at maximum canal flow expected from March through May (Table 6). Approach velocity criteria for protection of fry (≤ 0.12 m/s) was met at 26-79% of the sampling locations in front of drum screens at maximum canal

Table 6. Percent of maximum canal flow expected in March-May (max.), canal flow when water velocity measurements were collected (OWRD gauge readings), canal flow estimated from velocity measurements, error of estimate, and percent of velocity measurements meeting approach velocity (AV) and sweep to approach velocity (S:AV) criteria at maximum canal flow expected in March-May at irrigation canals on the lower Umatilla River, Oregon.

	Canal flow				Percent of measurements expected to meet criteria		
Canal	Percent of max.	Gauge reading (m^3/s)	Estimate (m^3/s)	Error of estimate	0.12 m/s AV	0.24 m/s AV	2:1 S:AV
West Extension	46	1.8	1.1	-42%	64	100	100
Maxwell	93	1.0	0.9	-16%	52	100	41
Westland	85	6.0	5.0	-17%	49	100	100
Feed	86	5.9	5.6	-5%	26	96	91
Furnish	100	3.5	4.1	+17%	79	100	94

flow expected from March through May (Table 6). Highest approach velocities were regularly measured at screens closest to the bypass channel. Approach velocities were closest to meeting criteria for fry protection at Furnish Canal and furthest from meeting criteria at Feed Canal.

Ratio of sweep to approach velocity was within criteria (≥ 2) at more than 90% of the sampling locations at all study sites except Maxwell Canal. At this site, only 41% of the velocity measurements met sweep to approach criteria (Table 6). Ratio of sweep to approach velocity steadily decreased with increasing distance from the bypass channel at Maxwell Canal (Figure 12).

Flow patterns in front of drum screens varied with the number of screens at each site. At sites with seven or ten screens (Westland, Feed, and Furnish canals), the highest approach velocities and lowest sweep to approach velocity ratios were measured at screens at the ends and middle of the screening facility (Figures 13-15). Non-laminar flow increased the variability of measurements in these areas. At West Extension Canal, approach velocities were fairly uniform among all four screens with the exception of a few high readings at 20% water depth near the middle of the screening facility (Figure 12). At Maxwell Canal, approach velocities were generally highest at 50% water depth and at the ends of the three-screen facility.

Water velocity at bypass channel entrances met NMFS velocity criteria and were fairly uniform among depths and study sites (Table 7). Velocity was highest at the Furnish Canal bypass (0.79-0.82 m/s) and ranged from 0.58-0.73 m/s at all other study sites.

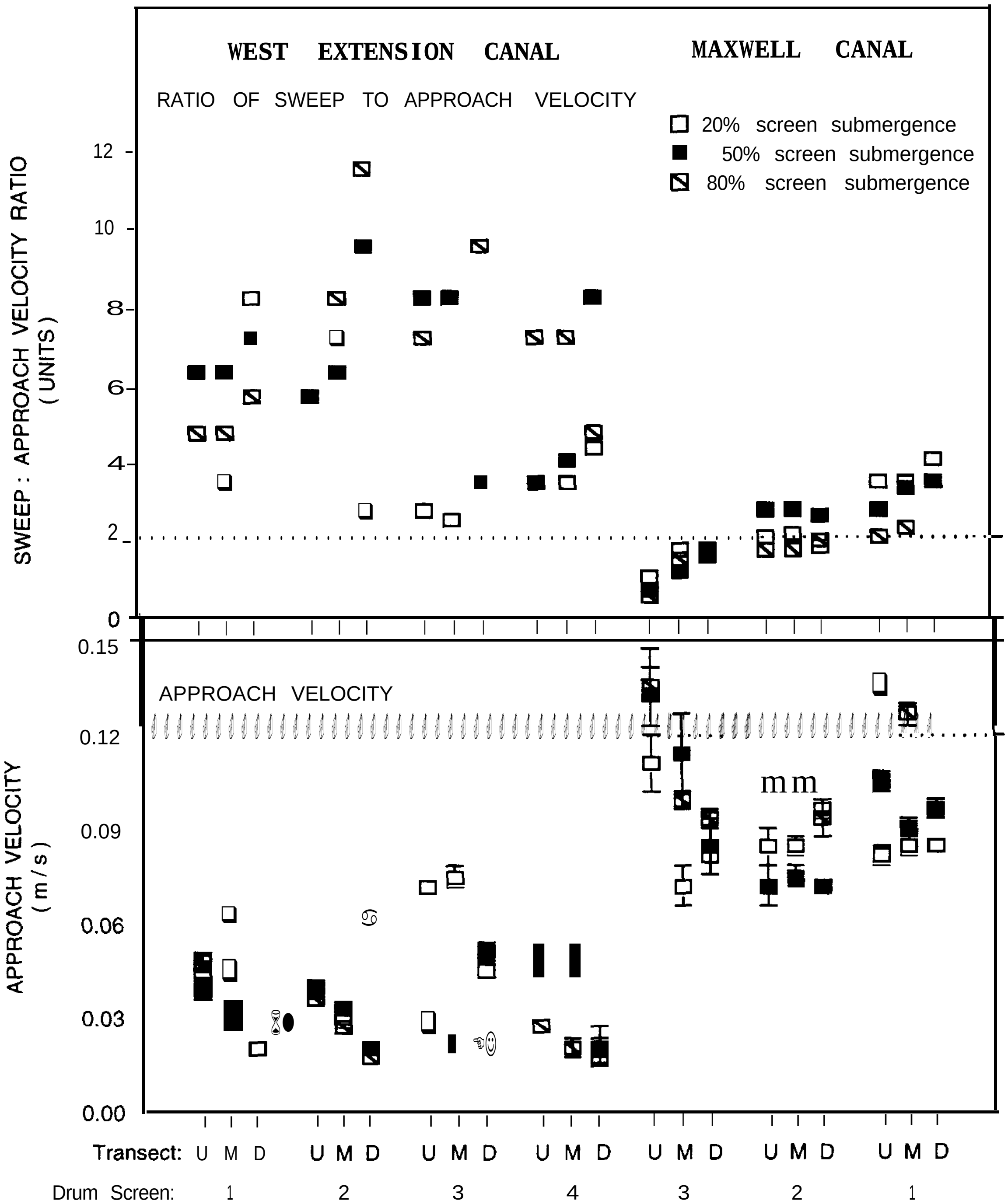


Figure 12. Ratio of sweep to approach water velocity and approach water velocity measured in front of drum screens at West Extension and Maxwell canals, Umatilla River, Oregon. Measurements were collected along upstream (U), midscreen (M), and downstream (D) vertical transects (N = 5, error bars = SD). Drum screens are numbered in ascending order at West Extension Canal and descending order at Maxwell Canal from the furthest upstream screen to the screen closest to the bypass channel.

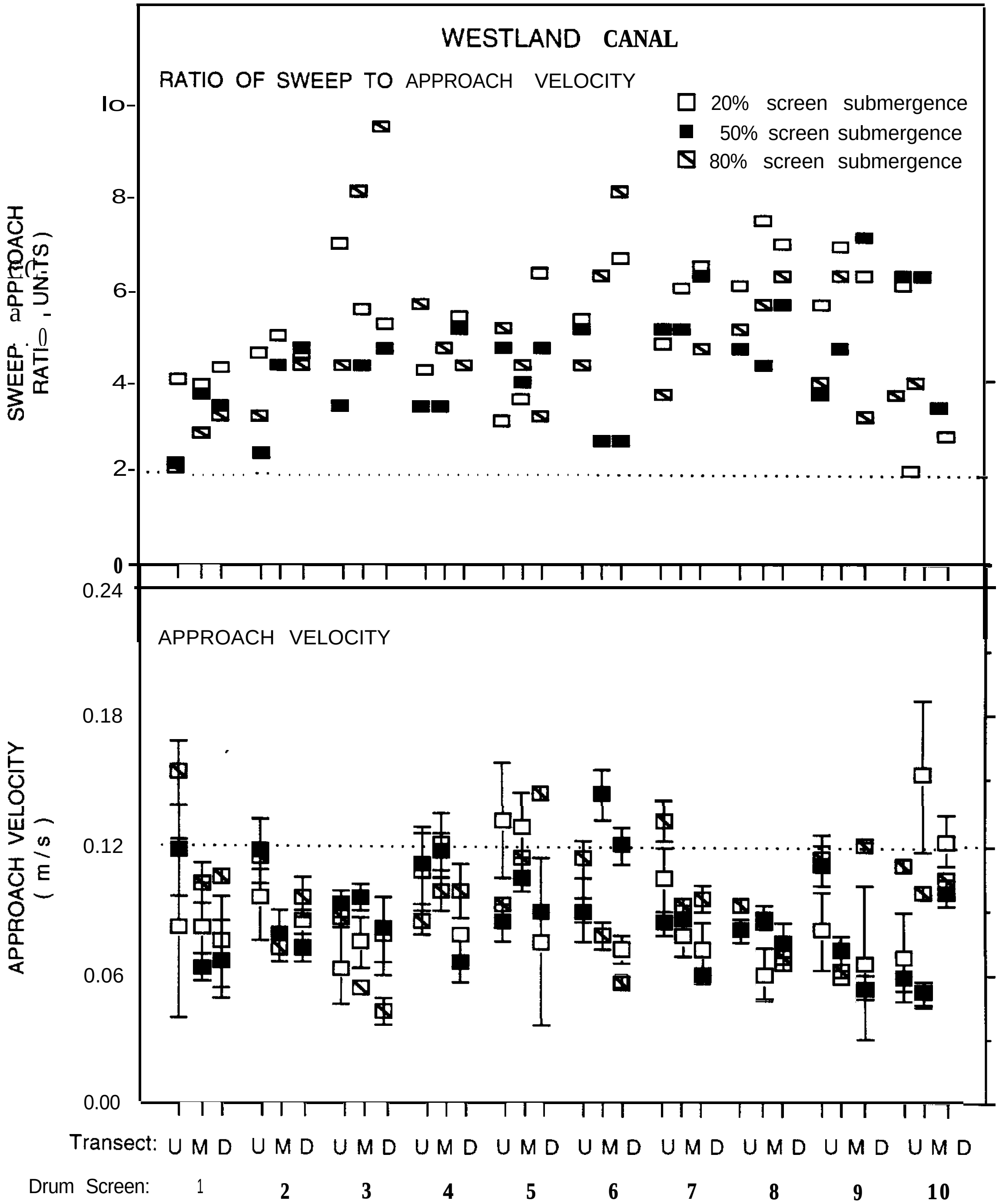


Figure 13. Ratio of sweep to approach water velocity and approach water velocity measured in front of drum screens at Westland canal, Umatilla River, Oregon. Measurements were collected along upstream (U), midscreen (M), and downstream (D) vertical transects (N = 5, error bars = SD). Drum screens are numbered in ascending order from the furthest upstream screen to the screen closest to the bypass channel.

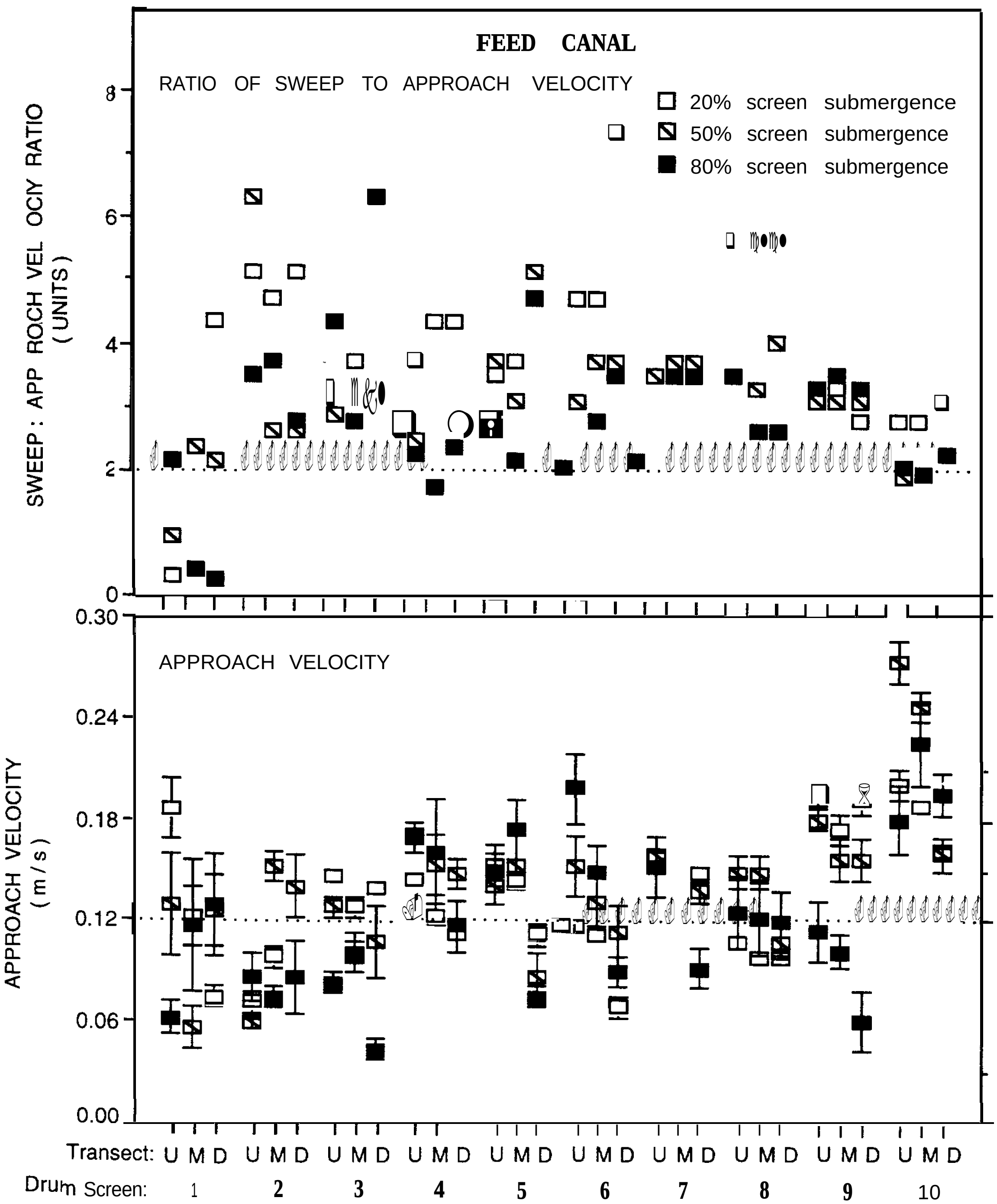


Figure 14. Ratio of sweep to approach water velocity and approach water velocity measured in front of drum screens at Feed canal, Umatilla River, Oregon. Measurements were collected along upstream (U), midscreen (M), and downstream (D) vertical transects (N = 5, error bars = SD). Drum screens are numbered in ascending order from the furthest upstream screen to the screen closest to the bypass channel.

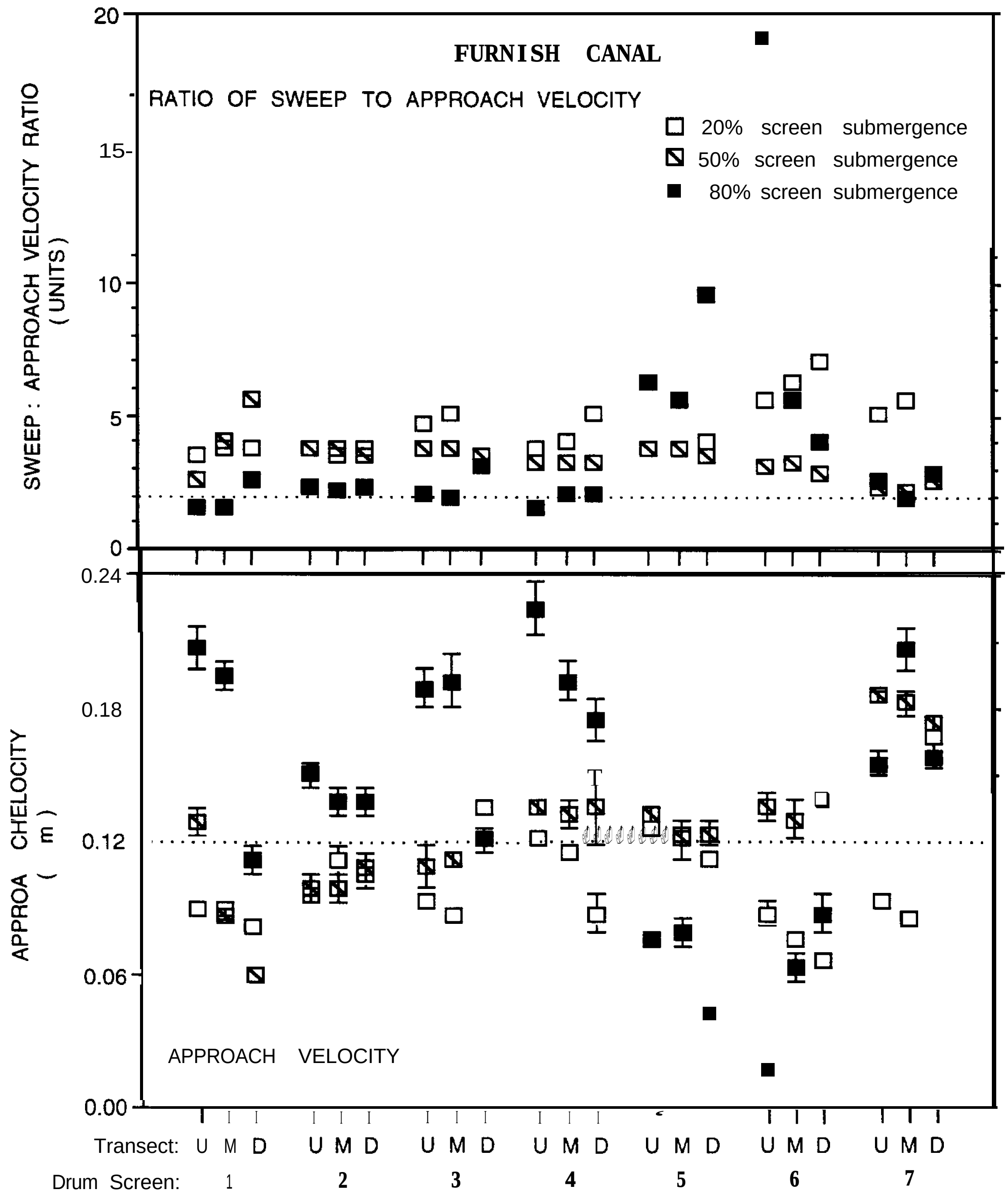


Figure 15. Ratio of sweep to approach water velocity and approach water velocity measured in front of drum screens at Furnish Canal, Umatilla River, Oregon. Measurements were collected along upstream (U), midscreen (M), and downstream (D) vertical transects (N = 5, error bars = SD). Drum screens are numbered in ascending order from the furthest upstream screen to the screen closest to the bypass channel.

Table 7. Water velocity (m/s) measured at bypass channel entrances during high flow bypass operations at irrigation canals on the lower Umatilla River, Oregon.

Location	Date	Water velocity			
		20% depth	50% depth	80% depth	Mean
West Extension Canal	7/27/95	0.58	0.61	0.70	0.63
Maxwell Canal	5/4/94	0.70	0.73	0.64	0.69
Westland Canal	4/29/94	0.64	0.64	0.67	0.65
Feed Canal	4/14/94	0.70	0.73	0.64	0.69
Furnish Canal	512194	0.79	0.79	0.82	0.80

At West Extension Canal, sweep velocities in front of the belt screen met criteria during all six pumpback operations tested (Table 8). Approach velocity criteria for fry protection (I 0.12 m/s) was slightly exceeded at a few sampling locations during one- or two-pump operations or when the pumpback bay drain pipe was 20% open. Approach velocities exceeded 0.12 m/s when the drain pipe was 30% (2 locations) and 40% (6 locations) open. Excessive approach velocities were primarily located at either 20% depth or the upstream transect of the screen. All operations tested met approach velocity criteria for smolt protection (I 0.24 m/s), except a 40%-open drain pipe. Back-flow from the orifice plate created turbulent non-laminar current across the downstream one-third of the belt screen, particularly when the drain pipe was 40% open.

A two-pump operation and a 20%-open drain pipe created similar flows through the belt screen and mean velocities at the bypass channel entrance (Table 8). Flow and velocity steadily increased with a 30%- and 40%-open drain pipe. Velocity at the bypass channel entrance produced by the two-pump operation or 20%-open drain pipe approximated design velocity (0.61 m/s) for facility operations with a bypass flow of 0.71 m^3/s.

Ladder

At the Three Mile Falls Dam east-bank fish ladder, flow moved across the face of Diffuser 1 toward Transect 1 (Figure 16). Flow approached the diffuser at angles ranging from 24-83° (90° = flow perpendicular to diffuser). Sweep velocity ranged from 0.06-0.58 m/s (mean = 0.19 m/s) and approach velocity ranged from 0.13-0.58 m/s (mean = 0.31 m/s). Sweep velocity decreased and approach velocity increased at Transect 1 where flow was directed more perpendicular to the diffuser. Approach velocities were generally higher near the surface and sides of the diffuser than in the middle. Water turbulence associated with a midchannel I-beam resulted in

Table 8. Water velocity (m/s) and flow (m^3/s) at the belt screen and bypass channel entrance of West Extension Canal during pumpback operations with one or two 0.28-m^3/s pumps on and when the pumpback bay drain pipe was 20%, 30%, or 40% open. Measurements were collected at three depths along an upstream (U). middle (M) and downstream (D) transect on 3 October 1995.

Percent of water depth	Velocity component	Water velocity: Pump 1 U	M	D	Pump 2 U	M	D	Pumps 1+2 U	M	D
20	approach	**0.10**	**0.06**	**0.03**	**0.16**	**0.07**	**0.05**	**0.14**	**0.07**	**0.10**
20	sweep	0.26	0.30	0.21	0.35	0.32	0.27	0.44	0.42	0.40
50	approach	**0.05**	**0.03**	**0.05**	0.07	0.06	0.06	0.09	0.11	0.11
50	sweep	0.34	0.30	0.23	0.35	0.28	0.23	0.50	0.43	0.29
80	approach	**0.04**	**0.03**	**0.03**	**0.19**	**0.04**	**0.05**	0.10	0.08	0.06
80	sweep	0.38	0.28	0.24	0.40	0.29	0.20	0.59	0.41	0.20
	Velocity at bypass channel entrance[a]	--			0.37			0.59		
	Estimated flow through belt screen	0.20			0.27			0.38		
		Drain pipe 20% open U	**M**	**D**	**Drain pipe 30% open U**	**M**	**D**	**Drain pipe 40% open U**	**M**	**D**
20	approach	**0.14**	**0.13**	**0.09**	**0.12**	**0.23**	**0.21**	0.34	0.23	0.16
20	sweep	0.55	0.42	0.28	0.70	0.33	0.35	0.76	0.53	0.34
50	approach	**0.12**	**0.12**	0.11	0.11	0.10	0.10	0.28	0.09	0.08
50	sweep	0.43	0.37	0.31	0.61	0.41	0.40	0.76	0.61	0.39
80	approach	0.11	0.18	0.08	0.10	0.11	0.10	0.33	0.18	0.11
80	sweep	0.57	0.39	0.30	0.79	0.43	0.41	0.77	0.55	0.46
	Velocity at bypass channel entrance[a]	0.63			0.75			0.82		
	Estimated flow through belt screen	0.46			0.52			0.79		

[a] *Mean of 20%, 50%, and 80% sampling depths.*

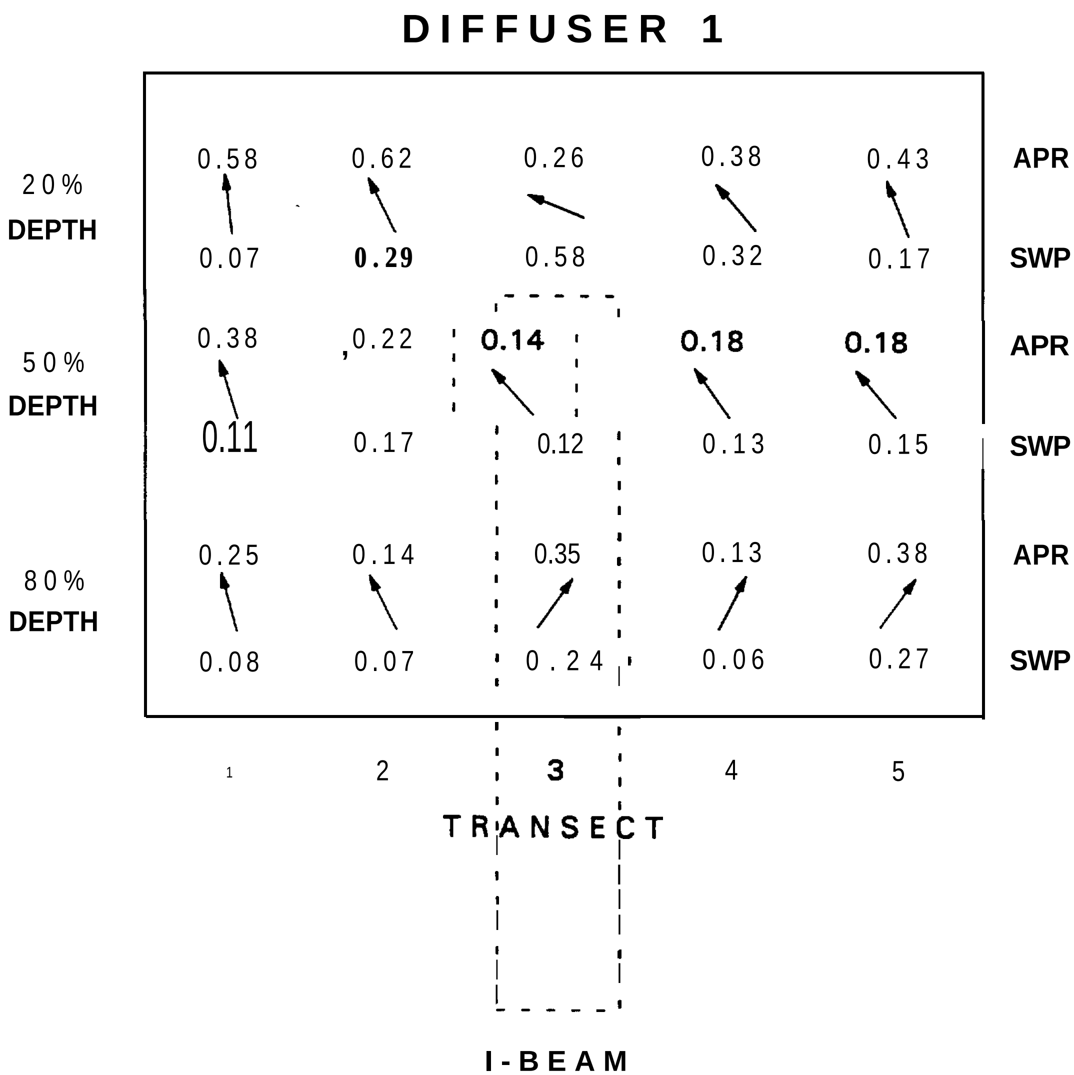


Figure 16. Approach (above arrows) and sweep (below arrows) water velocity (m/s) measured in front of Diffuser 1 located in the passage section of the fish ladder at Three Mile Falls Dam, Umatilla River, Oregon. Arrows indicate direction of flow. Flow perpendicular to the diffuser is depicted by arrows pointing straight up.

variable approach and sweep velocities at transects 2-4.

Almost all water movement in front of Diffuser 2 at the auxiliary water system flowed east to west (Figure 17). Currents were more often directed across the face of the diffuser on the east panel than the west panel. Angle of flow approaching the diffuser averaged 37° for the east panel and 75° for the west panel. Flow was virtually parallel to the diffuser at three sampling locations on the east panel where sweep velocities ranged from 0.32-0.36 m/s. In contrast, flow was directed straight at the diffuser at two sampling locations in front of the west panel, where approach velocity was 0.11 m/s and 0.27 m/s. Mean approach velocity was higher at the west panel (0.28 m/s) than the east panel (0.14 m/s). Mean sweep velocity was higher at the east panel (0.23 m/s) than the west panel (0.09 m/s).

DISCUSSION

Injury

Bypass

Overall, our findings concur with studies on the Yakima River in that current designs of fish bypass facilities using angled drum screens, vertical-slot bypass channels, and large diameter bypass pipes return juvenile salmonids to the river with negligible injury (Neitzel et al. 1985, 1987, 1988, 1990a, 1990b, 1991; and Hosey and Associates 1988a, 1988b, 1989, 1990). Differences in treatment and control injury were within confidence limits in all but two bypass injury tests. In these two tests, significant differences were probably an artifact of sampling error or handling injury.

Significance in the night-time screen injury test with subyearling fall chinook salmon at West Extension Canal was a result of biased pre-test subsampling of control fish. Irrespective of the biased estimate of control injury, post-test injury to treatment fish was comprised only of partial descaling (8.2%). Studies conducted with coho salmon (*Oncorhyncus kisutch*, Bouck and Smith 1979) and chinook salmon (Basham et al. 1982) indicated partial descaling did not result in mortality in freshwater systems. Significance in the facility injury test at Feed Canal was a result of higher handling injury incurred by treatment fish than control fish. Control fish released in the trap net were quickly recaptured with few other fish; treatment fish received rougher handling when they were recaptured with large numbers of salmonid migrants later in the evening. We did not expect treatment fish to temporarily hold in the screen forebay, based on previous test experience (Hayes et al. 1992; Cameron and Knapp 1993; Cameron et al. 1994). Large influxes of migrant fish similarly biased tests conducted at the Wapato Canal bypass facility (Neitzel et al. 1991).

Poor precision in outfall and downwell injury tests at West Extension Canal was a probable result of variable injury rates associated with inconsistent trap placement among replicates. Even though outfall and downwell injury tests were not statistically significant, test results suggest some fish are injured in the lower bypass. Injury was consistently higher for treatment fish than control fish in outfall injury tests with spring chinook and subyearling fall chinook salmon. Injuries to spring chinook salmon in the

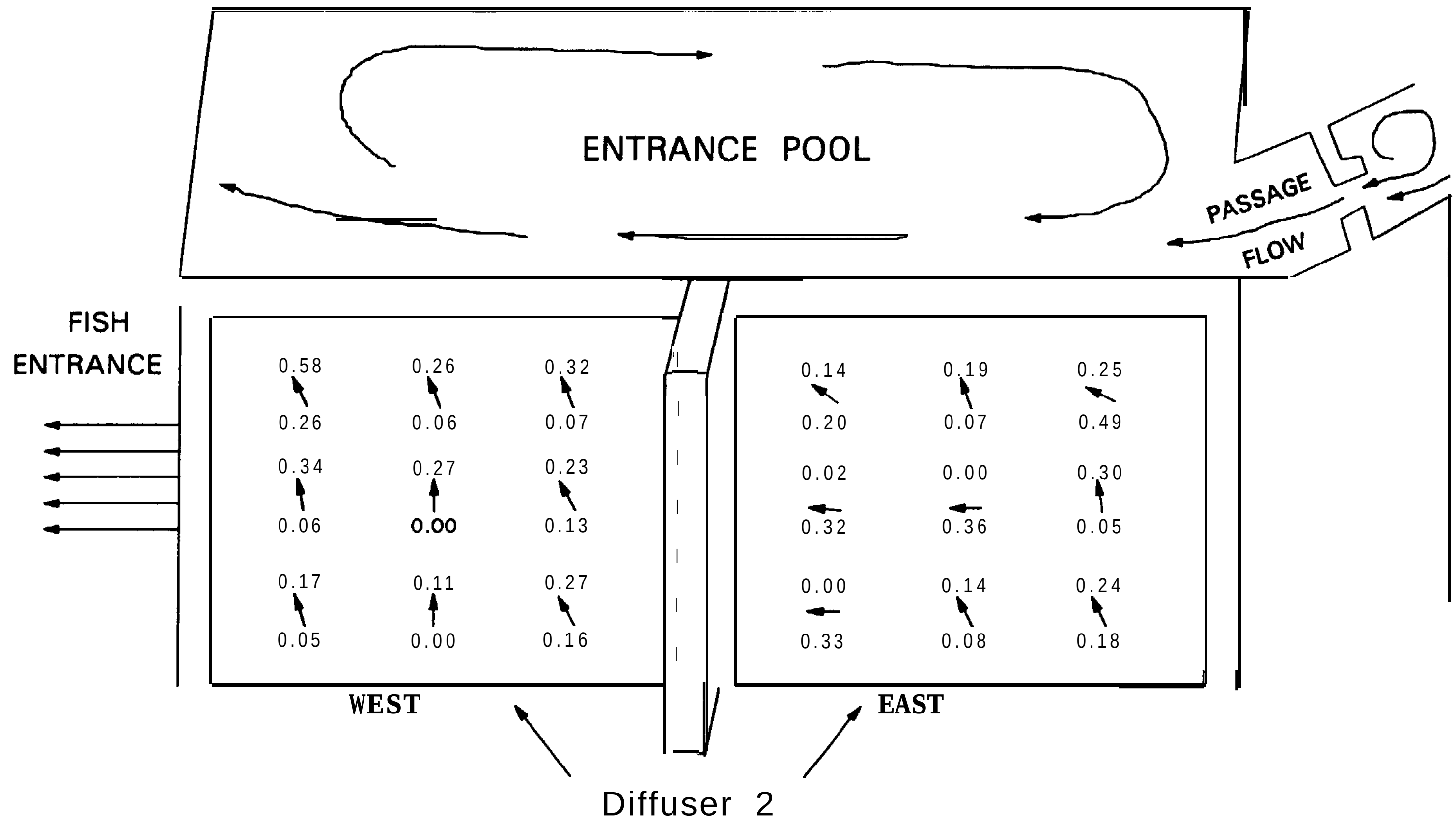


Figure 17. Approach (above arrows) and sweep (below arrows) water velocity (m/s) measured in front of Diffuser 2 located between the auxiliary water system and entrance pool of the fish ladder at Three Mile Falls Dam, Umatilla River, Oregon. Arrows indicate direction of flow. Flow perpendicular to the diffuser is depicted by arrows pointing straight up.

lower bypass were not severe (partial descaling). However, injuries to subyearling fall chinook salmon in the outfall injury test (descaling and mortality) were the most severe of any of the bypass injury test results. Weaker swimming ability of subyearling fall chinook salmon was the most probable reason injuries were severe. In addition, fall chinook salmon were more prone to injury when bypass flow was high (0.71 m^3/s). Reduction of flow through the lower bypass when fall chinook salmon are present (late-May and June) should be considered to reduce potential injury. Non-standard operations with a high downwell pool depth did not provide additional protection from injury.

Ladder

Midchannel diffusers were the most probable cause of injury to juvenile salmonids in fish ladders on the lower Umatilla River. Juvenile salmonids moved safely through the unobstructed passage sections of fish ladders at Westland, Feed, and Stanfield dams. In contrast, injuries were most severe to subyearling fall chinook salmon in the passage section of the ladder at Three Mile Falls Dam. The passage section of this ladder has two sets of midchannel diffusers. Two-thirds of the descaling detected in the passage side of the ladder was associated with diffusers.

We conducted underwater video work in 1996 that documented large numbers of fish in front of Diffuser 1 (Knapp et al. 1997). Hundreds of fish were observed on numerous occasions following currents across the upstream side of Diffuser 1 and frequently impacting on it. Subyearling fall chinook salmon appeared to impact the diffuser more frequently than the yearling chinook salmon or steelhead, apparently because of weaker swimming ability. These observations are consistent with laboratory experiments indicating normal movement of juvenile salmon is interrupted by vertical bar openings less that 76 mm (Hanson and Li 1983). Current openings are at the maximum design criteria (25 mm) established to prevent gilling of immature adult salmon. Both yearling and subyearling chinook salmon appeared to pass more readily through portions of Diffuser 1 where flow was directed at (rather than across) the diffuser. Fish exit gates were only 55% open when we conducted the injury tests. Partial openings of the gates appear to increase the velocity and turbulence of flow through the gates. Flow patterns in front of the diffuser might be improved by raising the fish exit gates to full open.

Subyearling chinook salmon were also injured in the slot-and-pool segment of the passage section of the fish ladder at Three Mile Falls Dam. Flow patterns associated with a 46° slot jet orientation at the Three Mile Falls Dam fish ladder may be the primary cause of injury. Juvenile salmon were not injured in the passage section of the fish ladders at Westland, Feed, and Stanfield dams which incorporate a slot jet orientation of 36°. All the fish ladders n the Umatilla River have the same slot and pool dimensions and slope. Unique flow patterns associated with the 46° slot jet orientation only caused injury to the weaker swimming subyearling chinook salmon and not yearling chinook salmon. Underwater video could be used in the slot and pool section of the fish ladder to gain more insight into design factors that may be causing injury to subyearling fish.

Juvenile salmonids were injured in the auxiliary water system of the fish ladder at Westland Dam which is also obstructed by a diffuser panel. However, neither subyearling chinook or yearling chinook salmon were injured when they passed through a similar auxiliary water system in the fish ladder at Three Mile Falls Dam. Differences in injury at these sites may be related to differences in positioning of baffles that dampen water velocity in front of the auxiliary water diffusers. Baffles are positioned parallel to and 0.6 m in front of Diffuser 2 inside the fish ladder at Three Mile Falls Dam. At Westland Dam, baffles are positioned at a 68° angle to the auxiliary water diffuser. The baffles range from 0.6-6.9 m away from the diffuser as a result of their angled orientation. Positioning baffles parallel to and 0.6 m in front of diffusers appears to be a better configuration for juvenile salmonid passage through auxiliary water systems in fish ladders. However, juvenile salmonid passage through-the auxiliary water system at Westland Dam may not be a major passage concern because although injury was significant, it consisted of low levels of descaling. In addition, the design of the auxiliary water trashracks (38 mm slats spaced 25 mm apart) and their parallel orientation to river flow is expected to guide most juvenile salmonids past the auxiliary water intake. Bates and Vinsonhaler (1957) found slats with 25 mm opening and an orientation to flow similar to the auxiliary water trashracks at Westland Dam had guidance efficiencies of 88-100% for chinook salmon (73 mm mean standard length) when water velocity ranged from 0.4-1.4 m/s.

Travel Rate and Recapture

Bypass

Relevant questions associated with travel rate and recapture are whether fish bypass designs delay "normal" fish movement and whether canal operations affect the rate of fish passage through the facilities. However, these questions are difficult to answer because travel rate and recapture data were ancillary information collected during the conduct of injury tests. Nevertheless, we observed some general patterns of fish movement through the fish bypass facilities that are consistent with findings of other studies.

Our only legitimate comparisons of travel time, travel speed, and recapture were based on simultaneous releases of test fish. Comparison of median travel speed of subyearling fall chinook salmon released downstream of the headgates (485 m/h) to those released at the same time in the screen forebay (62 m/h) at Furnish Canal indicated that fish movement was delayed near the screens. Slower travel through screen forebays is also suggested by data collected at other study sites. Median travel speed of summer steelhead, spring chinook, and subyearling fall chinook salmon through the screen forebays at West Extension, Westland, and Feed canals was relatively slow (5-65 m/h). Median travel speed of fall chinook salmon was considerably faster through the long headworks canal at Maxwell Canal (831 m/h). Travel speed is even faster in the river. Based on peak passage times, subyearling chinook and yearling chinook salmon released in the upper Umatilla River (rkm 136 or 148) traveled to the lower river (rkm 5.6) at speeds of 1,000-3,000 m/h (Knapp et al. 1996). Peak passage time is a close approximation for median travel time. Delay near screening facilities should be brief because of the short travel distance through screen forebays. It is unknown whether even a brief delay will affect migration success of juvenile salmonids because cumulative effects of delays at multiple dams and energetic costs associated with the delays are unknown.

Simultaneous releases of test fish indicated the headgates at West Extension Canal delayed passage of summer steelhead and subyearling fall chinook salmon by about 20 hours and prevented some fish from entering the canal. Headgates that deter fish from entering a canal are preferable at sites where juvenile salmonids can pass safely and quickly over the dam crest or spillway, or through a fish ladder. However, the fish bypass at West Extension Canal is the preferred passage route past Three Mile Falls Dam. The three headgates at West Extension Canal open from the bottom and are usually set to identical heights (15 cm to 1.2 m). Fish attraction to small headgate openings is probably minimal, particularly when river elevation is high and canal flow relatively low. Opening the fewest number of headgates when canal withdrawals are low may enhance fish passage at West Extension Canal.

General patterns of fish movement were similar in the upper portions of bypass facilities on the Umatilla and Yakima rivers. Data collected at all study sites on the Umatilla River suggest there was no relationship between travel time and canal flow. Fast and slow travel times were recorded at both high and low canal flows. However, there was a tendency for fish released on earlier dates to travel slower than fish released on later dates. We concur with Neitzel et al. (1986, 1988) and Hosey and Associates (1990) that these patterns of fish movement are attributable to varying degrees of smolting and migratory behavior exhibited by test fish. Large numbers of fish may hold upstream of the drum screens prior to their development of migratory behavior. Therefore, observations of fish holding in bypass facilities do not necessarily imply fish are being delayed. We have observed large numbers of yearling salmonids holding in the wide, slow-velocity sections of canals upstream of the screens at Westland and Furnish canals. Facility designers should strive to maintain a uniform canal profile upstream of the screens to reduce potential fish holding.

Facility operators need to be aware that large numbers of fish may be present in the screen forebay when canals are dewatered. Tens of thousands of fish have been present in the screen forebay when Westland and Feed canals were dewatered (Zimmerman et al. 1991, 1992). The forebay drain pipe provides a means of returning fish to the river if it is unscreened, at least 100 mm in diameter, free of debris and sharp turns, and located at the low end of the screen forebay. Water leakage through the headgates typically provides several days of flow through the drain pipe. If the-drain pipe is not sited at the low end of the screen forebay, manual removal of fish may be required.

Diel patterns of fish movement at bypass facilities may vary among river systems and fish stocks. For example, most species of hatchery fish moved within a few hours of dawn and dusk and in the midday at fish bypasses on the Umatilla River (Knapp et al. 1996). In contrast, peak fish movement can be at night at bypass facilities in river systems with substantial numbers of naturally produced salmonids, particularly age 0 fish (Neitzel et al. 1985; Hosey and Associates 1990; Cramer et al. 1992). Facility operators should be provided information on local patterns of fish movement to prevent conduct of potentially harmful operations during periods of peak fish movement (e.g. sluicing pumpback bays, draining forebays, algacide applications).

The basic lower bypass design consisting of a downwell, bypass pipe, and outlet passed subyearling fall chinook salmon without delay. Fish were delayed in the more complex lower bypass system at Westland Canal. In our tests, recapture of spring chinook salmon released in the lower bypass was low and protracted. Tying the drain pipe for the fish trap and pumpback bay into the bypass pipe provides calm areas for fish to hold. Juvenile and adult salmonids have swum up the drain pipe and entered the flapgate box and pumpback bay (Zimmerman et al. 1993). The problem of fish accessing the drain pipe is probably exacerbated by the low head differential between pipe intakes and outlet, which allows the lower bypass system to back up at moderate to high river flows. A screen was installed over the drain pipe at the flapgate box in 1994 to prevent further movement of fish into the pond and pumpback bay drain system. Blockage of the pond drain system by debris accumulation on the screen is an operational concern. Design of future facilities should consider 1) adding a checkvalve to the drain pipe at its junction with the bypass pipe or 2) separating the bypass and drain pipes.

Reduced water velocity in the outfall structure at West Extension Canal also provides a temporary holding area for juvenile salmonids. Only subyearling fall chinook salmon moved quickly through the lower bypass when bypass flow was 0.71 m^3/s. The sloping channel floor in the outfall structure was designed to dissipate water velocity at the higher 0.71-m^3/s bypass flow. At the slower 0.14-m^3/s bypass flow, a calm pool is created that provides an unintended sanctuary for fish. We have observed yearling steelhead and chinook salmon preying on subyearling fish in the outfall pool; extent of predation was unknown. Outfall structures incorporating designs for energy dissipation at higher flows should be designed to quickly pass fish at lower flows.

The new design of a large diameter pipe with smooth joints and gradual bends has alleviated most problems with debris occlusions. Debris accumulation at the bypass weir or pipe entrance can potentially delay fish passage and cause injury. Canal trashracks intercept most large debris, but jams inside the pipe do occasionally occur when debris enters the screening facility (Neitzel et al. 1989b; Knapp and Ward 1990). Bypass pipes should be thoroughly checked for blockage before water up, and after temporary shut-downs and flood events. Camera systems are available that simplify the inspection process. A regular maintenance program that includes inspection and removal of debris in the bypass system is essential.

Occlusion of the submerged bypass outlet by bedload movement during floods can be a chronic problem that completely precludes bypass flow and fish passage, and causes fish injury. This has been an ongoing problem at Westland Canal and sites on the Yakima River (Neitzel et al. 1990a). In addition, erosion of the shoreline by flooding caused the bypass pipe outlet at Westland Canal to terminate in midchannel (Zimmerman and Duke 1993, 1995). Relocation of the outlet nearer to shore was necessary to permit gravel removal by heavy equipment at higher river flows. Operating the bypass at maximum flow (0.74 m^3/s) during high river flow was attempted, but not successful in preventing gravel occlusion. Submerged outlet siting requires careful evaluation of river hydraulics, bank stability, and potential bedload movement during the pre-design stage to prevent or minimize problems with outlet blockage.

Maintaining proper bypass flow is also important for safe and quick fish passage through the lower bypass. This can only be achieved if facility operating criteria is available and adhered to by operators. Stable headworks water elevation and proper bypass weir settings are crucial to maintaining constant spill levels over the bypass weir. Automated headgates at Furnish Canal have been very effective for these purposes. However, there is about a half-hour time lag between checkgate adjustment and stabilization of the headworks elevation due to the long distance between headgates and checkgates. Fluctuation in bypass flow during this lag period is not a major concern. However, fish spilling into the overflow wasteway at Furnish Canal during the rises in water elevation will probably be injured or stranded. Increasing the height of the wasteway sill could alleviate potential fish spillage. Automated checkgates at Westland Canal are located closer to the bypass facility and have recently been performing well. Initially, considerable effort was required to debug errors in the instrumentation and operation. Manual headgate adjustments are least effective in maintaining constant headworks elevation and bypass flow. Fluctuations in canal elevation are most difficult to control at the lowermost dam (West Extension Canal) due to frequent changes in water diversion rates upriver. Daily adjustments by operators in the morning and evening are adequate when river flow is fairly stable, but more frequent adjustments are required when river flow changes rapidly.

Ladder

Juvenile salmonids passed quickly through unobstructed segments of fish ladders, but were delayed in segments of ladders with midchannel diffusers. Recapture was lowest for test fish (spring chinook and fall chinook salmon) released upstream of Diffuser 1 in the passage section of the fish ladder at Three Mile Falls Dam. Recapture was intermediate for test fish released in the auxiliary water systems of fish ladders at Three Mile Falls and Westland dams. Delay of juvenile salmonids in these auxiliary water systems should not be a passage problem because most fish are expected to be guided away from the auxiliary water intake by the louver-like design of the trashracks. Delay of juvenile salmonids is a passage concern at Diffuser 1. Fish exit gates should be operated full open, velocity measurements retaken, and fish behavior monitored with underwater video to assess whether altered flow patterns in front of Diffuser 1 improves fish passage. Means of guiding fish around or through the fish ladder should also be considered.

Screen Efficiency and Impingement

Drum Screens

Our tests indicated the rotary drum screens were greater than 99% efficient at excluding chinook salmon (> 50 mm) from the canals. The high screening efficiencies are largely the result of improvements in screen technology developed through operational experiences in the Yakima River and a thorough screen inspection and maintenance program.

Several improvements in screen technology were incorporated in the design of bypass facilities on the Umatilla River. Solid-bulb seals were more effective for sealing the sides of the larger diameter screens at West Extension Canal. Stainless steel bands or epoxy was placed over areas of the screen that contact the side seal to reduce seal wear. Plastic wedges in the frame guide shift the frame forward to close the gap between the screen frame and guide. Wedges were installed at Furnish Canal during construction but retrofitted at other canal sites after we conducted screen efficiency tests. Screen efficiency was highest for the most recently constructed bypass facility at Furnish Canal where all new technologies were used and seals had the least wear.

Closing gaps at the bottom of the screens has been more challenging. Underwater video and diver observations suggest many of the juvenile salmonid fry that travel past screens move along the canal bottom (Moock and Steitz 1985; Mueller et al. 1995) Annual inspection and replacement of worn bottom seals is essential for maintaining high screening efficiency. Maintenance personnel must be able to recognize when seal replacement is required and be trained in seal adjustment. Adjusting the amount of pressure the seal exerts on the screen is critical. Excessive pressure causes rapid seal wear. Not enough pressure allows gaps to form if the screen is not perfectly round and debris is more likely to get caught between the seal and screen. A new design for the bottom seal mount has made fine adjustments easier. Proper bottom seal thickness and width are also important to maintaining a tight fitting seal. Thicker bottom seals were retrofitted to the drum screens at West Extension Canal after yearling salmon (> 100 mm) passed through the screens (Knapp and Ward 1990). Gaps will form at the overlap of the bottom and side seals if they are not properly joined. Debris wedged between the screen frame and canal bottom also creates gaps. A hollow-bulb seal has been added to the bottom of the screen frame to seal this gap.

Even though the rotary drum screens were more than 99% efficient for preventing fingerling-sized chinook salmon (57-67 mm mean fork length) from entering the canal, leakage of salmon fry through the screens is still a concern. Salmon fry as small as 30 mm have been captured at the bypass facilities in March, April, and May (Knapp et al. 1996). Our test results may have overestimated screening efficiency for salmon fry. At bypass facilities on the Yakima River, screening efficiencies of 75-91% were documented for wild chinook salmon fry (32-40 mm) when tests with larger-sized rainbow trout (49-55 mm mean fork length) indicated screening efficiency was 96-100% (Neitzel et al. 1990a, 1990b). Periodic monitoring for fry leakage from March through May is advisable when populations of wild fall chinook and coho salmon become established in the lower river.

Impingement and roll-over on rotary drum screens is an infrequent occurrence during normal canal operations. However, impingement and roll-over can result in substantial fish losses if canal elevation or flow is excessive or fish are in a weakened condition. Bypass facilities are operated at a water elevation of 80% screen submergence to balance the need to have debris, but not fish, roll over the screens. Fish losses due to roll-over are probable if flash floods cause headwork elevations to approach or exceed 100% screen submergence. On one occasion in 1996, we observed the drum screens at West Extension Canal close to 100% submerged when river flow increased rapidly overnight and the headqates were not manually adjusted until morning. Unidentified fish (appro imately 100-300 mm) were observed rolling over the screens. Impingement and roll-over caused by excessive canal flow can be a problem during trapping operations at Westland Canal. Trapping operations require the entire river to be diverted into the canal to prevent stranding fish below the dam in low flow. Fish entering the canal are restricted to the screen forebay by a screen in the bypass channel to prevent overcrowding in the trap. If river flow exceeds design capacity of the canal when trapping operations are initiated, fish restricted to the screen forebay may weaken in swift currents (about 0.6-1.0 m/s) and become impinged on and roll over the screens (Zimmerman and Duke 1993, 1994; Cameron et al. 1994). During normal canal operations, we have observed only moribund or stressed fish impinged on or rolling over drum screens. Subyearling fall chinook salmon are particularly susceptible to roll-over because of their weak swimming abilities and stress induced by warm water temperatures during their outmigration in May, June, and July. In 1995 and 1996, many of the fall chinook salmon collected at West Extension and Westland canals during the later portion of the outmigration appeared weak or diseased (Knapp et al. 1996).

Belt Screens

Our tests indicated leakage, impingement, and roll-over of chinook salmon (> 50 mm) associated with belt screens at West Extension and Westland canals is negligible (< 1%) when canals are operated within criteria. However, test fish had less opportunity to encounter the belt screens at Westland Canal than they normally would because flow past the screens was considerably higher during simulated trapping operations (0.57 m^3/s) than normal trapping operations (0.14 m^3/s). Leakage and impingement rates for fry may be higher at both sites than our tests indicated because the smaller size of fry (30-40 mm) compared to our test fish allows fry to slip through smaller gaps (Fisher 1978; Bell 1986) and their weaker swimming ability makes them more vulnerable to impingement (Easterbrooks 1984). At West Extension Canal, sluicing silt from the pumpback bay with a wide open drain pipe has the greatest potential to impinge fish on the belt screen. In 1990, subyearling fall chinook salmon (approximately 75 mm mean fork length) were impinged and rolled over the belt screen when facility operators sluiced silt from the pumpback bay following a flood in May (Hayes et al. 1992). Fish have also been impinged on the belt screen when the pumpback bay was operated with a fully open drain pipe during fish trapping operations. In 1991, 107 subyearling fall chinook salmon (61 mm mean fork length) released in drum screen efficiency tests were impinged on the belt screen when the drain pipe was fully open (Hayes et al. 1992). High flow (> 0.85 m^3/s) through the pipe created excessive approach velocities and turbulence in front of the belt screen. Most fish were impinged on the downstream portion of the belt screen where turbulence is produced by backflow from the orifice plate. Some of the impinged chinook salmon had squeezed between the seal and screen and were crushed by the movement of the screen. Sluicing operations should be avoided during the juvenile salmonid outmigration season (March through June). In addition, high debris loads appear to increase the probability of fish impingement and roll-over on screens (Neitzel 1988; Hayes et al. 1992). This may be the result of one or more factors including increased approach velocity in front of partially clogged screens, weakened condition of fish during floods, and entanglement of fish in debris trapped on the screen. At West Extension Canal, debris regularly accumulates in front of the orifice plate immediately downstream of the belt screen. Daily maintenance should include removing debris from this area.

Water Velocity

Bypass

Water velocity in front of drum screens is expected to exceed approach velocity criteria for fry protection (≤ 0.12 m/s) during periods of peak water diversion in March, April, and May. Drum screens were not able to meet the current ≤ 0.12 m/s criteria because the facilities were designed to meet an older approach velocity criteria of 0.15 m/s. Most canals operate at peak water diversion about one-third of the time when salmon fry are most likely to be present (March, April, and May). Impingement of salmon fry on drum screens by high approach velocities is a concern. However, high sweep velocity should reduce the potential for impingement at locations where approach velocity criteria was exceeded. We have not observed salmon fry impinged on drum screens thus far during normal facility operations, but production of fry in the lower river is currently low. Approach velocity was usually highest at the screen closest to the bypass channel entrance, particularly at Feed Canal. Screens closest to the bypass channel are where fish impingement and roll-over is most commonly observed (Neitzel et al. 1988; Cameron et al. 1994). Baffling could be increased behind Screens 10 at Feed Canal to reduce excessive approach velocity and potential fish impingement, similar to changes made at bypasses in the Yakima River (Neitzel et al. 1988).

Approach velocity among screens, depths, and transects was not uniform at most sites. This variability was within ranges occurring at fish bypass facilities on the Yakima River (Abernethy et al. 1989). An overall pattern of high approach velocity at the end and middle screens was consistently measured at bypass facilities in the Umatilla River with long and shallow screen forebays (Westland, Feed, Furnish canals). The absence of this pattern at West Extension and Maxwell canals suggests flow patterns in front of the screens were affected by forebay length. Forebay depth, and flow control flumes upstream of the screens may have been additional factors influencing flow patterns in front of screens at West Extension Canal. High approach velocities near the surface of middle screens at West Extension Canal may also be affected by the sidewall geometry of the forebay. Observation of surface water currents suggests that flow heading toward the bypass channel bottlenecks near the middle screens and increases flow (approach velocity) through the screens in this area. Bottlenecking flow in the forebay was probably unavoidable because limited space at this site precluded a bypass design with more screens and a longer forebay.

Sweep to approach velocity criteria was met at almost all locations sampled. However, low sweep velocity at the screen furthest from the bypass channel at Maxwell Canal (Screen 3) and Feed Canal (Screen 1) increases the potential for fish holding and impingement. At Feed Canal, low sweep velocities at Screen 1 were measured along the upstream portion and bottom of the screen. The baffle board behind Screen 1 should be enlarged to increase sweep velocity in these locations. Low sweep velocity was measured in all sampling locations in front of Screen 3 at Maxwell Canal, but particularly along the upstream transect. A more appropriate method for increasing sweep velocity in front of Screen 3 at Maxwell Canal might be to add fill to the canal wall opposite of Screen 3 for a distance of perhaps 1.2 m upstream of the screens (personal communication 24 February 97, Steve Rainey, National Marine Fisheries Service, Portland, Oregon).

Minimum water velocity at the bypass channel entrance must equal or exceed the maximum water velocity in front of the screens to meet NMFS criteria (NMFS 1989). Water velocity at the bypass channel entrances met criteria at all sites. The intent of the criteria is to ensure fish recognize and use the bypass channel as an exit route. Avoidance behavior of fish to excessive changes in velocity (faster or slower) at the bypass channel entrance is a concern (Rainey 1985). Our travel time tests documented a short delay in fish movement in the vicinity of the drum screens and we have occasionally observed fish pausing at bypass channel entrances (Cameron et al. 1994). However, fish readily moved through the bypass channel entrance during hours of peak movement and did not show signs of fatigue when trapped and handled (lethargy or sensitivity to anesthetic).

Delay of fish associated with low water velocity at the bypass channel entrance is also a concern when bypasses are operated in a low flow mode. We were not able to collect velocity measurements when Maxwell, Feed, and Furnish canals operated in low bypass flow modes. Feed and Furnish canals rarely operate at low bypass flow because their upriver location provides sufficient river flow for canal and bypass needs. However, low bypass flow operations are common at Maxwell Canal in late spring. Poor fish attraction to the bypass channel during low flow operations will compound fish passage concerns associated with low sweep velocity in front of the screens. Therefore, the bypass at Maxwell Canal should be operated in normal bypass flow mode (0.25 m^3/s) as much as possible.

All six pumpback operations tested at West Extension Canal resulted in non-uniform approach velocity in front of the belt screen and varying amounts of turbulence near the orifice plate. Non-uniform or turbulent flow can be caused by insufficient pool volume in front of the screen, hydraulics associated with the orifice plate, side wall geometry, or pump placement (Rainey 1985). At West Extension Canal, turbulent and non-uniform flow was primarily caused by the orifice plate being located immediately downstream of the belt screen. Limited construction space necessitated placement of the orifice plate closer to the belt screen than desired. Normally, orifice plates are placed further away from the screen because turbulent flow near the plate is expected. Turbulent-flow near the belt screen is undesirable because fish may attempt to hold in the back-eddies, weaken, then become impinged on the screen. In addition, back flow from the orifice plate appears to increase flow through the upstream portion of the screen which results in higher approach velocities in this area. Turbulence caused by the orifice plate was minimal when only one 0.28-m^3/s pump was on and greatest when the drain pipe was 40% open. A one-pump operation is within criteria, but should be avoided because fish attraction to the bypass channel will be compromised by low water velocity (< 0.4 m/s). A 40%-open drain pipe produced excessive turbulence and hot spots on the belt screen.

Pumpback operations with both 0.28-m^3/s pumps on or the drain pipe 20% open produced the best combination of water velocity at the belt screen and bypass channel entrance. During these operations, water velocity in front of the belt screen was fairly uniform, met NMFS criteria for fry protection in most locations, and produced adequate sweep velocity. Water velocities at the bypass channel entrance produced by these operations were nearly equal to design velocity at a 0.71-m^3/s bypass flow. Drain pipe operation has two advantages over pump operations. Opening the drain pipe does not require the expense of power for operation and it provides additional fish attraction flow through the headgates when canal flow is low (Knapp et al. 1996). However, these advantages must be balanced with the problem of false attraction of adult fish to the drain pipe outlet (Knapp et al. 1996).

Ladder

Design and operation of the fish ladder at Three Mile Falls Dam appeared to have a significant influence on flow patterns in front of Diffuser 1. Inflow is turned 45° shortly after entering the passage section of the ladder which causes it to approach the diffuser at an acute angle with moderate turbulence. Underwater video observations in 1996 suggest juvenile salmonids follow currents that guide their movements parallel to the diffuser until they encounter swifter currents directed perpendicular to the diffuser near Transect 1. At Transect 1, fish tended to swim upstream away from the diffuser and repeat the swimming loop again. Fish were occasionally observed passing through the diffuser near Transect 1 or impacting it when surging or turbulence occurred (Knapp et al. 1997). Fish passage through the diffuser appears to be inhibited by turbulence and flow sweeping across the face of the diffuser. Changing the fish exit gate operation from a partial to full opening may decrease inflow velocity and reduce sweep velocity and turbulence at Diffuser 1.

Flow from the passage section of the ladder sweeping across the backside of Diffuser 2 appears to influence the pattern of auxiliary water flow passing through the front side of the diffuser. Auxiliary water flow was directed parallel to the diffuser at several locations on the east diffuser panel where the influence of passage flow was strongest. Flow moving parallel to the diffuser created a turbulent back eddy upstream of the east panel when it encountered the wall dividing the east and west panels. Flow patterns in front of the east panel of Diffuser 2 are not conducive to juvenile fish passage based on video observations and water velocity measurements at Diffuser 1. Juvenile salmonids should pass through the west panel easier than the east panel because there is less of a sweeping component to the flow approaching the west panel. The long length of Diffuser 2 is probably key for providing some passage areas for juvenile salmonids while ensuring auxiliary water flow is diffused enough to prevent false attraction of adult fish.

RECOMMENDATIONS

Facility Modifications

1. Test operate the fish exit gates full open at the Three Mile Falls Dam (east-bank) fish ladder to improve hydraulic and fish passage conditions at Diffuser 1. Document changes in flow patterns with velocity measurements and changes in fish behavior with underwater video.

2. Methods for guiding juvenile fish past or through the east-bank fish ladder at Three Mile Falls Dam should be considered to minimize fish injury and delay. Potential modifications include a curtain or louver guidance system coupled with an Obermyer weir on the east end of the dam or a louver guidance system coupled with a bypass system in front of Diffuser 1.

3. Remove non-functional I-beam in front of Diffuser 1 in the east-bank fish ladder at Three Mile Falls Dam.

4. Automated headgates are the most effective means of maintaining proper headworks elevation and bypass flow. Where feasible, bypass facilities should be designed or retrofitted with automated headgates.

5. Increase wall height of wasteway overflow at Furnish Canal by adding a 102 mm sill to prevent fish from spilling into the wasteway when headworks elevation temporarily rises in response to headgate adjustments.

6. Baffle boards behind Screen 1 at Feed Canal should be modified to decrease approach velocity and increase sweep velocity in front of the screen. At Maxwell Canal, adding fill to the canal wall across and upstream of Screen 3 should be considered to increase sweep velocity in front of Screen 3.

Facility Operations

1. Facility operating criteria must be available and adhered to by bypass operators and amended by National Marine Fisheries Service when necessary.

2. Fishery managers should regularly provide facility operators with information on local patterns of fish movement to avoid conduct of potentially harmful canal or bypass operations during periods of peak fish movement (pumpback bay sluicing, draining forebays, algacide applications, etc.).

3. Daily maintenance should include inspection and removal of debris at the canal trashracks and headgates, drum and belt screens, orifice plate, bypass channel and weir, downwell, bypass pipe, and outfall/outlet. Debris removal is particularly important during flooding, water up, and when canals are restarted after temporary shut downs. Checking bypass

pipes for debris blockage before water up and after flood events is critical.

4. Manual adjustment of the canal headworks elevation is usually required on a twice-a-day basis to ensure proper bypass flow and headworks elevation. More frequent adjustment is required if river elevation is changing rapidly.

5. Maintain screen submergence at 80% to reduce potential roll-over of small-sized fish, especially weakened subyearling fall chinook salmon.

6. Inspection and maintenance of screen seals should be conducted annually by knowledgeable maintenance personnel.

7. Periodic monitoring for leakage of salmon fry through the drum screens at canals on the lower Umatilla River is recommended between March and May when natural populations of fall chinook or coho salmon increase in the future. A simple monitoring program might involve overnight deployment of a small, easily retrievable fyke net at the canal checkgates at least one day a week.

8. When total headgate openings are less than 1 m at West Extension Canal, open the fewest number of headgates as wide as possible to improve fish attraction and passage. Initial testing should begin with opening the West Headgate first followed by the Middle and East headgates.

9. Preferred pumpback operations at West Extension Canal are two 0.28-m^3/s pumps on or the drain pipe 20% open.

10. Operate Maxwell Canal in normal bypass flow mode (0.25 m^3/s) as much as possible to help maintain sweep velocities in front of the drum screens.

Design Considerations

1. Future bypass facility designs should maintain a uniform canal and forebay profile to minimize potential holding areas for salmonids and predators.

2. Submerged outlet configuration and siting is critical during the facility design phase to prevent or minimize occlusion problems resulting from bedload movement. River hydraulics and bank stability should be taken into consideration.

3. Facility designs should avoid tying a secondary pipe into the bypass pipe to eliminate potential fish holding areas and delay.

4. Development of outfall designs that do not rely on a pool for energy dissipation should be considered to minimize fish holding areas and delay in bypass outfalls.

5. Drum screen designs should include rubber seals of proper width and thickness that seal gaps along the sides and bottom of the screen, and

between the screen frame and canal bottom. Wedges should also be installed in the rear of the frame guide slots to force the screen frame against the guide slots and close gaps.

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