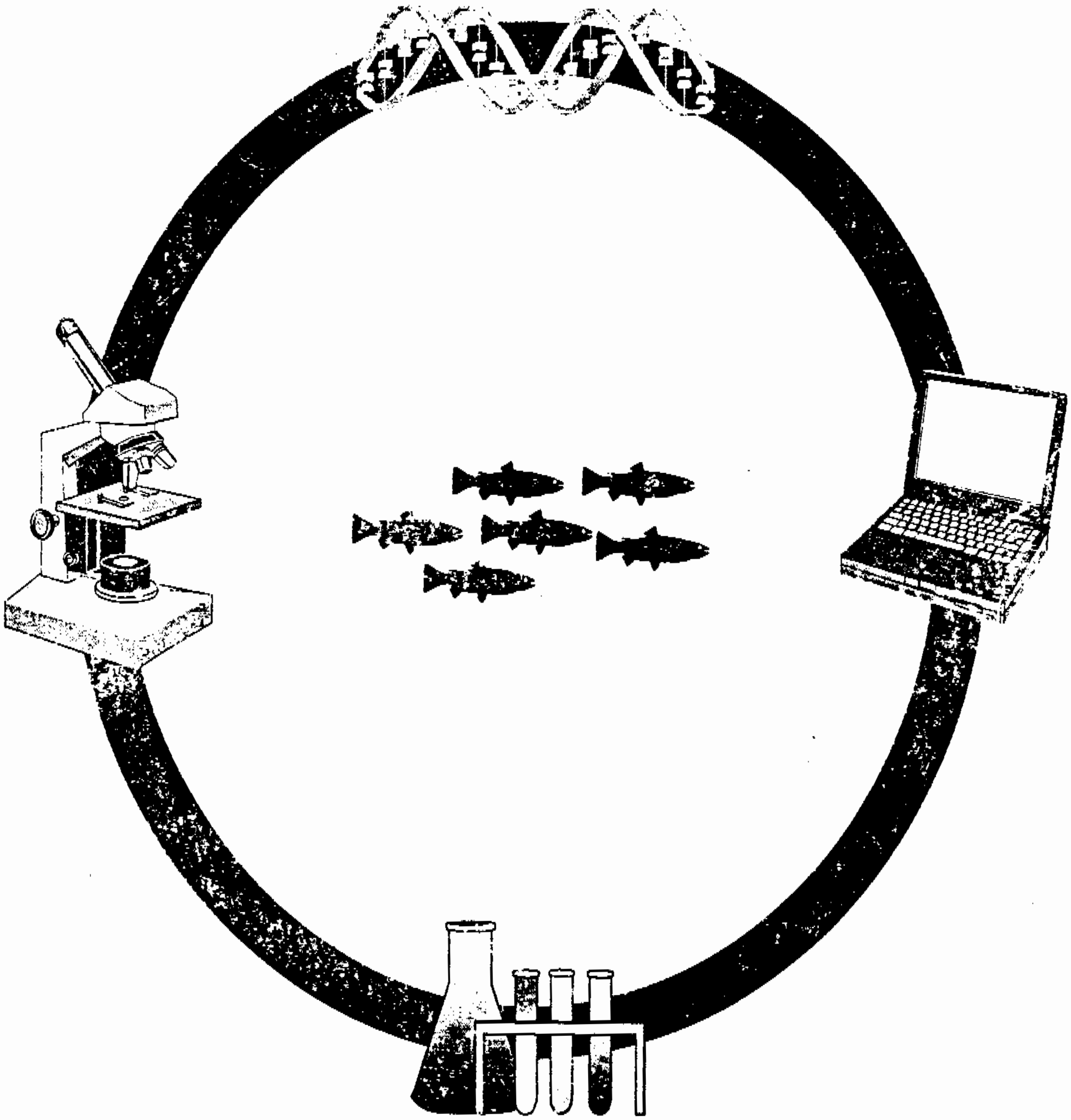
U. S. Fish & Wildlife Service
Fish Technology Centers
Technical Information Leaflet No. AB-00-01

Validation of Existing Fish Screen Criteria for Juvenile Bull Trout (*Salvelinus confluentus*)



Department of the Interior
U. S. Fish & Wildlife Service
Abernathy Fish Technology Center
Longview, WA 98632

Validation of Existing Fish Screen Criteria
for Juvenile Bull Trout (*Salvelinus confluentus*)

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by

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Key Words: bull trout, *Salvelinus confluentus*, screen criteria, diversion screens, swimming ability, behavior, fish passage

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October 2000

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The correct citation for this report is:

Zydlewski, G. B., J. Johnson, J. Stow, and C. Burger. 2000. Validation of existing fish screen criteria for juvenile bull trout (*Salvelinus confluentus*). U. S. Fish & Wildlife Service, Abernathy Fish Technology Center, Technical Information Leaflet No. AB-00-01, Longview, WA.

Technical Information Brief

Bull trout are currently listed as threatened in the Western United States. Entrainment at water diversion structures has been identified as one cause for the decline in bull trout populations in the West. The objective of this study was to evaluate whether existing fish screen criteria, based on tests using chinook, sockeye, and chum fry, are adequate to prevent bull trout fry from being impinged or entrained by screened water intakes at Pacific Northwest diversion structures. Bull trout were tested in a specially designed artificial stream. Test screens were those currently approved by National Marine Fisheries Service and Washington Department of Fish and Wildlife: Perforated Plate: opening not exceeding 2.4 mm (3/32 in.); Profile Bar: narrowest dimension not exceeding 1.75 mm; and Woven Wire: opening not exceeding 2.4 mm (3/32 in.). As a control, one experiment was conducted with no screen. Emergent bull trout, $\bar{x} = 25.0$ mm total length, were tested in groups of 25 at 6°C. Only one bull trout was entrained during all experiments. Bull trout were regularly impinged on the screens but in most cases were able to escape impingement and survive for at least 24 h. Therefore, at low temperatures and small sizes, bull trout exposed to the currently accepted screens are unlikely to be entrained or mortally damaged when impinged. This implies that currently specified screen regulations for salmonid fry do not need to be modified for bull trout fry. The potential bull trout population loss to entrainment at water diversion structures is adequately managed with the currently imposed screen criteria for juvenile fish.

Introduction:

If not properly screened, water diversion structures can negatively impact fish populations, especially those listed as species of concern, threatened, or endangered. Screening at facilities such as fish hatcheries, dams, and irrigation channels using natural water sources must effectively exclude fish from intake structures. If not excluded fish will be subjected to injurious or fatal devices such as pumps for irrigation or turbines for electrical generation.

The effectiveness of screens depends on several biological and physical factors. The foremost factor is swimming ability of the fish. Fish swimming ability is dependent on species, size, swimming stamina, and migrational stage. All of these factors influence the probability of impact and entrainment through diversion screening. Similarly, dissolved oxygen concentration, water temperature, and lighting conditions influence swimming ability and therefore the fates of fish at diversion screens. Two of the more important factors to be considered are time of emergence of the smallest life stage (e.g. salmonid fry) and low water temperatures. The smallest life stages will have the highest probability of entrainment based on size alone. Also, low water temperatures impart lower metabolic activity. This may result in poor swimming performance and slower escape responses at intake screens.

Currently established screen criteria, developed to provide sufficient protection for individual fishes, are expressed in general terms due to the number of variables affecting fish swimming ability. These criteria are based on physical exclusion and optimization of the condition of fish being passed back to the river. In general terms, state and federal law requires any diversion of water from streams, rivers, lakes, reservoirs and tidal areas to be screened to protect fish. The Washington Department of Fish and Wildlife (WDF&W, State Law RCW <u>77.16.220</u>; RCW <u>75.20.040</u>; RCW <u>75.20.061</u>) and the National Marine Fisheries Service (NMFS 1995) have adopted screen criteria based primarily on the behavior of several salmonids (Bates & Fuller 1992).

Existing screen requirements for water diversions:
Approach velocity for salmonid fry less than 60.0 mm fork length (FL) must be 0.12 m/s (0.40 feet per s). Approach velocity is defined as the water velocity component perpendicular to and approximately three inches in front of the screen face, where juveniles must be able to swim at speeds equal to or greater than the approach velocity for an extended length of time to avoid impingement. **Screen face material** (size and shape of screen) for salmonid fry must provide a minimum of 27% open area. Screen materials include: Perforated Plate: opening not exceeding 2.4 mm (3/32 in.); Profile Bar: narrowest dimension not exceeding 1.75 mm; and Woven Wire: opening not exceeding 2.4 mm (3/32 in.).

The existing screen requirements have been adequately tested on only a few salmonids. Screen criteria exist for fall chinook *Oncorhynchus tshawytscha*, sockeye *O. nerka*, and chum *O. keta* fry (Bates & Fuller 1992). Both state and federal agencies indicate the necessity for research on site-specific variables (e.g. resident fish populations and fish behavioral response to hydraulic conditions) critical to the development of screen criteria. Adequate data must be identified to describe the relationship of new variables to screen criteria (NMFS 1995). Bull trout (*Salvelinus confluentus*) differ from other salmonids in manners that may affect their probability of encountering and being entrained at diversion screening, thus is a strong need to determine whether the existing salmonid criteria are suitable to protect other species at screened water diversions.

Bull trout have more specific habitat requirements than most salmonids: preference for colder temperatures; more complex forms of cover; higher channel stability; and loose clean gravel for rearing substrates (Fraley & Shepard 1989; Rieman & McIntyre 1993). Colder temperatures result in a smaller size at emergence for bull trout than other salmonids. Bull trout are believed to emerge from the gravel and "swim up" at approximately 25 - 28 mm total length (TL) (Ratliff pers. comm. Portland General Electric Company, Madras, OR; Shepard et al. 1984) whereas emergent fry used by Bates and Fuller (1992) ranged from 30 – 37 mm. The basic preferences and biological differences (particularly size at emergence) between bull trout and other salmonids may influence the effects of screens on bull trout. Scenarios such as encountering screens at a small size and when seeking cover or stream margins may result in different consequences for bull trout encountering currently accepted screens.

Historically ranging from southeast Alaska to California and Nevada, bull trout are now listed as threatened in the Western United States (USFWS Endangered Species Final Rule, 1 December 1999). The causes of bull trout population declines have been identified as: habitat degradation; competition with and predation from introduced non-native species; fish passage issues caused by dams and diversion structures; incidental harvest; and impingement and entrainment at water diversion structures (USFWS Endangered Species Final Rule, 1 December 1999). Impingement and entrainment are defined as the processes by which aquatic organisms make contact with and are pulled through, respectively, water diversion or other devices into structures at dams, fish hatcheries, and irrigation facilities. The objective of this study is to evaluate if existing screen criteria are adequate in preventing juvenile bull trout fry from being impinged or entrained by screened water intakes at diversion structures.

Methods and Materials

Origin of Test Fish:
Bull trout were approved for transfer from an experimental broodstock cultured at the Fish and Wildlife Service's Creston National Fish Hatchery (Creston NFH) in Kalispell, MT to Abernathy Fish Technology Center (AFTC) in Longview, WA. The Creston NFH bull trout broodstock is from the Swan River drainage in northwestern Montana. Eyed bull trout eggs were received at AFTC on 5 November 1999. Bull trout eggs were cultured at 6°C before shipping.

Maintenance of Test Fish:
Eyed eggs were incubated in Heath trays at the AFTC. The water source for the eggs was maintained between 5° and 6°C, the preferred thermal regime for bull trout eggs (Fredenberg et al. 1995). On 20 January 2000 the majority of fish absorbed most of their yolk and were released from the Heath trays into two 76.2 cm diameter tanks. A dim light was placed over each tank to simulate dusk and dawn when overhead lights in the hatchery turned off and on via a photocell. On 24 January 2000 fish were close to "button up" (considered fry) and were fed a daily ration of Biodiet starter (Bio-Oregon, Warrenton, OR). Water temperatures for all experiments were targeted at 6° since this was their rearing temperature and bull trout are

typically distributed in cold water habitats (Ratliff 1992; Rieman & McIntyre 1995; Bonneau & Scarnecchia 1996). Bull trout were incubated, reared, and tested in incubators and tanks with safety-screened outflow to prevent any escape. Following the tests, all remaining bull trout were euthanized.

Test chamber:
Fry were tested in a specially designed oval-shaped fish tank (Figure 1A) designed by Smith-Root, Inc., Vancouver, WA. Water depth in the tank was maintained at 35.6 cm. The tank had a flow-inducing propeller system with adjustable control for setting precise velocities. The test area was located on the opposite side of the tank from the propeller system. The test chamber was 102 cm long (Figure 1B). At each end of the test chamber a barrier screen constructed of nylon mesh (0.159 cm stretch mesh) retained fish in the chamber. In the center of the test chamber, 66 cm downstream of the upper barrier screen, experimental test screens were positioned for testing impingement and entrainment of fish. Downstream of the experimental screen was a 35.6 cm capture area where entrained fish were collected. The test chamber was constructed of aluminum that had been etched, resulting in a gray color throughout the chamber including the test screens. This uniform coloration prevented refuge areas based on coloration and allowed us to see the fish.

Water velocity and temperature
Before experiments were initiated, the hydrodynamics of the test chamber were quantified (Appendix 1). Water velocity was measured in four areas of the chamber at six positions in each area. The six positions included three measurements horizontally across the chamber at two water depths (3 positions at 7.6 cm off the chamber bottom and 3 positions at 10.2 cm below the water surface). The four areas were 7.6 cm downstream of the upper barrier screen, midway between the upper barrier screen and the experimental screen, 7.6 cm upstream of the experimental screen, and 7.6 cm upstream of the lower barrier screen. Water velocity was measured with a Swoffer velocity meter (Seattle, WA) calibrated for low velocities. Initial testing at 0.12 m/s water velocity revealed that water flow at the propellor was turbulent but throughout the test chamber water flow was laminar. Water velocities were adjusted before each experiment to achieve laminar flow in the test chamber, horizontal and vertical uniformity in the test area (Appendix 1a). During experiments average velocities measured 7.6 cm in front of the screen ranged from 0.114 to 0.129 m/s for individual locations. The average velocity across the entire screen ranged from 0.118 $\pm$ 0.001 to 0.123 $\pm$ 0.001 m/s for the different experiments (Table 1).

Once the velocity structure of the test chamber was determined, the velocity meter was placed at 18.3 cm depth behind the lower barrier screen as a reference to monitor velocity throughout the experiments. During experimentation, water velocity behind the barrier screen was maintained within 0.01 standard deviations of the established velocity at the beginning of the experiment (Appendix 1b).

A temperature probe was placed in the portion of the tank away from the test chamber for continuous monitoring of water temperature throughout trials. Water temperature was maintained between 6^{o} and $7\,^{o}$ C throughout the experiments (Appendix 2).

Test screens:
Test screens were those screens currently approved by NMFS and WDF&W: Perforated Plate (PP): opening not exceeding 2.4 mm (3/32 in.); Profile Bar (PB): narrowest dimension not exceeding 1.75 mm (Vertical (PBV) and horizontal (PBH) profile bars were tested); and Woven Wire (WW): opening not exceeding 2.4 mm (3/32 in.). One additional test was run as a control (CL): no screen was placed in the central slot for the experimental screens. The control provided baseline information of fish distribution throughout the chamber under the artificial test conditions of the simulated stream.

Experimental procedure:
Initial testing was done to determine the number of fish to introduce per experiment while retaining the ability to count individual fish. For bull trout (25 mm TL), we determined that 25 individuals could be counted accurately in all sections of the test chamber. The trials were run on fish between 24 - 28 mm TL that had been feeding for at least one week.

Groups of fish were introduced into the release area (Figure 1B) of the test chamber with the experimental screen or no screen (Control) in place. Fish were allowed to acclimate to static-water tank conditions for 15 min at which time the motorized propellor was turned on at the lowest setting to generate a velocity of approximately 0.03 m/s. At 15-min intervals, over 1 h, velocity was increased to 0.12 m/s at 7.6 cm in front of the experimental screen, which is the approach velocity of the current screen criteria. Water velocity was maintained at 0.12 m/s throughout the remainder of the experiment.

Experiments were run from 1545 hours - 0800 hours (16.25 h) in order to observe behaviors associated with dusk and dawn periods which have shown to be important in other screen retention studies (Stelfox 1997). Dim lights were installed above the test chamber to simulate the same dawn and dusk conditions fish experienced during rearing. Fish behavior was video taped from above the tank. Infrared light allowed video observation under dark conditions. Once water velocity was recorded at 0.12 m/s fish were continuously observed for 1 h and then checked at 30-min intervals. The number of fish impinged on the experimental screen and the number of fish passing through or entrained by the experimental screen (in the lower section of the test chamber) was recorded. Individual time to impingement and time to pass through the experimental screen was subsequently observed from the videotapes.

Once experimentation was complete live fish from each section of the test chamber (above the screen, below the screen, and impinged on the screen) were transferred to separate holding tanks for a 24-h survival test. After 24 h the number of fish surviving from each group was noted and each fish was measured for TL (mm) and wet weight (g).

Experimental screens and the control were tested in random order (chosen with a computer random number generator): CL, PBV, PP, PBH, and WW. Each screen condition: CL, PBV, PP, PBH, and WW was considered an experiment. The average number of fish entrained and impinged at the end of each 30-min observation are reported as mean ± Standard Error (SE).

Video Analysis:
Video tapes were analyzed to establish whether bull trout contacted test screens during the experiments. The most active period of day was determined for one experiment before analyzing all video tapes. The frequency distribution of contacts over time for Experiment 2 (PBV) revealed that 90% of the contacts occurred between 1700 hours and 0000 hours (Figure 2A). Therefore, the remainder of the experimental tapes were examined from 1700 to 0000 hours. Videotapes were not analyzed for the control group since videos were used to ensure that fish were making contact with test screens.

Video tapes from experiments 2 - 5 (PBV, PP, PBH, WW) were examined for the following parameters:

- total number of contacts, between 1700 and 0000 hours.
- position of contact on the screen surface (open face of the screen, edge of the screen where it contacted the walls, or the bottom of the screen where it contacted the bottom of the test chamber).
- fish orientation to the screen upon contact (head first, tail first, whole body perpendicular to the screen openings, parallel to the screen openings, or at an oblique angle to the screen openings).
- whether or not the fish escaped from the screen.
- the start and end time of the contacts with the screen.

Note that position of contact on the screen can be classified as both bottom and edge, therefore the total number of contacts does not always equate to the number of contact positions. Categorical data analysis techniques (chi square contingency tables) were used to examine for statistical differences within experiments for location and orientation of screen contact. Mean time ± SE of impingement (contact time) is reported for individual screens.

For experiments 2-5, impinged is defined as extended contact (> 1s) with the test screen; entrained is defined as passing through the test screen and being observed in the capture area; and free is defined as being observed in the release area not in contact with the test screen. For the control experiment (no screen) impinged is defined as extended contact (> 1s) with the lower barrier screen (different from experiments 2 - 5); entrained is defined as being present in the area below where the test screen would be placed (i.e. in the capture area); and free is defined as above where the test screen would be placed (i.e. in the release area).

Results and Discussion:

Experiment 1 - Control
Bull trout were distributed over the bottom, primarily near the edges, of the entire test chamber. On average just as many bull trout spent time in the capture area, entrained, as in the release area, free (Table 2). Throughout the experiment individuals made contact with the lower barrier screen (Table 3). All individuals tested survived the experiment. Twenty-four h after the experiment one individual was dead.

Experiment 2 - Profile Bar, Vertical (PBV)

Bull trout were distributed over the bottom, primarily near the edges, of the release area. Sixty-nine individual contacts were made with the test screen between 1700 and 0000 hours (Table 3). Most of the contacts occurred between 1700 and 2000 hours (75%) and the number declined to 0 by 0400 hours (Figure 2A). Approximately three fish were impinged on the test screen at the end of each 30-min interval (Table 2). During all 30-min observation periods fish were found impinged on the screen. On average fish spent 12.9 ± 3 min impinged on the test screen. Significantly more fish were impinged on the bottom edge of the screen as on the side edges or open face (Table 4). Whole body initial contact with the screen was more common than head- or tail-first contact (Table 5). Of the 46 whole body contacts fewer were parallel to the vertical openings in the screen (12) than at some other angle to the vertical opening (34). Six fish contacted the screen head first and 13 contacted tail first.

One fish was entrained through the screen in this experiment. The fish was entrained between 1700 and 1730 hours. This was the smallest fish (23.0 mm) tested in the experiment (Table 3). Once entrained the fish spent time on the bottom of the capture area and impinged on the barrier screen. All individuals survived the experiment and were alive 24 h post-experimentation.

Experiment 3 - Perforated Plate (PP)

Bull trout were distributed over the bottom, primarily near the edges, of the release area. Thirty-three individual contacts were made with the test screen between 1700 and 0000 hours. Most of the contacts (94%) occurred between 1800 and 2100 hours (Figure 2B). Less than one fish, 0.39 ± 0.10, was impinged on the test screen at the end of each 30-min interval (Table 2). There were many occasions,13 of 23 (57%) 30-min observation periods, when no fish were impinged on the screen. On average fish spent 17.2 ± 14.8 min impinged on the test screen. Significantly more fish were impinged on the bottom edge of the screen than on the side edges or open face of the screen (Table 4). Approximately one-quarter of the fish were impinged on the side edges of the screen and the remainder on the open face. Whole body contact with the screen was more common than head first contact (Table 5).

Entrainment through the screen into the capture area never occurred during this experiment. All individuals survived the experiment and were alive 24 h post-experimentation.

Experiment 4 - Profile Bar, Horizontal (PBH)

Bull trout were distributed over the bottom, primarily near the edges, of the release area. Sixty-nine individual contacts were made with the test screen between 1700 and 0000 hours. Most of the contacts (83%) occurred between 1900 and 2100 hours (Figure 2C). On average 1.61 ± 0.31 fish were impinged on the test screen at the end of each 30-min interval (Table 2). There were 7 of 23 (30%) 30-min observation periods, when no fish were impinged on the screen. On average fish spent 7.1 ± 1.8 min impinged on the test screen. Significantly more fish were impinged on the bottom edge of the screen than on the side edges or open face (Table 4). Approximately one-quarter of the fish were impinged on the open face of the screen and the remainder on the side edges. The majority of the fish contacted the screen with their whole body (Table 5). Of the 38 whole body contacts equal numbers were parallel to the horizontal opening and at some angle to the horizontal opening.

Entrainment through the screen into the capture area never occurred during this experiment. All individuals survived the experiment and were alive 24 h post-experimentation.

Experiment 5 - Woven Wire (WW)
Bull trout were distributed over the bottom, primarily near the edges, of the release area. Forty-eight individual contacts were made with the test screen between 1700 and 0000 hours. All contacts occurred by 23:00 but there were two peaks of activity at 1800 and 2300 hours (Fig. 2D). On average, 1.26 ± 0.20 fish were impinged on the test screen at the end of each 30-min interval (Table 2). There were 5 of 23 (22%) 30-min observation periods when no fish were impinged on the screen. On average fish spent 6.8 ± 2 min impinged on the test screen. Significantly more fish were impinged on the bottom edge of the screen and it was equally common for fish to be impinged on the open face of the screen as on the side edges of the screen (Table 4). The majority of the fish contacted the screen with their whole body rather than head or tail first (Table 5).

Entrainment through the screen into the capture area never occurred during this experiment. All individuals survived the experiment and were alive after 24 h post-experimentation.

Discussion
The control experiment provides evidence that bull trout tested in this experimental unit move throughout the entire chamber. The fish did not favor any particular lateral section of the experimental chamber based on water velocity gradients, lighting, or structural design.

Vertically positioned vertical bar diversion screens are unlikely to entrain emergent, $\bar{x} = 25$ mm TL, bull trout at 6°C. Bull trout impinged on vertical bar screens at 0.12 m/s demonstrate the swimming ability to escape the screens and survive for at least 24 h after impingement.

Our results also suggest that vertically positioned perforated plate, horizontal bar, and woven wire mesh should not entrain emergent, $\bar{x} = 25$ mm TL, bull trout at 6°C. Bull trout impinged on these screens at 0.12 m/s should have the swimming ability to escape and survive for at least 24 h after impingement.

Conclusions and Management Implications:

Behavioral observations of juvenile bull trout revealed that existing screen criteria are appropriate for fry-sized bull trout. In particular, at 6 – 7 °C temperatures and small sizes, bull trout exposed to the currently accepted screens are unlikely to be entrained or mortally damaged when impinged on those screens. This implies that currently specified juvenile fish screen criteria (NMFS 1995) do not require modification to safeguard bull trout fry.

This study provides evidence that screen criteria currently accepted for fall chinook, sockeye, and chum fry can be used in watersheds with bull trout populations. Listed species such as bull trout occur in Pacific Northwest watersheds that have numerous water diversion units. Entrainment of juvenile bull trout at water diversions presents a potentially large loss to the bull trout populations in these watersheds. This potential source of population loss is adequately managed with the currently imposed screen criteria for juvenile salmonids.

This study was restricted to testing currently imposed screen criteria for bull trout. However, there is little information about size and temperature at emergence for bull trout. The criteria, as tested, are appropriate for bull trout larger than 24.0 mm TL emerging at 6°C. More studies need to be conducted to better identify water temperature and size at emergence of bull trout. These studies will provide better information for running further screen experiments on bull trout emerging at different water temperatures.

Most water diversion structures have screens oriented at some angle to the water flow. Although results from this study cannot be directly applied to angled screens, the results represent the worst case scenario: fish experiencing a vertically oriented structure with no sweep velocity. NMFS criteria explicitly state that the sweeping velocity, or the water velocity component parallel and adjacent to the screen face, shall be greater than the approach velocity. This implies that the fish in our study were not given the opportunity of an alternative water flow for movement past the diversion screen. Future studies should examine the currently accepted screen criteria for different screen angles and various sweeping velocities.

Acknowledgements:

Stephen Zylstra of the U.S. Fish and Wildlife Service (Portland Regional Office) secured financial assistance. Wade Fredenberg and the staff of Creston NFH reared and provided the bull trout for the experiments. John McAllister of Smith-Root, Inc. designed and constructed the test chamber for the Smith-Root, Inc. annular tank. Erika Henyey of the Conte Anadromous Fish Research Center – USGS/BRD provided infrared lights and an infrared-sensitive video camera. Jeff Poole of AFTC reared and maintained the bull trout. Judith Gordon of AFTC provided statistical assistance and reviewed the text.

References:

Bates, K., and R. Fuller. 1992. Salmon fry screen mesh study. State of Washington, Department of Fisheries Habitat Management Division, Olympia, WA, 22 pp.

Bonneau, J.L. and D.L. Scarnecchia. 1996. Distribution of juvenile bull trout in a thermal gradient of a plunge pool in Granite Creek, Idaho. *Transactions of the American Fisheries Society.* 125: 628-630.

Fraley, J.J. and B.B. Shepard. 1989. Life history, ecology and population status of migratory bull trout (*Salvelinus confluentus*) in the Flathead Lake and river system, Montana. *Northwest Science.* 63:133-143.

Fredenberg, W., P. Dwyer, and R. Barrows. 1995. Experimental bull trout hatchery. Progress Report 1993-1994. U.S. Fish and Wildlife Service, Kalispell, MT, 29 pp.

NMFS. 1995. Juvenile Fish Screen Criteria. Environmental and Technical Services Division, Portland, Oregon, 7pp. Revised February 16, 1995.

Ratliff, D.E. 1992. Bull trout investigations in the Metolius River-Lake Billy Chinook system. Proceedings of the Gearhart Mountain Bull Trout Workshop, Oregon Chapter of the American Fisheries Society. pp. 37-44.

Rieman, B.E. and J.D. McIntyre. 1993. Demographic and habitat requirements of bull trout *Salvelinus confluentus.* U.S. Forest Service General Technical Report INT-302.

Rieman, B.E. and J.D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. *Transactions of the American Fisheries Society.* 124: 285-296.

Shepard, B.B., K.L. Pratt, P.J. Graham. 1984. Life histories of West slope cutthroat and bull trout in the Upper Flathead River basin, Montana. Environmental Protection Agency. Steering Committee for the Flathead River Environmental Impact Statement.

Stelfox, J.D. 1997. Seasonal movements, growth, survival, and population status of the adfluvial bull trout population in the Lower Kananaskis Lake, Alberta. Friends of the Bull Trout Conference Proceedings. pp. 309-316.

Tables

Table 1. Water velocity measurements (m/s) taken 7.6 cm in front of test screens used to evaluate existing fish screen criteria for bull trout. Values are mean and (SE).

Experimental condition	Three inches above bottom			Four inches below surface			Average Velocity across Screen face
	5 cm from far wall	center	5 cm from near wall	5 cm from far wall	center	5 cm from near wall	
Control	0.114 (0.0005)	0.116 (0.0007)	0.120 (0.0009)	0.118 (0.001)	0.120 (0.001)	0.128 (0.005)	0.120 (0.002)
PBV	0.120 (0.0009)	0.117 (0.0008)	0.124 (0.001)	0.123 (0.0008)	0.122 (0.0009)	0.126 (0.0005)	0.122 (0.001)
PP	0.118 (0.001)	0.116 (0.0005)	0.128 (0.001)	0.116 (0.001)	0.114 (0.0005)	0.126 (0.001)	0.120 (0.002)
PBH	0.122 (0.0007)	0.120 (0.0008)	0.123 (0.0008)	0.126 (0.001)	0.118 (0.0007)	0.125 (0.001)	0.123 (0.001)
WW	0.121 (0.0006)	0.118 (0.0009)	0.119 (0.001)	0.116 (0.0006)	0.112 (0.0007)	0.124 (0.0006)	0.118 (0.001)

Table 2. Entrainment, impingement, and survival data for bull trout used to evaluate the effectiveness of current fish screen criteria. Values for 30-min intervals are mean ± SE.

Experimental condition	Condition at end of each 30-min interval		Condition at end of experiment.			# surviving 24 h after the expt.
	# entrained	# impinged	# entrained	# impinged	# surviving	
Control	12.7 ± 1.3	2.1 ± 0.3	12	2[a]	25	24
PBV	0.05 ± 0.05	2.75 ± 0.20	1	3	25	25
PP	0	0.39 ± 0.10	0	1	25	25
PBH	0	1.61 ± 0.31	0	2	25	25
WW	0	1.26 ± 0.20	0	1	25	25

[a] Two individuals were impinged on the rear barrier screen

Table 3. Contact times (mean and SE) and lengths of bull trout fry entrained or impinged on four different types of screens to evaluate impacts on 24-h survival.

Experimental condition	total # of contacts	Contact time		Length (mm)		
		mean (SE)	median	Entrained	Impinged	Free
Control	NA	NA	NA	-	25.0 ± 1.0	24.4 ± 0.2
PBV	69	12.9 min (3 min)	4.2 min	23.0	23.8 ± 0.3	24.9 ± 0.2
PP	33	17.2 min (14.8 min)[a]	0.4 min	-	22.5	24.7 ± 0.2
PBH	69	7.1 min (1.8 min)	2.0 min	-	-[b]	25.0 ± 0.2
WW	48	6.7 min (2.1 min)	1.0 min	-	24.5	25.5 ± 0.4

[a] PP contact time without outlier (488.1 min) = 2.5 min ± 1.4 min.
[b] At the end of the PBH experiment the two impinged fish could not be isolated from the others.

Table 4. Location of impinged bull trout in screen criteria tests (Experimental condition = screen type).

Experimental condition	edge	bottom	open face
PBV	21	38[a,b]	19
PP	8	25[a,b]	3
PBH	9	47[a,b]	16
WW	11	28[a,b]	10

[a,b] Significant difference with edge and open face, respectively.

Table 5. Orientation of bull trout upon contact with test screens (Experimental condition = screen type).

Experimental condition	Head	tail	whole body	parallel		other angle
PBV	6	13	46[a,b]	12	*	34
PP	2	11	20[a]		NA	
PBH	14	16	38[a,b]	25	NS	13
WW	10	5	32[a,b]		NA	

[a,b]Significant difference with head and tail, respectively.

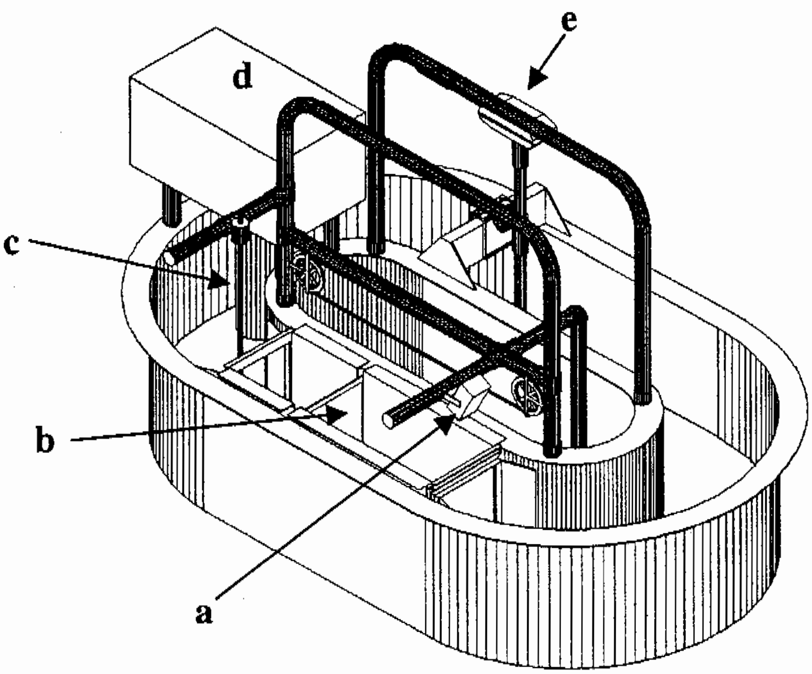
* Significant difference between parallel and other angle.

NS indicates no significant difference.

Figures

Figure 1. Schematic of test tank and insert for bull trout screening study. A. Test tank showing (a) video camera, (b) test chamber, (c) velocity meter, (d) cooling unit, and (e) propeller system. B. Test chamber showing (a) release area, (b) capture area, and (c) position of removable test screens.

A.



B.

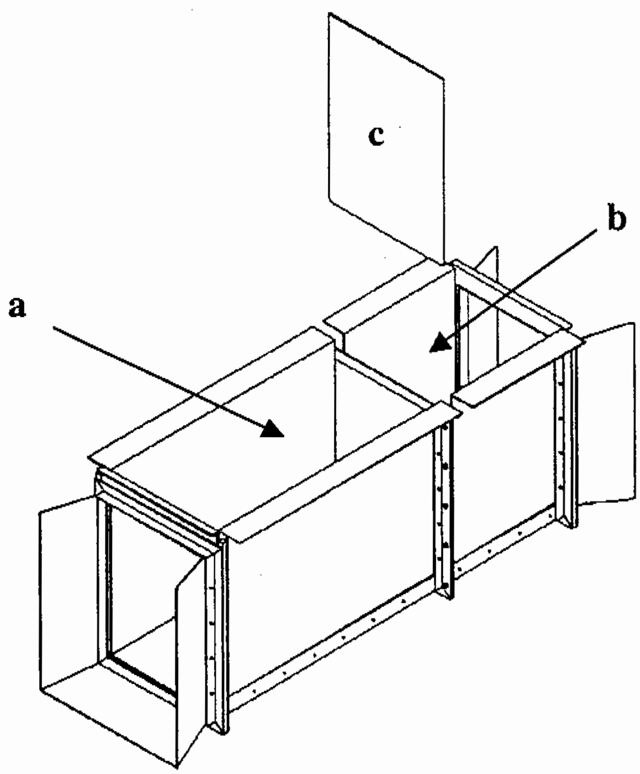
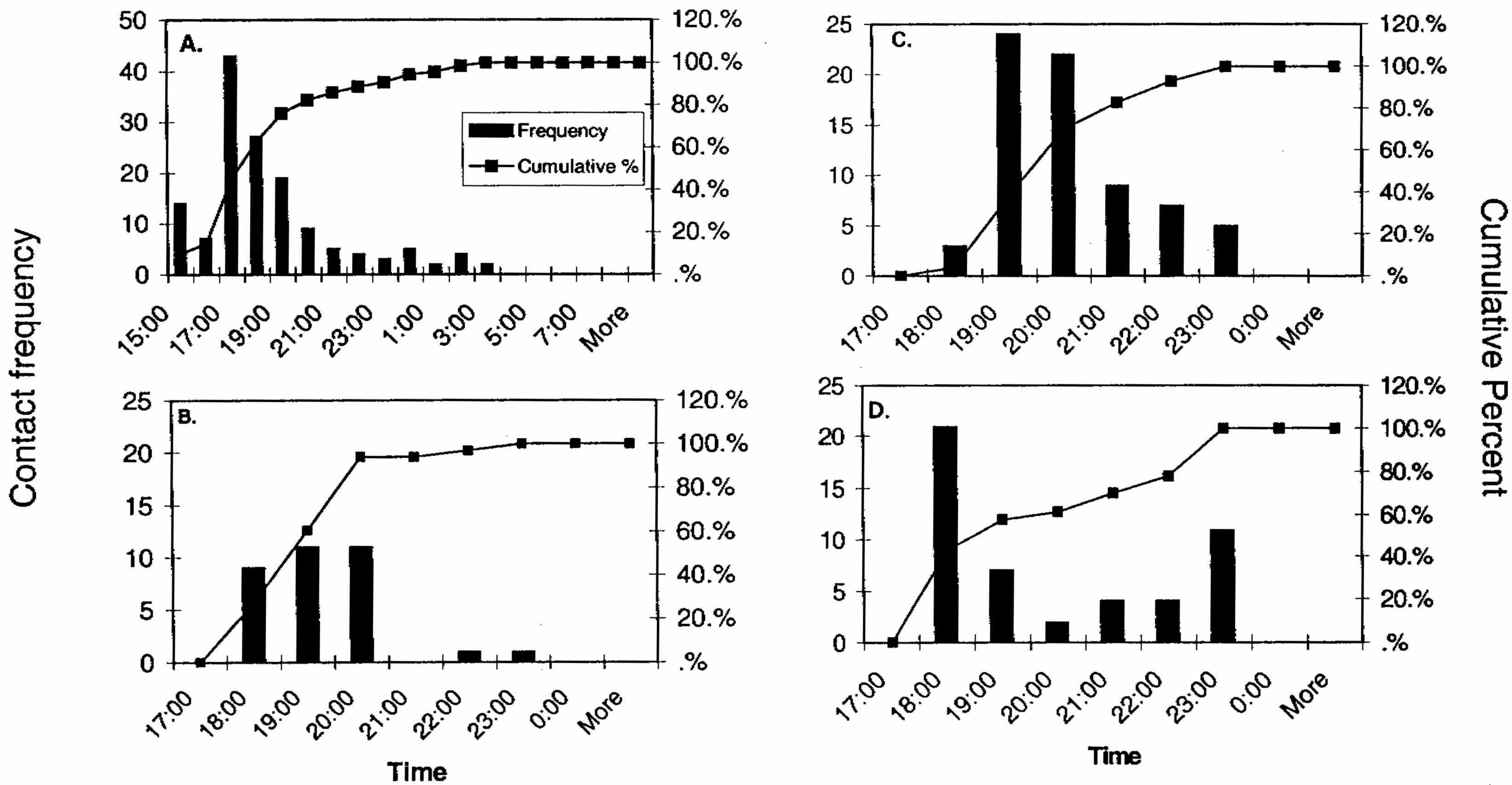


Figure 2. Frequency distribution of contact time for four different experimental screen treatments used to evaluate fish screen criteria for bull trout. A. Screen used was Profile Bar, Vertical, B. Screen used was Perforated Plate, C. Screen used was Profile Bar, Horizontal, D. Screen used was Woven Wire. N = 25 fish per treatment.



Appendix 1a. Water velocities, m/s, measured at 24 locations in the flume. Six measurements were taken at each location before beginning each experiment. Mean m/s and SE reported below individual velocity measurements.

Experiment 1: Control

Location	7.6 cm above bottom			10.2 cm below surface		
	5 cm from far wall	center	5 cm from near wall	5 cm from far wall	center	5 cm from near wall
7.6 cm in front of	0.123	0.120	0.129	0.123	0.120	0.117
Rear barrier	0.120	0.123	0.129	0.120	0.114	0.120
	0.123	0.126	0.132	0.123	0.117	0.120
	0.123	0.126	0.126	0.123	0.117	0.120
	0.120	0.123	0.129	0.123	0.117	0.120
	0.120	0.129	0.132	0.123	0.120	0.123
Mean	0.122	0.124	0.130	0.123	0.118	0.120
SE	0.0007	0.0013	0.0009	0.0005	0.0009	0.0008
7.6 cm in front of	0.117	0.117	0.120	0.117	0.117	0.129
Test screen	0.114	0.114	0.120	0.117	0.123	0.129
	0.114	0.114	0.123	0.123	0.123	0.129
	0.114	0.117	0.123	0.120	0.117	0.126
	0.114	0.117	0.120	0.117	0.120	0.129
	0.114	0.114	0.117	0.114	0.120	0.129
Mean	0.114	0.116	0.120	0.118	0.120	0.128
SE	0.0005	0.0007	0.0009	0.0013	0.0011	0.0005
Center of flume	0.111	0.123	0.123	0.120	0.123	0.129
	0.117	0.120	0.117	0.126	0.123	0.129
	0.117	0.123	0.120	0.126	0.123	0.129
	0.117	0.117	0.120	0.123	0.123	0.135
	0.117	0.117	0.117	0.123	0.126	0.129
	0.117	0.117	0.123	0.123	0.123	0.129
Mean	0.116	0.120	0.120	0.123	0.124	0.130
SE	0.0010	0.0012	0.0011	0.0009	0.0005	0.0010
7.6 cm behind	0.117	0.123	0.129	0.117	0.120	0.135
Front barrier	0.117	0.120	0.132	0.117	0.117	0.138
	0.120	0.120	0.135	0.117	0.120	0.135
	0.117	0.126	0.135	0.117	0.120	0.135
	0.117	0.123	0.132	0.117	0.120	0.135
	0.117	0.126	0.138	0.120	0.120	0.132
Mean	0.118	0.123	0.134	0.118	0.120	0.135
SE	0.0005	0.0011	0.0013	0.0005	0.0005	0.0008

Appendix 1a (continued). Water velocities, m/s, measured at 24 locations in the flume. Six measurements were taken at each location before beginning each experiment. Mean m/s and SE reported below individual velocity measurements.

Experiment 2: PBV

	7.6 cm above bottom			10.2 cm below surface		
Location	5 cm from far wall	center	5 cm from near wall	5 cm from far wall	center	5 cm from near wall
7.6 cm in front of	0.114	0.123	0.135	0.111	0.117	0.132
Rear barrier	0.120	0.120	0.138	0.111	0.120	0.138
	0.117	0.123	0.135	0.111	0.114	0.135
	0.111	0.126	0.129	0.111	0.114	0.135
	0.114	0.129	0.132	0.111	0.117	0.132
	0.117	0.120	0.141	0.117	0.120	0.138
Mean	0.116	0.124	0.135	0.112	0.117	0.135
SE	0.0013	0.0014	0.0017	0.0010	0.0011	0.0011
7.6 cm in front of	0.120	0.117	0.129	0.126	0.123	0.126
Test screen	0.123	0.117	0.123	0.123	0.123	0.126
	0.120	0.117	0.120	0.123	0.120	0.126
	0.117	0.120	0.126	0.123	0.123	0.126
	0.117	0.117	0.126	0.120	0.126	0.129
	0.120	0.114	0.123	0.123	0.120	0.126
Mean	0.120	0.117	0.124	0.123	0.122	0.126
SE	0.0009	0.0008	0.0013	0.0008	0.0009	0.0005
Center of flume	0.120	0.114	0.123	0.117	0.117	0.123
	0.120	0.114	0.117	0.114	0.114	0.129
	0.117	0.114	0.114	0.114	0.120	0.126
	0.114	0.117	0.117	0.120	0.114	0.126
	0.114	0.117	0.117	0.120	0.114	0.120
	0.114	0.117	0.114	0.114	0.117	0.126
Mean	0.116	0.116	0.117	0.116	0.116	0.125
SE	0.0012	0.0007	0.0013	0.0012	0.0010	0.0013
7.6 cm behind	0.114	0.111	0.117	0.111	0.114	0.129
Front barrier	0.111	0.114	0.120	0.111	0.117	0.126
	0.117	0.111	0.123	0.117	0.117	0.126
	0.114	0.114	0.120	0.111	0.117	0.123
	0.114	0.114	0.123	0.120	0.117	0.123
	0.114	0.114	0.117	0.114	0.117	0.123
Mean	0.114	0.113	0.120	0.114	0.116	0.125
SE	0.0008	0.0006	0.0011	0.0015	0.0005	0.0010

Appendix 1a (continued). Water velocities, m/s, measured at 24 locations in the flume. Six measurements were taken at each location before beginning each experiment. Mean m/s and SE reported below individual velocity measurements.

Experiment 3: PP

Location	7.6 cm above bottom			10.2 cm below surface		
	5 cm from far wall	center	5 cm from near wall	5 cm from far wall	center	5 cm from near wall
7.6 cm in front of	0.111	0.120	0.120	0.114	0.114	0.141
Rear barrier	0.114	0.123	0.129	0.114	0.111	0.138
	0.111	0.117	0.129	0.114	0.111	0.132
	0.111	0.120	0.123	0.114	0.114	0.138
	0.111	0.123	0.126	0.117	0.114	0.132
	0.114	0.123	0.132	0.114	0.114	0.135
Mean	0.112	0.121	0.126	0.114	0.113	0.136
SE	0.0006	0.0010	0.0018	0.0005	0.0006	0.0015
7.6 cm in front of	0.120	0.117	0.126	0.111	0.114	0.126
Test screen	0.120	0.117	0.132	0.117	0.114	0.126
	0.114	0.117	0.126	0.117	0.114	0.120
	0.120	0.114	0.126	0.114	0.114	0.129
	0.117	0.117	0.129	0.117	0.117	0.126
	0.120	0.117	0.126	0.117	0.114	0.129
Mean	0.118	0.116	0.128	0.116	0.114	0.126
SE	0.0010	0.0005	0.0010	0.0010	0.0005	0.0013
Center of flume	0.114	0.114	0.120	0.117	0.111	0.114
	0.114	0.114	0.120	0.111	0.111	0.117
	0.114	0.114	0.120	0.114	0.111	0.114
	0.114	0.114	0.123	0.111	0.108	0.120
	0.114	0.111	0.120	0.108	0.111	0.117
	0.114	0.111	0.120	0.111	0.111	0.117
Mean	0.114	0.113	0.120	0.112	0.110	0.116
SE	0.0000	0.0006	0.0005	0.0013	0.0005	0.0009
7.6 cm behind	0.108	0.111	0.120	0.105	0.108	0.120
Front barrier	0.105	0.111	0.120	0.108	0.111	0.120
	0.105	0.111	0.114	0.108	0.111	0.123
	0.105	0.114	0.120	0.105	0.108	0.120
	0.105	0.111	0.117	0.111	0.111	0.120
	0.108	0.114	0.117	0.105	0.111	0.117
Mean	0.106	0.112	0.118	0.107	0.110	0.120
SE	0.0006	0.0006	0.0010	0.0010	0.0006	0.0008

Appendix 1a (continued). Water velocities, m/s, measured at 24 locations in the flume. Six measurements were taken at each location before beginning each experiment. Mean m/s and SE reported below individual velocity measurements.

Experiment 4: PBH

Location	7.6 cm above bottom			10.2 cm below surface		
	5 cm from far wall	center	5 cm from near wall	5 cm from far wall	center	5 cm from near wall
7.6 cm in front of	0.126	0.126	0.126	0.123	0.120	0.117
Rear barrier	0.123	0.126	0.123	0.129	0.120	0.120
	0.126	0.123	0.126	0.123	0.123	0.114
	0.126	0.123	0.129	0.126	0.120	0.114
	0.129	0.129	0.126	0.126	0.123	0.117
	0.129	0.126	0.129	0.126	0.123	0.120
Mean	0.126	0.126	0.126	0.126	0.122	0.117
SE	0.0009	0.0009	0.0009	0.0009	0.0007	0.0011
7.6 cm in front of	0.123	0.123	0.126	0.126	0.120	0.129
Test screen	0.120	0.120	0.123	0.126	0.117	0.126
	0.120	0.120	0.123	0.129	0.117	0.126
	0.120	0.120	0.123	0.123	0.117	0.123
	0.123	0.117	0.123	0.129	0.120	0.123
	0.123	0.120	0.120	0.123	0.120	0.123
Mean	0.122	0.120	0.123	0.126	0.118	0.125
SE	0.0007	0.0008	0.0008	0.0011	0.0007	0.0010
Center of flume	0.117	0.120	0.114	0.120	0.120	0.120
	0.114	0.120	0.117	0.123	0.117	0.120
	0.123	0.117	0.114	0.123	0.117	0.123
	0.117	0.117	0.114	0.117	0.114	0.120
	0.117	0.117	0.111	0.123	0.114	0.120
	0.117	0.120	0.114	0.120	0.114	0.120
Mean	0.118	0.118	0.114	0.121	0.116	0.120
SE	0.0012	0.0007	0.0008	0.0010	0.0010	0.0005
7.6 cm behind	0.120	0.120	0.114	0.117	0.120	0.126
Front barrier	0.123	0.120	0.117	0.117	0.114	0.117
	0.123	0.123	0.117	0.117	0.114	0.120
	0.120	0.120	0.108	0.114	0.114	0.117
	0.120	0.120	0.111	0.120	0.117	0.120
	0.120	0.117	0.111	0.123	0.117	0.120
Mean	0.121	0.120	0.113	0.118	0.116	0.120
SE	0.0006	0.0008	0.0015	0.0013	0.0010	0.0013

Appendix 1a (continued). Water velocities, m/s, measured at 24 locations in the flume. Six measurements were taken at each location before beginning each experiment. Mean m/s and SE reported below individual velocity measurements.

Experiment 5: WW

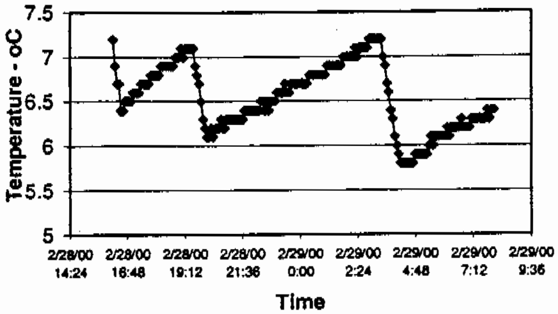
Location	7.6 cm above bottom: 5 cm from far wall	7.6 cm above bottom: center	7.6 cm above bottom: 5 cm from near wall	10.2 cm below surface: 5 cm from far wall	10.2 cm below surface: center	10.2 cm below surface: 5 cm from near wall
7.6 cm in front of	0.123	0.120	0.126	0.126	0.123	0.129
Rear barrier	0.123	0.114	0.126	0.123	0.120	0.132
	0.120	0.114	0.129	0.126	0.123	0.129
	0.126	0.111	0.129	0.123	0.126	0.129
	0.126	0.114	0.129	0.123	0.123	0.129
	0.120	0.117	0.132	0.123	0.120	0.129
Mean	0.123	0.115	0.128	0.124	0.122	0.130
SE	0.0011	0.0013	0.0009	0.0006	0.0009	0.0005
7.6 cm in front of	0.120	0.120	0.123	0.117	0.111	0.126
Test screen	0.120	0.120	0.120	0.117	0.111	0.126
	0.120	0.114	0.120	0.114	0.114	0.123
	0.120	0.117	0.117	0.117	0.111	0.123
	0.123	0.117	0.117	0.117	0.114	0.123
	0.123	0.117	0.117	0.114	0.114	0.123
Mean	0.121	0.118	0.119	0.116	0.112	0.124
SE	0.0006	0.0009	0.0010	0.0006	0.0006	0.0006
Center of flume	0.111	0.111	0.120	0.114	0.111	0.117
	0.111	0.117	0.120	0.111	0.111	0.117
	0.111	0.117	0.120	0.111	0.114	0.117
	0.111	0.117	0.120	0.114	0.108	0.120
	0.111	0.117	0.117	0.114	0.111	0.120
	0.111	0.114	0.117	0.111	0.111	0.117
Mean	0.111	0.116	0.119	0.112	0.111	0.118
SE	0.0000	0.0010	0.0006	0.0007	0.0008	0.0006
7.6 cm behind	0.108	0.111	0.123	0.111	0.114	0.126
Front barrier	0.108	0.117	0.120	0.108	0.111	0.117
	0.105	0.111	0.120	0.111	0.111	0.123
	0.105	0.114	0.126	0.108	0.114	0.123
	0.105	0.114	0.120	0.108	0.108	0.120
	0.108	0.117	0.123	0.108	0.114	0.123
Mean	0.106	0.114	0.122	0.109	0.112	0.122
SE	0.0007	0.0011	0.0010	0.0006	0.0010	0.0013

Appendix 1b. Water velocities, m/s, measured at a static location behind rear barrier screen before and during experiments.

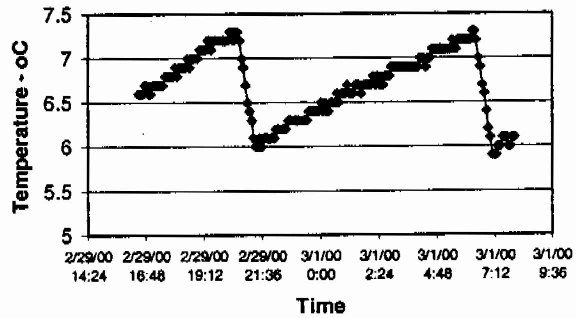
Time	CL	PBV	PP	PBH	WW
		Before experiment			
	0.075	0.090	0.087	0.093	0.096
	0.075	0.090	0.084	0.096	0.099
	0.072	0.087	0.090	0.096	0.096
	0.069	0.090	0.087	0.096	0.099
	0.072	0.093	0.084	0.096	0.096
	0.075	0.093	0.087	0.096	0.099
		During experiment			
15:15	0.000				
15:30	0.000				
15:45			0.000	0.000	0.000
16:00	0.000	0.000	0.000	0.000	0.021
16:15		0.015	0.030	0.045	0.045
16:30	0.057	0.045	0.075	0.093	0.069
17:00	0.057	0.087	0.084	0.093	0.093
17:30	0.057	0.090	0.078	0.090	0.096
18:00	0.057	0.087	0.084	0.093	0.096
18:30	0.060	0.00	0.081	0.090	0.096
19:00	0.057	0.087	0.084	0.096	0.096
19:30		0.084	0.084	0.096	0.099
20:00		0.087	0.087	0.093	0.096
20:30		0.090	0.087	0.093	0.093
21:00	0.054	0.087	0.084	0.096	0.093
21:00	0.060				
21:30		0.087	0.084	0.093	0.093
22:00			0.090	0.090	0.093
22:30		0.087			
2:15	0.063				
4:00			0.090	0.093	0.093
4:30		0.093	0.087	0.090	0.093
5:00		0.090	0.087	0.090	0.093
5:30		0.087	0.087	0.090	0.096
6:00		0.087	0.090	0.090	0.093
6:30	0.060	0.093	0.087	0.087	0.096
7:00	0.060	0.093	0.087	0.093	0.090
7:30	0.060	0.093	0.087	0.093	0.093
8:00		0.093	0.090	0.093	0.093

Appendix 2: Temperatures recorded in the test tank throughout each experiment.

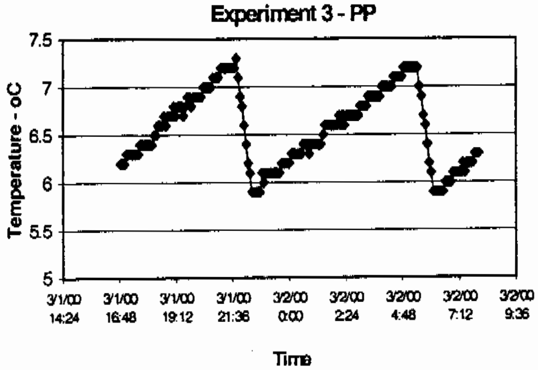
Experiment 1 - Control



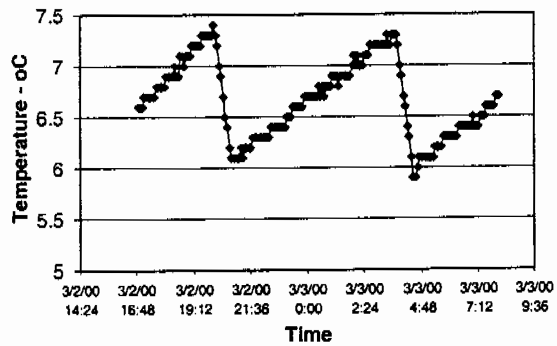
Experiment 2 - PBV



Experiment 3 - PP



Experiment 4 - PBH



Experiment 5 - WW