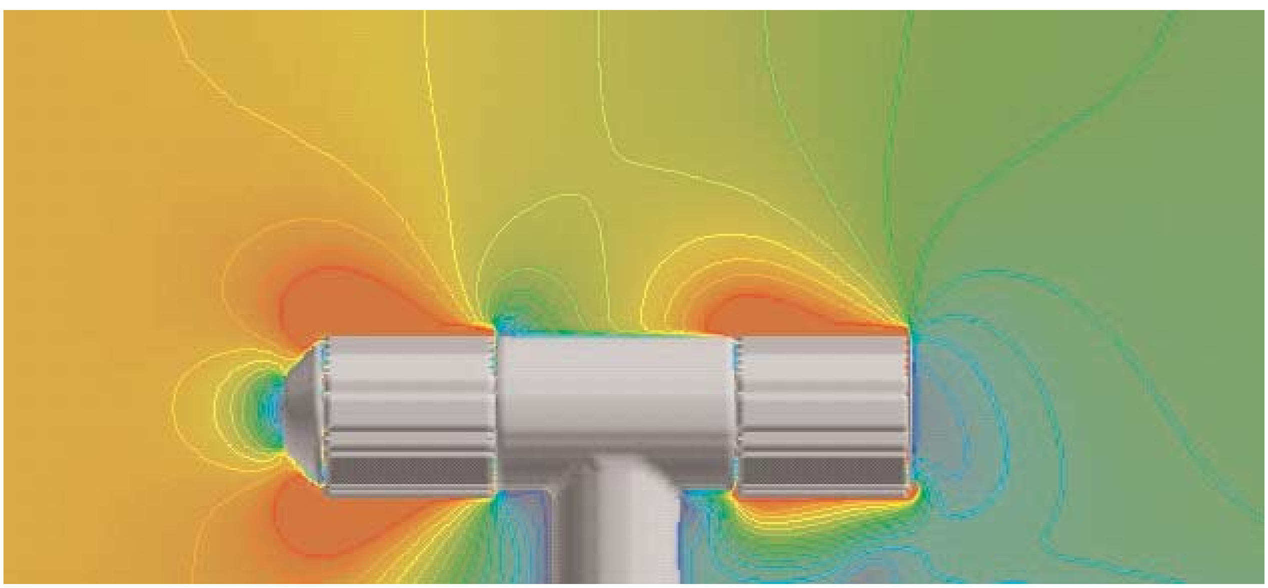
Laboratory Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes

Technical Report



Laboratory Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes

1005339

Final Report, May 2003

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REPORT SUMMARY

This report presents the results of a laboratory study examining the effectiveness of cylindrical wedgewire screens for protecting the early life stages (eggs and larvae) of fish at water intakes. A three-dimensional computational fluid dynamics (CFD) evaluation was also performed to gather pertinent hydraulic data describing the flow fields associated with operation of these screens. Information in this report increases the performance database for this technology and supports its evaluation for potential application at cooling and other water intakes.

Background
Following passage of the Clean Water Act (CWA) in 1972, wedgewire screens were the subject of research in both laboratory and field studies to evaluate their ability to minimize entrainment and impingement of aquatic organisms at cooling water intake structures (CWIS). These studies examined various biological and engineering aspects of wedgewire screens, including slot sizes, velocities, and orientations with the potential for optimizing passive protection of early life stages of fish. A few quantitative biological evaluations were conducted in the laboratory with live eggs and larvae of selected species of interest. Because this research ended with the slowdown in new power plant construction in the early 1980s, the database on wedgewire screens falls short of allowing scientists and engineers to determine the optimal screen design and operational parameters and to estimate the biological effectiveness of this technology. EPRI—with supporting funds from the U.S. Environmental Protection Agency under the CWA § 104(b)(3) Water Quality Cooperative Agreements Program—sponsored this study.

Objectives
- To determine, under controlled laboratory conditions, the relative importance of various screen design parameters and hydraulic conditions in minimizing entrainment and impingement of selected fish species in early life stages.
- To perform a CFD analysis in order to determine the degree of similarity between flow patterns associated with test conditions (bounded flume flows) and flow patterns associated with field conditions (unbounded flows).
- To examine the similarity between the bounded and unbounded flows in order to extrapolate the results of the laboratory biological tests to similar field operating conditions.

Approach

The project team evaluated entrainment and impingement of eight species of fish in early life stages. Screen design and hydraulic parameters examined in the laboratory flume included screen orientation to approach flow, slot size, through-slot velocity, and approach flow velocity. Known numbers of fish were released upstream of the screens for each set of test conditions evaluated. The team estimated impingement by counting eggs and larvae impinging on a screen at the completion of a test. Similarly, they estimated entrainment by collecting and enumerating organisms that passed through the screens. The CFD evaluation involved the use of three-dimensional computer modeling techniques to examine the effects of approach velocity and screen flow on velocity distributions around the wedgewire screens. The team conducted analyses for the laboratory flume geometry and for a laterally unbounded installation, which was similar to a field application.

Results

In general, entrainment increased with both slot size and slot velocity and decreased with channel velocity and larval length. Impingement also increased with slot and channel velocity, but decreased with slot size. Interrelationships existed among the various test parameters (for example, the effects of slot velocity were not uniform for all slot sizes evaluated, and response of larvae to varying hydraulic conditions was related to fish size and swimming ability). The results of this study demonstrate that cylindrical wedgewire screens are capable of reducing entrainment and impingement rates to low levels for most species and life stages of fish. However, optimum design criteria will differ depending on biological factors and hydraulic conditions. Future studies, whether conducted in the laboratory or field, should focus on a narrower range of screen design and hydraulic parameters in order to better define the relationships between the various parameters and effective protection for fish larvae and eggs. The CFD evaluation demonstrated that the hydraulic environment of the laboratory test flume was similar to that of screens in an unbounded setting such as field installation. Additionally, the flow fields described by the CFD models supported observations of egg and fish approach paths and locations where organisms were most likely to be impinged on the screens.

EPRI Perspective

This report provides CWIS and other water intake operators with information on the ability of cylindrical wedgewire screens to minimize entrainment and impingement of fish in early life stages. Research results will permit water intake designers to configure these screens for optimal effectiveness in different water body types and will allow resource managers to more accurately predict the potential for biological effectiveness at a given site.

Keywords

Fish Protection
Water Intakes
Clean Water Act Section 316(b)
Computational Fluid Dynamics Analysis

ABSTRACT

Section 316(b) of the Clean Water Act (CWA) requires that the location, design, construction, and capacity of a cooling water intake structure (CWIS) reflect the "best technology available" (BTA) for minimizing adverse environmental impacts (AEI). Cylindrical wedgewire screens are considered a technology that has potential for minimizing entrainment and impingement of aquatic organisms at cooling water intakes. A laboratory evaluation of cylindrical screens was conducted to determine hydraulic and design criteria that contribute to greater protection of fish larvae and eggs. Entrainment and impingement rates associated with various slot sizes, slot velocities, and channel velocities were estimated for early lifestages of eight species of fish (striped bass, winter flounder, yellow perch, rainbow smelt, common carp, white sucker, alewife, and bluegill) that are commonly impinged and/or entrained at CWIS. Entrainment and impingement rates varied considerably depending on velocity conditions and slot width, ranging from about 0 to 95%. For most combinations of test conditions that were evaluated, the mean percent of fish lost to entrainment and impingement was less than 50%, with rates as low as 0 to 10% for tests that included the highest approach velocity and the lowest through-slot velocity. In general, entrainment increased with slot size and slot velocity and decreased with channel velocity and larval length. Impingement also increased with slot and channel velocity, but decreased with slot size. Interrelationships existed among the various test parameters (e.g., the effects of slot velocity were not uniform for all slot sizes evaluated and response of larvae to varying hydraulic conditions was related to fish size and swimming ability). The results of this study demonstrate that cylindrical wedgewire screens are capable of reducing entrainment and impingement rates for a wider range of fish species and lifestages than has previously been reported. Reductions in fish losses may be considerable if an optimum ratio of ambient velocity (i.e., flow approaching a screen) to through-slot velocity can be identified and maintained for target species and lifestages. However, optimum design criteria will differ depending on biological factors and local hydraulic conditions. Future studies, whether conducted in the laboratory or field, should focus on a narrower range of screen design and hydraulic parameters in order to better define the relationships between the various parameters and effective protection for fish larvae and eggs.

ACKNOWLEDGMENTS

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Section 316(b) of the Clean Water Act (CWA) requires that the location, design, construction, and capacity of a cooling water intake structure (CWIS) reflect the “best technology available” (BTA) for minimizing adverse environmental impacts (AEI). Adverse environmental impacts from CWISs may occur as the result of entrainment of small aquatic organisms into the cooling water system via the CWIS and the impingement of larger life stages on traveling water screens. In 1999, the Electric Power Research Institute (EPRI) published a comprehensive review of the status of technologies that have been studied or considered for application at CWIS (EPRI 1999). One of the more promising technologies reviewed in the EPRI report is the cylindrical wedgewire screen. In EPA’s proposed § 316(b) rule for new facilities, this technology is one of only three that was selected for detailed engineering and economic analysis as part of the rule development process.

Cylindrical wedgewire screens have a "V" or wedge-shaped, cross-section wire welded to a framing system that forms a slotted screening element (Figure 1-1). It is generally believed that the following conditions are important for preventing or reducing entrainment and impingement associated with wedgewire screens (EPRI 1999): (1) a sufficiently small slot size to physically block passage of the smallest lifestages to be protected; (2) low through-slot velocity to minimize the hydraulic zone of influence in which passive or weak swimming organisms can become entrained; and (3) an adequate ambient current (i.e., “sweeping” velocity) passing across a screen to carry organisms and debris along and away from the screen. When all of these factors exist, it is expected that the biological effectiveness of wedgewire screens will be high. However, large reductions in entrainment and impingement may occur when sub-sets of these conditions exist. For example, it may be possible for low through-slot velocities and high approach velocities to reduce entrainment and impingement to acceptable levels, even when aquatic organisms are physically capable of passing through slots. The available data, however, are not adequate for determining which parameters, or combinations of parameters, may need to be optimized for effective future applications. The present study has attempted, under controlled laboratory conditions, to determine the influence of important biological and engineering parameters on entrainment rates and how their interaction may contribute to reductions in entrainment and impingement at cylindrical wedgewire screen facilities.

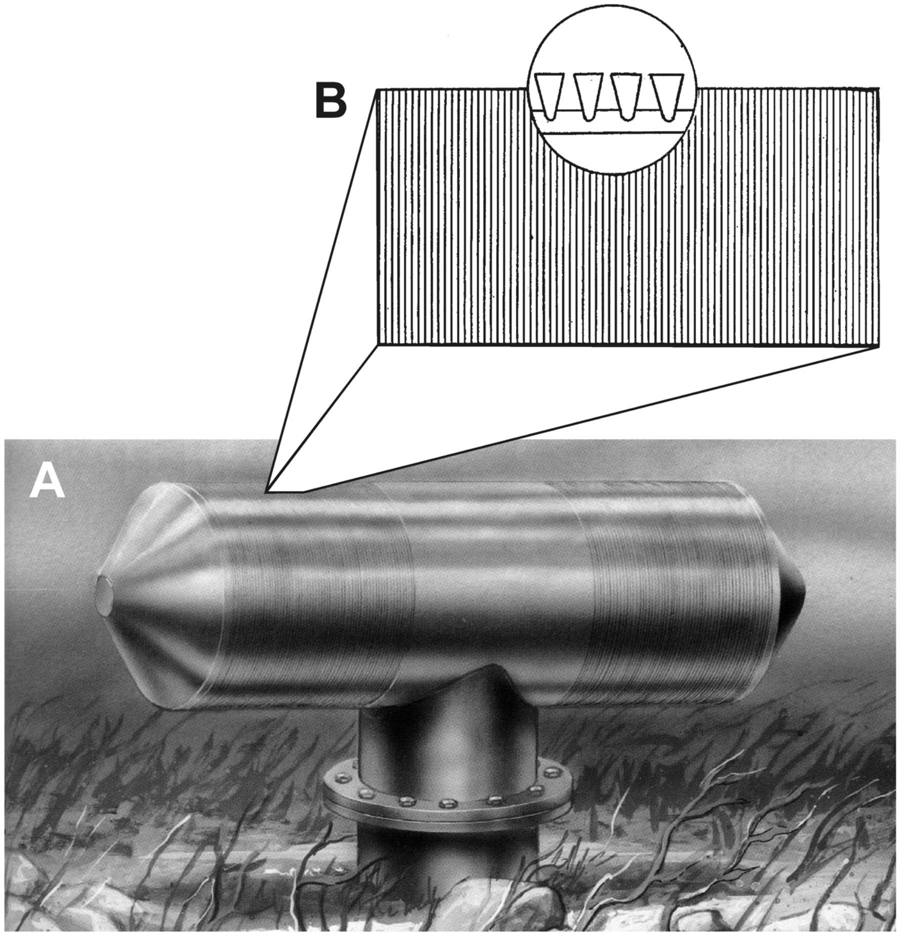

Figure 1-1
Depiction of a Cylindrical Wedgewire Screen Installation (A) and Close-up of Slotted Wedgewire Elements (B) (Modified from Hanson 1978 and EPRI 1999).

Previous Studies

Biological factors that have been shown to influence entrainment and impingement of fish exposed to cylindrical wedgewire screens include fish size (length, width, body depth), lifestage or age, and swimming ability. All of these factors are closely related (i.e., as fish mature they become larger and have greater swimming capabilities) and contribute to the susceptibility of fish larvae to entrainment and impingement. Because fish egg sizes within a species are fairly uniform, the risk to entrainment and impingement of this lifestage generally will depend on their size, design of screens (e.g., slot size), and hydraulic conditions. The size of fish can lead to physical or behavioral exclusion if they are larger than a screen's slot width and/or are capable of avoiding intake flows that can lead to impingement or entrainment. Weisburg et al. (1987) determined that exclusion of fish larvae from cylindrical wedgewire screens with varying slot widths was highly dependent on fish length. During this study, larvae less than 5 mm were not excluded by any of the slot sizes evaluated (1, 2, and 3 mm), whereas larger fish (greater than 10 mm) were excluded at rates greater than 80% for all slot sizes. Other studies have also demonstrated that many fish greater than about 10 mm in length can be effectively excluded by screens with 1-mm slot widths (Hanson et al. 1978, 1981; Heuer and Tomljanovich 1979; Otto 1981). In addition to length, body depth or width may also preclude fish from becoming entrained through wedgewire screens (Schneeberger and Jude 1981).

Although fish length is an important biological factor with respect to physical exclusion, the entrainment and impingement of fish through wedgewire screens is also dependent on active avoidance by larvae. Visual observations and estimated entrainment rates of fish that are physically capable of passing through slots indicate that a portion of larvae exposed to screens will avoid entrainment (Hanson 1978; Zeitoun and Gulvas 1981a; Otto 1981).

The relationship between wedgewire screen slot width and impingement and entrainment rates is mainly dependent on fish size. Most fish that are physically too large to pass through a screen probably will not become entrained. However, at higher slot velocities, some larger fish, as well as eggs, may be extruded through screen slots. Also, fish that cannot physically pass through a screen mesh may become impinged if they cannot swim or be swept away from intake flow. A direct relationship between slot size and entrainment has been demonstrated in some previous studies (Hanson 1978; Heuer and Tomljanovich 1978; Browne 1979; Weisburg et al. 1984, 1987), but the strength or importance of this relationship may vary with fish size (Weisburg et al. 1987).

Through-slot velocity and ambient velocity (also referred to as channel or approach velocity) can have considerable effects on impingement and entrainment of fish exposed to wedgewire screens. Impingement and entrainment have been positively correlated with slot velocity and inversely related to ambient velocity (Hanson et al. 1978; Heuer and Tomljanovich 1978). The interaction between these two velocity parameters also is important, with available data suggesting that the ratio of ambient velocity to slot velocity should be maximized for effective exclusion of aquatic organisms (Hanson 1978). The ability to "sweep" fish past cylindrical wedgewire screens most likely contributes to lower entrainment and impingement rates of larvae and eggs that otherwise would become entrapped.

The orientation of wedgewire screens with respect to ambient currents has not been extensively evaluated, but available data indicate that it can be an important parameter that influences the ability of fish larvae and eggs to avoid impingement and entrainment. Most previous studies have evaluated cylindrical screens that are positioned perpendicular to the approaching flow. This orientation results in the wire mesh running parallel to the flow (Figure 1-2). Studies that have evaluated both perpendicular and parallel screen orientations have shown that both configurations can protect aquatic organisms from entrainment and impingement, but that some differences in the level of protection may exist (Hanson 1979). Radial slots (i.e., screen oriented parallel to flow; Figure 1-2) were determined to provide greater protection for larvae, whereas axial slots (perpendicular screen) demonstrated better exclusion for eggs in a study that examined entrainment and impingement of striped bass (Hanson 1979). The perpendicular screen orientation may minimize contact time for approaching organisms, but the probability of contact is high, whereas a parallel screen orientation produces the opposite conditions (minimal probability of contact, but longer exposure time) (Cook 1978). Debris removal also is optimized with screens oriented parallel to ambient currents (i.e., radial slots).

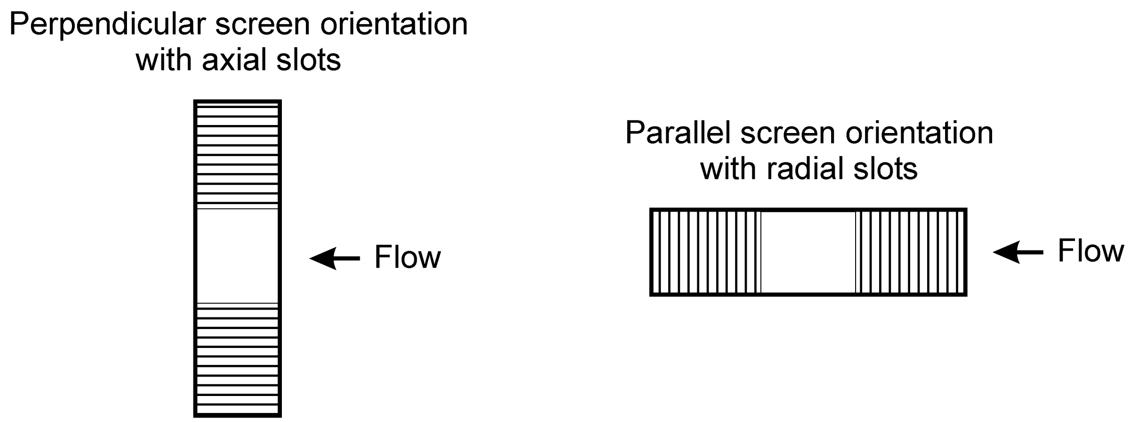

Figure 1-2
Schematic of Wedgewire Screens (Plan View) Oriented Perpendicular and Parallel to Ambient Flow Direction

Many of the biological and engineering parameters that influence entrainment and impingement are interrelated (e.g., swimming ability is related to fish size and will be affected by hydraulic conditions). Changes in one or more parameters can alter their relative influence on larvae and egg exclusion. Therefore, it can be difficult to determine which parameters may have the strongest influence on successful application of cylindrical wedgewire screens with respect to overall performance or for specific species and lifestages. Additional studies that focus on the relative effects of pertinent biological and engineering parameters will add important information to the existing database and will be useful in developing criteria that optimize the hydraulic and biological performance of cylindrical wedgewire screens.

Study Objectives

As discussed above, from the early 1970s to the mid-1980s, wedgewire screens were the subject of research in both laboratory and field studies. These studies examined various biological and engineering aspects of these screens, including slot sizes, velocities, and orientations that were considered to have potential for optimizing passive protection of early life stages of fish. The relatively few quantitative biological evaluations were conducted in the laboratory with live eggs and larvae of selected species of interest. Unfortunately, this research ended with the slowdown in new power plant construction in the early 1980s. Thus, the available database on wedgewire screens falls short of allowing current scientists and engineers to determine the optimal design and operational parameters and to estimate the potential biological effectiveness of this technology. EPRI has sponsored the current study with the objective of expanding the existing database by evaluating wedgewire screens under controlled laboratory conditions with species that are representative of those that are commonly impinged and entrained at CWIS. The data obtained during this study will permit CWIS designers to configure these screens for optimal effectiveness in different water body types and allow resource managers to more accurately predict the potential for biological effectiveness at a given site.

The goal of the biological evaluation of wedgewire screens was to determine the relative importance of various screen design parameters and hydraulic conditions in minimizing entrainment and impingement of selected species and life stages. To achieve this goal, biological testing was conducted with striped bass larvae and a surrogate egg type in 2001 and with seven additional species in 2002. The species selected for testing represent fishes with a range of life histories and swimming capabilities that commonly occur in entrainment and impingement samples at CWIS located in diverse water body types (e.g., estuaries, lakes, rivers). Life history, swimming capability, and water body type are all parameters that have considerable potential to influence species-specific risks to entrainment and impingement. The tests conducted in 2001 were primarily designed to determine if the test facility and procedures functioned as needed for accurately evaluating the relative effectiveness of the wedgewire screens. These tests also provided the initial set of data on relative impingement and entrainment rates of the organisms that were evaluated. Based on the results and observations from the 2001 tests, the test facility and procedures were modified for the more comprehensive testing that was conducted in 2002.

In addition to biological testing, a three-dimensional Computational Fluid Dynamics (CFD) analysis was conducted for the screen design and velocity conditions that were evaluated with live organisms. CFD modeling techniques enable scientists and engineers to study complex three-dimensional flow patterns using computer-generated models. An important goal of the CFD analysis was to determine the degree of similarity between flow patterns associated with the test conditions (bounded flume flows) and flow patterns associated with field conditions (unbounded flows). This information was considered necessary to assess the assumption that laboratory test conditions were similar to field conditions, thereby allowing the results of the laboratory biological tests to be extrapolated to similar field operating conditions. An additional goal of CFD modeling was to identify hydraulic conditions that may strongly influence entrainment and impingement rates (e.g., flow direction and magnitudes at various locations along a screen). A comprehensive description of flow fields will allow for potential hot spots (i.e., areas of high entrainment and/or impingement risk) to be identified and for possible design improvements to be developed.

2

BIOLOGICAL EVALUATION METHODS

Test Facility

The biological evaluation of cylindrical wedgewire screens was conducted in Alden Research Laboratory, Inc. (Alden) Fish Testing Facility, which is specifically designed for evaluating fish passage and protection technologies (Figure 2-1). The section of the test facility flume where testing is performed has a maximum depth and width of 2.1 m and 3.0 m, respectively. For 2001 testing, the width of the flume channel was about 1.5 m and water depth was 1.3 m. Flume width and water depth for 2002 tests were both 1.8 m (a temporary wall was removed and the plexiglass window was repositioned to widen the flume prior to 2002 testing). Channel velocities up to 0.9 m/sec can be maintained at full depth. Flow is re-circulated through the flume by a bow thruster that is driven by an electric motor.

The location of the screens was about 11.4 m downstream of where water is returned to the flume from the bow thruster (Figure 2-1). At this location, one side of the flume consists of a plexiglass window that allows for real-time visual and video observations to be recorded during testing. The wedgewire screen test facility consists of a fish larvae and egg release system, the wedgewire screens, an entrainment collection system, and a downstream collection system. The design of the test facilities used in 2001 and 2002 are presented in Figures 2-2 and 2-3, respectively.

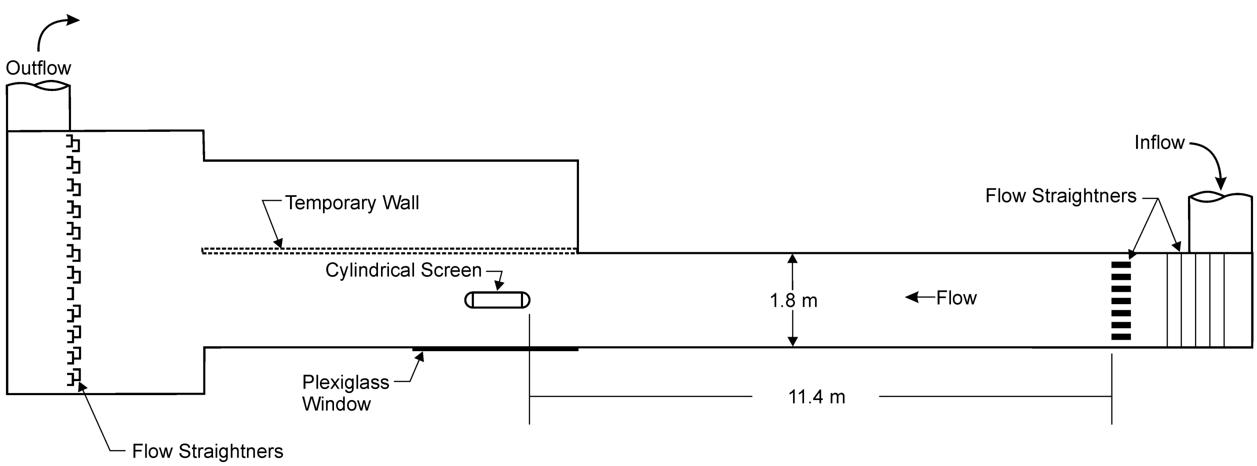

Figure 2-1
Fish Testing Facility and Approximate Location of Cylindrical Wedgewire Screens

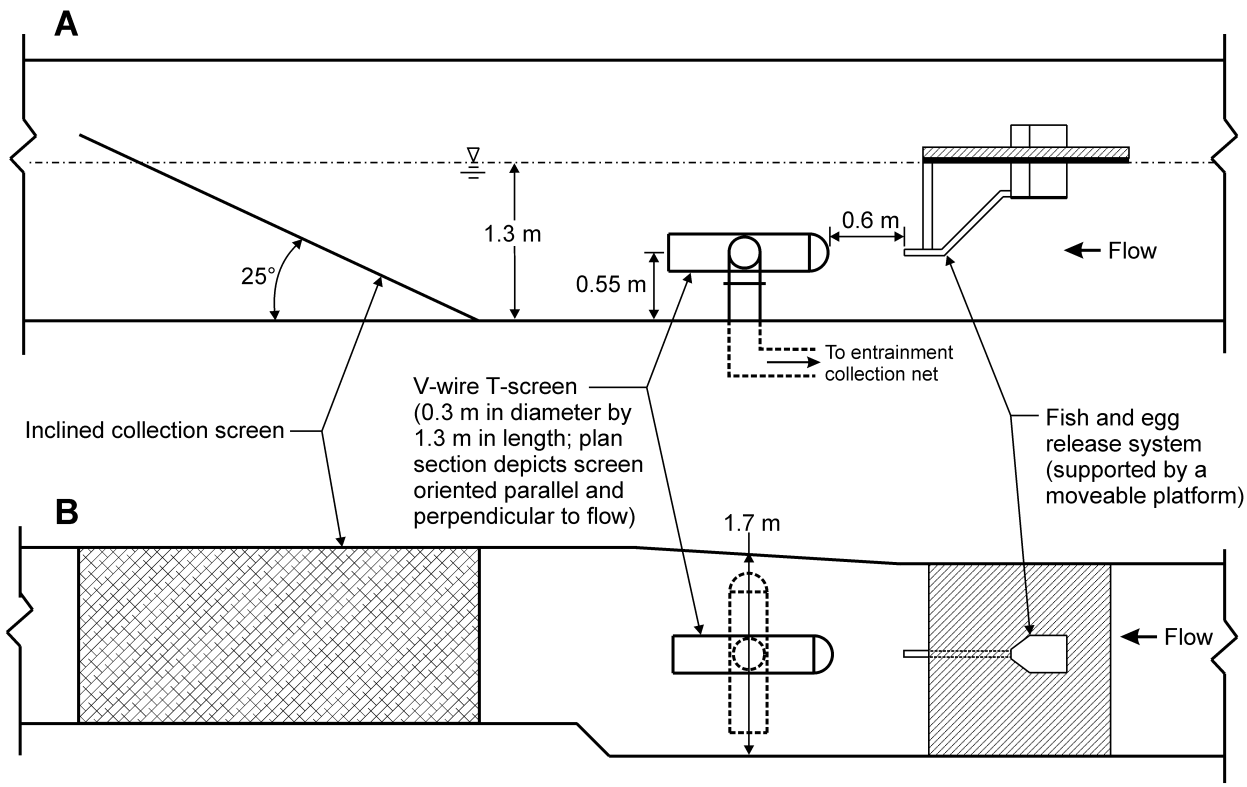

Figure 2-2
2001 Wedgewire Screen Test Facility

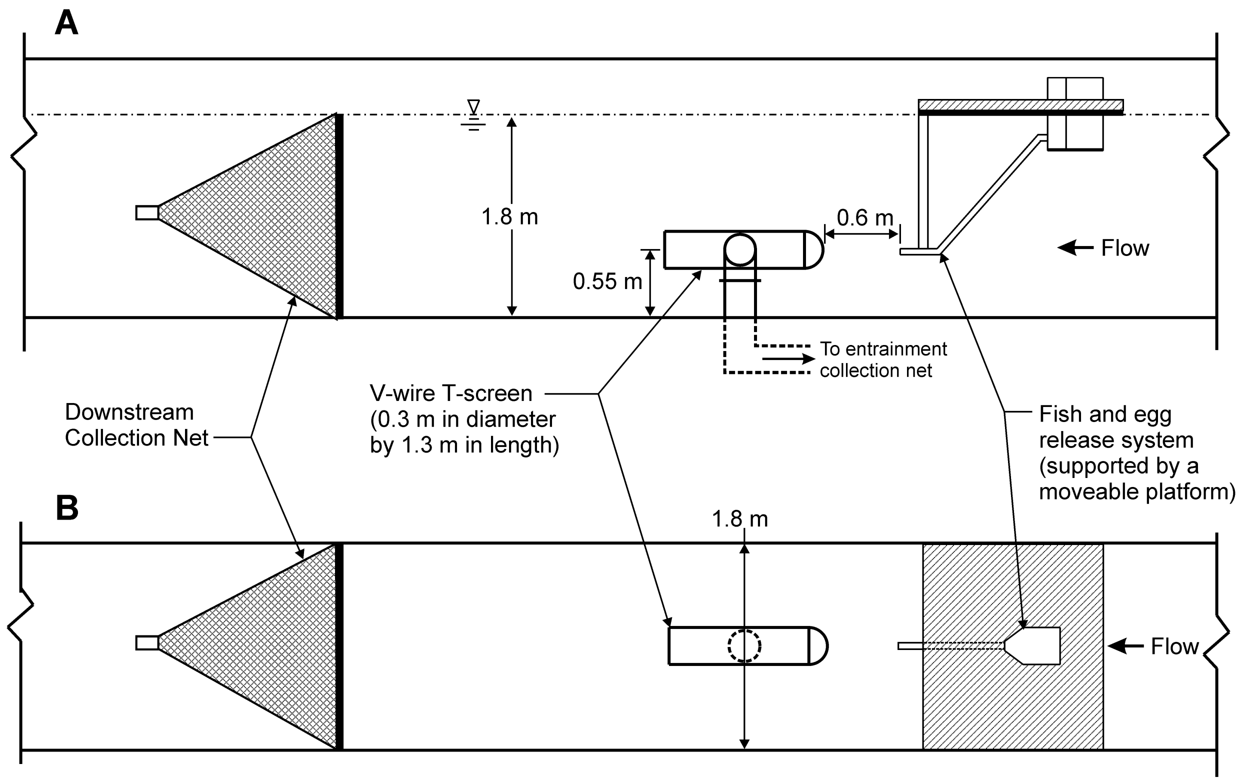

Figure 2-3
2002 Wedgewire Screen Test Facility

The screens that were used for the laboratory evaluation were T-12 (12-inch diameter [30.5 cm]) cylindrical wedgewire screens supplied by Johnson Screen (Figure 2-4). The T-12 screens have two 31-cm long sections through which water is withdrawn. Three screens constructed with different slot sizes (0.5, 1.0, and 2.0 mm) were evaluated to determine fish egg and larval entrainment and impingement rates under different channel and screen flow conditions. All three screens had 1.5-mm wide wedgewire bars. The porosities of the screens were 24.7% for the 0.5-mm slot screen, 39.6% for the 1.0-mm screen, and 56.8% for the 2.0-mm screen. Design information and flow rates at each through-slot velocity that was evaluated are presented in Table 2-1.

Eggs and larvae were introduced upstream of the screens using a release system designed to have a flow velocity similar to the channel velocity. The release system consisted of a small holding tank from which fish entered a tube that had an exit located upstream of the screens (Figure 2-5). The location of the release tube exit was determined during preliminary testing in 2001 and was designed to deliver organisms at the centerline of the screens, thereby maximizing exposure for laboratory testing purposes.

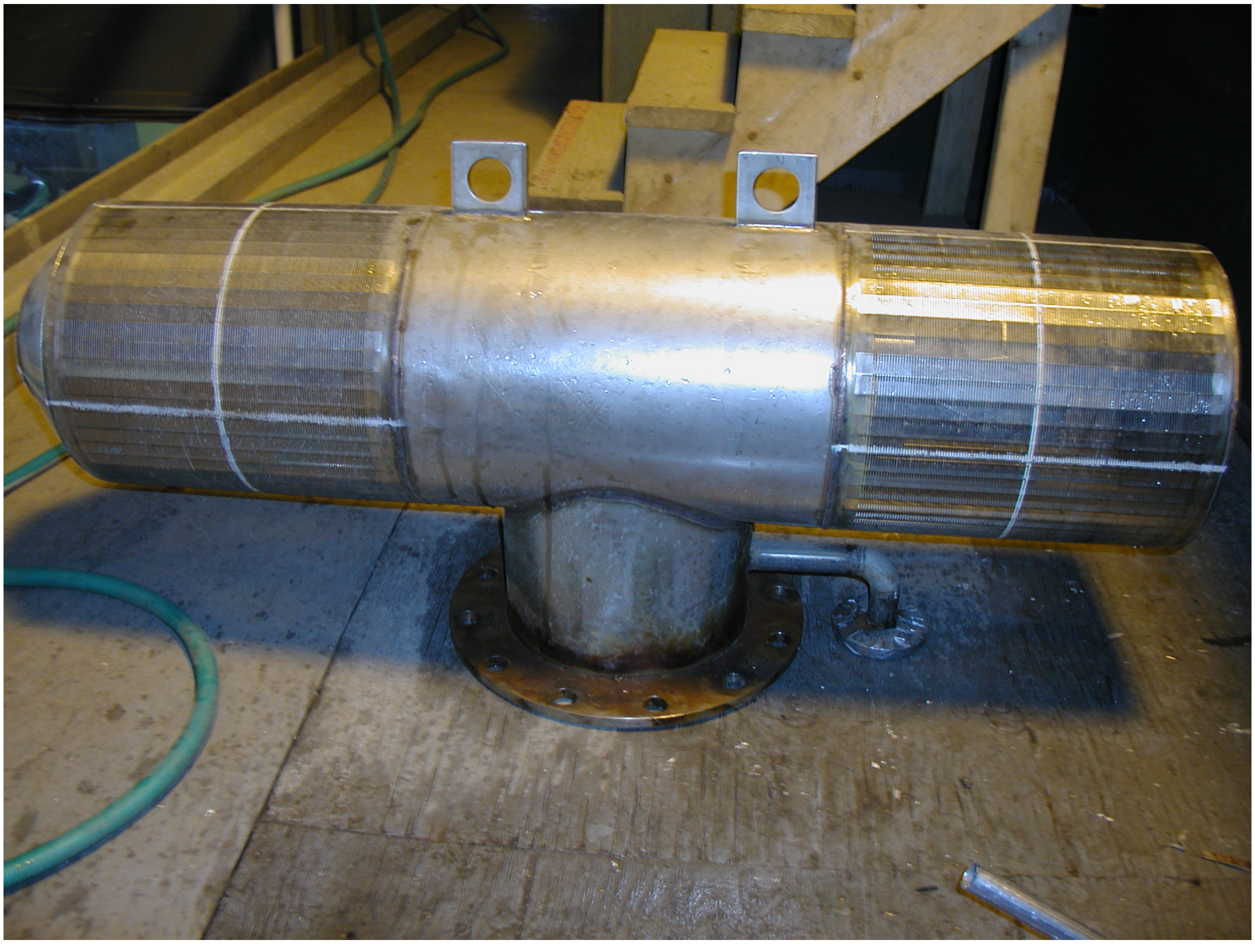

Figure 2-4
Johnson T-12 Cylindrical Wedgewire Screen (white lines delineate sections of the screen for which impingement locations were recorded)

Table 2-1
Wedgewire Screen Design and Operation Parameters Evaluated During the Laboratory Study

Slot size (mm)	Screen Open Area (m^2)	Screen Porosity (%)	Slot Velocity (m/s)	Screen Withdrawal Rate		Channel Velocity (m/s)	Channel Flow Rate			
							2001		2002	
				m^3/s	gpm		m^3/s	gpm	m^3/s	gpm
0.5	0.15	24.7	0.15	0.023	363	0.08	0.15	2376	0.26	4039
						0.15	0.30	4753	0.51	8078
						0.30	0.60	9506	1.02	16,157
			0.30	0.046	726	0.08	0.15	2376	0.26	4039
						0.15	0.30	4753	0.51	8078
						0.30	0.60	9506	1.02	16,157
1.0	0.24	39.6	0.15	0.037	582	0.08	0.15	2376	0.26	4039
						0.15	0.30	4753	0.51	8078
						0.30	0.60	9506	1.02	16,157
			0.30	0.073	1164	0.08	0.15	2376	0.26	4039
						0.15	0.30	4753	0.51	8078
						0.30	0.60	9506	1.02	16,157
2.0	0.35	56.8	0.15	0.053	834	0.08	0.15	2376	0.26	4039
						0.15	0.30	4753	0.51	8078
						0.30	0.60	9506	1.02	16,157
			0.30	0.105	1667	0.08	0.15	2376	0.26	4039
						0.15	0.30	4753	0.51	8078
						0.30	0.60	9506	1.02	16,157

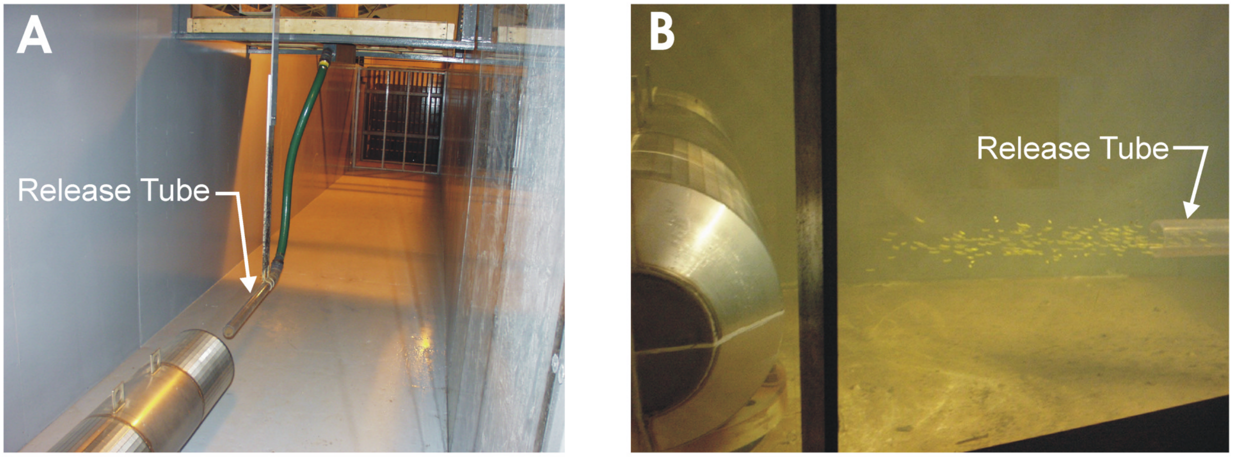

Figure 2-5
Larvae and Egg Release System (screen is parallel to the flow in A; perpendicular to flow in B with artificial eggs being released)

Organisms that were entrained through the screens were transported to a collection tank equipped with a 330-micron plankton net (Figure 2-6). The plankton net was lifted from the collection tank using a pulley system and jars were attached to the net to collect entrained larvae and eggs. Organisms that were not entrained or impinged were collected downstream on an inclined screen during 2001 tests and in a 330-micron plankton net during 2002 tests (Figures 2-2 and 2-3).

Velocity Measurements

Velocity measurements were recorded during both test years to verify that the flume operating conditions produced the selected channel velocities with a relatively uniform distribution upstream of the wedgewire screens. Velocity measurements for the test conditions evaluated in 2001 were recorded using a Swoffler meter. In 2002, velocities were recorded using an acoustic Doppler velocimeter (ADV) for each set of test conditions. Similar to Swoffler meter recordings in 2001, the ADV measurements were used in 2002 to calibrate the flume to the proper pump settings and to provide data for the development of computational fluid dynamics (CFD) models. The velocity data recorded with the ADV are reported in Section 4.

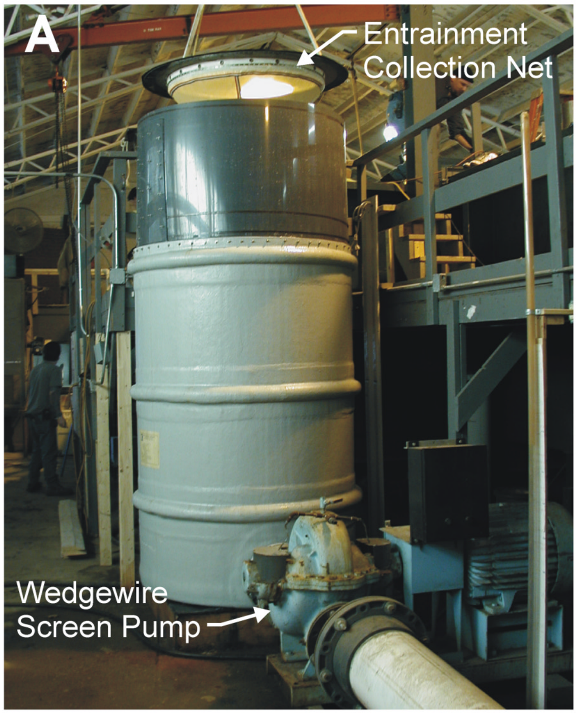

Figure 2-6
Entrainment Collection System (collection net in raised position in A and in fishing position in B with water being pumped through cylindrical screen)

Test Species and Lifestages

Eight species were tested during the evaluation of entrainment and impingement rates: striped bass (*Morone saxatilis*), winter flounder (*Pleuronectes americanus*), yellow perch (*Perca flavescens*), rainbow smelt (*Osmerus mordax*), common carp (*Cyprinus carpio*), white sucker (*Catostomus commersoni*), alewife (*Alosa pseudoharengus*), and bluegill (*Lepomis macrochirus*). These species were selected primarily because they represent fishes that are most commonly entrained at cooling water intakes located in a variety of water body types (e.g., rivers, lakes, estuaries, and coastal areas). They also represent fishes with a range of body shapes and swimming capabilities. The lifestages that were evaluated for each species included those that are typically susceptible to entrainment and impingement. Life stages that were evaluated for each species tested included the following: striped bass and white sucker eggs and larvae; winter flounder stage 3 and 4 larvae; yellow perch, rainbow smelt, common carp, and bluegill larvae; and alewife eggs.

Striped bass was the only species evaluated in 2001 and was the only species for which a surrogate egg was used to represent live eggs. Striped bass larvae were acquired from Delmarva Aquatics in Delaware and were the progeny of wild fish collected from Delaware Bay. These fish were held in 95-l tanks that were heated and aerated. Water quality was maintained by conducting 25 to 50% water changes on a daily basis. Water quality data for 2001 striped bass testing are presented in Appendix A. Soft beads manufactured by Technology Flavors and

Fragrances, Inc. were used as surrogate striped bass eggs (Figure 2-7). These spherical beads were about the same size (diameter range: 3.6 - 6.3 mm) and buoyancy (slightly negative) as striped bass eggs and have been used in striped bass egg drift studies conducted by researchers at the University of Georgia.

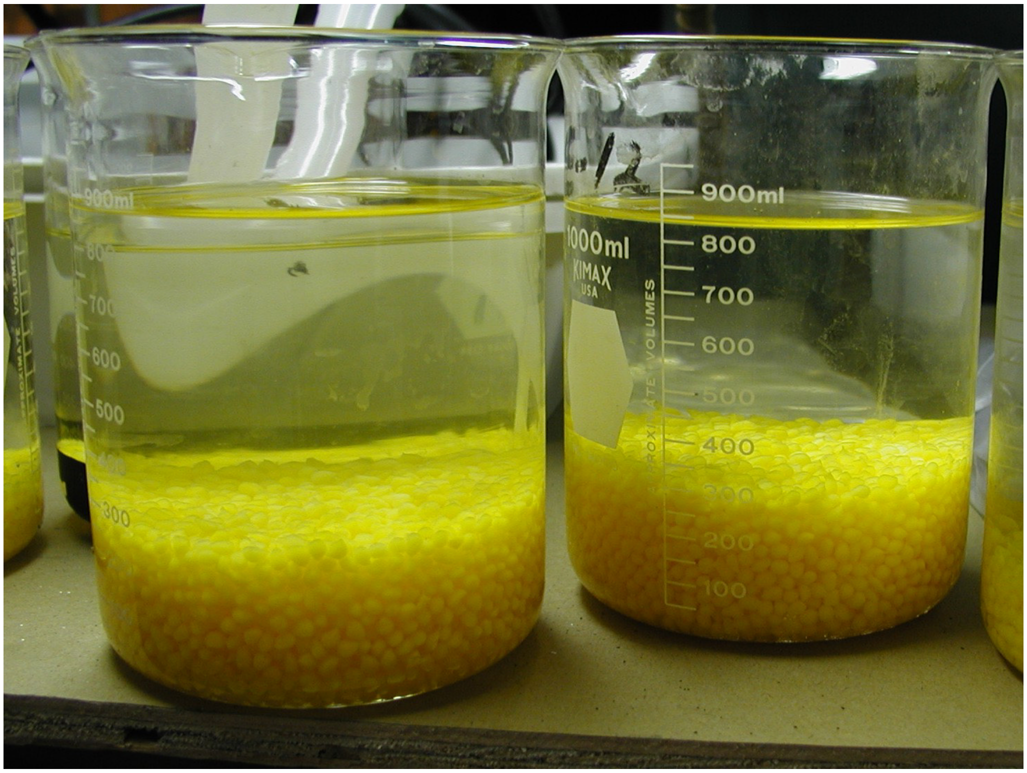

Figure 2-7
Surrogate Striped Bass Eggs

Species evaluated in 2002 included winter flounder, yellow perch, rainbow smelt, common carp, white sucker, alewife, and bluegill. Winter flounder larvae were acquired from Llennoco Inc. located in Massachusetts. These fish were the progeny of wild fish that were spawned in captivity. Yellow perch were obtained from Delmarva Aquatics in Maryland and were hatched from eggs collected from hatchery ponds. Harmon Brook Farm in Maine provided rainbow smelt larvae, white sucker eggs and larvae, alewife eggs, and bluegill larvae, all of which were acquired from wild stocks. Common carp eggs were obtained from Osage Catfisheries in Missouri and were the progeny of pond-reared fish. Common carp and some white sucker larvae were reared from eggs that were hatched at Alden.

For 2002 tests, all eggs and larvae were held in one of two re-circulating systems adjacent to the test flume. Each system had a biofilter, cartridge filter, carbon filter, and a UV sterilization filter. Temperatures were maintained within narrow ranges using chiller/heater units. Water changes (5 – 20%) were performed on a daily basis. The water quality conditions of the flume were similar to those of the holding facility (i.e., temperature, DO, salinity, pH, hardness, alkalinity). Water quality data for 2002 are presented in Appendix B.

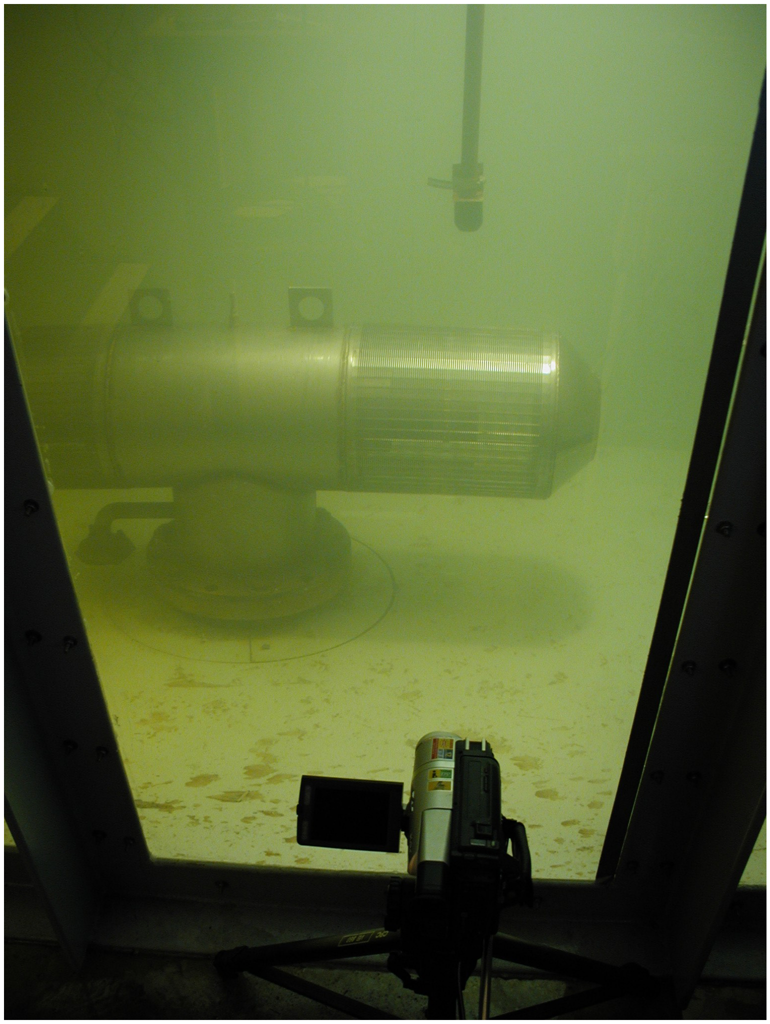

Figure 2-8
Video Systems for Recording Larvae and Egg Interaction with the Screens (Sony Digital Handicam recording through window and Subsea underwater camera positioned above screen)

Test Procedures

The number of organisms entrained and impinged was estimated by releasing known numbers of larvae and eggs for a given set of test conditions (i.e., slot width, slot velocity, channel velocity). At the end of each trial, the number of larvae and/or eggs that were entrained and impinged were enumerated. The number of organisms entrained was estimated by a count of larvae and eggs captured in the entrainment collection net. The number impinged was estimated by visually scanning the screens through a plexiglass window and with an underwater video camera that could be moved along the surface of the screens at very close proximity (Figure 2-8). The contrast between organisms and the screen surface was sufficient for effectively counting impinged eggs and larvae in this manner (Figure 2-9).

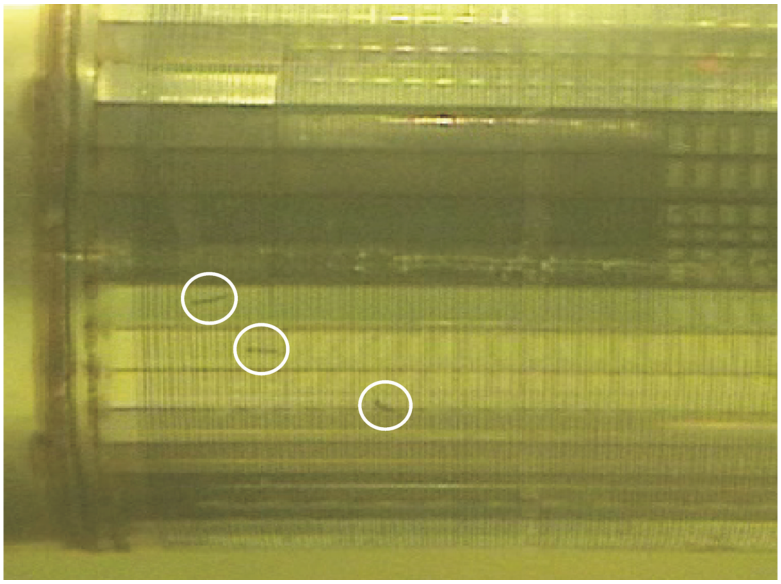

Figure 2-9
Video Image Capture of White Sucker Larvae Impinged on 1-mm Slot Screen

The following are the general test procedures that were used for each trial that was conducted during the wedgewire screen evaluation in 2001 and 2002:

1. Fish larvae/eggs for each trial to be conducted on a given test day were counted into labeled beakers and set in a water table in the morning prior to scheduled tests.

2. After all larvae/eggs test groups were counted, the flume test conditions (approach and through-screen velocity) were set for the first test.

3. Prior to each test, the collection nets (entrainment and downstream) were cleaned and secured in fishing positions.

4. Larvae/eggs were placed in the release box and exit gate was lifted releasing fish into the flume.

5. After 10 minutes, larvae/eggs that were visible on the screens were counted using a Subsea underwater camera and by visually inspecting the screen through the plexiglass window.

6. With flow passing through, the entrainment collection net was slowly raised and rinsed thoroughly along the water line; the collection jar was removed after all water was drained from net. A clean jar was attached to the collection net and a second rinse (and third, if necessary) was performed. The same procedure were used for removing organisms from the collection net located downstream of screen in 2002.

7. Entrained and bypassed larvae/eggs were counted (only entrained larvae and eggs were counted during 2001 tests with striped bass).

8. The cylindrical screen was manually cleaned to remove any impinged larvae and/or eggs before the next test was conducted.

Collection Efficiency

Entrainment net collection efficiency was estimated for most species and lifestages that were evaluated during both years of the study. Collection efficiency of the downstream collection net that was used during 2002 tests was also evaluated. Collection efficiency of the entrainment net was conducted by releasing known numbers of fish or eggs directly into the entrainment collection tank. After 10 minutes (i.e., the duration of an entrainment and impingement test), the net was raised and collected organisms were recovered and counted. Entrainment collection efficiency tests were conducted with both live and dead fish in 2001 and live fish only in 2002. When possible, entrainment collection efficiency tests for a given species/lifestage were conducted at the two through-slot velocities that were evaluated during entrainment and impingement testing. Attempts were made to conduct a minimum of 5 replicate trials per collection efficiency test condition, but limited numbers of fish and eggs resulted in fewer trials being conducted for some species and conditions. Estimates of entrainment collection efficiency were considered to be unaffected by damaged specimens and net extrusion because entrained organisms did not pass through the screen withdrawal pump prior to collection (i.e., fish were not injured or mutilated before entering the collection tank) and flow velocities through the collection net were not direct or excessive (water entered the collection tank perpendicular to the net axis resulting in non-uniform, upwelling flows).

In 2002, collection efficiency tests were also conducted for the downstream net by releasing a known number of fish at the centerline of the wedgewire screen approximately 0.15 m from the downstream end of the screen. Collection efficiency of the downstream net was evaluated at all three channel velocities that were tested during entrainment and impingement testing if enough larvae or eggs were available.

Experimental Design and Data Analysis

Three replicates were conducted with striped bass larvae and/or eggs for each set of test conditions (i.e., slot size, slot velocity, slot orientation, and channel velocity) that were evaluated in 2001. Up to five replicates were conducted with each test condition evaluated with species and lifestages tested in 2002. Individual tests were initiated by introducing fish into the flume upstream of the screens. A sample size of 50 to 100 larvae or eggs was used for each test. The number of organisms used per test depended on the number of fish or eggs available for testing, with a maximum target sample size of 100 in 2001 and 75 in 2002. For larval evaluations, attempts were made to evaluate the screen with the smallest slot size first and the largest slot size last to account for size effects related to the growth of fish during testing. That is, as fish grew they would be exposed to greater risks to entrainment due to larger slot sizes, but also would have greater ability to avoid entrainment and impingement due to stronger swimming capabilities. Constraints to this approach occurred if one species was obtained while another was being tested and was subsequently incorporated into the test program that was ongoing (i.e., more than one species was evaluated at the same time). Also, not all screen slot sizes and velocity conditions could be evaluated if there were limited numbers of larvae or eggs available.

A slot velocity of 0.3 m/s was not evaluated with the 2 mm slot screen in 2001 because the collection tank had insufficient depth to prevent the screen pump from withdrawing water below the intake entrance into the tank. The collection tank height was extended in 2002 allowing for this test condition to be evaluated. However, tests at this slot velocity with the 2 mm screen were only conducted with bluegill larvae and alewife eggs. Bluegill larvae were first evaluated with the 2 mm screen and highest slot velocity because there was only a small number of fish available for tests and it was believed that their large size (average length greater than 15 mm) and strong swimming ability would result in minimal, if any, entrainment or impingement at the smaller slot sizes and lower slot velocity. Alewife eggs were only available at the time bluegill larvae were being evaluated and their relatively short incubation period required they be tested within a short time frame. This resulted in alewife eggs initially being evaluated with the conditions that were selected for bluegill larvae (i.e., 2 mm slot width 0.3 m/s slot velocity). The 0.5 slot width was selected to verify that bluegill were not susceptible to entrainment and impingement with the smallest slot size, as well as to determine if alewife eggs could be protected with this screen.

The parameters that were estimated from the cylindrical wedgewire screen evaluation included the number and percent of fish and eggs impinged and entrained, and the total number and percent of organisms lost to impingement and entrainment combined. The number of fish and eggs entrained per unit flow was also estimated. The percent of fish lost to impingement and entrainment combined should not be interpreted as a percent mortality. In most field applications, entrainment and impingement survival rates are likely to be greater than zero. For example, impinged fish can be washed from screens alive during debris removal operations (e.g., air bursting or back washing) or when ambient water velocities increase (e.g., increasing tidal velocities after slack conditions). The percent lost, as used in this report, represents the number of organisms that were affected by the withdrawal of water through the screens in reference to the number that were exposed. The affected proportion of organisms (i.e., percent lost) indicates a risk to entrainment and impingement for larvae and eggs that pass in very close proximity to a screen’s surface, and does not represent a any type of mortality risk.

Impingement was estimated as the percent of fish released and entrainment was estimated by adjusting the number of fish recovered for collection efficiency. Entrainment estimates were standardized among test conditions (i.e., slot velocities and widths) by calculating the number of fish entrained per unit flow withdrawn (i.e., number of fish entrained divided by volume of water withdrawn during a test).

The general approach to analysis of the impingement, entrainment, and percent loss responses was to compare marginal means using a general linear model. This analysis was performed using a three-way factorial design of slot size, slot velocity, and channel velocity. For striped bass, a fourth factor of orientation was also introduced. Where appropriate, larval length was measured and introduced as a covariate to the response. The analytical model was a three (or four) factor analysis of covariance (ANCOVA) (Milliken and Johnson 1984). The model was implemented using the GLM procedure of the SAS software system (SAS Institute, Inc. 1989).

The three responses were all recorded as percent or proportion of a total number of larvae or eggs released. The inverse sine of the square root of the proportion (Govindarajulu 2001) was used as a variance stabilizing transformation. The GLM assumption of homogeneity of variance was tested using Levene's test (Milliken and Johnson 1984). If the assumption of homogeneity of variance was violated, the source of the unequal variance was identified and the data were re-analyzed using the MIXED procedure of the SAS software system which is capable of modeling unequal variances (SAS Institute, Inc. 1996).

Normality of the residuals from the ANCOVA model was examined using normal probability plots, box and whisker plots, and the Shapiro-Wilks test as implemented by the UNIVARIATE procedure of the SAS Software system (SAS Institute, Inc. 1990). Some non-normal distributions were identified and attributed to outliers, rather than skewness of the data or some other condition that could have been corrected by a transformation of the data. The outliers were noted and no action was taken.

Follow-up analysis to the ANCOVA was performed using the Student-Newman-Keuls test for marginal means or the LSD test for pair wise comparison of cell means (Milliken and Johnson 1984).

3
BIOLOGICAL EVALUATION RESULTS

The results from the laboratory evaluation of the cylindrical wedgewire screens are discussed in terms of percent impingement, percent entrainment, and percent lost (entrainment and impingement combined). Entrainment densities are also presented for each species. Because a known number of fish or eggs were released for each set of test conditions evaluated, percent entrainment and entrainment density demonstrate the same trends with respect to the various test conditions (i.e., both are estimates of entrainment based on a known number of organisms exposed to the screens). However, because entrainment density rates are based on a unit of flow withdrawn, they provide a standardized entrainment estimate for the three slot sizes that were evaluated at the two through-slot velocities. At a given slot velocity, the 1 mm slot screen withdraws about 1.5 times the flow of the 0.5 mm screen and the 2 mm screen withdraws about 1.5 times the flow of the 1 mm screen. For each slot size, twice as much water is withdrawn at the 0.3 m/s slot velocity than at the 0.15 m/s slot velocity.

Collection Efficiency Estimates

Collection efficiency of striped bass in the entrainment collection net was estimated for both through-slot velocities that were evaluated in 2001 (Table 3-1). Mean collection efficiency rates were similar for live fish and dead fish at a slot velocity of 0.5 m/s and about 14% lower for live fish at a slot velocity of 0.3 m/s (Table 3-1). The differences in the collection efficiency estimates with respect to slot velocity and live/dead condition were not statistically significant (Two-Factor ANOVA; $P > 0.05$). Subsequently, entrainment collection efficiency estimates for striped bass larvae were averaged over all test conditions for which they were evaluated and a single mean estimate was applied to adjust all larval entrainment rates. Collection of surrogate striped bass eggs was facilitated by low entrainment rates (0% for many test conditions) and their relatively large size and bright color. These conditions produced entrainment net recovery rates of 100% for the surrogate eggs.

Entrainment collection efficiencies for species and lifestages evaluated in 2002 generally were high (> 90%) and did not vary considerably between slot velocities (Table 3-2). Collection efficiency of alewife eggs and rainbow smelt larvae were relatively low, most likely due to their small size, opaque color, and fragility. The entrainment collection efficiency estimate for white sucker eggs at a slot velocity of 0.15 m/s was used to adjust entrainment estimates for tests with this species and lifestage at the 0.3 m/s slot velocity. Given their similar size and shape, common carp entrainment rates for tests at a slot velocity of 0.3 m/s were adjusted with yellow perch collection efficiency estimates at the same velocity. Collection efficiency of bluegill larvae was assumed to be 100% because of their large size.

Table 3-1
2001 Striped Bass Larvae Entrainment Net Collection Efficiency Estimates

Slot Velocity (m/s)	Live or Dead Larvae Release	Number of Trials	Mean Collection Efficiency (SE) (%)
0.5	Live	7	86.9 (3.7)
	Dead	7	88.9 (3.7)
1.0	Live	4	79.0 (4.9)
	Dead	7	92.9 (3.7)

Table 3-2
2002 Entrainment Net Collection Efficiency Estimates

Species	Lifestage	Slot Size (mm)	Slot Velocity (m/s)	Number of Trials	Mean Collection Efficiency (SD) (%)
alewife	Egg	0.5	0.15	5	59.6 (4.2)
common carp	Larvae	1.0	0.15	5	99.2 (0.8)
rainbow smelt	Larvae	0.5	0.15	1	80.0 (--)
winter flounder	Larvae	0.5	0.15	5	98.0 (3.5)
			0.30	5	93.4 (8.6)
		1.0	0.15	3	98.3 (3.8)
			0.30	2	100.0 (0.0)
white sucker	Egg	0.5	0.15	2	98.5 (1.5)
	Larvae	0.5	0.15	1	97.0 (--)
yellow perch	Larvae	0.5	0.15	5	87.8 (7.4)
			0.30	5	94.4 (4.0)

Striped Bass

Striped bass larvae and surrogate eggs were evaluated at all test conditions with the screens oriented parallel to the flow and for most conditions with the screens placed perpendicular to the flow. The mean length of striped bass larvae was 6.3 mm (range: 3.5 to 10.6 mm) and mean body width was 1 mm (range: 0.1 to 2.0 mm). Mean diameter of surrogate eggs was 4.5 mm (range 3.6 to 6.3 mm).

Entrainment of surrogate eggs did not occur with the screens oriented parallel to the flow, most likely due to their size in relation to the slot sizes that were evaluated, their ability to maintain their shape and not be forced through the screens, and the direction of flow along the screens. Consequently, the percent of eggs lost to impingement and entrainment was equivalent to the percent of eggs impinged for this screen orientation (Table 3-3 and 3-4). For screens oriented perpendicular to the flow, entrainment of eggs was low (< 3%) and only occurred at the largest slot size (2 mm). Eggs impinged near the center of the upstream face of the perpendicular screen (Figure 3-1) could not be swept downstream as easily because the channel flow moved in the same direction as the entraining flow (i.e., there was no sweeping flow moving parallel to the screen). This also resulted in a small number of impinged eggs being forced through the screen.

For tests with the screens oriented parallel to the flow, impingement of surrogate eggs generally increased with slot size and slot velocity, but decreased with increasing channel velocity (Table 3-3; Figure 3-2). Mean impingement rates approached 100% at the lowest channel velocity (0.08 m/s) for tests with the 1-mm and 2-mm screens and a slot velocity of 0.15 m/s and for all tests with the 0.3 m/s slot velocity. However, there were considerable decreases in impingement when channel velocities were increased to 0.15 and 0.3 m/s for most test conditions. Impingement of eggs did not occur at the highest channel velocity during tests with both slot velocities and with all three slot sizes (Table 3-3). Similar trends were observed in surrogate egg impingement rates with the screens oriented perpendicular to the flow (Table 3-4; Figure 3-3), but impingement generally was considerably lower for this orientation than it was for the parallel configuration. The primary areas of egg impingement on the parallel screens were around the entire circumference of the downstream ends of each screen section.

Table 3-3
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for surrogate striped bass eggs (mean diameter of 4.5 mm) evaluated with the screens oriented parallel to the flow. Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.15	0.08	13.0 (10.6)	0.00 (0.00)	0.0 (0.0)	13.0 (10.6)
		0.15	0.7 (1.2)	0.00 (0.00)	0.0 (0.0)	0.7 (1.2)
		0.30	0.00(0.0)	0.00 (0.00)	0.0 (0.0)	0.00(0.0)
	0.30	0.08	97.3 (2.3)	0.00 (0.00)	0.0 (0.0)	97.3 (2.3)
		0.15	21.3 (16.7)	0.00 (0.00)	0.0 (0.0)	21.3 (16.7)
		0.30	0.0 (0.0)	0.00 (0.00)	0.0 (0.0)	0.0 (0.0)
1.0	0.15	0.08	91.0 (14.7)	0.00 (0.00)	0.0 (0.0)	91.0 (14.7)
		0.15	0.3 (0.6)	0.00 (0.00)	0.0 (0.0)	0.3 (0.6)
		0.30	0.0 (0.0)	0.00 (0.00)	0.0 (0.0)	0.0 (0.0)
	0.30	0.08	98.7 (1.2)	0.00 (0.00)	0.0 (0.0)	98.7 (1.2)
		0.15	88.7 (3.5)	0.00 (0.00)	0.0 (0.0)	88.7 (3.5)
		0.30	0.0 (0.0)	0.00 (0.00)	0.0 (0.0)	0.0 (0.0)
2.0	0.15	0.08	93.7 (4.9)	0.00 (0.00)	0.0 (0.0)	93.7 (4.9)
		0.15	4.7 (3.2)	0.00 (0.00)	0.0 (0.0)	4.7 (3.2)
		0.30	0.00 (0.0)	0.00 (0.00)	0.0 (0.0)	0.0 (0.0)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

Table 3-4
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for surrogate striped bass eggs evaluated with the screens oriented perpendicular to the flow. Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.15	0.08	0.3 (0.6)	0.0 (0.0)	0.00 (0.00)	0.3 (0.6)
		0.15	0.0 (0.0)	0.0 (0.0)	0.00 (0.00)	0.0 (0.0)
		0.30	0.0 (0.0)	0.0 (0.0)	0.00 (0.00)	0.0 (0.0)
	0.30	0.08	46.7 (5.8)	0.0 (0.0)	0.00 (0.00)	46.7 (5.8)
		0.15	0.6 (0.6)	0.0 (0.0)	0.00 (0.00)	0.7 (0.6)
		0.30	0.0 (0.0)	0.0 (0.0)	0.00 (0.00)	0.0 (0.0)
1.0	0.30	0.08	44.3 (3.2)	0.0 (0.0)	0.00 (0.00)	44.3 (3.2)
		0.15	39.3 (15.3)	0.0 (0.0)	0.00 (0.00)	39.3 (15.3)
2.0	0.15	0.08	28.3 (24.2)	2.7 (2.5)	0.08 (0.08)	31.0 (21.8)
		0.15	16.3 (10.1)	2.6 (2.3)	0.08 (0.07)	19.0 (7.8)
		0.30	3.7 (3.5)	1.7 (1.5)	0.05 (0.05)	5.3 (2.1)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

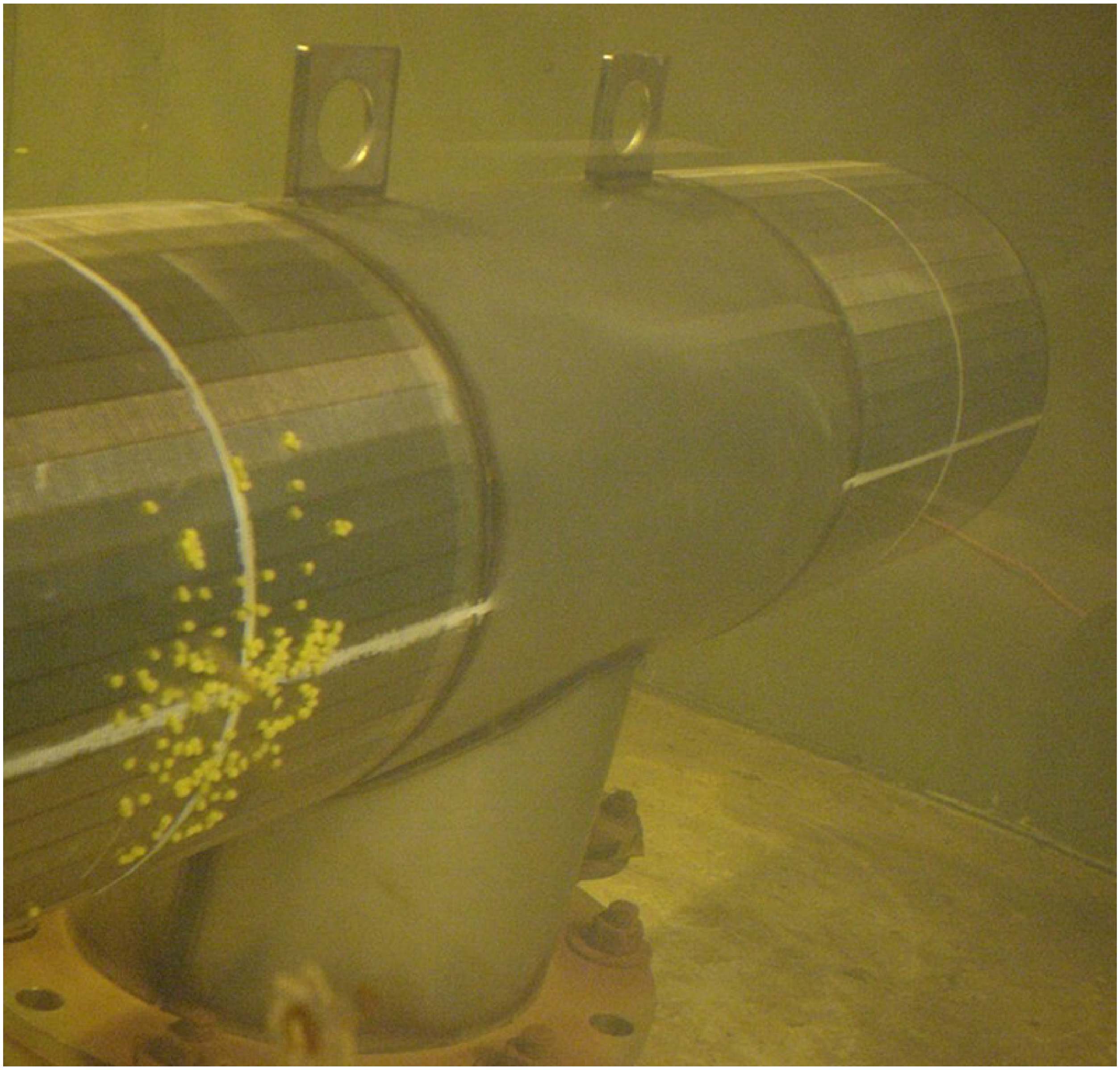

Figure 3-1
Impingement of Surrogate Striped Bass Eggs on the Upstream Face of Screen Oriented Perpendicular to Flow

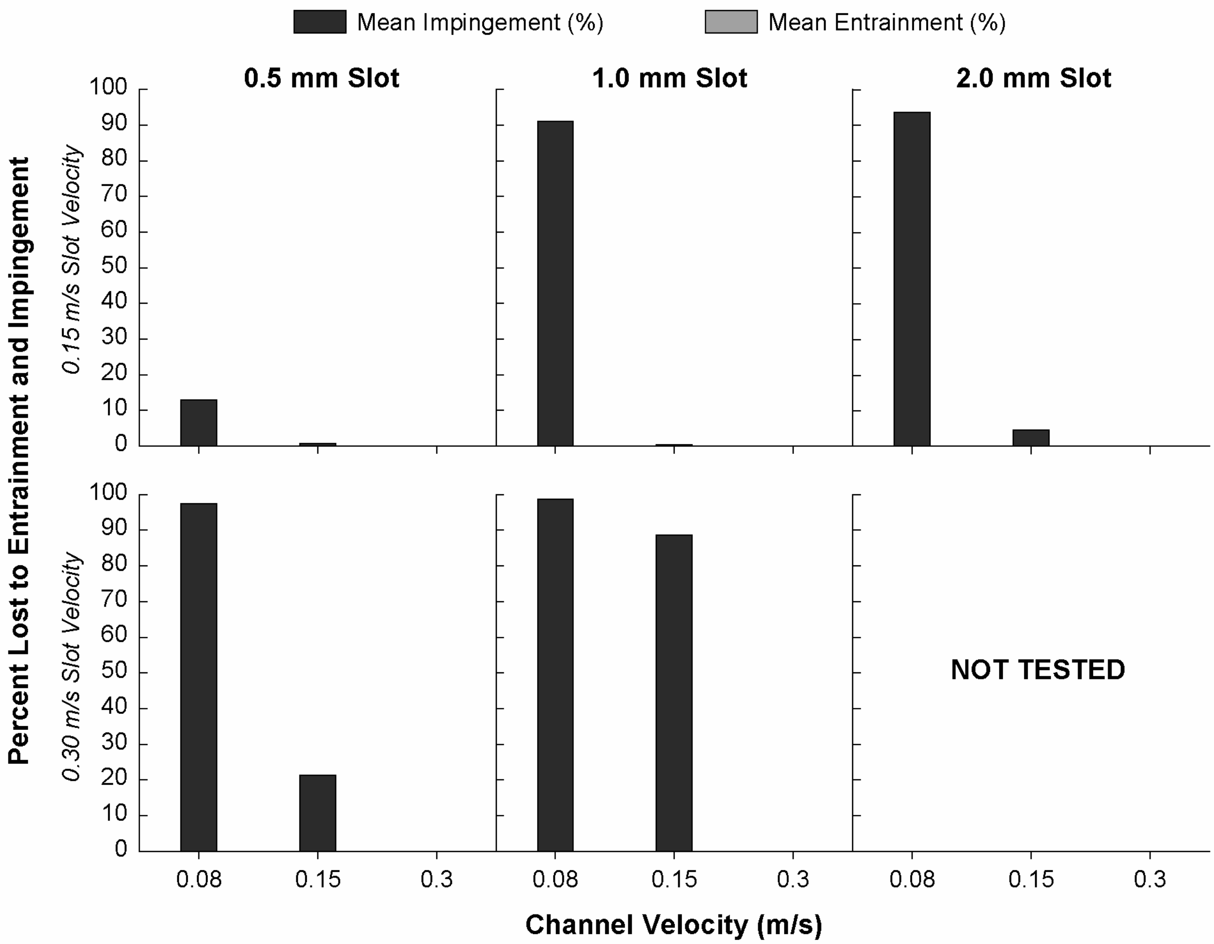

Figure 3-2
Mean Percent of Striped Bass Surrogate Eggs Lost to Impingement and Entrainment During Tests with the Screens Oriented Parallel to the Flow

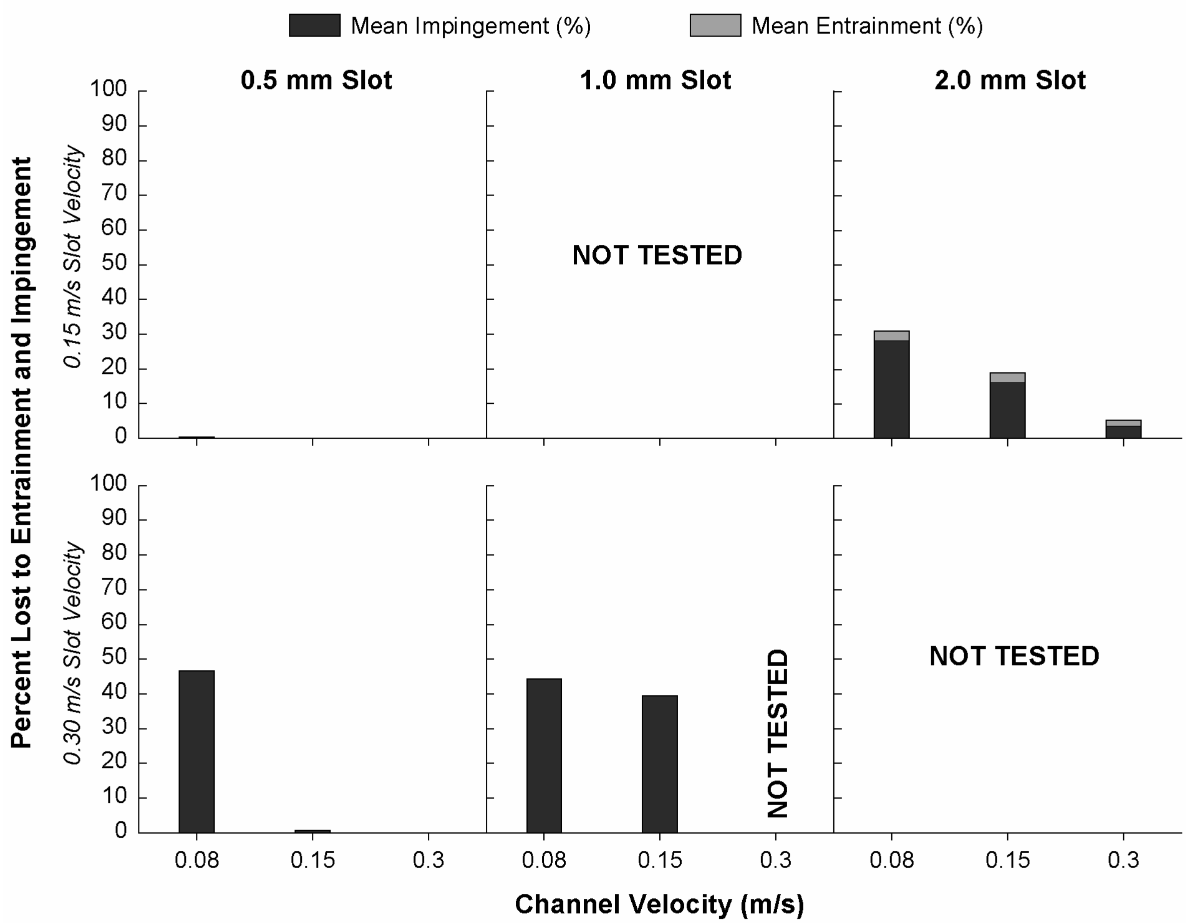

Figure 3-3
Mean Percent of Striped Bass Surrogate Eggs Lost to Impingement and Entrainment During Tests with the Screens Oriented Perpendicular to the Flow

Larval impingement was 0% for all tests with the screens oriented parallel to the flow (Table 3-5; Figure 3-4). With the screens oriented perpendicular to the flow, larval impingement was 0% for tests with the 1 and 2 mm slot sizes and less than 30% with the 0.5 mm slot size (Table 3-6). For the test conditions at which impingement occurred, the percent of impinged larvae increased significantly with slot velocity and decreased significantly with channel velocity ($P < 0.05$) (Table 3-6; Figure 3-5). The low rates of larval striped bass impingement, particularly at the larger slot sizes, can be attributed to greater susceptibility to entrainment and the ability of some fish to be swept downstream past the screens. Higher impingement rates for the perpendicular screen orientation at the larger slot sizes probably were due to the lack of sweeping flows as fish approached the center of the upstream face of the screen (i.e., most fish encounter the screen at a location where the approach flow vector is perpendicular to the screen face).

With the screens oriented parallel to the flow, mean percent entrainment of striped bass decreased with increasing channel velocity for tests at the 0.5 m/s slot velocity for all three slot sizes (Table 3-5; Figure 3-4). Conversely, larval entrainment generally increased with increasing channel velocity for tests at a slot velocity of 0.3 m/s. Entrainment rates increased significantly with slot size ($P < 0.05$) and were higher at the 0.3 m/s slot velocity. Similar trends in entrainment were observed during tests with the screens oriented perpendicular to the flow (Table 3-6; Figure 3-5).

The percent of striped bass larvae lost to impingement and entrainment combined demonstrated similar trends as entrainment rates for the parallel screens because impingement did not occur for this orientation (Table 3-5). The effects of slot velocity, slot size, and channel velocity on the percent of larvae lost during tests with the perpendicular screens were statistically significant ($P < 0.05$). For this orientation, the percent lost increased with slot velocity and slot size, and decreased with channel velocity (Table 3-6).

Table 3-5
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for striped bass larvae evaluated with screens oriented parallel to the flow. Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Fish Length (SD) (mm)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.15	0.08	4.7 (0.9)	0.0 (0.0)	3.4 (3.8)	0.25 (0.28)	3.4 (3.8)
		0.15	4.7 (0.7)	0.0 (0.0)	4.6 (7.6)	0.33 (0.55)	4.6 (7.6)
		0.30	4.3 (0.9)	0.0 (0.0)	2.7 (2.4)	0.19 (0.17)	2.7 (2.4)
	0.30	0.08	4.4 (0.9)	0.0 (0.0)	18.2 (6.3)	0.66 (0.23)	18.2 (6.3)
		0.15	4.5 (0.8)	0.0 (0.0)	27.3 (14.2)	0.99 (0.52)	27.3 (14.2)
		0.30	4.3 (0.7)	0.0 (0.0)	28.2 (20.5)	1.03 (0.74)	28.2 (20.5)
1.0	0.15	0.08	7.0 (0.1)	0.0 (0.0)	41.4 (10.3)	1.88 (0.47)	41.4 (10.3)
		0.15	7.0 (0.1)	0.0 (0.0)	27.00 (5.4)	1.22 (0.24)	27.00 (5.4)
		0.30	7.0 (0.1)	0.0 (0.0)	16.7 (3.5)	0.76 (0.16)	16.7 (3.5)
	0.30	0.08	8.8 (0.0)	0.0 (0.0)	21.3 (2.4)	0.48 (0.05)	21.3 (2.4)
		0.15	7.6 (0.1)	0.0 (0.0)	58.9 (27.1)	1.34 (0.62)	58.9 (27.1)
		0.30	7.5 (0.0)	0.0 (0.0)	39.1 (4.0)	0.89 (0.09)	39.1 (4.0)
2.0	0.15	0.08	8.3 (0.1)	0.0 (0.0)	61.1 (31.5)	1.94 (1.00)	61.1 (31.5)
		0.15	8.3 (0.0)	0.0 (0.0)	61.1 (7.6)	1.94 (0.24)	61.1 (7.6)
		0.30	8.3 (0.1)	0.0 (0.0)	45.9 (10.8)	1.46 (0.34)	45.9 (10.8)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

Table 3-6
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for striped bass larvae evaluated with screens oriented perpendicular to the flow. Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Fish Length (SD) (mm)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.15	0.08	7.1 (0.3)	8.3 (5.8)	0.0 (0.0)	0.00 (0.0)	8.3 (5.8)
		0.15	7.1 (0.3)	1.7 (1.5)	0.4 (0.7)	0.03 (0.1)	2.1 (0.9)
		0.30	7.0 (0.4)	1.7 (1.2)	0.4 (0.7)	0.03 (0.1)	2.1 (1.0)
	0.30	0.08	7.2 (0.1)	29.3 (14.0)	0.0 (0.0)	0.00 (0.0)	29.3 (14.0)
		0.15	7.2 (0.1)	22.0 (17.1)	0.0 (0.0)	0.00 (0.0)	22.0 (17.1)
		0.30	7.0 (0.4)	6.7 (4.0)	0.8 (0.7)	0.03 (0.0)	7.4 (3.4)
1.0	0.30	0.08	8.9 (0.0)	0.0 (0.0)	66.8 (4.6)	1.14 (0.1)	89.1 (6.1)
		0.15	8.9 (0.0)	0.0 (0.0)	68.3 (9.2)	1.16 (0.2)	91.1 (12.3)
2.0	0.15	0.08	8.0 (0.2)	0.0 (0.0)	97.0 (5.1)	3.07 (0.2)	97.0 (5.1)
		0.15	7.3 (0.4)	0.0 (0.0)	98.6 (2.5)	3.12 (0.1)	98.6 (2.5)
		0.30	7.3 (0.4)	0.0 (0.0)	95.3 (3.5)	3.02 (0.1)	95.3 (3.5)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

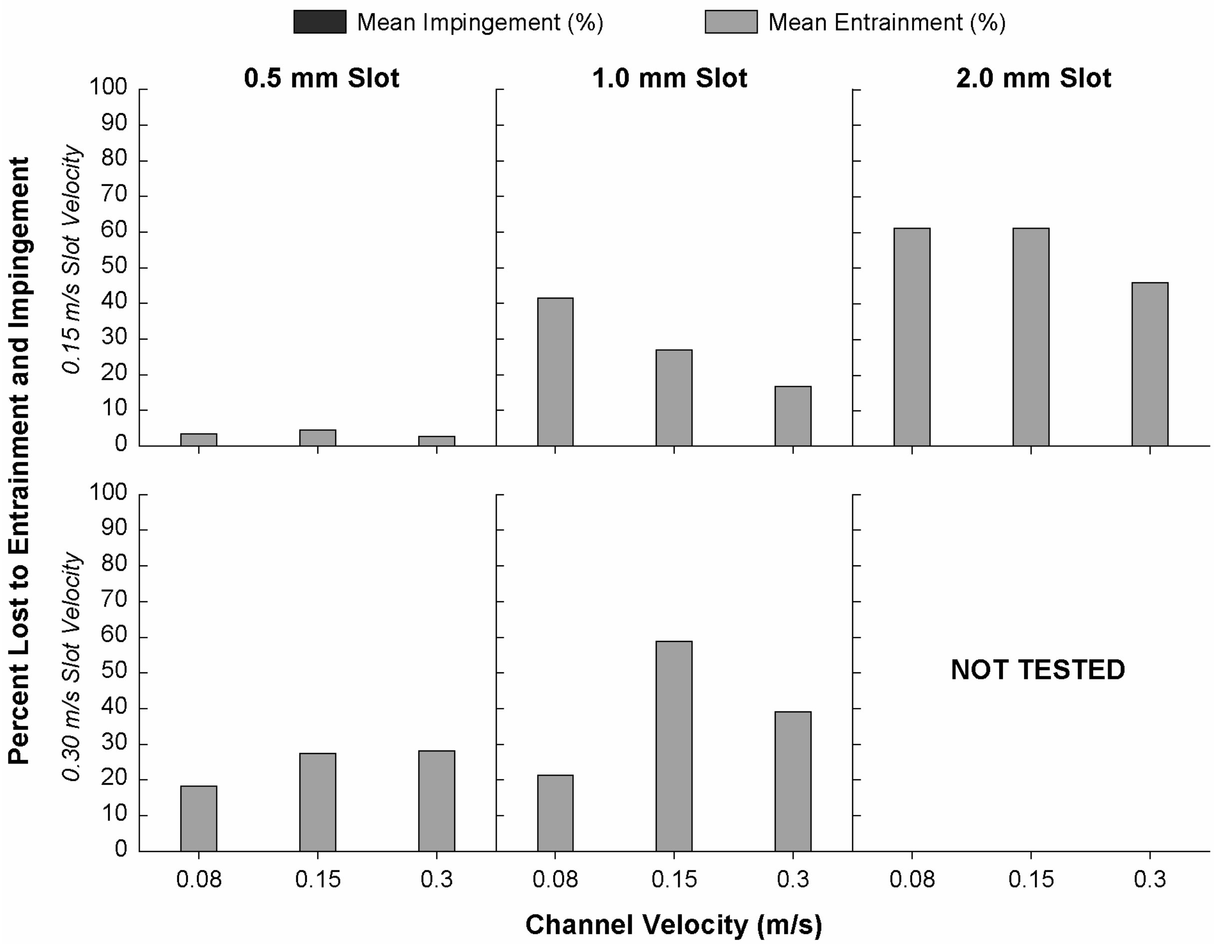

Figure 3-4
Mean Percent of Striped Bass Larvae Lost to Impingement and Entrainment During Tests with the Screens Oriented Parallel to the Flow

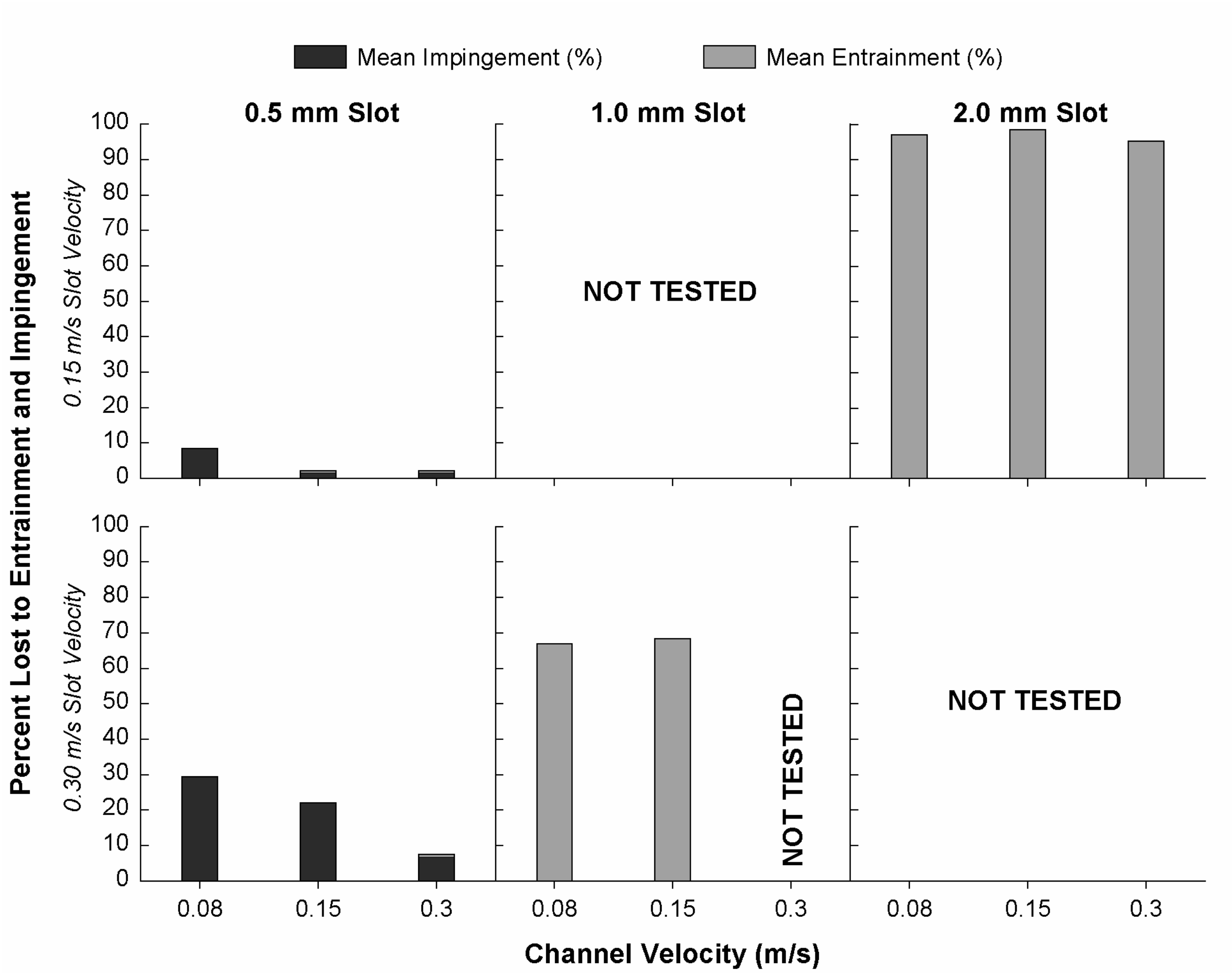

Figure 3-5
Mean Percent of Striped Bass Larvae Lost to Impingement and Entrainment During Tests with the Screens Oriented Perpendicular to the Flow

Winter Flounder

Winter flounder larvae were evaluated for impingement and entrainment with all slot sizes and velocity conditions. The average length of winter flounder was 6.1 mm (range: 2.4 to 11.0 mm). Body widths averaged 1.7 mm (range: 0.5 to 4.9 mm). Based on the mean lengths (Table 3-7), the winter flounder were classified as being in either stage 3 or 4 of larval development. Stage 3 and 4 larvae have been the most abundant stages collected in entrainment samples at cooling water intakes located in areas where winter flounder occur.

Mean percent impingement of winter flounder larvae was low (less than 20%) for all velocity conditions and slot sizes that were evaluated (Table 3-7; Figure 3-6). Slot velocity was a statistically significant factor ($P < 0.05$) that affected impingement rates, with greater impingement occurring at the higher slot velocity. The effect of slot size also was statistically significant. Impingement rates were greatest during tests with the 1.0 mm slot screen at slot velocity of 0.3 m/s (Table 3-7). The lowest impingement rates were observed during tests with 2 mm slot screen. There were no distinctive trends in impingement rates with respect to channel velocity and effects associated with interactions among the test parameters or fish size were not detected ($P > 0.05$).

Table 3-7
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for winter flounder larvae. Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Fish Length (SD) (mm)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.15	0.08	5.4 (0.9)	1.6 (2.2)	0.8 (1.2)	0.06 (0.09)	2.4 (2.4)
		0.15	5.0 (0.9)	8.8 (18.9)	0.5 (0.7)	0.03 (0.05)	9.3 (18.7)
		0.30	5.1 (0.7)	0.0 (0.0)	2.5 (2.5)	0.18 (0.19)	2.5 (2.5)
	0.30	0.08	5.5 (0.8)	6.7 (5.6)	10.00 (11.00)	0.36 (0.40)	12.4 (7.0)
		0.15	5.2 (0.7)	12.8 (7.9)	11.1 (6.5)	0.41 (0.24)	23.9 (11.3)
		0.30	5.4 (0.7)	8.7 (2.3)	6.0 (3.7)	0.22 (0.12)	14.0 (3.1)
1.0	0.15	0.08	6.1 (0.6)	1.1 (1.7)	84.6 (5.9)	3.84 (0.27)	85.7 (5.7)
		0.15	6.2 (0.7)	2.4 (1.1)	72.4 (13.1)	3.29 (0.59)	74.8 (12.7)
		0.30	6.1 (0.6)	1.3 (1.3)	61.3 (3.8)	2.78 (0.17)	62.6 (3.5)
	0.30	0.08	7.8 (1.1)	19.8 (6.5)	64.5 (11.0)	1.46 (0.25)	84.3 (12.9)
		0.15	7.9 (1.1)	7.2 (5.3)	78.4 (20.8)	1.78 (0.47)	85.6 (16.2)
		0.30	7.4 (1.1)	9.6 (3.9)	74.1 (15.5)	1.68 (0.35)	83.7 (13.8)
2.0	0.15	0.08	6.0 (0.5)	0.0 (0.0)	82.7 (16.2)	2.62 (0.51)	82.7 (16.2)
		0.15	6.1 (0.6)	0.0 (0.0)	84.1 (8.5)	2.67 (0.27)	84.1 (8.5)
		0.30	6.1 (0.5)	0.3 (0.6)	73.3 (5.6)	2.32 (0.18)	73.5 (6.0)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

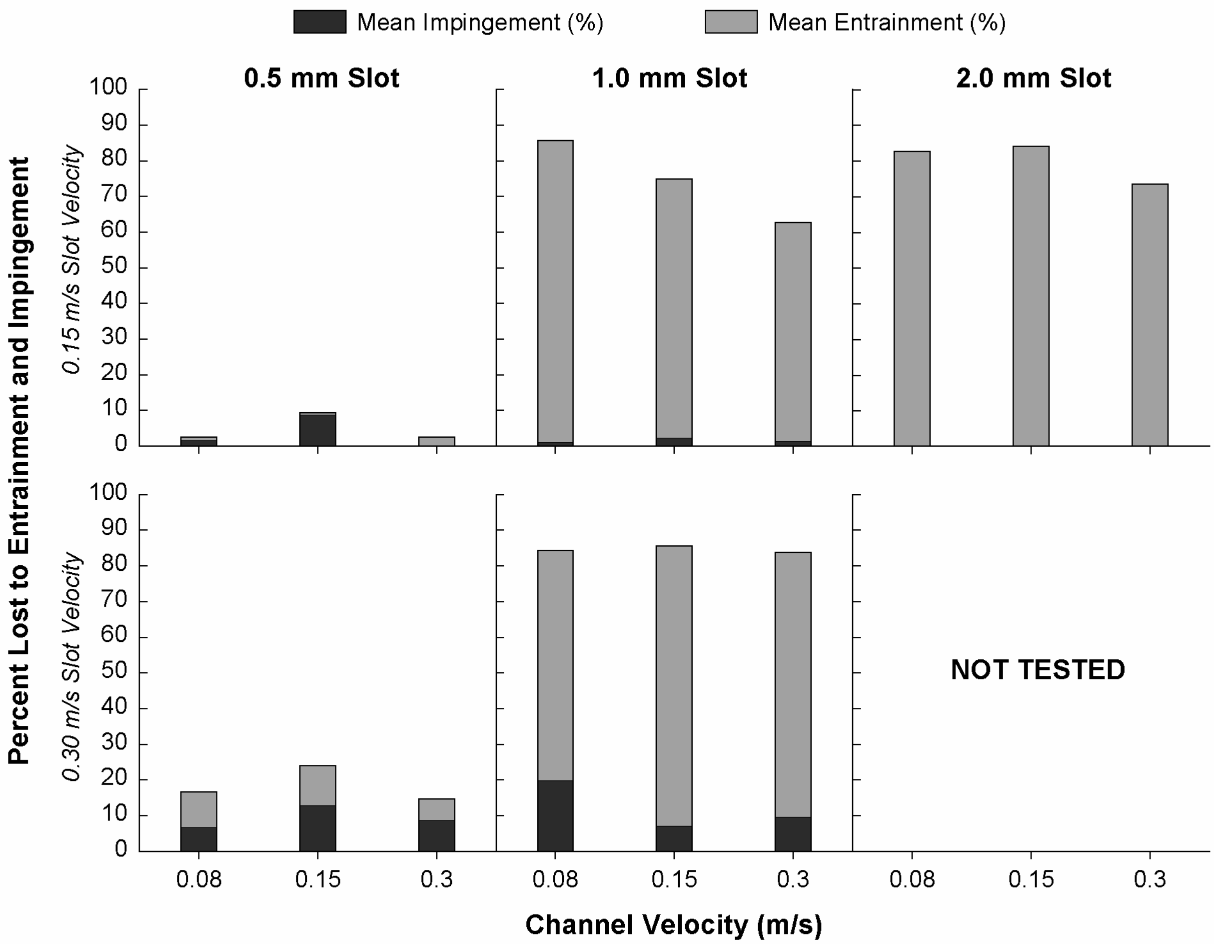

Figure 3-6
Mean Percent of Winter Flounder Larvae Lost to Impingement and Entrainment

Mean percent entrainment of winter flounder larvae was low (about 11% or less) for tests with the 0.5 mm slot screen (Table 3-7; Figure 3-6). Similar to impingement, slot velocity and slot size effects were statistically significant ($P < 0.05$). Entrainment was considerably greater for tests with the 1 and 2 mm slot screens than for tests with the 0.5 mm screen. Entrainment rates typically were less at the lower slot velocity (0.5 m/s) than at the higher velocity (0.3 m/s). The statistical analysis results, although not significant, indicated that increases in slot velocity with the smallest slot size had a greater effect on entrainment rates than increasing slot velocity with the next larger slot size. A decrease in entrainment with increasing channel velocity was evident for tests with the 1 mm slot screen at slot velocity of 0.15 m/s, but not at a slot velocity of 0.3 m/s. The lowest entrainment rate for the 2 mm screen occurred at the highest channel velocity (0.3 m/s), but entrainment increased slightly from tests with a channel velocity of 0.08 m/s to a velocity of 0.15 m/s.

Due to greater entrainment rates, the percent of larvae lost to entrainment and impingement combined was considerably higher for tests with the two larger slot sizes than for tests with the 0.5 mm slot screen (Table 3-7; Figure 3-6). The percent of winter flounder lost was significantly less ($P < 0.05$) for tests with the 0.5 mm slot screen and for tests with the lower slot velocity (0.15 m/s).

White Sucker

White sucker eggs were evaluated with the 0.5-mm slot screen at the two selected slot velocities and all three channel velocities. Tests with white sucker larvae were conducted with the 0.5-mm and 1.0-mm slot screens. Larvae tests with the 0.5-mm screen were only conducted at the lower slot velocity (0.15 m/s), whereas tests with the 1.0 mm screen were conducted at both of the selected slot velocities. White sucker eggs averaged 3.2 mm in diameter (range: 2.8 to 3.5 mm) and larval lengths averaged 13.9 mm (range: 12.5 to 15.5).

The effects of slot and channel velocities on white sucker egg impingement were statistically significant ($P < 0.05$). In general, white sucker egg impingement rates increased with slot velocity and decreased with channel velocity, with the differences in impingement between the two slot velocities being less at the higher channel velocities. At the 0.15 m/s slot velocity, mean percent impingement of white sucker eggs was low (about 1.1% or less) for the three channel velocities that were evaluated (Table 3-8; Figure 3-7). Impingement of eggs was about 60% at a channel velocity of 0.08 m/s, but declined sharply to levels less than 5% for tests at channel velocities of 0.15 and 0.3 m/s (Figure 3-7). Because there was no or minimal entrainment at both slot velocities, the percent of white sucker eggs lost was generally equivalent to percent impingement. The low entrainment rates at both slot velocities can be attributed to the size of white sucker eggs, which had diameters greater than the 0.5 mm slot size that was evaluated. Similar to striped bass eggs, most white sucker egg impingements occurred at the downstream end of each screen section.

Table 3-8
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for white sucker eggs (Mean egg diameter = 3.2 mm). Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.15	0.08	0.5 (0.7)	0.0 (0.0)	0.00 (0.00)	0.5 (0.7)
		0.15	1.1 (1.1)	0.0 (0.0)	0.00 (0.00)	1.1 (1.1)
		0.30	0.0 (0.0)	0.0 (0.0)	0.00 (0.00)	0.0 (0.0)
	0.30	0.08	59.8 (25.0)	0.3 (0.6)	0.01 (0.02)	60.0 (24.8)
		0.15	4.8 (2.8)	0.0 (0.0)	0.00 (0.00)	4.8 (2.8)
		0.30	0.5 (1.2)	0.0 (0.0)	0.00 (0.00)	0.5 (1.2)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

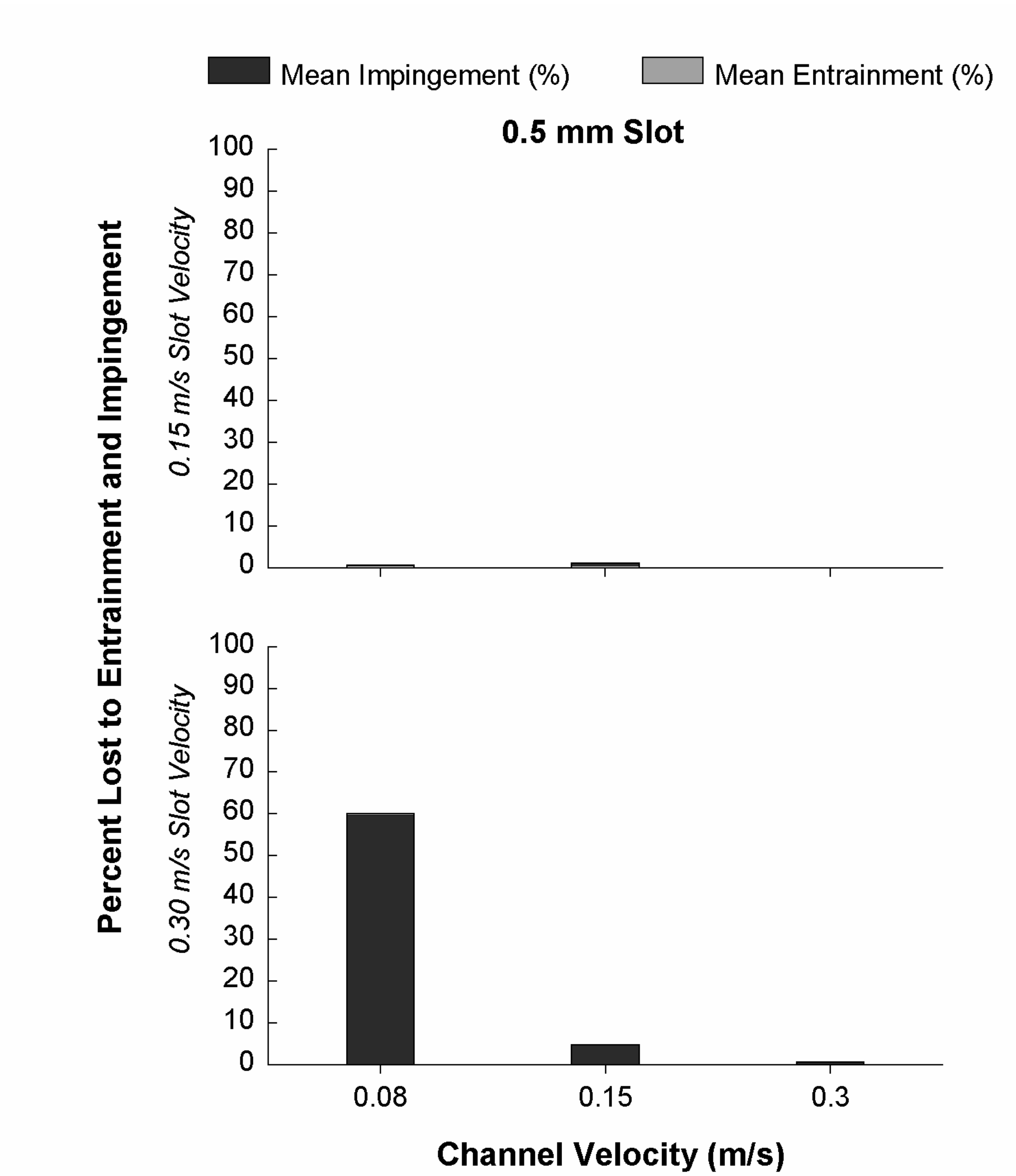

Figure 3-7
Mean Percent of White Sucker eggs Lost to Impingement and Entrainment

Mean percent impingement of white sucker larvae also was low (about 10% or less) for all tests with the two slot sizes that were evaluated (0.5 and 1.0 mm) (Table 3-9; Figure 3-8). Despite these low levels, impingement rates were significantly lower ($P < 0.05$) at the highest channel velocity (0.3 m/s) than at the two lower velocities (0.08 and 0.15 m/s).

Mean percent entrainment of larvae was negligible (0% at 0.08 and 0.15 m/s channel velocities and 0.3% at 0.3 m/s) for tests with the 0.5 mm slot screen (Table 3-9; Figure 3-8) and were significantly lower than entrainment rates observed with the 1 mm slot screen. Larval entrainment rates for tests with the 1 mm screen were significantly less ($P < 0.05$) at the lower slot velocity (0.15 m/s). Entrainment rates also decreased with channel velocity at the lower slot velocity, whereas this trend was not as evident at the higher slot velocity (Table 3-9; Figure 3-8).

Table 3-9
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for white sucker larvae. Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Fish Length (SD) (mm)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.15	0.08	13.7 (0.9)	7.2 (5.5)	0.0 (0.0)	0.00 (0.00)	7.2 (5.5)
		0.15	13.7 (0.9)	5.9 (5.7)	0.0 (0.0)	0.00 (0.00)	5.9 (5.7)
		0.30	13.7 (0.9)	0.3 (0.6)	0.3 (0.6)	0.02 (0.04)	0.5 (0.7)
1.0	0.15	0.08	13.9 (0.6)	10.8 (4.2)	12.4 (12.4)	0.56 (0.56)	23.2 (14.1)
		0.15	13.9 (0.6)	2.7 (3.1)	8.3 (5.5)	0.37 (0.25)	10.9 (8.5)
		0.30	13.9 (0.6)	4.0 (1.4)	5.8 (2.3)	0.26 (0.10)	9.8 (3.4)
	0.30	0.08	13.9 (0.7)	2.9 (3.3)	36.4 (19.0)	0.83 (0.43)	39.4 (22.1)
		0.15	14.0 (0.6)	8.8 (5.4)	47.9 (10.9)	1.09 (0.25)	56.7 (15.5)
		0.30	14.0 (0.6)	2.80(5.2)	23.6 (10.4)	0.53 (0.24)	26.4 (10.4)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

For the 0.5 mm slot screen, the percent of white sucker larvae that were lost to entrainment and impingement combined was basically equivalent to impingement rates because entrainment did not occur or was less than 1% at the three channel velocities evaluated. Because impingement and entrainment rates demonstrated similar relationships among the test variables for the evaluation of the 1 mm screen, the mean percent of larvae lost for this slot size also had similar trends and statistical results with respect to slot and channel velocities (Table 3-9; Figure 3-8).

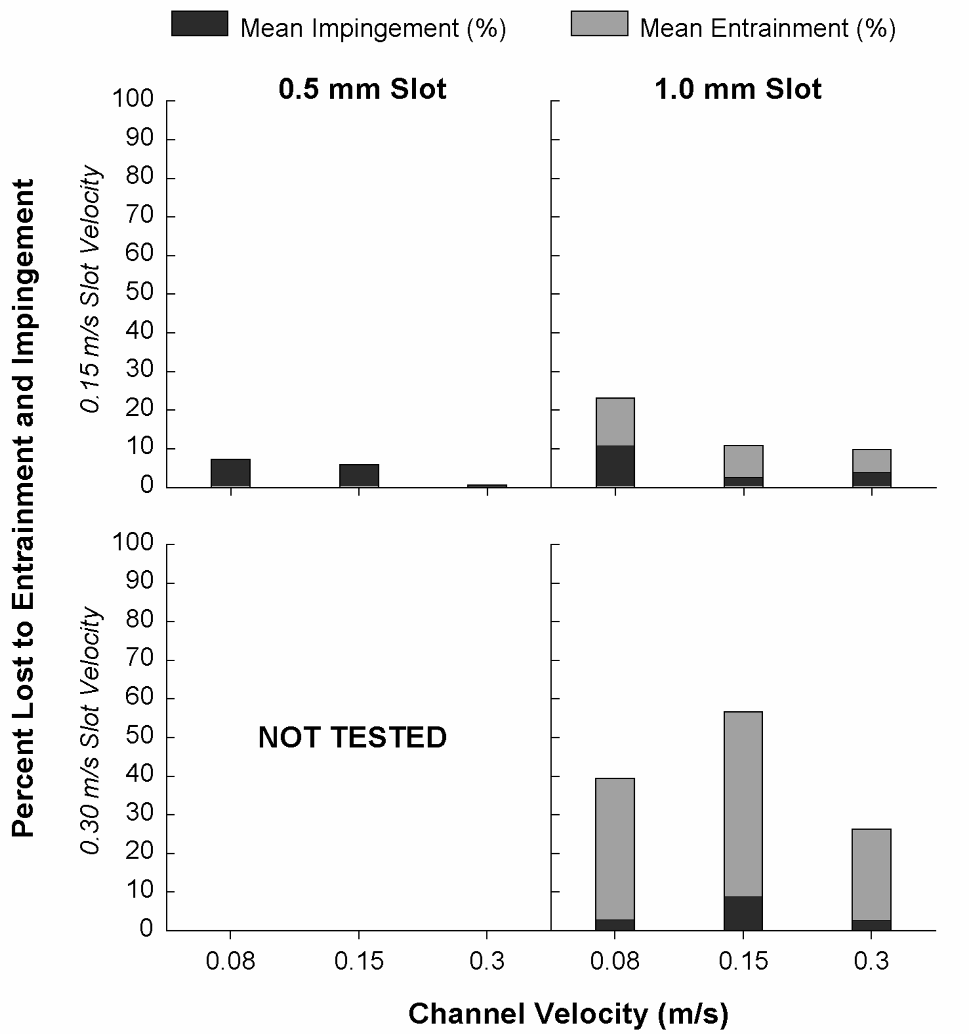

Figure 3-8
Mean Percent of White Sucker Larvae Lost to Impingement and Entrainment

Rainbow Smelt

Rainbow smelt larvae were evaluated only with the 0.5 mm slot screen at the lower slot velocity and all three channel velocities. Rainbow smelt larvae had a mean length of 6.3 mm (range: 4.9 to 8.0 mm) and a mean body width of 0.9 mm (range: 0.5 to 1.8 mm).

Impingement of rainbow smelt did not occur at channel velocities of 0.08 and 0.3 m/s and the mean percent impingement at 0.15 m/s was 0.3% (Table 3-10). Mean percent entrainment was high at the two lower channel velocities, but was significantly less ($P < 0.05$) at the highest channel velocity (Table 3-10). Percent of rainbow smelt lost to impingement and entrainment was roughly equivalent to percent entrainment because impingement rates were less than 0.5%. The percent of fish lost at the highest slot velocity was significantly less than at the two lower slot velocities ($P < 0.05$).

Table 3-10
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for rainbow smelt larvae. Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Fish Length (SD) (mm)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.15	0.08	6.3 (0.8)	0.0 (0.0)	75.0 (23.5)	5.46 (1.71)	75.0 (23.5)
		0.15	6.3 (0.8)	0.3 (0.6)	67.3 (28.4)	4.90 (2.06)	67.6 (28.9)
		0.30	6.0 (0.8)	0.0 (0.0)	25.3 (15.2)	1.85 (1.10)	25.3 (15.2)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

Yellow Perch

Yellow perch larvae were evaluated only with the 0.5 mm slot screen at both slot velocities and all three channel velocities. Mean length of yellow perch was 6.5 mm (range: 4.9 to 7.8) and mean body width was 0.8 mm (range: 0.4 to 1.1 mm).

Mean percent impingement of yellow perch larvae was slightly lower at a slot velocity of 0.15 m/s than at 0.3 m/s for each of the channel velocities evaluated (Table 3-11; Figure 3-9), but this effect was not statistically significant ($P > 0.05$). There was no detectable relationship between impingement and channel velocity at either slot velocity ($P > 0.05$), but impingement did decrease with channel velocity at a slot velocity of 0.15 m/s. Fish length also did not demonstrate an effect on impingement rates ($P > 0.05$).

Mean percent entrainment of yellow perch larvae was less than 1% for tests at a slot velocity of 0.15 m/s. Entrainment increased significantly ($P < 0.05$) at the higher slot velocity for each of the channel velocities and decreased significantly ($P < 0.05$) as channel velocity increased (Figure 3-11). The percent of larvae lost was dominated by impingement at a slot velocity of 0.15 m/s and by entrainment at 0.3 m/s (Figure 3-9). Also, mean percent lost was significantly greater at the higher slot velocity ($P < 0.05$). At both slot velocities, percent of fish lost declined with increases in channel velocity, but this relationship was not statistically significant ($P > 0.05$). As with impingement, fish length did not demonstrate an effect on entrainment rates ($P > 0.05$).

Table 3-11
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for yellow perch larvae. Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Fish Length (SD) (mm)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.15	0.08	6.5 (0.5)	8.0 (5.3)	0.0 (0.0)	0.00 (0.00)	8.0 (5.3)
		0.15	6.3 (0.7)	6.7 (2.8)	0.9 (1.4)	0.07 (0.10)	7.6 (2.9)
		0.30	6.6 (0.5)	5.9 (2.5)	0.0 (0.0)	0.00 (0.00)	5.9 (2.5)
	0.30	0.08	7.3 (0.3)	9.7 (3.8)	28.6 (15.8)	1.04 (0.57)	38.2 (13.2)
		0.15	7.0 (0.5)	9.6 (5.5)	26.3 (8.3)	0.96 (0.30)	35.9 (13.3)
		0.30	7.0 (0.5)	11.2 (4.9)	11.9 (6.0)	0.43 (0.22)	23.1 (7.5)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

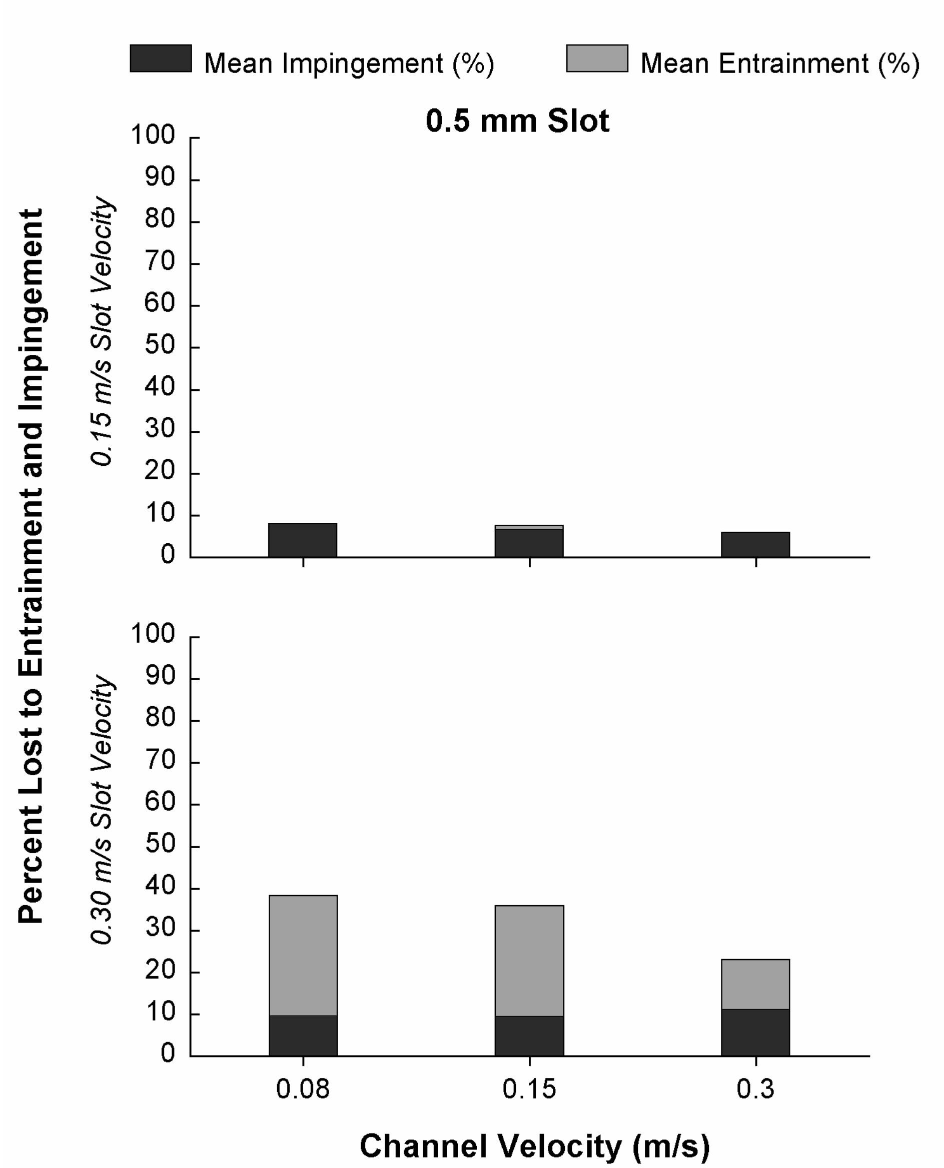

Figure 3-9
Mean Percent of Yellow Perch Larvae Lost to Impingement and Entrainment

Common Carp

Common carp larvae were evaluated with the 1 mm slot screen at both slot velocities and all three channel velocities. Common carp averaged 6.4 mm in length (range: 5.6 to 7.5 mm) and mean body width was 2.0 (range: 0.4 to 1.8 mm).

Mean percent impingement of common carp larvae was less than 10% for tests at the two slot velocities and did not vary considerably among the three channel velocities evaluated (Table 3-12; Figure 3-10). There were no statistically significant effects on impingement exhibited by slot velocity, channel velocity, or fish length.

Table 3-12
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for common carp larvae. Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Fish Length (SD) (mm)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
1.0	0.15	0.08	6.4 (0.4)	5.2 (3.0)	94.0 (7.8)	4.26 (0.35)	99.2 (9.8)
		0.15	6.5 (0.4)	6.0 (3.7)	81.9 (6.9)	3.71 (0.31)	87.9 (6.9)
		0.30	6.4 (0.4)	4.8 (3.0)	64.5 (5.5)	2.93 (0.25)	69.3 (5.8)
	0.30	0.08	6.4 (0.4)	9.1 (5.6)	89.6 (8.1)	2.03 (0.18)	98.6 (3.8)
		0.15	6.5 (0.3)	7.6 (2.6)	94.5 (4.9)	2.14 (0.11)	102.1 (6.2)
		0.30	6.5 (0.3)	6.4 (2.2)	89.8 (8.8)	2.04 (0.20)	96.2 (7.5)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

Mean percent entrainment of common carp larvae was high (about 65% or greater) for all test conditions (Table 3-12; Figure 3-10). At a slot velocity of 0.15 m/s, mean percent entrainment of carp decreased by about 30% from the lowest to highest channel velocity ($P < 0.05$; Table 3-12). The effect of slot velocity on entrainment rates was statistically significant ($P < 0.05$), with greater entrainment occurring at the higher slot velocity (0.3 m/s) during tests at channel velocities of 0.15 and 0.3 m/s. Because impingement was low and varied little among velocity conditions, the percent of larvae lost was composed primarily of entrained fish (Figure 3-10). Similar to entrainment, the effects of slot and channel velocities on entrainment were statistically significant ($P < 0.05$).

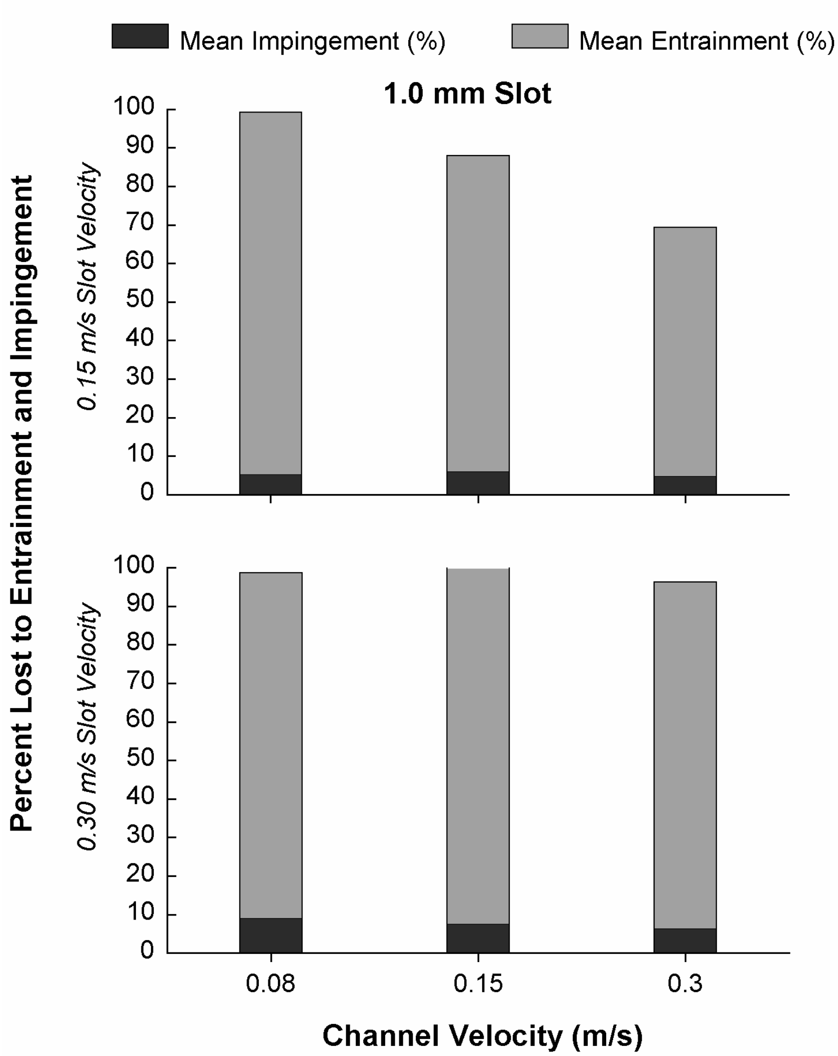

Figure 3-10
Mean Percent of Common Carp Larvae Lost to Impingement and Entrainment

Alewife

Alewife eggs were evaluated at one slot velocity (0.3 m/s) and two channel velocities (0.08 and 0.15 m/s) for tests with the 0.5 mm slot screen and at one slot velocity (0.3 m/s) and all three channel velocities during tests with the 2 mm slot screen; tests with the 1 mm screen were not conducted with alewife. The mean diameter of alewife eggs was 0.7 mm (range: 0.5 to 0.9 mm).

Impingement of alewife eggs did not occur during tests with the two screens that were evaluated with this species and lifestage. Mean percent entrainment of alewife eggs decreased with increasing channel velocity and was lower for tests with the 0.5 mm slot screen than with the 2 mm screen (Table 3-13; Figure 3-11). The effect of slot size on entrainment was statistically significant ($P < 0.05$), whereas the effect of channel velocity was not, despite the evident decline in entrainment with increasing channel velocity. Because impingement of alewife eggs did not occur, the percent of eggs lost was equivalent to percent entrainment.

Table 3-13
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for alewife eggs. Mean egg diameter = 0.7 (0.1). Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.30	0.08	0.0 (0.0)	19.7 (8.6)	0.72 (0.31)	19.7 (8.6)
		0.15	0.0 (0.0)	10.1 (15.2)	0.37 (0.55)	10.1 (15.2)
2.0	0.30	0.08	0.0 (0.0)	52.8 (31.6)	0.84 (0.50)	52.8 (31.6)
		0.15	0.0 (0.0)	29.5 (40.1)	0.47 (0.63)	29.5 (40.1)
		0.30	0.0 (0.0)	26.4 (11.3)	0.42 (0.18)	26.4 (11.3)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

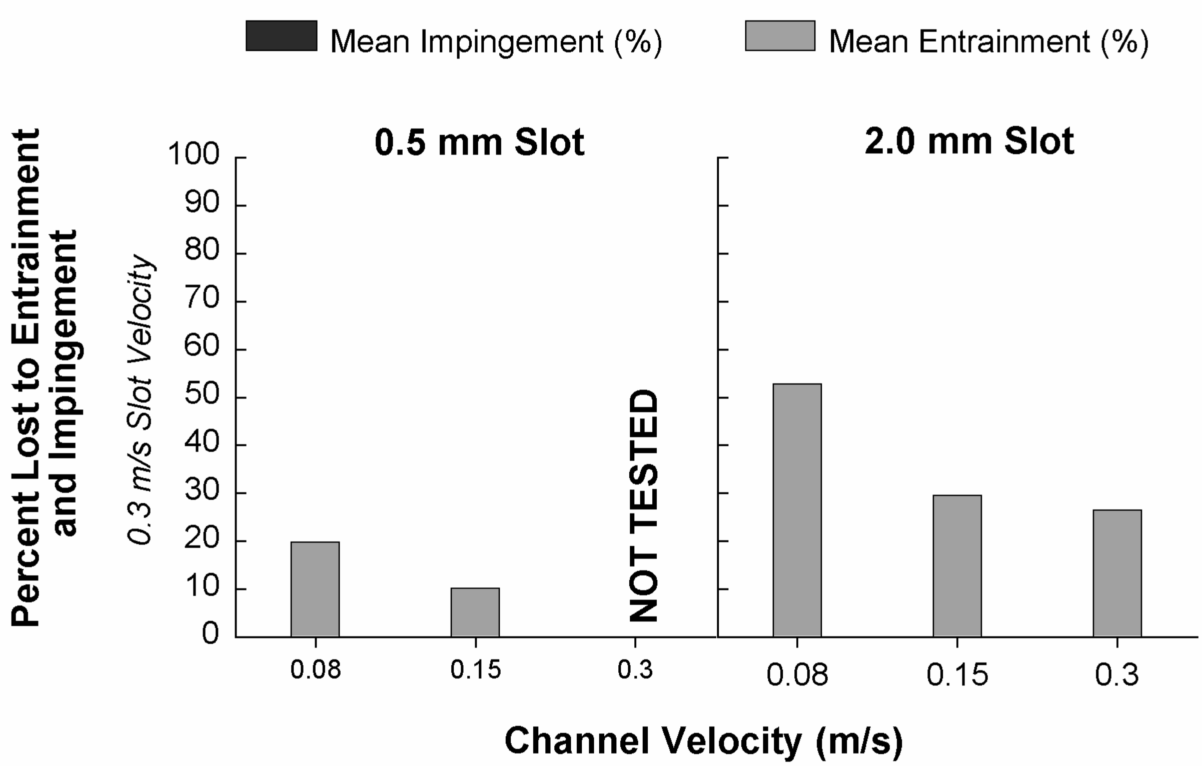

Figure 3-11
Mean Percent of Alewife Eggs Lost to Impingement and Entrainment

Bluegill

Bluegill larvae were tested at the same time as alewife eggs and, consequently, were evaluated with the same test conditions. The number of conditions evaluated with bluegill were limited by the small number of fish that were available for testing. Mean length of bluegill larvae was 18.5 mm (range: 12.1 to 25.0 mm) and mean body width was 5.4 mm (range: 3.5 to 7.2 mm).

Mean percent impingement of bluegill larvae was low (about 5.5% or less) for all tests with the two screens that were evaluated with this species (Table 3-14). Mean percent entrainment was also low (< 5%) for all test conditions evaluated with this species (Table 3-14; Figure 3-12). Although the differences were small, entrainment of bluegill larvae decreased as channel velocity increased (Table 3-14; Figure 3-12).

Table 3-14
Mean rates of impingement, entrainment (percent and per unit flow), and total lost (entrainment and impingement combined) for bluegill larvae. Entrainment rates are adjusted for collection efficiency.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Fish Length (SD) (mm)	Mean Percent Impingement (SD)	Mean Percent Entrainment (SD)	Mean Number Entrained per m^3	Mean Percent Lost (SD)
0.5	0.30	0.08	19.5 (1.8)	4.0 (2.5)	0.8 (0.8)	0.03 (0.07)	4.8 (2.3)
		0.15	19.5 (1.6)	0.0 (0.0)	0.0 (0.0)	0.00 (0.00)	0.0 (0.0)
2.0	0.30	0.08	18.5 (2.5)	3.2 (4.2)	4.4 (3.0)	0.07 (0.05)	7.7 (5.3)
		0.15	19.2 (2.3)	5.6 (2.2)	3.2 (1.8)	0.05 (0.03)	8.8 (3.0)
		0.30	18.3 (2.1)	1.6 (1.7)	0.4 (0.9)	0.01 (0.01)	2.0 (2.4)

NOTE: Percent lost represents the proportion of exposed organisms that experienced either impingement or entrainment; it should not be interpreted as a mortality estimate.

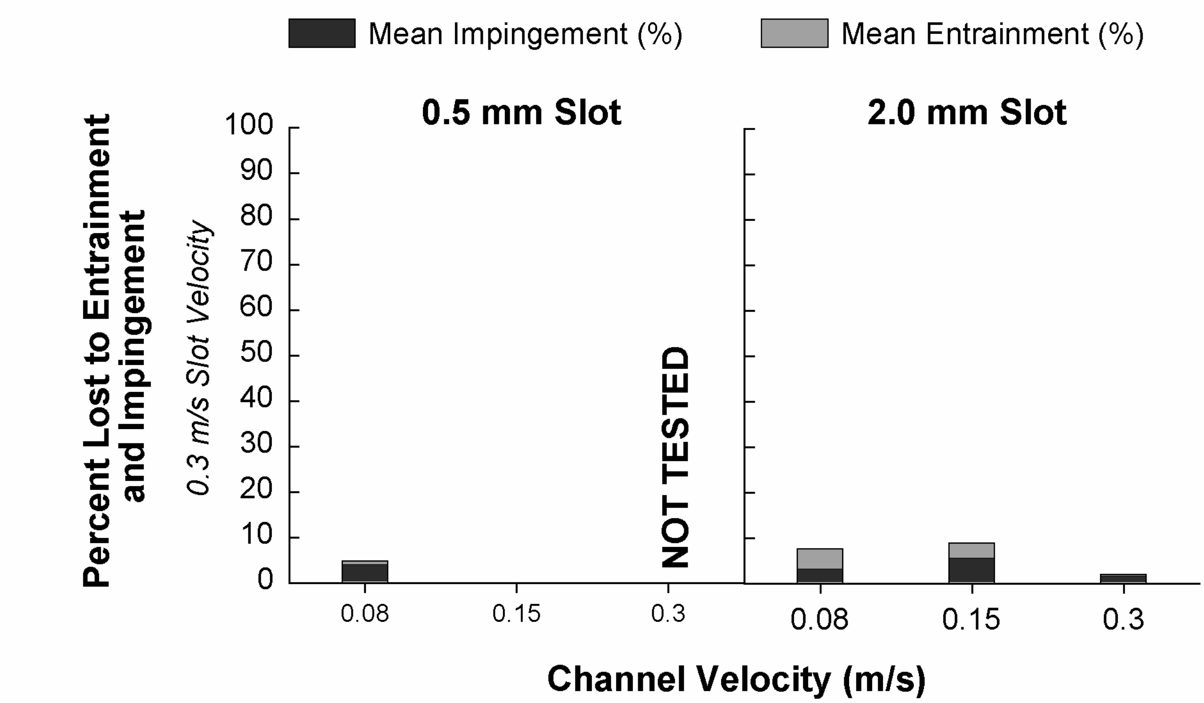

Figure 3-12
Mean Percent of Bluegill Larvae Lost to Impingement and Entrainment

4
COMPUTATIONAL FLUID DYNAMICS (CFD) EVALUATION

Introduction

The ability of wedgewire screens to protect early life stages of fish is strongly influenced by the orientation of the screen relative to ambient currents, the ambient velocity, and screen flow and velocity. These factors determine the near field hydraulic conditions at the screen/water interface, which in turn influence whether an organism will be diverted, impinged, or entrained. To date, investigations into the detailed hydraulics of wedgewire screens have not been conducted. To fully realize the potential of wedgewire screens as a fish protection technology, it is important to understand how hydraulic factors may influence organism movement. Therefore, in combination with the biological studies described in previous sections, EPRI sponsored a mathematical study using Computational Fluid Dynamic (CFD) techniques to examine the hydraulic characteristics of wedgewire screens.

In this study, CFD modeling techniques were used to evaluate the effects of approach velocity and screen flow on velocity distributions around cylindrical wedgewire screens (Figure 4-1). The analyses were conducted with the laboratory flume geometry that was used during biological testing (discussed previously) and for a laterally unbounded (field-type) installation. The results of these studies were used:

1. to estimate the dimensions of the limiting surface within which all water passes through the wedgewire screen and outside of which all water passes by the screen (*i.e.,* defining the zone of withdrawal of the screen and the hydraulic conditions within that zone), and

2. to determine for which flume/screen flow ratios the flume walls may affect flow patterns approaching the screen face (to ensure that the hydraulic conditions used in the biological studies were similar to those that would exist in an actual CWIS application).

The procedures developed for this study can also be used to determine flow patterns affected by the interaction between multiple screening modules, the effect of screen orientation relative to near-field hydraulic conditions, and the ability of design variations to change flow patterns at the screen faces. Such investigations may be undertaken in future efforts.

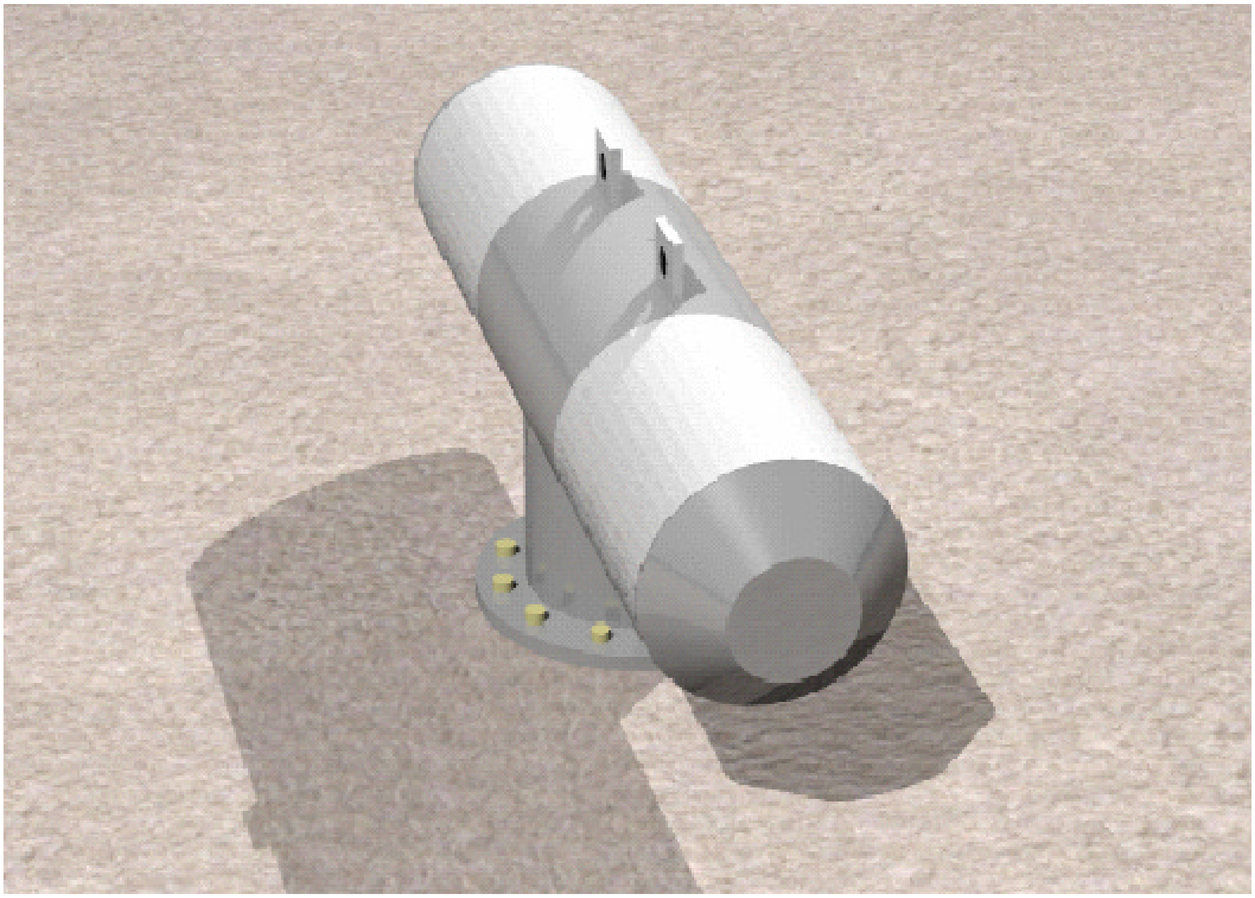

Figure 4-1
Cylindrical Wedgewire Screen (CAD Model)

Problem Statement

The primary objective of the CFD evaluation was to calculate flow patterns (*i.e.,* velocity distributions) that develop at the screen face for different operating conditions. Although the impingement of fish eggs and larvae was not modeled, the entrainment and bypassing of these organisms is governed by the flow patterns that exist near the screen. In this study, calculated flow patterns associated with the screening configuration used for the biological testing (bounded/flume flow) were compared to flow patterns calculated for a field installation (unbounded flow).[1]

Flow patterns around the screen were calculated for two flume flows and two screen withdrawal flows. The CFD model included the wedgewire screen geometry as well as the geometry of the flume (side walls). The wedgewire screen itself was approximated as a porous media. Each of three flow combinations was modeled for the same screen orientation (parallel to the approach

[1] If the results of the laboratory studies are to be representative of field conditions, then the flow patterns produced in the laboratory flume must be similar to those developed in the field.

flow) with and without the flume side walls in place. A total of six simulations were performed in all.

Approach

The numerical analyses were performed with a commercial, CFD computer software system known as ***FLOW-3D®***. This program uses the three-dimensional Navier-Stokes equations as the governing equations for fluid flow and solves these equations within a fixed (Eulerian) grid of rectangular control volumes.[2] A special technique called the **FAVOR** (**F**ractional-**A**rea-**V**olume-**O**bstacle-**R**epresentation) method was used to define general geometric regions within the rectangular grid. **FAVOR** uses partial control volumes to provide the advantages of a body-fitted grid but retains the construction simplicity of an ordinary rectangular grid.[3] With **FAVOR,** the curvature of the screening elements could be included in the analysis without having to resort to stair-stepped boundaries at the solid-water interfaces. Elements of **FAVOR** were also used to define porous baffles to represent the screening elements in the computer simulations.

Model development involved two fundamental elements: construction and calibration (each of these tasks is discussed in the two following sections). After the model was calibrated, simulation of the six flow conditions was conducted. Then, a comparison of calculated flow patterns was used to study changes in near-field hydraulic conditions resulting from differences in flume/screen flows for the six bounded and unbounded flow conditions.

Numerical Model Development

The CFD model of the wedgewire screening structure was developed from design drawings. As a first step in the development of the CFD model, a three-dimensional CAD rendering was constructed from the design drawings (Figures 4-1 and 4-2) and used as direct input to the ***FLOW-3D®*** system. The location of the wedgewire screens was specified in the second step of the setup, and the physical properties of the screens were defined (*e.g.,* the porosity of the screens was set). The location of the flume walls was defined in the final step of the setup.

[2] Rectangular control volumes are simple to generate and possess many desirable properties (*e.g.,* increased accuracy, smaller demands on memory, and simpler numerical approximations).

[3] A discussion of this technique appears in: Hirt, C.W. & J.M. Sicilian, (1985) A Porosity Technique for the Definition of Obstacles in Rectangular Cell Meshes, Proc. Fourth International Conference on Ship Hydrodynamics, National Academy of Science, Washington, DC.

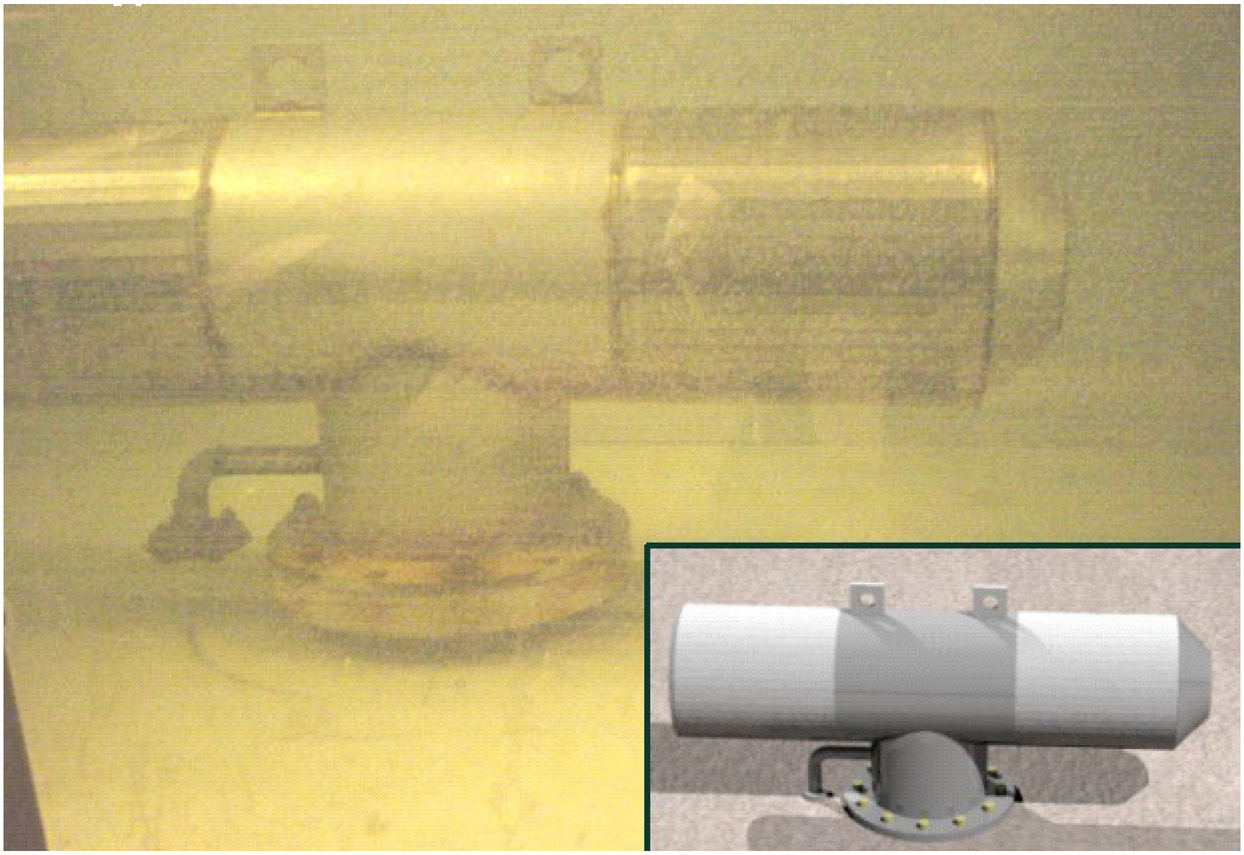

Figure 4-2
T12 Screen (Photograph and CAD Model)

The calculation of flow patterns near the wedgewire screen depicted in Figure 4-2 was the focus of this study. This screen is 122 cm long. The diameter of the main body of the structure is 30.5 cm. The screen is located 39.4 cm above the flume floor. The screen slot size was 2 mm, and the screening structure was oriented parallel to the sidewalls of the flume.

Computational Mesh

The bounded flow simulations were performed within a rectangular, fixed (Eulerian) grid (Figure 4-3 through 4-5). This grid contains a total of 234,000 control volumes; 156 control volumes in the X-direction (the primary direction of flow), 30 control volumes in the Y-direction (the lateral dimension), and 50 control volumes in the Z-direction (the vertical dimension). The flow in only one-half of the flume was simulated because it was assumed to be symmetric about the (vertical) center plane of the channel (*i.e.,* the computational mesh extends from the center plane of the screening structure out to the wall of the flume). The size of the control volumes within the fixed grid varied so that increased grid resolution was provided in the vicinity of the wedgewire screen. The smallest control volumes appearing in Figures 4-3 through 4-5 correspond to areas where the wedgewire screen is located.

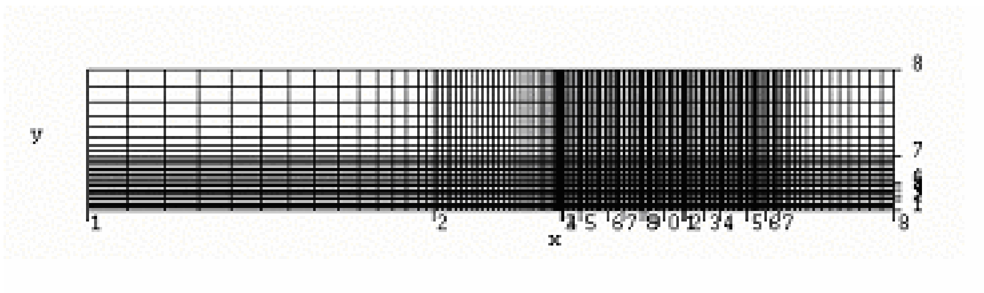

Figure 4-3
Computational Mesh: X-Y grid

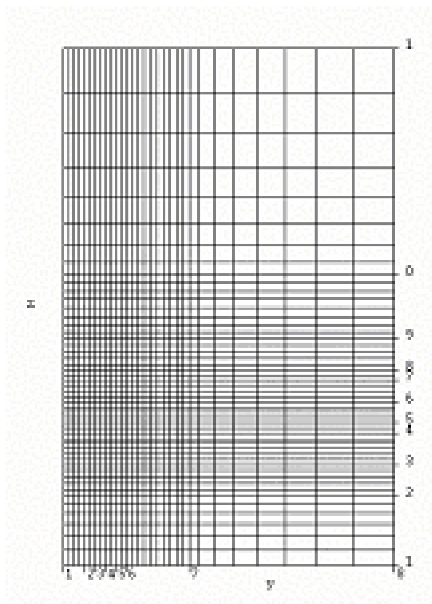

Figure 4-4
Computational Mesh: X-Z grid

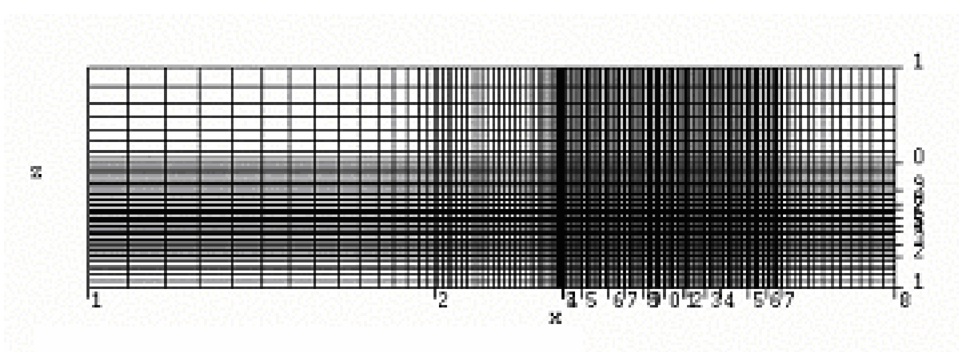

Figure 4-5
Computational Mesh: Y-Z grid

Figures 4-6 through 4-8 show the location of the wedgewire screen in the computational mesh used for the model calibration (in Figure 4-6 and 4-7, the computed flow was moving from the right to the left). The inflow boundary was located about two cylinder diameters upstream of the screening structure. Moving the boundary further upstream did not change the computed flow field in the vicinity of the screening device. Since the ***FLOW-3D***® computer program relies on explicit methods of computation, a significant amount of computer time is required to return a solution. Accordingly, care was taken to minimize the size of the computational mesh used for the analyses.

The outflow boundary was located about 12 diameters downstream of the screening device. Locating the boundary at this location minimized the influence of the outflow boundary on flow patterns that developed downstream of the screen structure.

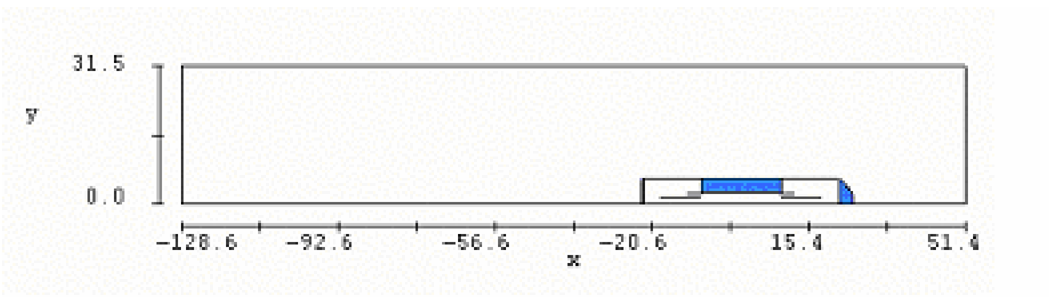

Figure 4-6
Obstacle Plot – Calibration Exercise: X-Y Plane

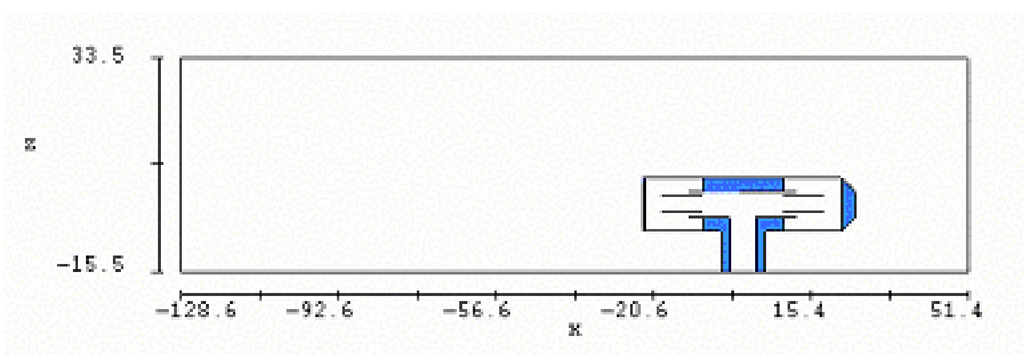

Figure 4-7
Obstacle Plot – Calibration Exercise: X-Z Plane

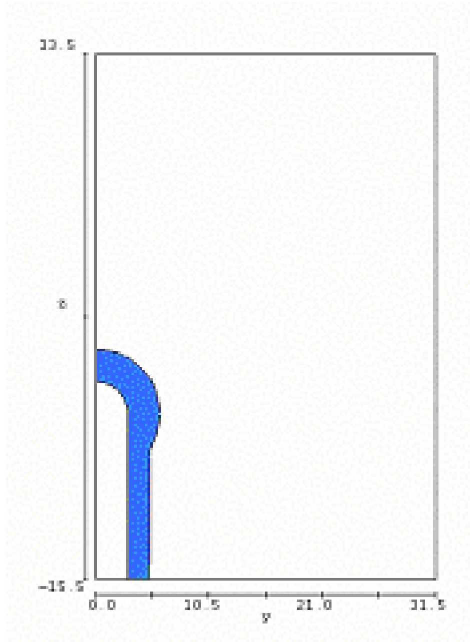

Figure 4-8
Obstacle Plot – Calibration Exercise: Y-Z Plane

Boundary Conditions

Mathematical expressions known as boundary conditions are used to control flow at the boundaries of CFD computations (*i.e.*, at the perimeters of the mesh and at solid boundaries). The boundary conditions presented in Table 4-1 were used for the calibration exercise and for the bounded flow simulations. The boundary conditions presented in Table 4-2 were used for the unbounded flow simulations. The boundary conditions used for all of the computations are the same with the exception of the presence of a no-slip wall in the bounded condition.

Table 4-1
Mathematical boundary conditions (bounded flow)

Boundary	Flow Condition
Inflow	Specified Velocity
Outflow (Downstream)	Continuative (Zero Derivative)
Outflow (Screening Structure)	Specified Velocity
Bottom	No-Slip (Wall)
Surface	Symmetry (Rigid Lid)
Vertical Center Plane of Flume	Symmetry
Vertical Flume Wall	No-Slip (Wall)

Table 4-2
Mathematical boundary conditions (unbounded flow)

Boundary	Flow Condition
Inflow	Specified Velocity
Outflow (Downstream)	Continuative (Zero Derivative)
Outflow (Screening Structure)	Specified Velocity
Bottom	No-Slip (Wall)
Surface	Symmetry (Rigid Lid)
Vertical Center Plane of Flume	Symmetry
Vertical Flume Wall	Pressure

The operating conditions used for the model calibration included an approach velocity of 7.6 cm/s and a screen flow withdrawal rate of 0.8 m^3/s. In this case, the volumetric withdrawal rate through the screening structure was converted to an equivalent velocity based on the inside diameter of the vertical pipe that is part of the screening structure. This velocity was then specified in the withdrawal pipe of the screening structure.

The operating conditions used in the test scenarios are presented Table 4-3. The same four flow conditions were studied with the bounded and unbounded flow models.

Table 4-3
Operating conditions – bounded and unbounded flow scenarios

Test Case	Approach Velocity (cm/s)	Flow Rate through Screening Structure (m^3/s)
1	7.6	0.05
2	7.6	0.21
3	15.2	0.21

Analysis

Qualitative and quantitative methods were used to compare the results of the different computations. Graphical renderings took the form of streamline plots showing the trajectory of fluid particles moving through the model domain (Figure 4-9) and contour plots showing the distribution of velocities in the vicinity of the screening structure (Figure 4-10). Tabular data were also derived from the computed results and were used to compare velocities at similar locations in the different scenarios. Together, this information was used to assess similarities and differences in the bounded and unbounded flow patterns calculated.

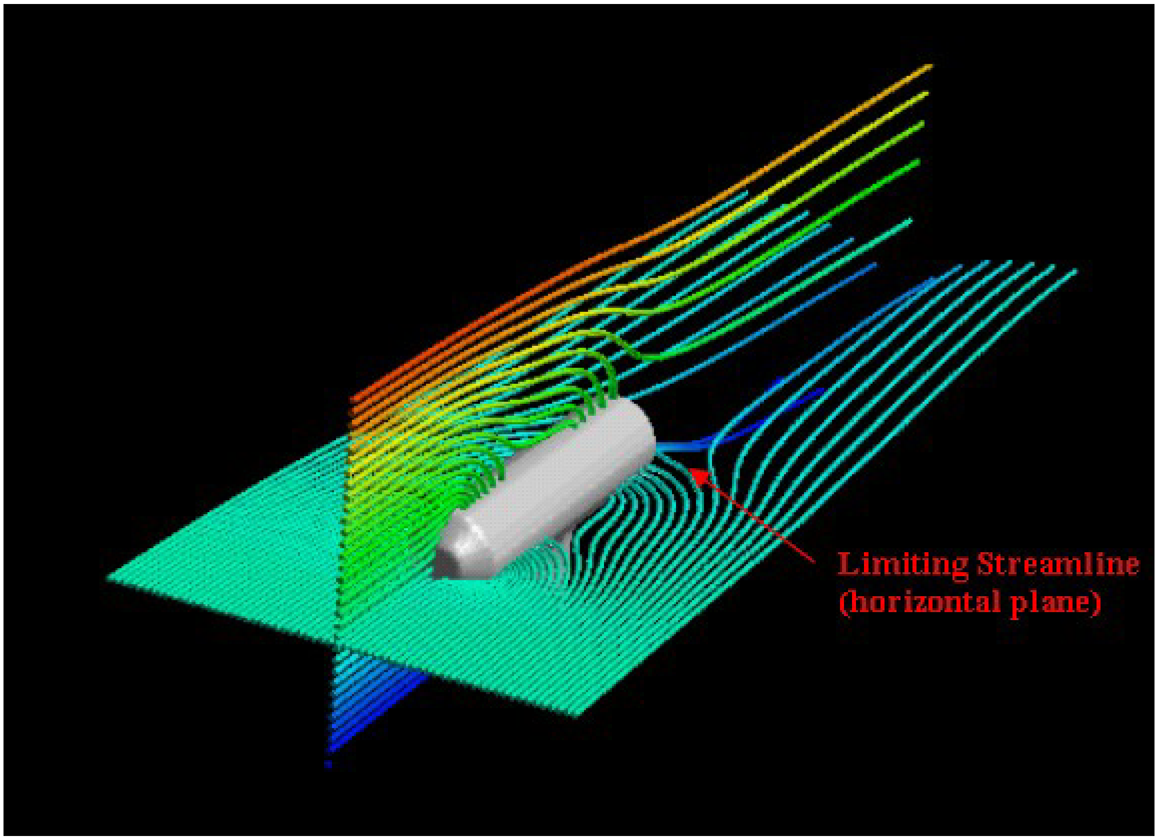

Figure 4-9
Streamlines of flow (colored by elevation)

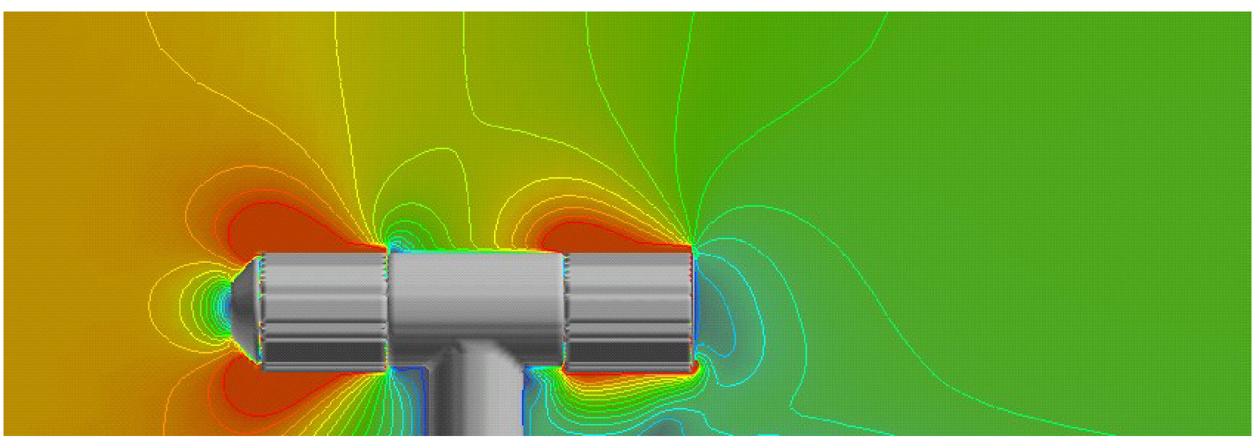

Figure 4-10
Flow Distribution (colored by speed, flow is from left to right)

Model Calibration

A comparison of computed and measured velocities and headloss (across the wedgewire screens) was performed with the numerical model prior to completing the computational analysis. In this preliminary phase of the project, velocity measurements in the vicinity of the wedgewire screen were made with an Acoustic Doppler Velocimeter (ADV) manufactured by Sontek/YSI, Inc. These measured velocities were then compared to velocities computed for the same operating conditions with the numerical model. Differences between the measured and computed results were attributed to the choice of parameter values used to control the amount of energy lost by the flow as it passed through the wedgewire screens. These parameter values can be estimated from theory; however, some adjustment/calibration of these terms was helpful in bringing the calculated results into the sharpest focus possible. With minor adjustments made to these input parameters, the computed results (velocity distributions and headloss) were comparable to the measured data. The same parameter values determined by the model calibration were used in the remainder of the study.

Operating Conditions

The approach velocity used in the model calibration was equal to 7.6 cm/s and the withdrawal rate through the wedgewire screen was equal to 0.8 m^3/s. The flow depth in the flume was equal to 1.3 m and the total width of the flume was equal to 1.7 m (2001 biological test conditions).

Data Acquisition

A laboratory grade Acoustic Doppler Velocimeter (ADV) was used to measure velocities at different locations around the screening structure. Pressure taps located on the floor of the flume (upstream of the screening structure) and inside the screening structure were used to measure the headloss induced by the screens (about 0.5 cm for the study conditions). Coefficients that control the amount of headloss that occurs as flow moves through the screens were adjusted until the calculated pressure difference (at the virtual tap locations) matched those measured in the flume. The calculated flow patterns were then compared to those measured in the flume. Results of the ADV data acquisition effort are shown in Figure 4-11.

Similar velocity measurements were also made in a horizontal plane aligned with the centerline of the screening structure. The magnitude and direction of these velocities were comparable to those measured in the vertical plane (*i.e.,* shown in Figure 4-11). Therefore, only the results in the vertical plane have been reproduced here.

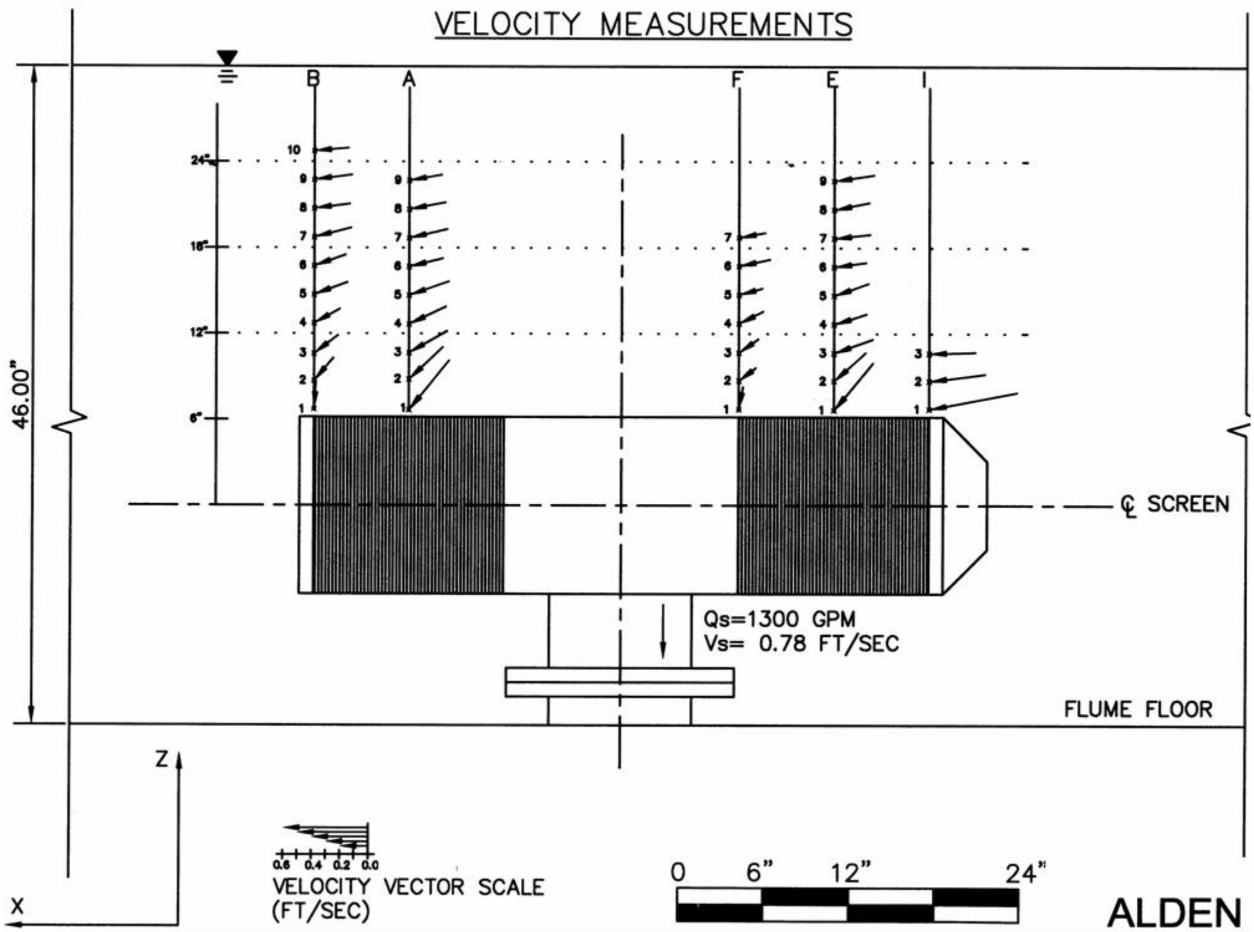

Figure 4-11
ADV Measurements

Calibration Results

In the first step of the model calibration, the calculated pressure difference across the screens was matched to data ($\Delta P = 0.5$ cm) and calculated velocities were compared to the measured velocities shown in Figure 4-11. The agreement between the calculated and measured values was high (Tables 4-4 and 4-5). Therefore, the settings used to control the headloss through the wedgewire screens for these calculations were also used for the remainder of the study (since the 2 mm screen size was the same for all study scenarios[4]).

[4] If the slot size of the screens had been changed, then a second calibration would have been necessary.

Table 4-4
X-Z Resultant Velocity Angle (degrees)

Point	Measured	Calculated	Difference (+/-)
B1	86.0	87.0	1.0
A1	50.8	56.0	5.2
F1	79.5	76.0	3.5
E1	50.3	50.5	0.2
I1	10.9	13.5	2.6
		Average Difference	2.6

Table 4-5
X-Z Resultant Velocities (inch/second)

Point	Measured	Calculated	Difference (+/-)
B1	6.1	7.1	1.0
A1	13.7	13.7	-
F1	5.1	5.1	-
E1	13.2	12.7	0.5
I1	19.3	19.1	0.2
		Average Difference	0.4

In the second step of the calibration exercise, the analysis methods proposed for use in the main body of the study were tested. Streamline plots, showing the trajectory of flow past the screening structure, were produced and the position of the "limiting streamline" was determined. For this effort, the position of the limiting streamline was defined as the radial distance from the centerline of the wedgewire screen to the starting location of the streamline that intersects the screening structure at its most downstream position. A red arrow on Figure 4-9 points to the limiting streamline seeded in the horizontal plane upstream of the screening structure. The radial distance between the centerline of the wedgewire screen and the origin of this streamline was calculated to be 58.4 cm. Similarly, the location of the limiting streamline released in the vertical plane was also calculated to be 58.4 cm.

A calculation can also be used to estimate the position of the limiting streamline for cases such as those where the screening structure is aligned with the predominant direction of flow (*i.e.,* the position of the limiting streamline would be more difficult to estimate with a hand calculation if multiple structures where placed near each other or if the structures were not aligned with the flow). In this case, the position of the limiting streamline can be estimated using Equation 4-1.

$$L = (Q_s /[\ V_a * \pi])^{1/2}$$ **Equation 4-1**

where: L = position of limiting streamline

Q_s = screening structure flow rate

V_a = approach velocity

For operating conditions used in the model calibration, the position of the limiting streamline (L) was calculated to be 22 inches, in good agreement with the position of the limiting streamline estimated graphically.

In a final analysis, the walls of the flume were removed and a comparison of streamline trajectories (Figure 4-12) and velocities was made (Tables 4-6 and 4-7). In these comparisons the differences between the bounded and unbounded flow solutions are small. For example, the average difference in flow angle was calculated to be 1.5 degrees, and the average difference in flow speed was calculated to be 0.4 cm/s. Additionally, streamline plots in Figure 4-8 show the direction of the approach flow changing significantly in the near vicinity of the screening structure. This implies that the presence of the flume wall bears less on the development of flow patterns near the screening structure than does the speed of the approach flow, the design of the wedgewire screens, and the withdrawal of flow through the screening structure for these operating conditions.

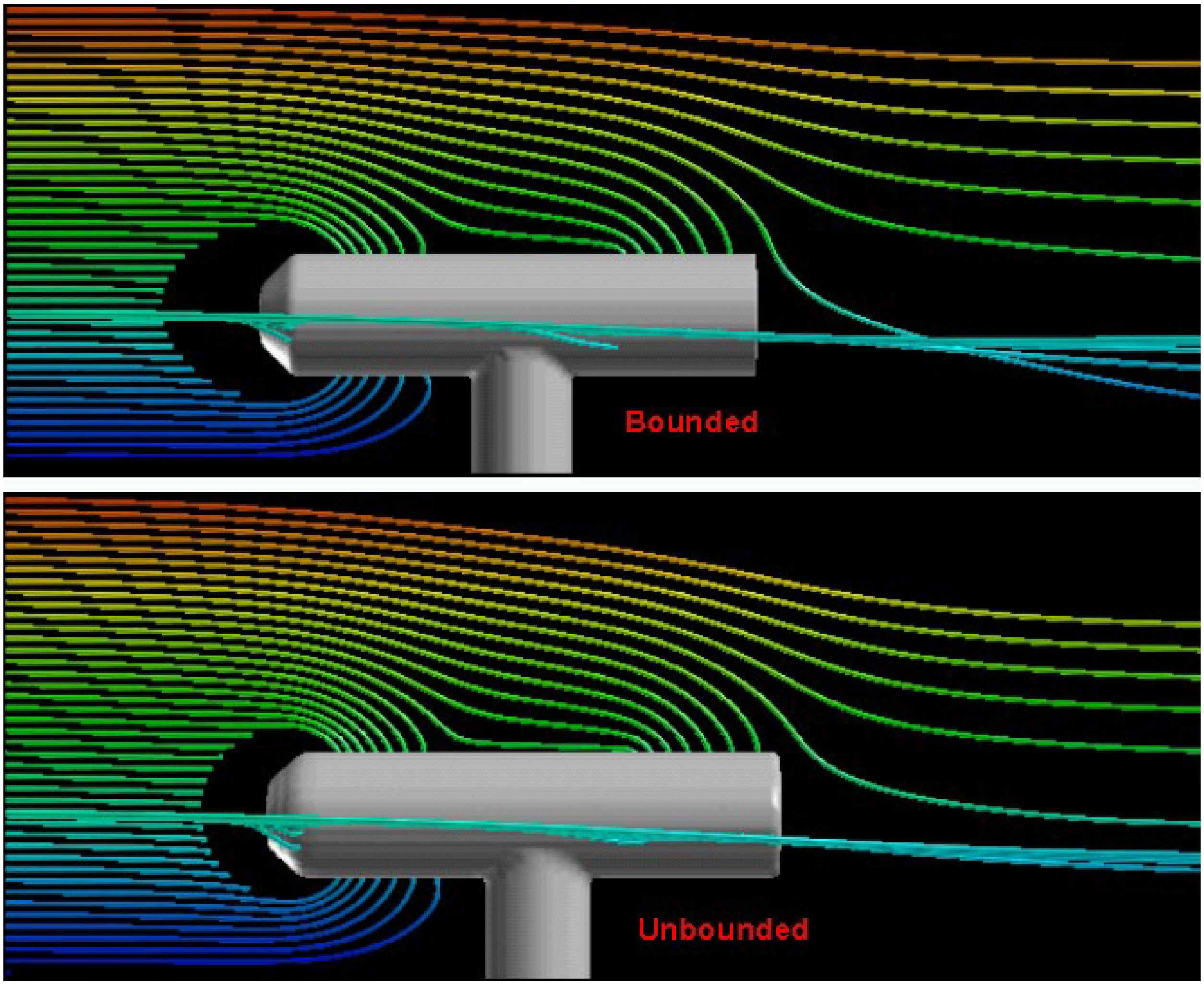

Figure 4-12
Computed Results (colored by elevation)

Table 4-6
X-Z Resultant Velocity Angles (degrees)

Point	6' Flume	Unbounded	Difference (+/-)
B1	87.0	85.0	2.0
A1	56.0	56.0	0.0
F1	76.0	79.0	3.0
E1	50.5	49.5	1.0
I1	13.5	12.0	1.5
		Average Difference	1.5

Table 4-7
X-Z Resultant Velocities (inch/second)

Point	6' Flume	Unbounded	Difference (+/-)
B1	7.1	6.6	0.5
A1	13.7	14.0	0.3
F1	5.1	5.1	0.0
E1	12.7	13.2	0.5
I1	19.1	19.6	0.5
		Average Difference	0.4

Results

The calibrated flow model provided the basis for a numerical study where flow patterns for four different operating conditions were calculated for conditions with and without the flume walls in place.

Test Matrix

Operating conditions for the four test cases are shown in Table 4-8. In this study, combinations of two different approach velocities and two different screen withdrawal rates were considered. For each test case, a simulation was performed with and without the flume walls in place. Thus, a total of eight different simulations were performed.

Table 4-8
Operating conditions – bounded and unbounded flow scenarios

Test Case	Approach Velocity (cm/s)	Flow Rate through Screening Structure (m^3/s)
1	7.6	0.05
2	7.6	0.1
3	15.2	0.1

The results of the CFD modeling are presented in the following section of this report. For the reader's convenience, the suffixes H and L appear in the heading for each test case. These suffixes refer to velocity of the approach flow and the flow rate through the screening structure, *i.e.,* whether the flow rates are high (H) or low (L). The suffixes appear in pairs; the first refers to the approach velocity and the second refers to the flow rate through the screening structure. Thus, the code L/H identifies a test case where the approach velocity was low and the flow rate through the screening structure was high.

Test Case 1 (L/L)

A low approach velocity (equal to 7.6 cm/second) and a low withdrawal rate (equal to 0.05 m^3/s) was considered in the first test case. Graphic results from this test scenario appear in Figures 4-13 through 4-22. Figures 4-13 through 4-17 show bounded results, whereas Figures 4-18 through 4-22 show the same plots under the unbounded condition.

Figures 4-13 and 4-18 were produced from data sampled along the vertical plane of symmetry (*i.e.,* the vertical plane down the center of the flume). Areas where the flow direction is downstream are colored blue and areas where the flow direction is upstream are colored red. The region of upstream flow direction to the left (downstream) of the standpipe is larger for the bounded condition (i.e., flume walls present; Figure 13) than it is for the unbounded condition (i.e., no flume walls; Figure 18). The area of recirculation is larger for the bounded condition because less water is available for withdrawal compared to the situation where the flume walls are not present and additional makeup water is available. In all other locations around the perimeter of the screening structure, the direction of flow (up or downstream) is the same in the presence or absence of the flume walls.

Figures 4-14 and 4-19 contain vector plots where the background has been shaded in various colors according to flow velocity. The data that is presented in these plots were sampled along the top of the upstream screen structure. The distribution of flow for the bounded and unbounded conditions is very similar. Figures 4-15 and 4-20 contain vector plots produced from data sampled along the top of the downstream screen. Similar to the upstream portion of the screen, only minor differences in flow speed and direction were detected between bounded and unbounded conditions towards the downstream end of the screen.

Figures 4-16 and 4-21 contain vector plots produced from data sampled along the bottom of the upstream screen. The computed flow fields presented in these figures demonstrate that the conditions for this portion of the screen are also similar between the bounded and unbounded conditions. Figures 4-17 and 4-22 contain vector plots produced from data sampled along the bottom of the downstream. These data indicate that there are slight differences between the bounded and unbounded conditions in the direction of flow approaching this portion of the screen. However, the direction of flow at the screen face is comparable. For this test case, only small differences in flow pattern were present at the downstream side of the screening device in the lee of the standpipe. At all other locations, the computed flow patterns are almost identical under bounded and unbounded conditions.

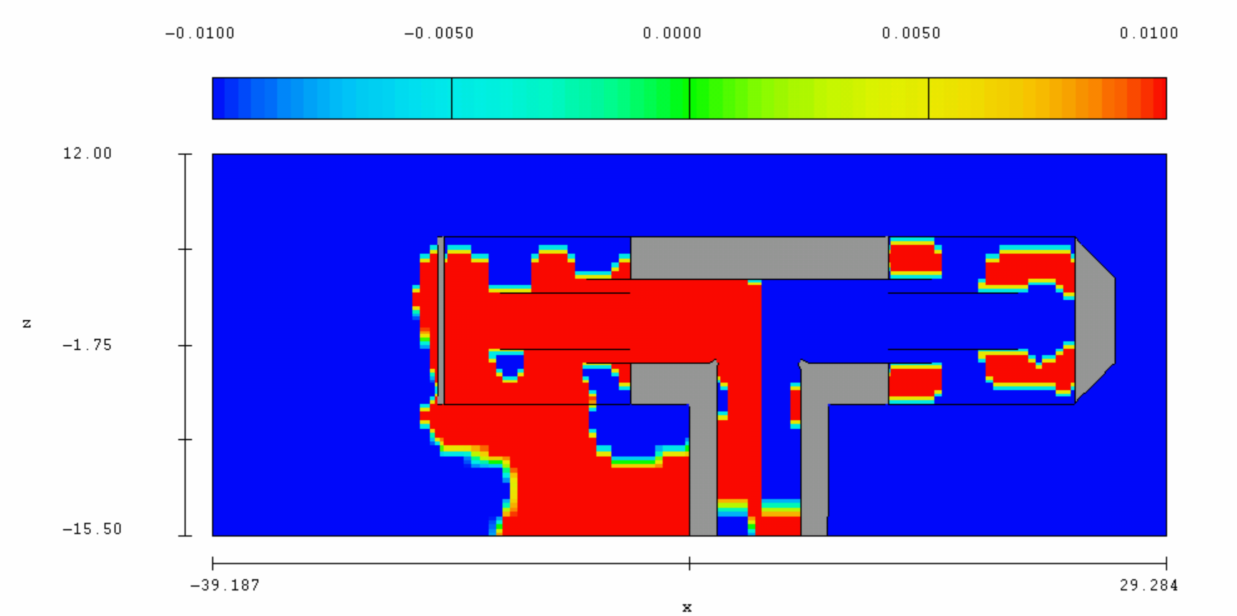

Figure 4-13
Case 1 – Bounded Flow - Direction of flow along vertical center plane (blue – downstream, red – upstream). Flow moves from right to left

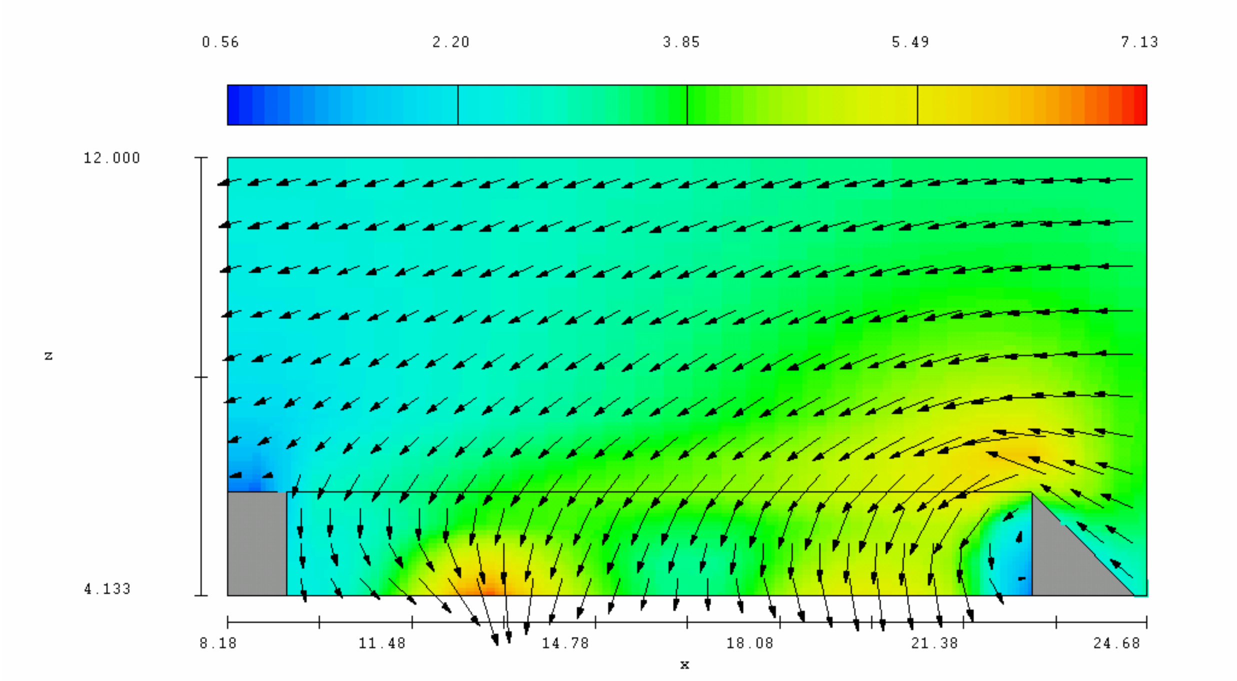

Figure 4-14
Case 1 – Bounded Flow - Upstream Screen (Top) - vectors colored by speed (inches/second). Flow moves from right to left

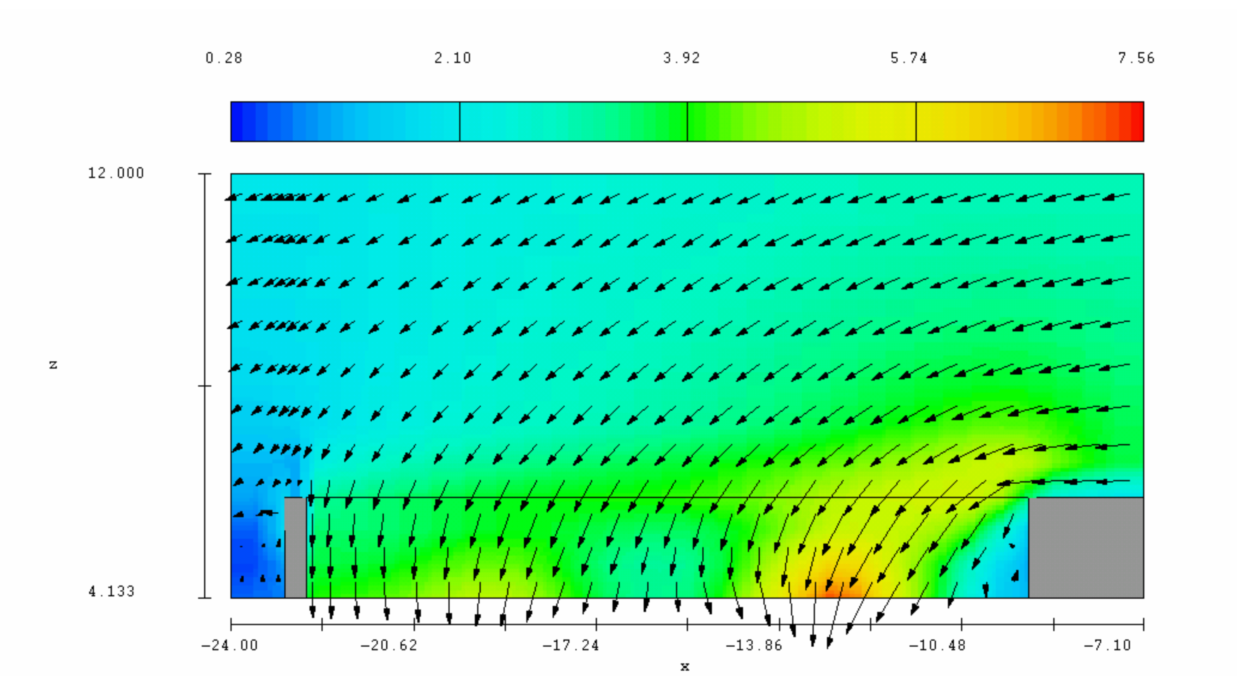

Figure 4-15
Case 1 – Bounded Flow - Downstream Screen (Top) – vectors colored by speed (inches/second). Flow moves from right to left

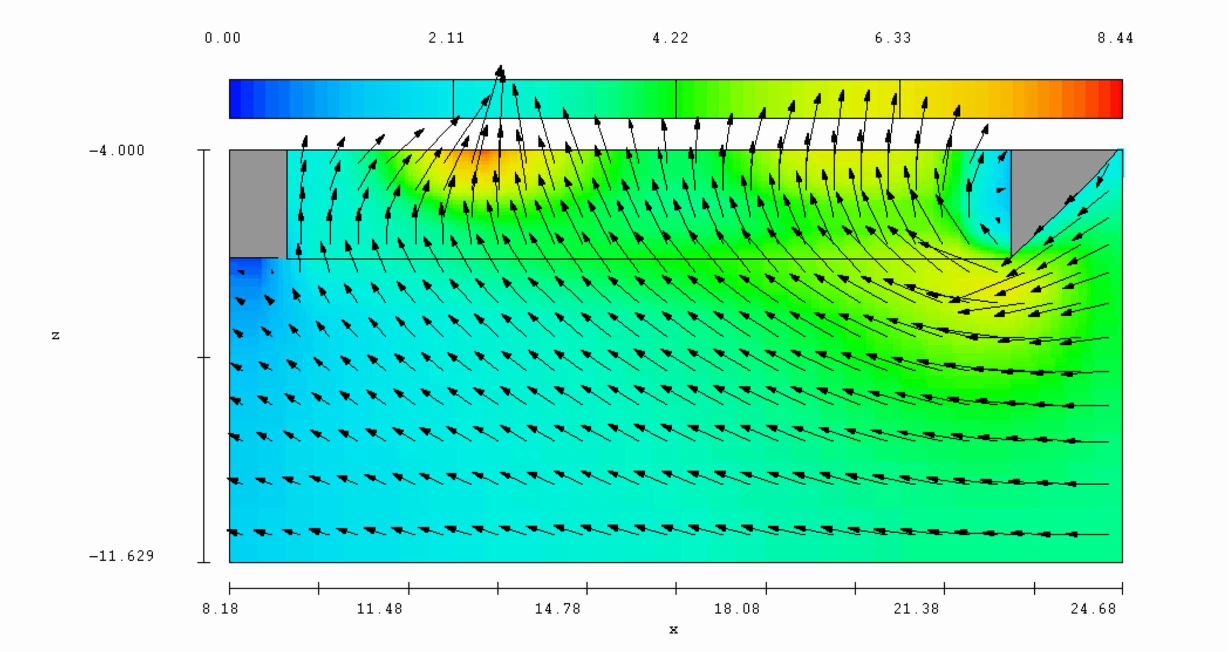

Figure 4-16
Case 1 – Bounded Flow - Upstream Screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

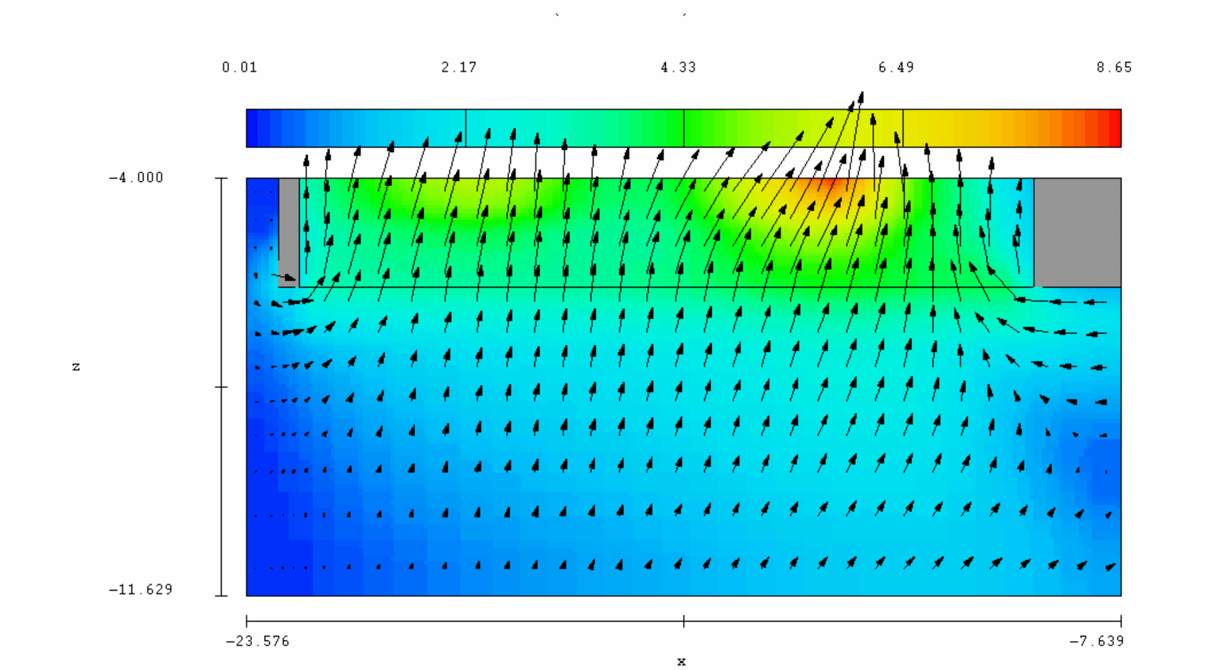

Figure 4-17
Case 1 – Bounded Flow - Downstream Screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

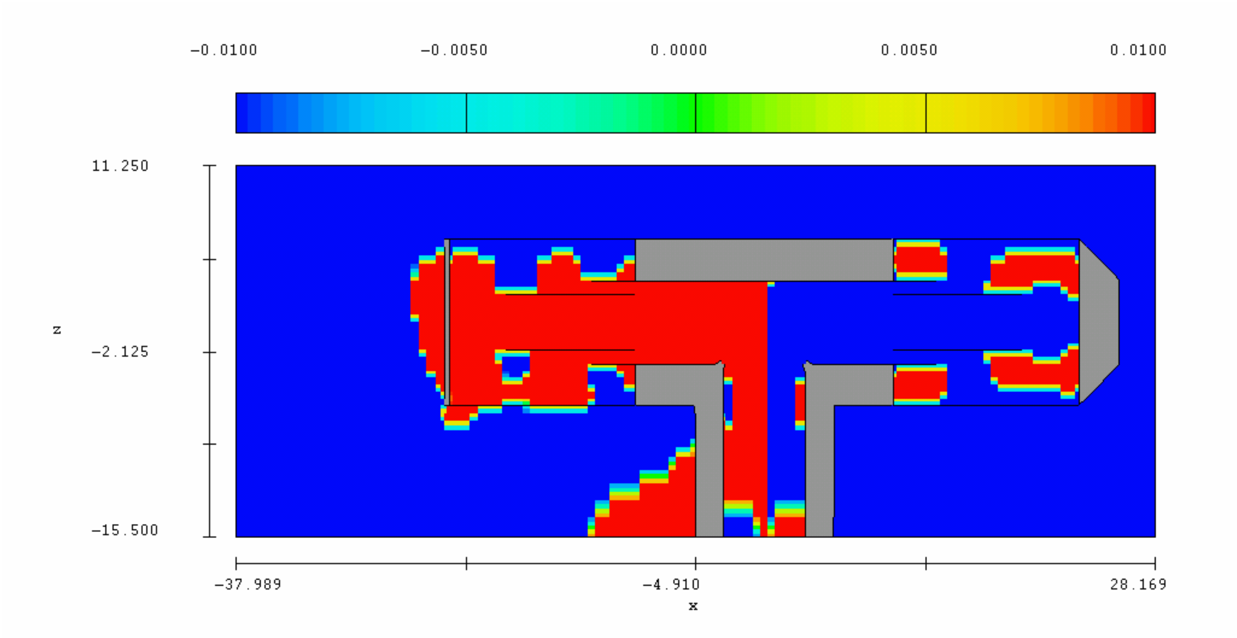

Figure 4-18
Case 1 – Unbounded Flow – Direction of flow along vertical center plane [blue – downstream; red – upstream]. Flow moves from right to left

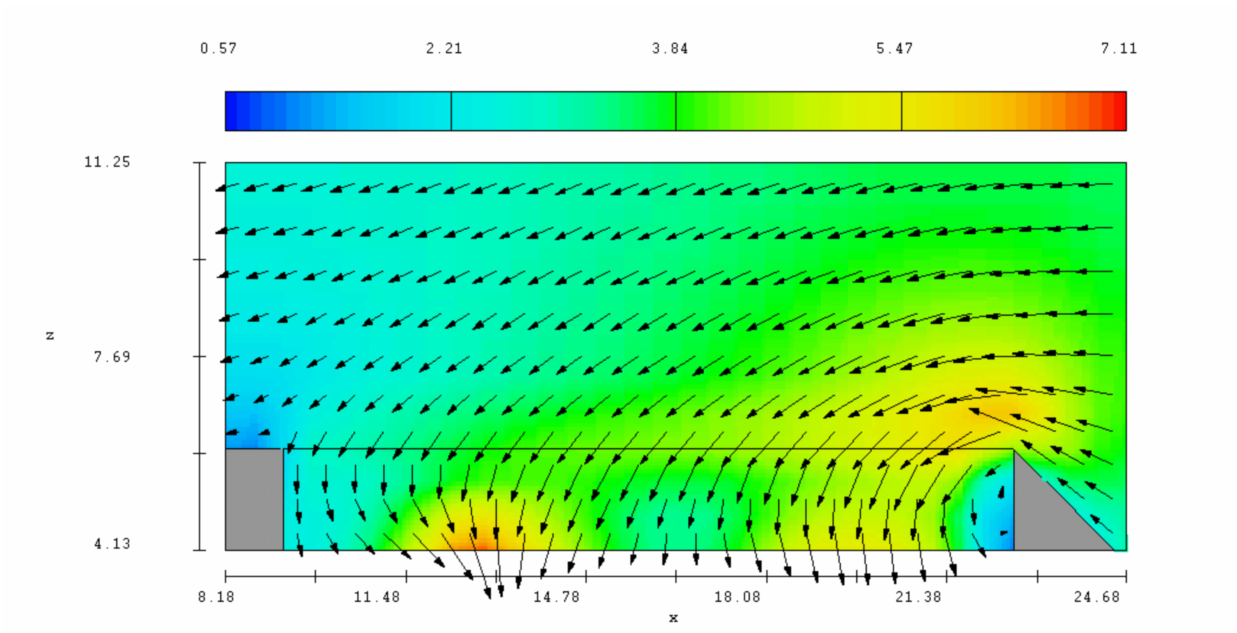

Figure 4-19
Case 1 – Unbounded Flow – Upstream screen (Top) – vectors colored by speed (inches/second). Flow moves from right to left

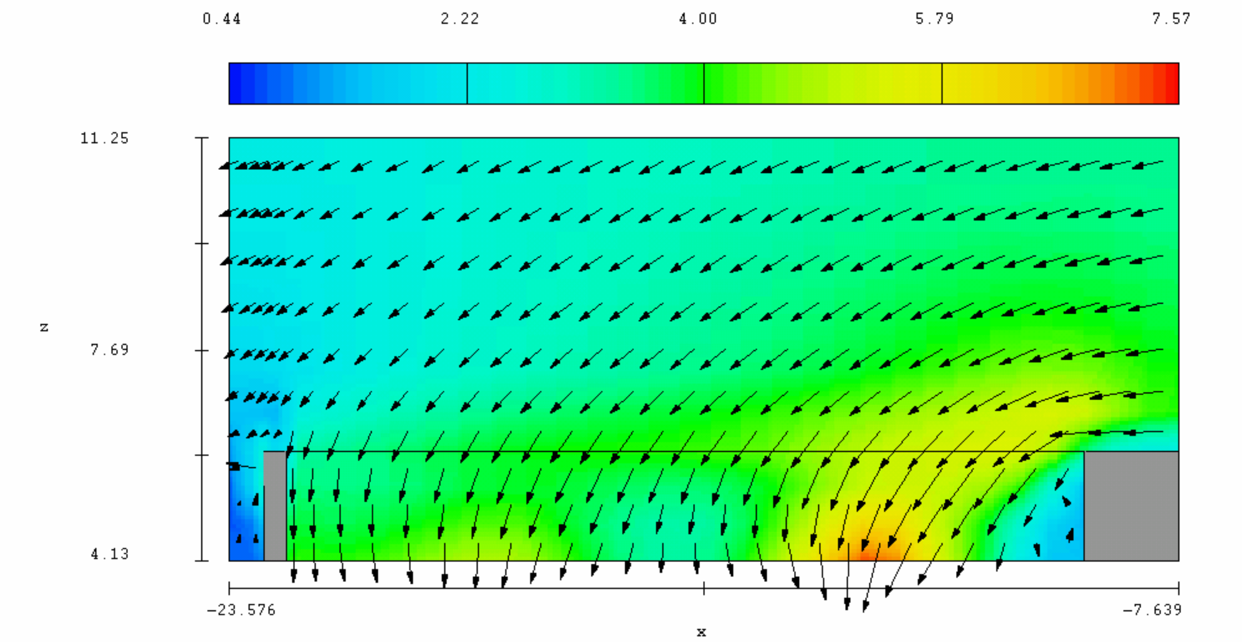

Figure 4-20
Case 1 – Unbounded Flow – Downstream screen (Top) – vectors colored by speed (inches/second). Flow moves from right to left

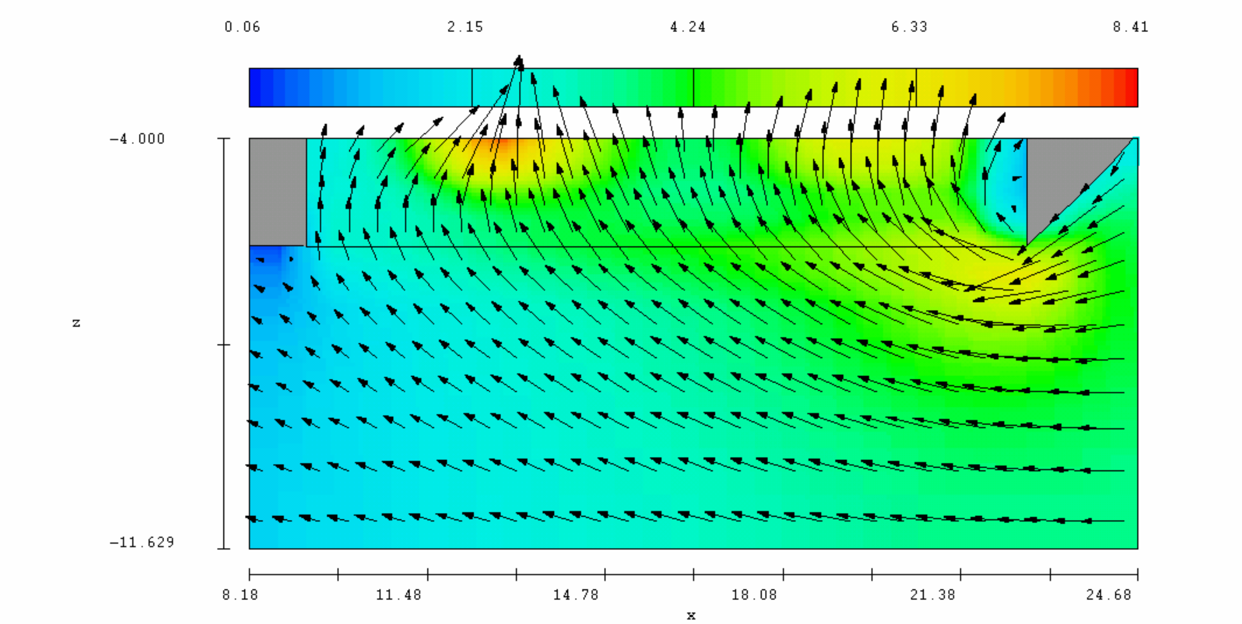

Figure 4-21
Case 1 – Unbounded Flow – Upstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

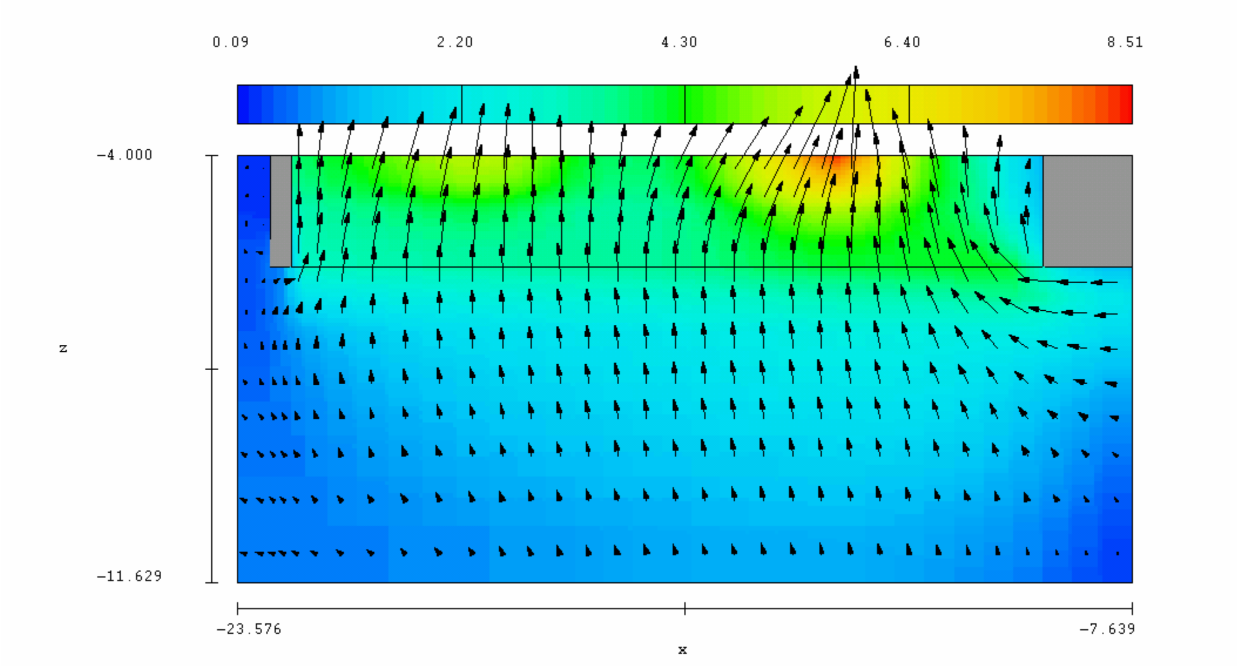

Figure 4-22
Case 1 – Unbounded Flow – Downstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

Test Case 2 (L/H)

A low approach velocity (7.6 cm/s) and a high withdrawal rate (0.1 m^3/s) was considered in the second test case. Graphic results from this test scenario appear in Figures 4-23 through 4-32; Figures 4-23 through 4-27 show bounded results, while Figures 4-28 through 4-32 show the same plots under the unbounded condition. This choice of flow conditions produced the greatest amount of difference between the computed flow fields. This result is due to the fact that a high percentage of approach flow was withdrawn through the screening device (69% of the total approach flow passed into the screen versus 35% in the first test case).

Figures 4-23 and 4-28 were produced from data sampled along the vertical plane of symmetry (*i.e.,* the vertical plane down the center of the flume). Areas where the flow direction is downstream are colored blue and areas where the flow direction is upstream are colored red. The red region to the left (downstream) of the standpipe is larger in Figure 4-23 that it is in Figure 4-28.

Figure 4-23 was produced from a simulation where the flume walls were in place (bounded), and Figure 4-28 was produced from a simulation where the flume walls were removed (unbounded). The area of recirculation is larger in Figure 4-23 because less water is available to the intake compared to the situation where the flume walls were removed and additional makeup water was present. In all other locations around the perimeter of the screening structure, the direction of flow (up or downstream) is very similar under the bounded and unbounded conditions.

Figures 4-24 and 4-29 contain vector plots with the background colored according to the speed of the flow. The data that were used to produce these plots were sampled along the top of the upstream section of the screen. The distribution of flow shown in both frames is essentially the same. Figures 4-25 and 4-30 contain vector plots produced from data sampled along the top of the downstream section of the screen. The only differences in flow speed and direction that were detected occurred at the downstream end of the screen.

Figures 4-26 and 4-31 contain vector plots produced from data sampled along the bottom of the upstream screen. The computed flow fields shown in both figures are very similar. Figures 4-27 and 4-32 contain vector plots produced from data sampled along the bottom of the downstream screen. Minor differences in the direction of flow approaching the screen is evident between the bounded and unbounded conditions. However, the direction of flow at the screen face is almost the same between the two conditions.

Overall, this test case produced only slight differences in flow patterns on the downstream side of the screening device in the lee of the standpipe (similar to the results of Test Case 1). At all other locations along the screen, the flow patterns are almost identical.

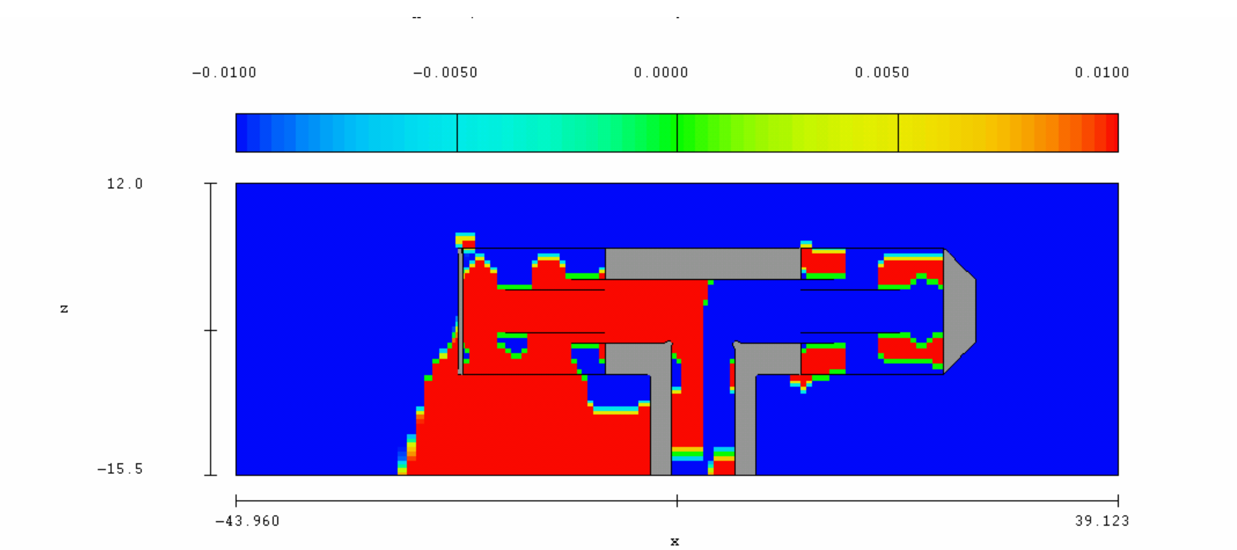

Figure 4-23
Case 2 – Bounded Flow - Direction of flow along vertical center plane [blue – downstream, red – upstream]. Flow moves from right to left.

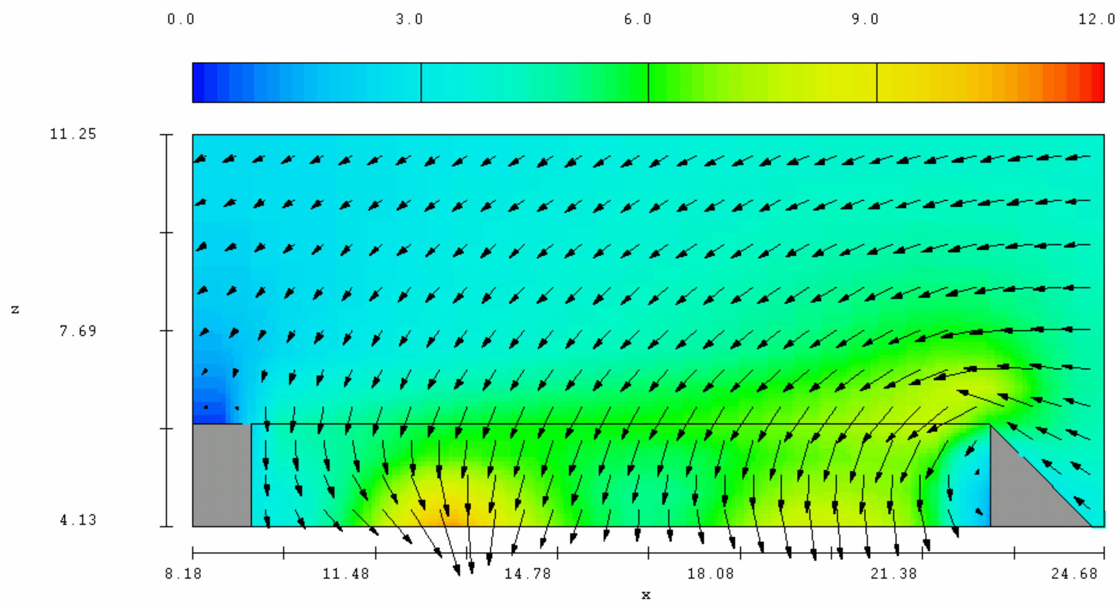

Figure 4-24
Case 2 – Bounded Flow– Upstream Screen (Top) – Vectors colored by speed (inches/second). Flow moves from right to left in all frames.

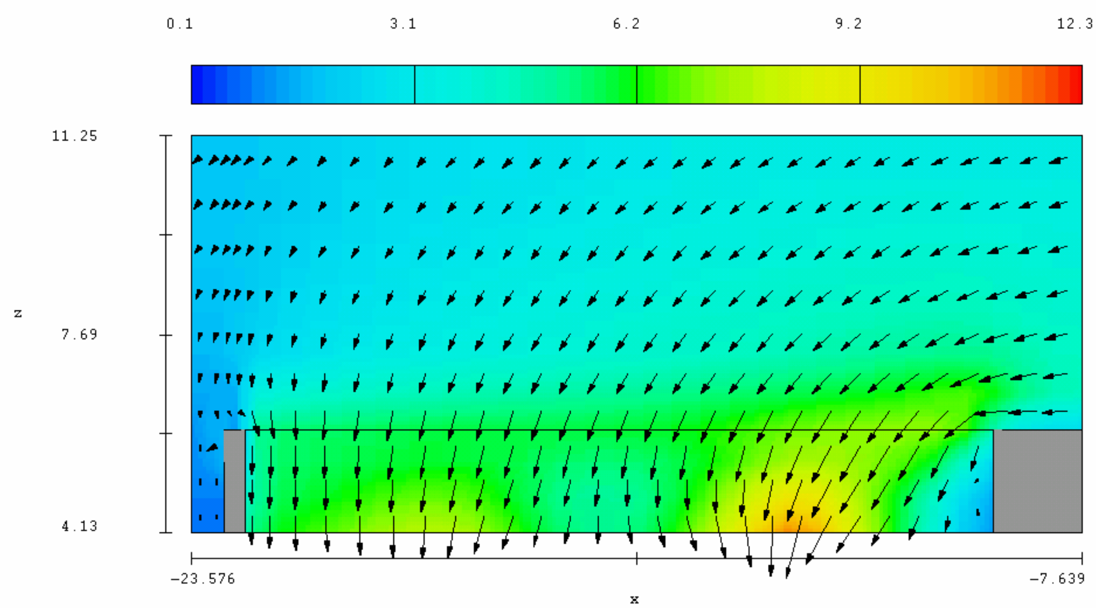

Figure 4-25
Case 2 – Bounded Flow – Downstream Screen (Top) – vectors colored by speed (inches/second). Flow moved from right to left in all frames.

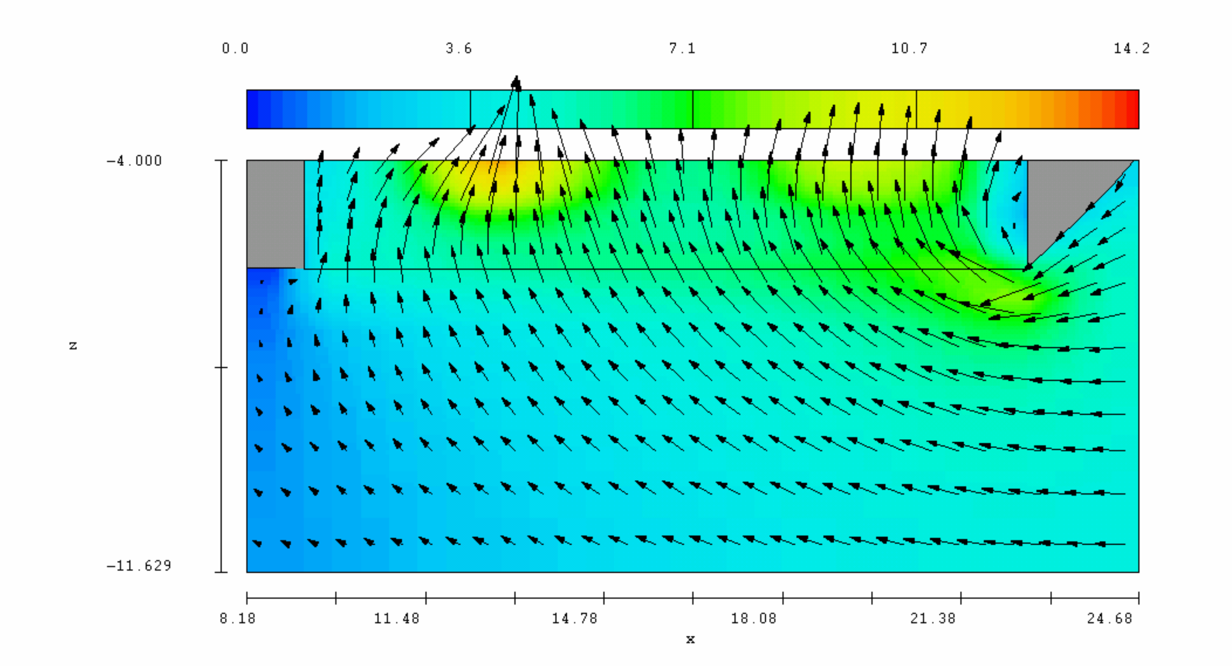

Figure 4-26
Case 2 – Bounded Flow – Upstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

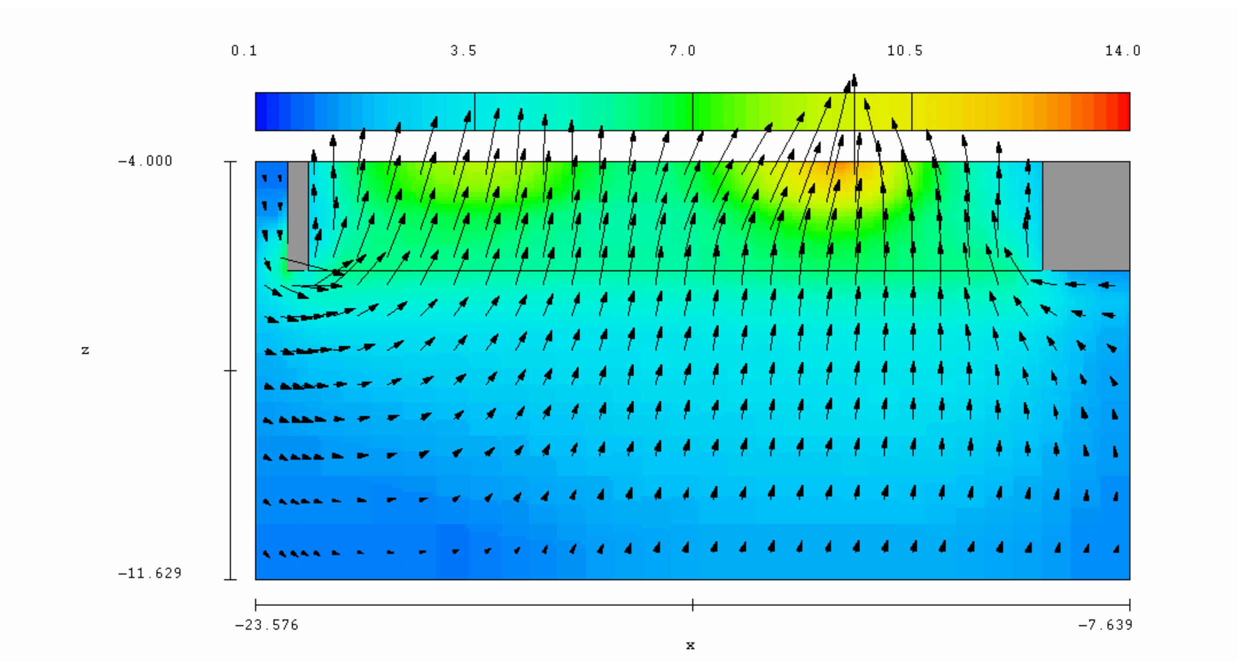

Figure 4-27
Case 2 – Bounded Flow – Downstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

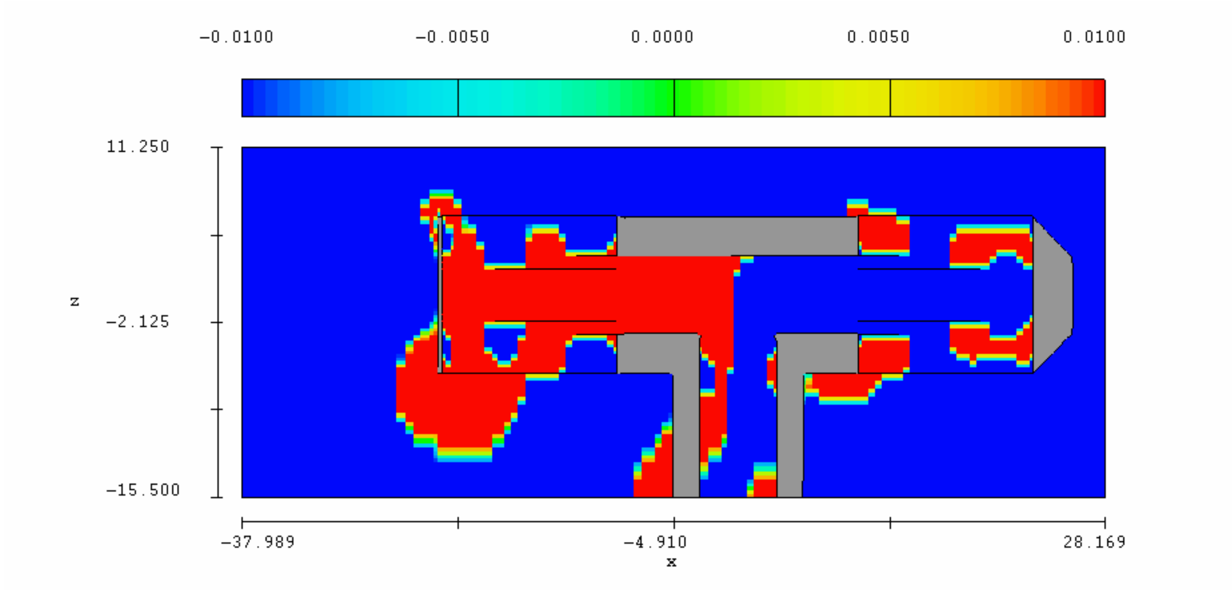

Figure 4-28
Case 2 – Unbounded Flow - Direction of flow along vertical center plane [blue – downstream, red – upstream]. Flow moves from right to left.

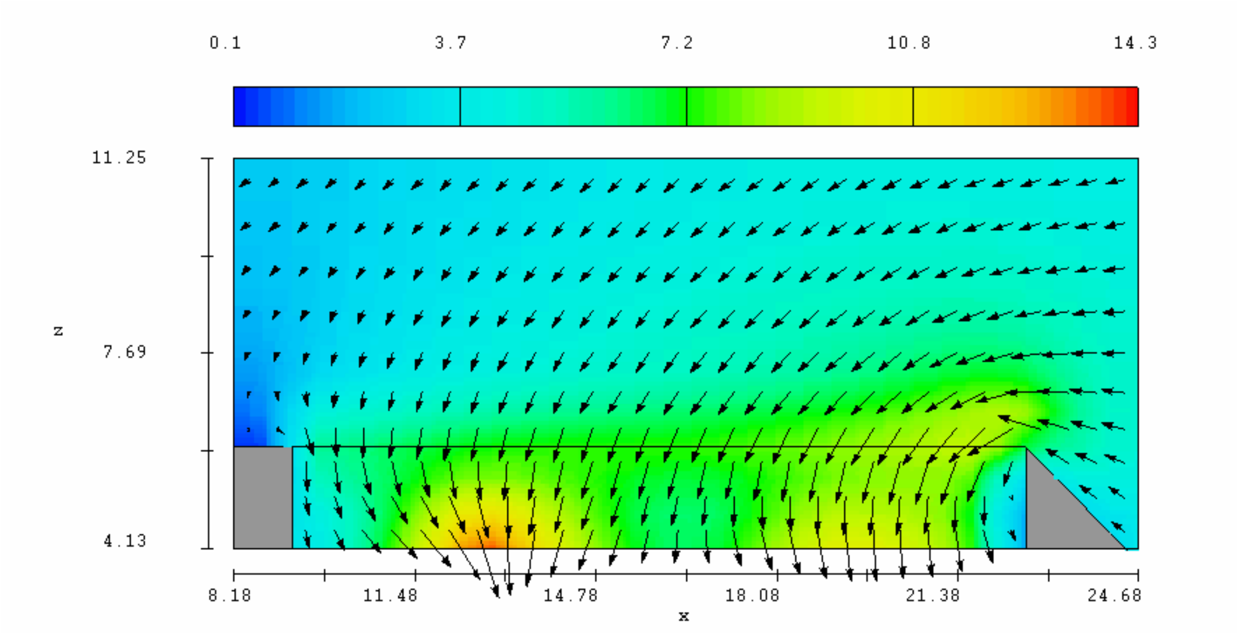

Figure 4-29
Case 2 – Unbounded Flow – Upstream Screen (Top)– Vectors colored by speed (inches/second). Flow moves from right to left in all frames.

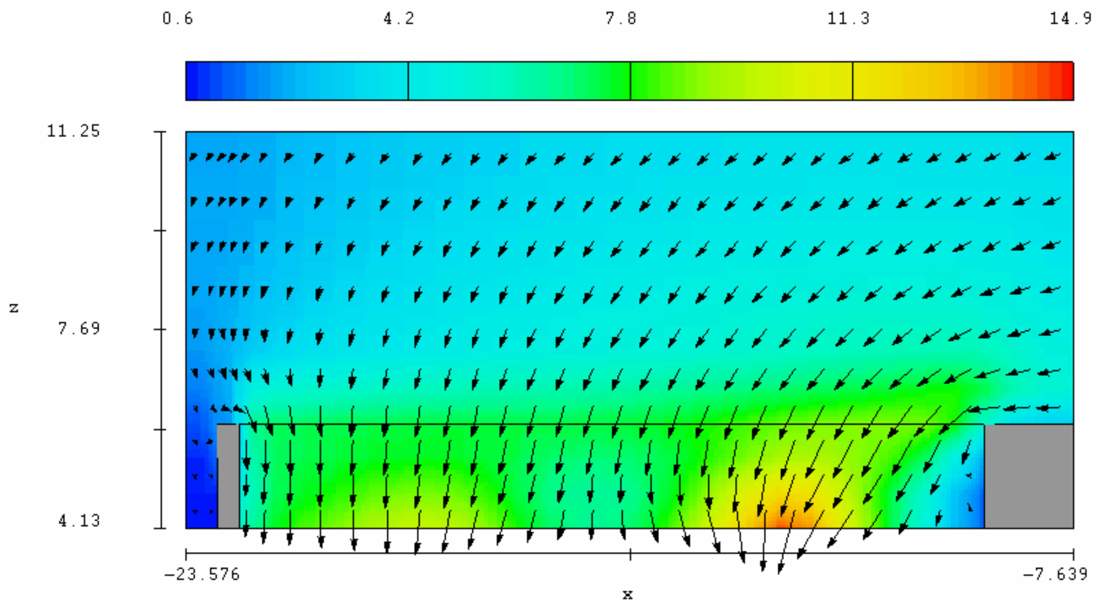

Figure 4-30
Case 2 – Unbounded Flow – Downstream Screen (Top)– vectors colored by speed (inches/second). Flow moved from right to left in all frames.

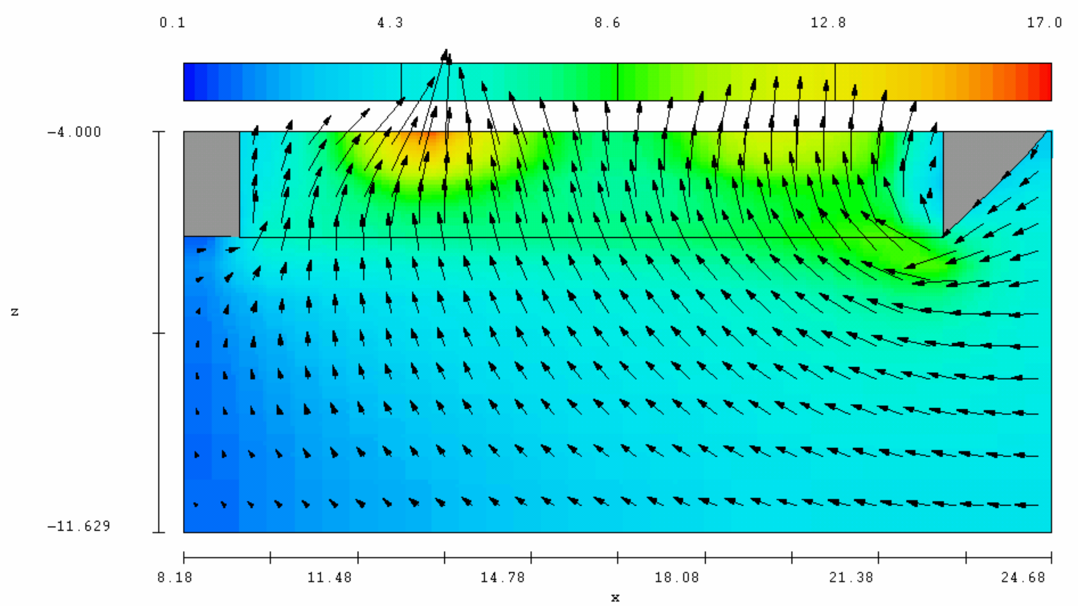

Figure 4-31
Case 2 – Unbounded Flow – Upstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

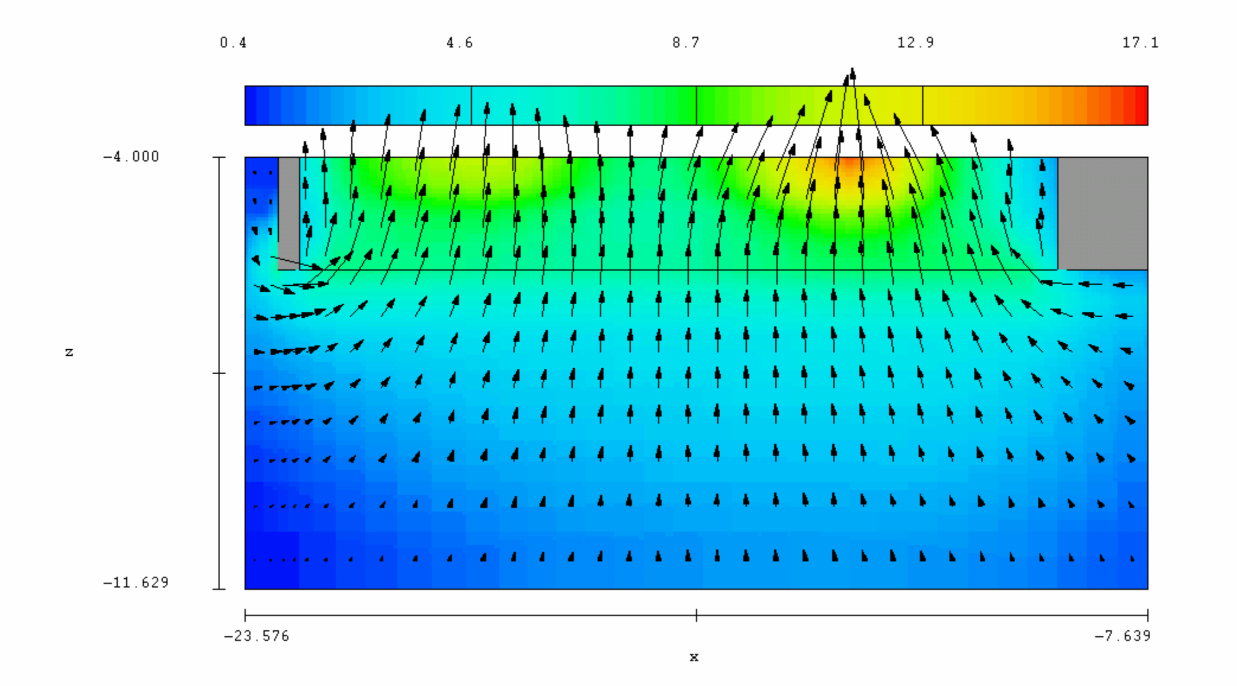

Figure 4-32
Case 2 – Unbounded Flow – Downstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

Test Case 3 (H/H)

A high approach velocity (15.2 cm/s) and a high withdrawal rate (0.1 m^3/sec) were evaluated for Test Case 3. Graphic results from this test case appear in Figures 4-33 through 4-37 for the bounded condition and Figures 4-38 through 4-42 for the unbounded condition.

Figures 4-33 and 4-38 were produced from data that were sampled along the vertical plane of symmetry (*i.e.,* the vertical plane down the center of the flume). Areas where the flow direction is downstream are colored blue and areas where the flow direction is upstream are colored red. The regions flow moving upstream occurred in the same locations for the bounded and unbounded scenarios, indicating that the flow is moving in a similar manner for both conditions.

Figures 4-34 and 4-39 contain vector plots for the bounded condition where the background has been colored by the velocity of the flow. The data used to produce the plots was sampled along the top of the upstream portion of the screen. The distribution of flow shown in both frames is essentially the same. Figures 4-35 and 4-40 contain vector plots produced for the unbounded condition from data sampled along the top of the downstream screen that is part of the structure. Again, the distribution of flow in these frames is nearly identical under both bounded and unbounded conditions.

Figures 4-36 and 4-41 contain vector plots for the bounded condition produced from data sampled along the bottom of the upstream portion of the screen. The computed flow fields shown in both figures are very similar. Figures 4-37 and 4-42 contain vector plots for the unbounded condition produced from data sampled along the bottom of the downstream screen structure. For this screen location, the direction of flow approaching the screens and the direction of flow at the screen face is nearly indistinguishable between the bounded and unbounded conditions.

Based on the analysis of the CFD models for this test case (i.e., flume flow is high and the screen withdrawal rate is high), the difference in computed flow fields between the bounded and unbounded flow conditions is negligible.

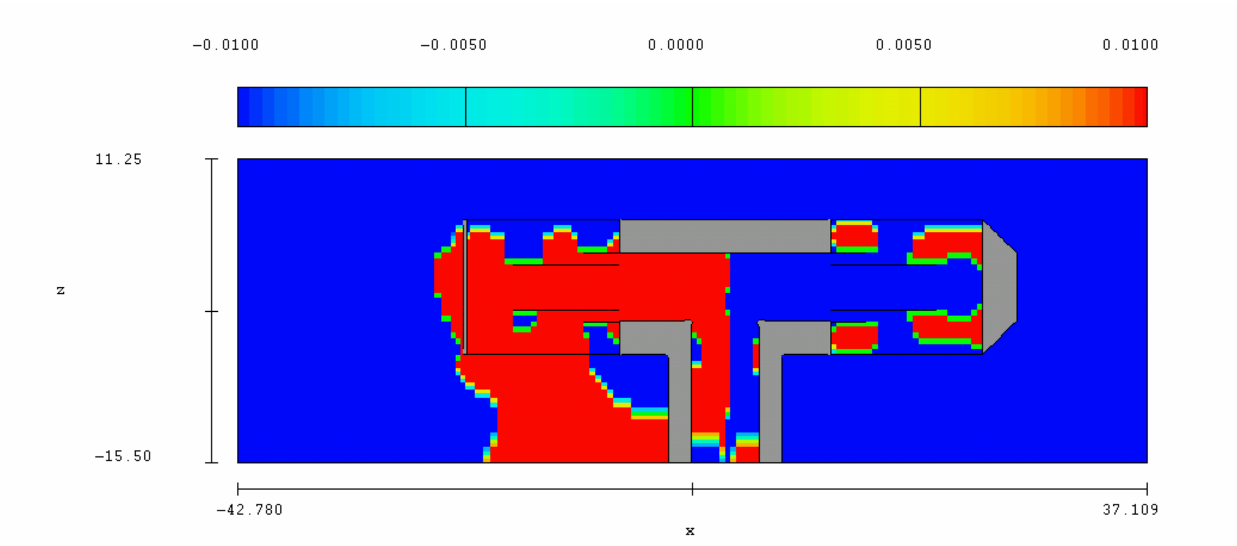

Figure 4-33
Case 3 – Bounded Flow - Direction of flow along vertical center plane [blue – downstream, red – upstream]. Flow moves from right to left.

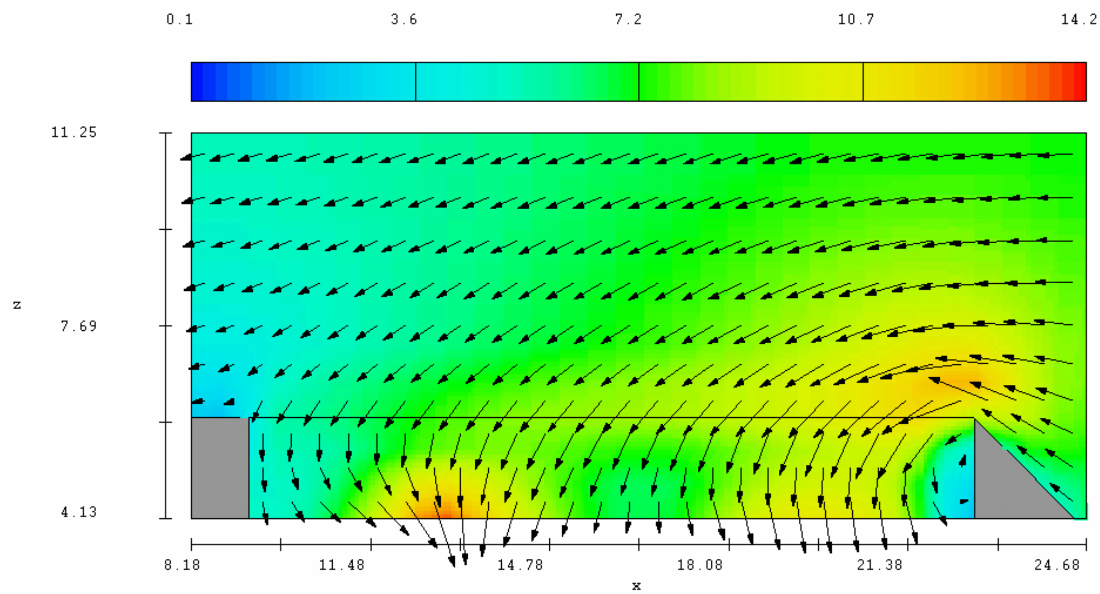

Figure 4-34
Case 3 – Bounded Flow – Upstream Screen (Top) – Vectors colored by speed (inches/second). Flow moves from right to left in all frames.

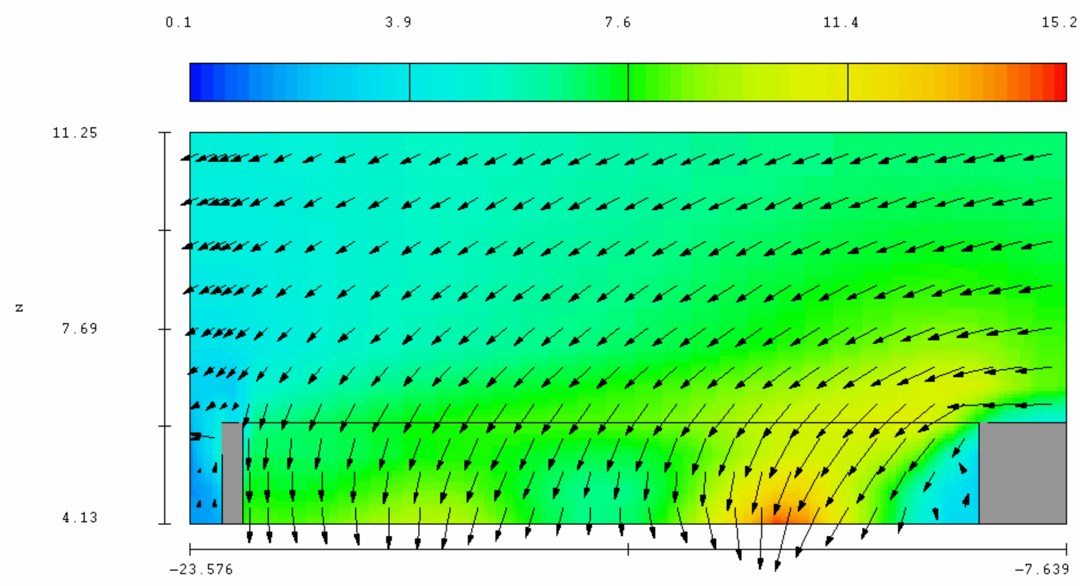

Figure 4-35
Case 3 – Bounded Flow – Downstream Screen (Top) – vectors colored by speed (inches/second). Flow moved from right to left in all frames.

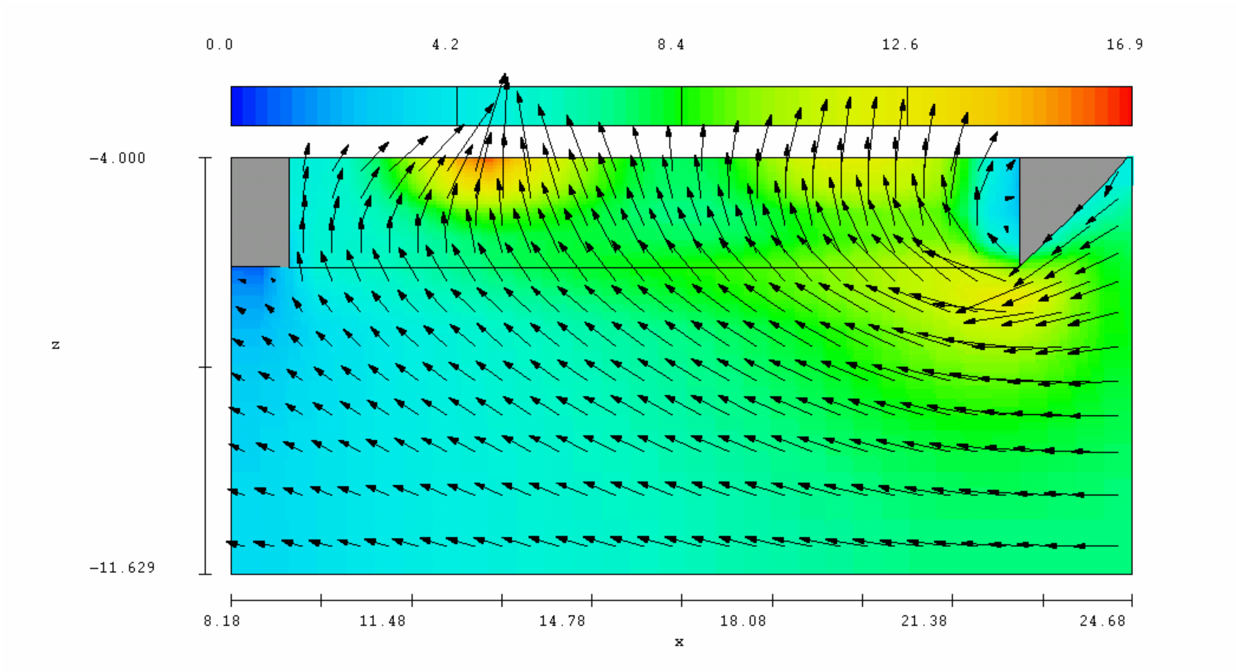

Figure 4-36
Case 3 – Bounded Flow – Upstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

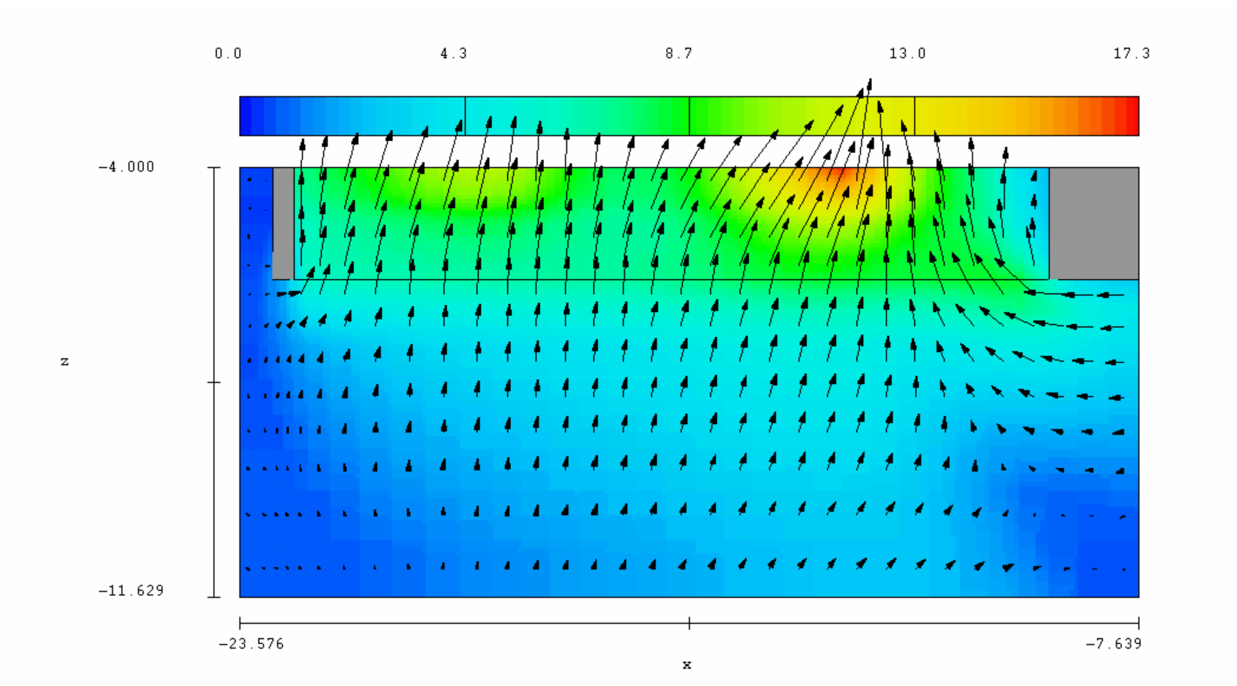

Figure 4-37
Case 3 – Bounded Flow – Downstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

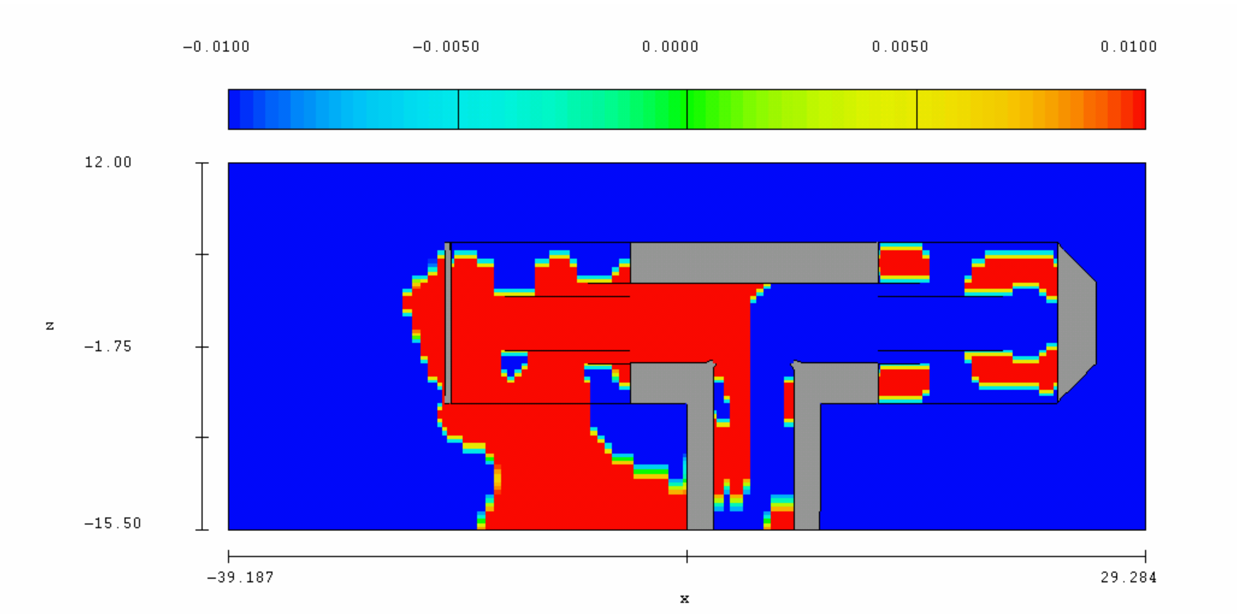

Figure 4-38
Case 3 – Unbounded Flow - Direction of flow along vertical center plane [blue – downstream, red – upstream]. Flow moves from right to left.

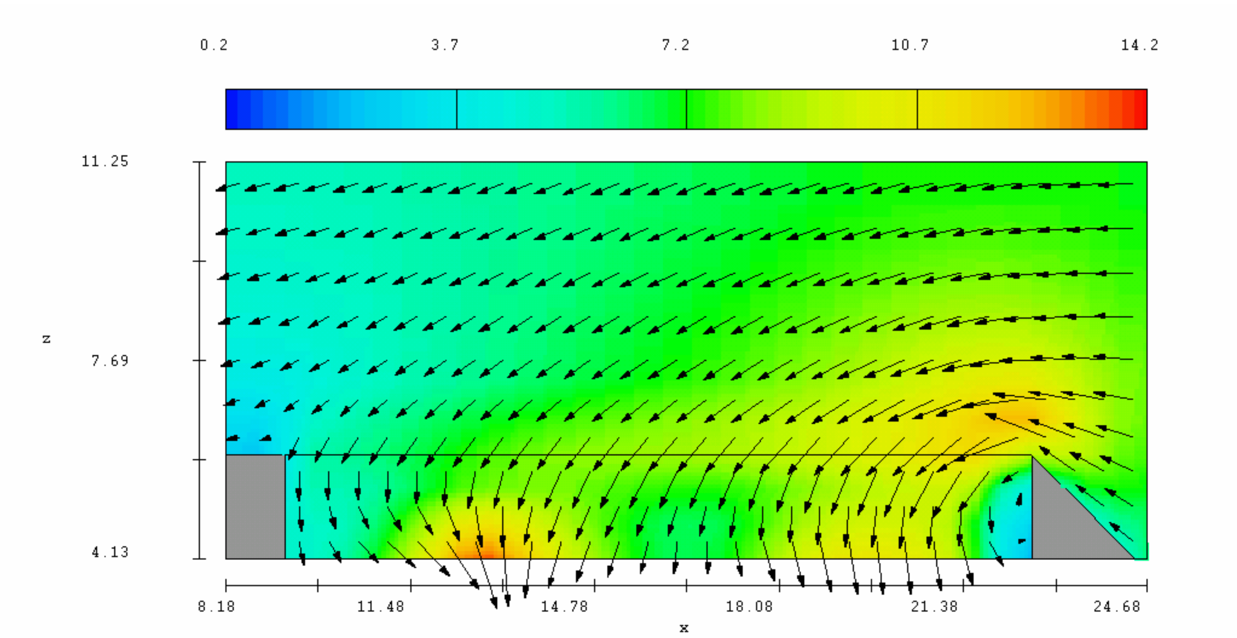

Figure 4-39
Case 3 – Unbounded Flow – Upstream Screen (Top)– Vectors colored by speed (inches/second). Flow moves from right to left in all frames.

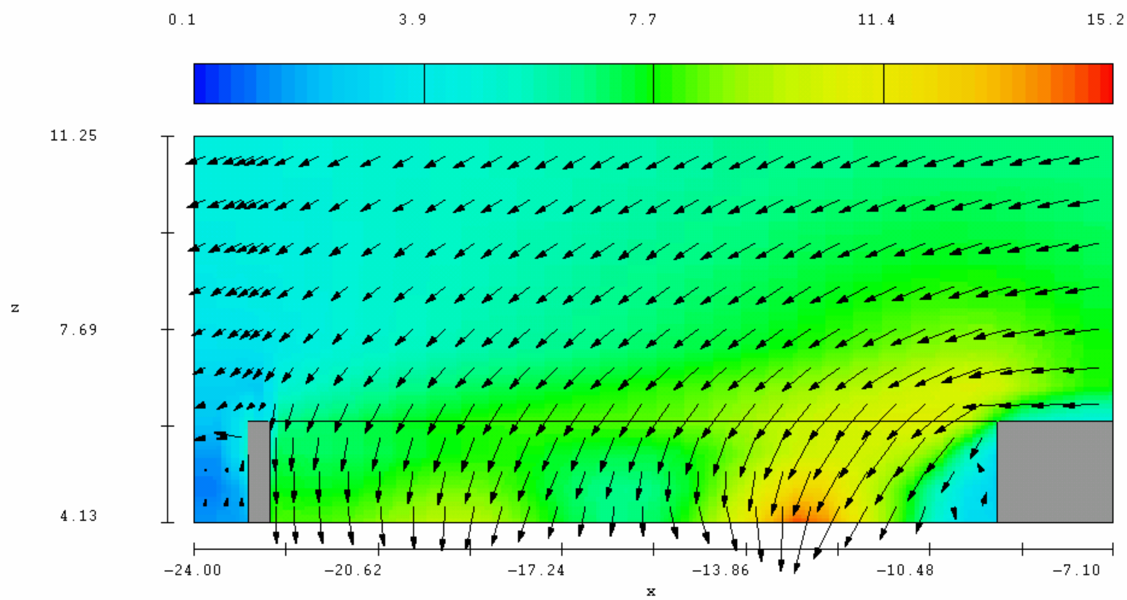

Figure 4-40
Case 3 – Unbounded Flow – Downstream Screen (Top) – vectors colored by speed (inches/second). Flow moved from right to left in all frames.

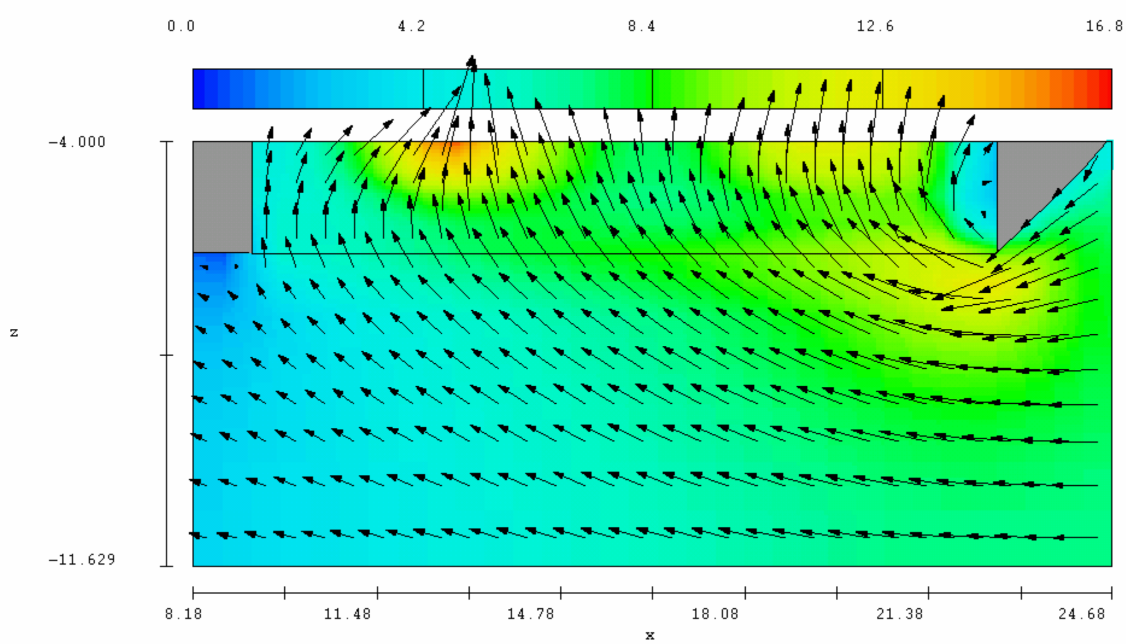

Figure 4-41
Case 2 – Unbounded Flow – Upstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

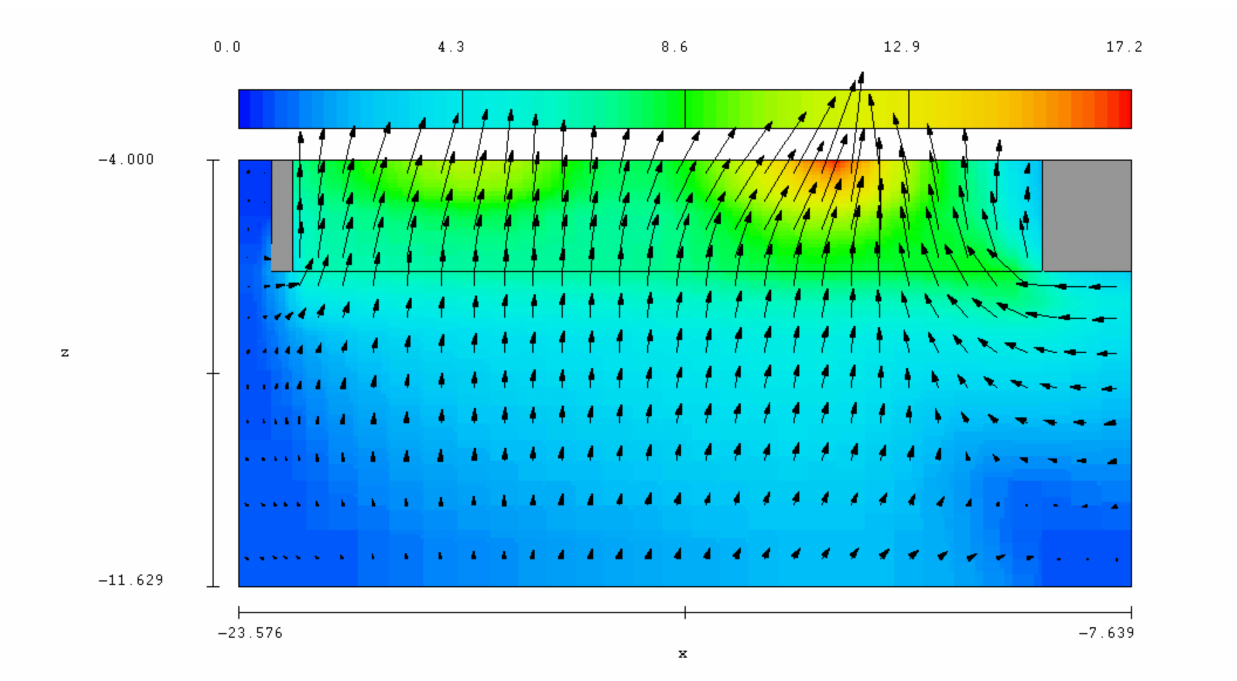

Figure 4-42
Case 2 – Unbounded Flow – Downstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left

Conclusions

The following conclusions are based on the results from the CFD numerical analyses of the wedgewire screens:

1. Flow patterns in the vicinity of the screening structure generally were not affected by the presence of the walls in the flume tests over the range of operating conditions studied. The only difference in calculated flow patterns was observed beneath the screening structure downstream of the standpipe for low flume flow rates. The area of re-circulation in this area was larger for the bounded flow scenarios than for the unbounded flow scenarios (especially when the flume flow rate was low [832 gpm in this analysis]). In the low flow scenarios, makeup water (available to the unbounded flows) fills in behind the standpipe and reduces the areas of recirculation.

2. For the high flume flow rate (1665 gpm), the appearance of the computed flow fields (bounded or unbounded) are similar even in the area downstream of the screening structure.

3. The location of the limiting streamline, calculated with Equation 1, does not intersect the flume walls for any of the test case operating conditions. Since this was the case, the trajectory of flow that enters the screening structure is not affected by the presence of the flume walls (at least to either side and above). If the width of the test flume was reduced, or if the withdrawal rate through the screening structure was increased, then the trajectory of

flow entering the screening structure could be changed and the similarity between bounded and unbounded flow patterns could be lost.

4. The magnitude and direction of flow occurring at the downstream end of each screen section (i.e., upstream and downstream cylinders) generally created conditions that were not conducive to minimizing entrainment and impingement of fish larvae and eggs. That is, velocities approaching the downstream region of each screen section were high and nearly perpendicular to the screen face. This observation from the CFD model was consistent with ADV measurements (magnitude and direction of flow) and impingement locations observed for eggs and larvae during biological testing.

Based on these conclusions, it is clear that the hydraulic conditions established in the flume used for biological tests are highly representative of the conditions that would exist in an open water environment. Therefore, the biological results can also be considered to be representative of those that would be expected in actual CWIS application for the species and life stages present. Additionally, the CFD results demonstrate that the downstream regions of each screen section are areas where aquatic organisms may be highly vulnerable to impingement and entrainment. Modifications to the screen design that create hydraulic conditions that facilitate downstream movement of larvae and eggs could lead to lower rates of entrainment and impingement.

5
CONCLUSIONS AND DISCUSSION

The biological evaluation of cylindrical wedgewire screens successfully identified several important relationships associated with the various factors that effect impingement and entrainment of aquatic organisms. However, these relationships were not always straightforward or easily detectable due to interactions among the test variables and the inability to collect data for all species and lifestages with all combinations of test conditions. The following are general conclusions from the analysis of the entrainment and impingement data that were collected:

- Impingement decreased with increases in slot size
- Entrainment increased with increases in slot size
- Entrainment and impingement increased with increases in through-slot velocities
- Entrainment and impingement decreased with increases in channel velocity
- Within a species, larval fish length did not appear to be a factor. However, with the exception of striped bass and winter flounder, the lengths of most species evaluated were within a narrow size range during testing. Additionally, multiple size groups were not evaluated with same test conditions, rather different conditions were evaluated as fish grew.

These conclusions support the results of most previous studies that have demonstrated similar trends in entrainment and impingement rates with respect to biological and design parameters evaluated. These conclusions also are consistent with what would be predicted based on screen hydrodynamics described by the CFD analysis, observations of larval swimming abilities, and physical constraints associated with the size of organisms in relation to slot width. The observed decreases in impingement can, in part, be attributed to greater susceptibility of organisms to entrainment as slot size increases. This also explains greater rates of entrainment at the larger slot sizes. That is, most larvae and eggs were physically excluded from passing through the 0.5 mm slot screen, but not the 1 and 2 mm screens. Physical exclusion resulted in higher impingement or bypass rates depending on slot velocity and channel velocity. Greater slot velocities resulted in increases in impingement and entrainment and greater channel velocities resulted in decreases. However, the data collected were not adequate to conclusively determine under what conditions one parameter had a stronger influence on impingement and entrainment rates compared to others.

Biological factors that can influence wedgewire screen impingement and entrainment rates include lifestage, size, and swimming ability. These factors are closely related given that as fish mature during early lifestages they grow larger and swimming ability improves. The development associated with size and swimming ability allows for greater physical and behavioral exclusion to occur. The most pronounced effect of lifestage is associated with differences between passive eggs and actively swimming larvae. The entrainment and impingement of eggs during our study were related to the size of eggs and hydraulic conditions that influenced downstream movement of eggs along the screen surface. Alewife eggs, which averaged 0.7 mm in diameter, did not impinge on the 0.5 mm slot screen, but were entrained at rates of 10 to 20% for the two channel velocities evaluated. The entrainment rate at the lower channel velocity was nearly 50% greater than at the higher velocity. In contrast to alewife, white sucker and surrogate striped bass eggs were not entrained, but were susceptible to impingement depending on the hydraulic conditions being evaluated. For both these species, egg impingement rates increased with slot velocity and decreased with channel velocity.

An evaluation of cylindrical wedgewire screens installed at an intake on the Hudson River determined that striped bass egg impingement and entrainment rates were relatively low compared to other species (EA Science and Technology 1986). These screens had a slot width of 0.5 mm, an intake velocity of 0.15 m/s, and were oriented parallel to ambient currents. These design features were all considered factors that contributed to reduced entrainment and impingement and are similar to the conditions that produced the best results with alewife, white sucker, and surrogate striped bass eggs during our laboratory evaluation.

Entrainment of surrogate striped bass eggs occurred only during tests with the 2 mm slot screen oriented perpendicular to the approach flow. The observed entrainment for these tests was probably due to eggs being forced through the screen slots by the approaching flow and by the intake flow. Hanson et al. (1978) concluded that approaching flow was the primary cause for entrainment of striped bass eggs evaluated with a 1 mm slot screen set perpendicular to the flow and with a slot velocity of 0.15 m/s. Most impingements we observed were located on the upstream face of the screen. Many eggs that passed over the screen were entrained and trapped in an eddy on the backside of the screen. Some of these eggs became impinged, while others remained in the swirling flow or eventually escaped the eddy and continued downstream. Hanson (1978) made similar observations of striped bass egg interactions with a cylindrical screen oriented perpendicular to the approaching flow; most impingements were recorded on the upstream face of the screen, while eggs that passed around the screen were swirled in an eddy on the backside. In an evaluation of axial (perpendicular screen) and radial (parallel screen) slot orientations, Hanson (1979) concluded that the axial orientation provided greater protection for striped bass eggs. Our results support this conclusion; we observed considerably greater impingement of surrogate eggs on the screen positioned parallel to the flow (radial slots) versus the perpendicular screen (axial slots) for test conditions evaluated with both orientations.

The effects of fish size on impingement and entrainment rates are associated with behavioral avoidance and physical exclusion (Hanson 1978, 1981; Zeitoun et al. 1981a; Weisberg 1987). Larger fish have a greater ability to actively avoid entraining flows and, depending on slot size, may be physically excluded from passing through screen slots. However, even though larger larvae may be less susceptible to entrainment as they grow, they may be more susceptible to impingement if they cannot avoid intake velocities and are too large to pass through slots. Previous studies suggest entrainment of fish between 5 and 10 mm in length can be low for screens with sufficiently small slot size (Hanson 1978; Browne 1979; Weisburg 1987) and that fish greater than about 10 mm can be protected by slot sizes as large as 2 mm. Depending on intake location and screen hydraulics, larger slot sizes may also be effective at minimizing entrainment due to low probabilities of vulnerable lifestages encountering screens, and the ability of those that do to actively avoid entrainment. An array of cylindrical wedgewire screens installed at an offshore intake located in Lake Michigan was determined to be effective at minimizing entrainment and impingement using a slot width of 9.5 mm (Zeitoun et al. 1981b). Comparisons of 9.5 mm slot screens to screens with 2 mm slots verified that the larger slot size was as effective as the smaller slot size in reducing entrainment and impingement for this particular installation (Zeitoun et al. 1981b).

Entrainment rates of species we evaluated with multiple slot sizes typically increased with slot width. The observed increases in entrainment at the larger slot sizes can be attributed to a lack of physical exclusion and behavioral avoidance for smaller fish (5-10 mm). Larger fish (>10 mm) also were entrained at the larger slot sizes (1 and 2 mm), but at lower rates than smaller larvae. Larger fish were capable of swimming along the screens, but when impinged, some were forced through the slots despite their physical size (body widths for all species evaluated averaged less than 2 mm, with exception of bluegill larvae which averaged 5.4 mm). Other studies also have identified a positive relationship between entrainment rates and slot size (Hanson 1978; Heuer and Tomljanovich 1978; Browne 1979; Weisburg et al. 1984, 1987). A slot width of 0.5 mm has been shown to be capable of preventing entrainment of most larvae and eggs (Browne 1978), whereas screens with slot widths 1 mm or greater have exhibited higher entrainment rates for fish less than 10 mm in length. Entrainment and impingement of fish greater than 10 mm in length have been effectively reduced for larger slots (1 mm or greater) (Hanson et al. 1978, 1981; Heuer and Tomljanovich 1979; Otto 1981). Our results also support the ability of screens with larger slot sizes to minimize entrainment and impingement of fish greater than 10 mm, as well as afford protection to smaller fish in the presence of hydraulic conditions that are conducive to carrying fish downstream.

Slot velocity had a considerable effect on impingement and entrainment rates for most species that we evaluated. Impingement and entrainment increased with slot velocity and this relationship was statistically significant for several of the species evaluated. Most previous research with cylindrical screens has been conducted with a slot velocity of 0.15 m/s, which was the recommended intake approach velocity criteria for minimizing entrainment and impingement of fishes at screening facilities at the time many studies were performed (Boreman 1977). However, our results demonstrate that a slot velocity as high as 0.3 m/s may be biologically effective for reducing entrainment and impingement, depending on fish size, slot width, and approach flow velocity.

Channel velocity (i.e., ambient current or approach flow) has been cited in past studies as an important parameter for minimizing entrainment and impingement of aquatic organisms exposed to wedgewire screens (Hanson 1978; Heuer and Tomljanovich 1978). Ambient currents produce a “sweeping” flow that carries aquatic organisms (and debris) along a screen until they are safely away from the influence of the intake flow. Our evaluation demonstrated that this sweeping flow can effectively carry larvae and eggs downstream even when they are extremely close to or contacting a screen’s surface. The effectiveness of ambient currents to move fish and eggs past a screen will depend on several factors, including the distance of an organism from the screen surface, slot velocity and width, and the size and swimming ability of exposed organisms. The results of our study demonstrate that the ability of approaching flow to effectively carry fish and eggs that are in close contact with a screen decreased at higher slot velocities and larger slot widths and increased for larger fish and eggs.

Because increasing through-slot velocities typically result in greater entrainment and impingement rates and ambient velocities have the opposite effect, optimizing the ratio of ambient velocity to slot velocity should improve the biological effectiveness of wedgewire screens for any given slot size (i.e., larger ratios lead to greater protection). We demonstrated that as this ratio increases, entrainment and impingement rates decrease. Optimum ratios of ambient to slot velocity may need to be greater for smaller larvae (< 10 mm) and eggs and for larger slot sizes through which organisms are more likely to pass if a screen is contacted. A high ambient velocity to slot velocity ratio has been cited previously as a means to reduce entrainment and impingement (Hanson et al. 1978).

Our results supported many previous conclusions regarding biological and engineering factors, and their relationships with one another, that are important in minimizing entrainment and impingement rates associated with wedgewire screens. Cylindrical wedgewire screens should be designed using hydraulic and biological criteria that will minimize impacts to the lifestages and species that are targeted for protection. One approach to this goal would be to address each screen design parameter separately (e.g., minimize slot velocity and width, maximize approach velocity). However, a more prudent approach would be to consider the interaction between design parameters as they relate to the species and lifestages that will be susceptible to entrainment and impingement. For example, a slot width that excludes all sizes of fish and eggs that will be exposed to a screen may not be required if sweeping velocities are sufficiently high and slot velocities sufficiently low that exposed organisms are carried away. Similarly, if a screen is located in an area where only larger fish are located, larger slot sizes or higher slot velocities may not contribute to greater rates of entrainment or impingement.

The orientation of cylindrical wedgewire screens to approaching flow also may influence entrainment and impingement rates. During our study, only striped bass larvae and surrogate eggs were evaluated with the screens both perpendicular and parallel to the channel flow. For surrogate eggs, no or minimal entrainment occurred with both orientations at the two larger slot sizes (1 and 2 mm), but impingement rates generally were lower with the perpendicular orientation. Striped bass larvae impinged at low to moderate rates during tests with the 0.5 mm slot screen parallel to the flow. In contrast, larvae impinged on the 0.5 mm screen positioned perpendicular to the flow, but did not become entrained. Impingement of both eggs and larvae during tests with the perpendicular screens was probably the result of channel flow approaching directly into the face of the screen. That is, fish and eggs were forced onto the screens by the approaching flow, without a "sweeping" flow to move them along the surface of the screens, as is the case when screens are positioned parallel to the channel flow. Hanson (1978) also attributed striped bass egg and larval entrainment to the direction of ambient flow against the surface of a perpendicular screen. Our results also demonstrate that perpendicular screens appear to offer greater protection to eggs and parallel screens provide better protection for larvae. Hanson (1979) reported similar observations from tests with striped bass that were exposed to radial and axial slots, which are comparable conditions to our tests of parallel (axial) and perpendicular screen orientations (radial).

Although screen orientation has differed among previous studies, the data that have been reported are difficult to compare due to differences in other design parameters and species and/or lifestages evaluated. Future evaluations (biological and CFD) would be useful in assessing the relationship between entrainment and impingement rates and screen orientation to the direction of ambient currents.

The CFD evaluation of the wedgewire screen was able to demonstrate that the bounded flume environment produced hydrodynamic conditions for the wedgewire screens that were comparable to what would be encountered in an unbounded field application. Subsequently, the results of the biological evaluation should be representative of those expected with larvae and eggs in the field that approach cylindrical screens near the centerline and pass close to the screen surface as they move downstream. Visual observations of surrogate striped bass eggs, white sucker eggs, and most larvae verified that they were following the flow paths that were defined in the CFD model and described by the ADV measurements recorded in the flume around the screens. In particular, the CFD and ADV data indicated that impingements would most likely occur at the downstream end of each screen section (i.e., high velocities moving almost directly into the screen with very little sweeping flow). The impingement locations of surrogate eggs and white sucker eggs matched these predictions. The CFD analysis and ADV measurements also indicate that the biological evaluation results represent a worst case scenario because larvae and eggs were released at a location that kept them in close contact with the screens (i.e., within several centimeters of the screen surface) where the influence of intake flow velocity and direction on aquatic organisms would be at its greatest. The potential for intake velocity and flow direction to affect passing organisms appears to dissipate quickly over a relative short distance from the screen surface (about 0.5 m). Therefore, risk to entrainment and impingement also probably decreases rapidly for larvae and eggs as distance from the screen increases.

Based on the estimates of entrainment and impingement for larvae and eggs, protection of aquatic organisms using cylindrical wedgewire screens will be optimized by minimizing slot size and slot velocity and maximizing ambient currents approaching a screen or screen array. Design and operation criteria that result in optimization of these parameters will be dependent on the target species and lifestages. Older and larger organisms will not require as stringent criteria as younger and smaller organisms that do not possess the size or swimming ability to avoid impingement and entrainment. Additionally, not all parameters may need to be optimized for effective protection of fish and eggs. Field studies indicate that intake location also will be important in determining design criteria (Zeitoun et al. 1981b). Specifically, using less than optimum slot size and velocity criteria may be appropriate if wedgewire screens are located where species and lifestages that are potentially susceptible to entrainment and impingement are not abundant.

The data that were gathered during the biological and CFD evaluations of cylindrical wedgewire screens clearly demonstrate that this technology can effectively protect early lifestages of fish from entrainment and impingement when designed according to appropriate biological and hydraulic criteria. Future studies, whether conducted in the laboratory or field, should focus on interrelationships among a smaller set of design criteria or for specific species and lifestages. Such studies will provide more specific descriptions and a better understanding of the relationships between biological and engineering design parameters that maximize fish protection effectiveness. This information will help advance the use of wedgewire screens at sites where they can be effectively operated from both a biological and engineering standpoint.

6
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A
WATER QUALITY DATA – 2001

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
4/21/2001	2000	1	15							
4/22/2001		1	14							
4/23/2001	900	1	15							
4/23/2001	1715	1	16							
4/24/2001	1015	1	15		8.2	7	0.6	0.004	40	52
4/25/2001	910	1	15		8	7	0.6	0.004	48	42
4/25/2001	1600	1	14							
4/26/2001	906	1	14		7.8	7	0.1	0.012	48	50
4/26/2001	1618	1	14							
4/27/2001	817	1	14		9.1	7	0.8		50	74
4/27/2001	1325	1	14							
4/30/2001	1346	2	20							
4/30/2001	1346	3	14							
4/30/2001	1346	4	14							
5/1/2001	1112	2	16		7.8					
5/1/2001	1112	3	18		6.2					
5/1/2001	1349	4	19		5.8					
5/1/2001	1349	5	18		9.1					
5/1/2001	1505	1	12		5.2					
5/2/2001	1110	1	16			8.59				
5/2/2001	1110	2	16.8			7.78				
5/2/2001	1110	3	16.3			7.72				

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
5/2/2001	1113	4	18.6			7.74				
5/2/2001	1113	5	18.5			7.77				
5/3/2001	809	4	22.4		5.8	7.34	0.2		42	62
5/3/2001	840	5	20		7	7.55	0.4		56	56
5/4/2001	945	5	19		7.4	7.21	0.6		52	56
5/4/2001	1000	4	18.5		8	6.85	0.4		42	64
5/5/2001	1630	4	16.5							
5/5/2001	1630	5	16.5							
5/6/2001	1539	5	13.5		5.4	7.2	0.5			
5/6/2001	1545	4	14			7.2	0.4			
5/7/2001	823	4	15.9		7.6	7.8	0.4		66	84
5/7/2001	823	5	16.1		8.1	8	0.5		56	68
5/8/2001	925	5	12.7		9.6	7.9	0.6		68	64
5/9/2001	830	2	15.6		8.2	8.16	0.2		90	72
5/9/2001	830	3	16		7.8	8.01	0.2		92	66
5/9/2001	830	5	14.9		7.8	8.03	0.4		76	80
5/10/2001	830	2	15.8		7.8	8.22	0.2		84	
5/10/2001	830	3	15.3		7.8	8.36	0.2		96	
5/10/2001	830	5	14.7		7.8	8.02	0.4		80	
5/11/2001	828	2	16.7		8	8.21	0.2		70	
5/11/2001	835	3	16.9		8.2	8.28	0.2		80	
5/11/2001	830	5	15.7		8.4	8.07	0.4		62	
5/12/2001	910	2	17.5		7.4	8.16	0.3		70	
5/12/2001	910	3	17.7		8.2	8.29	0.2		82	
5/12/2001	910	5	18.4		8	8.17	0.4		68	
5/13/2001	1435	2	17		7	8	0.3		72	
5/13/2001	1435	3	17.4		7.2	8.2	0.5		78	

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
5/13/2001	1435	5	18.1		8	8.13	0.4		64	
5/14/2001	840	5	17.8		8	8.02	0.4		60	
5/15/2001	945	2	15.2		8	7.96	0.4		50	
5/15/2001	945	3	15.6		7.2	7.86	0.4		50	
5/15/2001	945	5	17.8		7.2	7.69	0.4		42	
5/16/2001	930	2	16.2		8	7.65	0.4		44	
5/16/2001	950	3	16.2		8	7.72	0.2		46	
5/16/2001	1342	5	17.7		8.2	7.74	0.4		44	
5/17/2001	1105	2	16		7.2	7.54	0.4		24	
5/17/2001	1105	3	16		6.4	7.2	0.4		28	
5/17/2001	1105	5	18		7.8	7.59	0.2		26	
5/18/2001	1051	5	18.1		8	7.62	0.2		22	
5/18/2001	1110	3	16.9			7.56	0.4		28	
5/18/2001	1129	2	16.6			7.7	0.2		22	
5/19/2001	1600	3	18							
5/20/2001	1930	5	18							
5/20/2001	1930	3	17							
5/21/2001	836	3	16			7.65	2		30	48
5/22/2001	836	3	16.1			7.75	0.8		38	50
5/23/2001	826	1	13.2			8.21	0.4		128	68
5/23/2001	826	2	13.2			8.32	0.4		140	84
5/23/2001	826	3	15.5			8.11	0.6		72	60
5/24/2001	845	1	13			8.34	0.4		112	76
5/24/2001	845	2	13.1			8.46	0.2		112	64
5/24/2001	845	3	15.4			8.36	0.6		96	60

B
WATER QUALITY DATA – 2002

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
2/27/2002	0:00	1	16.00			6.8			26	46
2/27/2002	0:00	1		27.8		7.3			340	278
3/4/2002	9:15	1	10.60	28	8.27	7.5	0	0	362	252
3/4/2002	13:25	FLUME	7.10	2.9	11.72	6.5	0	0	50	80
3/5/2002	9:00	2	10.20	25	8.39	7.5	0	0	320	230
3/5/2002	9:35	3	9.50	27.5	8.58	7.5	0	0	284	222
3/6/2002	9:30	2	11.10	27.8	8.39	8	0	0	218	340
3/7/2002	8:10	2	12.10	27.8	8.11	7.5	0	0	260	210
3/8/2002	8:10	3	10.90	27.3	8.33	7.5	0	0	235	200
3/8/2002	8:20	FLUME	8.90	19.3	9.85	6.5	0	0	40	24
3/9/2002	11:30	3	13.00	28.4	7.71	7.5	0	0	320	200
3/10/2002	15:15	3	12.70	28.5	7.82	7.5	0	0		
3/11/2002	8:00	3	9.90	28.5	8.73	7.5	0	0	280	230
3/11/2002	8:15	FLUME	10.50	19.5	8.9	6.5	0	0	55	45
3/12/2002	8:06	3	10.10	28.5	9.45	7.5	0	0	308	210
3/12/2002	8:25	FLUME	9.90	19.8	9.03	6.5	0	0	40	54
3/13/2002	7:30	4	10.50	29	9.53	7.5	0	0	300	232
3/13/2002	7:55	FLUME	9.70	19.8	8.67	6.5	0	0	40	46
3/14/2002	8:10	4	10.90	29	8.2	7.5	0.4	0.00229	260	220
3/14/2002	8:35	FLUME	10.00	19.6	8.84	6.5	0	0	40	144
3/15/2002	8:10	3	11.40	29	8.09	7.5	0	0	288	220
3/15/2002	8:40	FLUME	10.30	19.7	8.54	6.5	0	0	50	54

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
3/15/2002	10:30	TROUGH		26.6					120	200
3/16/2002	11:15	3	11.30	29.2	7.99	7.5	0.8	0.0037	308	224
3/17/2002	19:30	3	11.00	29.2	8.33	7.5	1	0.005		
3/18/2002	7:30	3	11.10	29.2	8.12	7.5	0.8	0.0037	290	243
3/18/2002	7:50	FLUME	9.70	19.7	8.86	7	0	0	35	42
3/19/2002	8:10	4	10.50	29.1	8.51	7.5	0.8	0.0037	272	244
3/19/2002	8:26	FLUME	9.10	19.5	8.82	6.5	0	0	50	40
3/20/2002	7:30	FLUME	9.10	19.7	9.07					
3/20/2002	7:35	4	11.20	29	7.91	7.5	0.6	0.0037		
3/21/2002	8:11	3	11.50	29	8.2	7.5	0.8	0.0037		
3/21/2002	8:17	FLUME	10.20	19.2	8.85					
3/22/2002	8:10	4	10.10	29	8.22	7.5	0.8	0.0037	300	284
3/22/2002	8:20	FLUME	9.40	19.3	9.11					
3/23/2002	11:37	3	8.80	28.9	8.37	7.5	1	0.005	264	400
3/24/2002	12:30	3	9.30	29	8.3	7.5	1	0.005	262	248
3/25/2002	7:30	3	9.60	28.9	8.34	7.5	1	0.005	272	
3/25/2002	7:45	FLUME	9.19	19.2	7.7					
3/27/2002	7:40	3	11.30	28.7	8.12	7.5	1	0.005		
3/27/2002	12:00	FLUME	9.00	19	9.35					
3/28/2002	8:14	3	10.60	28.9	8.62	7.5	1	0.005		
3/28/2002	8:24	FLUME	8.70	19	9.52					
3/29/2002	8:14	4	10.80	28.8	8.41	7.5	1	0.005	280	230
3/29/2002	8:31	FLUME	9.10	18.5	9.44					
3/30/2002	15:00	4	11.30	28.5	8.14	7.3	1	0.005		
3/31/2002	18:30	4	11.20	29.2	8.13	7.5	1	0.005		
4/1/2002	7:30	FLUME	10.00	18.6	8.94					
4/1/2002	7:35	3	11.40	29	7.83	7.5	1	0.005		

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
4/2/2002	8:08	4	10.00	27.9	8.86	7.5	1	0.005	270	255
4/2/2002	8:28	FLUME	9.90	18.5	9.27					
4/3/2002	7:30	FLUME	10.40	18.4	9.09					
4/3/2002	7:35	4	11.20	27.4	8.04	7.5	0.8	0.0035		
4/4/2002	8:13	3	11.10	27.1	8.59	7.5	0.6			
4/4/2002	8:23	FLUME	10.60	18.3	8.84					
4/5/2002	13:13	4	11.00	26.7	8.5	7.5	0.2			
4/9/2002	8:09	3	11.10	0.3	10.24	6.7	0	0	50	120
4/10/2002	8:26	4	11.20	0.3	9.9	6.7	0	0	62	120
4/11/2002	8:39	4	11.10	0.3	10.11	6.7			78	108
4/12/2002	8:11	4	11.00	0.3	10.34	6.7			72	100
4/12/2002	8:13	FLUME	9.50	0.2	10.71					
4/13/2002	8:30	4	11.20	0.3	10.08	7			72	104
4/14/2002	10:20	4	11.10	0.3	9.81	7			160	124
4/15/2002	8:04	3	11.20	0.3	10.03	6.7			80	140
4/15/2002	8:16	FLUME	12.60	0.3	10.02					
4/16/2002	8:00	4	11.20	0.3	9.86	6.7			72	110
4/17/2002	16:30	4	11.40	0.4	9.3	6.7			74	120
4/18/2002	8:10	4	11.20	0.4	9.82	6.7			68	175
4/19/2002	8:05	4	11.30	0.4	9.97	6.7	0	0	64	124
4/19/2002	8:05	FLUME	16.30	0.2	8.78					
4/20/2002	16:50	4	11.30	0.4	9.97	7	0	0	64	126
4/22/2002	8:05	3	11.40	0.4	10.07	6.7	0	0	80	130
4/22/2002	8:47	FLUME	14.70	0.2	7.96					
4/23/2002	10:00	1	11.10	0.4	9.87	6.5			60	116
4/24/2002	8:40	2	11.20	0.4	9.71	6.5			76	120
4/25/2002	8:15	4	11.30	0.4	9.47	6.5	0	0	75	150

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
4/25/2002	8:30	FLUME	11.80	0.2	8.53					
4/26/2002	8:28	3	11.00	0.6	9.4	6.5	3	0.0057	60	123
4/26/2002	8:45	FLUME	11.80	0.2	9.36					
4/27/2002	14:05	4	11.20	0.5	9.56	6.5	3	0.0057	78	123
4/28/2002	11:25	3	11.30	0.5	9.79	7	3	0.0057	64	142
4/29/2002	8:34	3	11.60	0.5	9.71	6.5	3	0.0057	60	108
4/29/2002	8:50	FLUME	12.00	0.2	9.15					
4/30/2002	8:21	4	11.30	0.4	9.19	6.5	3	0.0057	55	123
4/30/2002	8:38	FLUME	11.60	0.2	9.1					
4/30/2002	10:45	6	11.50	0.2	11.76	6.5			44	96
5/1/2002	8:15	1	11.40	0.4	9.48	6.5	3	0.0057	37	130
5/1/2002	8:30	FLUME	11.80	0.2	9.12					
5/1/2002	8:34	6	12.10	0.2	9.54		0	0		
5/2/2002	8:13	4	11.40	0.4	9.05	6.7	3		48	120
5/2/2002	8:15	6	11.50	0.2	9.56	6.8	0	0	64	100
5/2/2002	8:17	FLUME	12.00	0.2	9.04					
5/3/2002	8:10	4	11.30	0.4	8.68	7	3		78	110
5/3/2002	8:10	6	11.80	0.2	9.34					
5/3/2002	8:10	FLUME	11.90	0.2	8.82					
5/4/2002	10:30	3	11.00	0.6	9.8	6.5	3		63	200
5/4/2002	10:30	8	10.70	0.2	10.01	6.5	1	0.0027	68	106
5/5/2002		4	11.30	0.8	9.7					
5/5/2002		6	12.70	0.3	9.34					
5/6/2002	8:00	2	11.10	0.8	9.94	7	3			210
5/6/2002	8:15	7	12.50	0.2	9.49	6.5	0	0		123
5/7/2002	8:22	4	11.10	1.1	9.94	7	3			220
5/7/2002	8:34	8	14.70	0.3	8.82	6.5	1	0.0027		117

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
5/8/2002	10:22	4	11.20	1.2	9.16	7	3		90	217
5/8/2002	10:34	6	15.70	0.3	8.77	5.5	0.4			140
5/9/2002	11:46	4	11.20	1.4	10.01	7	3	0.0057	90	200
5/10/2002	10:34	6	13.60	1.8	9.25					
5/10/2002	11:26	4	11.30	1.5	9.73		3			
5/11/2002	13:39	4	11.00	1.4	10.03	7	3		70	200
5/13/2002	7:50	3	11.00	1.3	9.94	7	3		80	200
5/13/2002	8:09	6	12.00	1.8	9.51	7	0	0	90	200
5/13/2002	13:59	6	12.20	1.8	9.49	7	0.2	0.0003		
5/13/2002	14:15	7	12.10	1.7	9.43	6.5	0	0		
5/14/2002	9:58	4	10.80	1.1	9.51	6.5	3	0.0057	78	160
5/14/2002	13:03	2	10.90	1	9.54	6.5	2.5	0.0047	88	180
5/14/2002	13:40	6	12.50	0.3	9.2	6.5	0	0	84	120
5/14/2002	13:44	7	12.60	1.5	9	6.5	0	0	88	128
5/14/2002	13:47	8	12.20	0.4	9.21	6.5	0	0	76	108
5/15/2002	13:06	2	11.30	1	9.78	7	2.5	0.0047	72	164
5/15/2002	13:10	6	11.30	0.3	9.63	6.5	0	0	72	116
5/16/2002	8:00	3	11.80	0.8	9.92	7	2	0.0038	80	140
5/16/2002	8:18	6	12.20	0.5	9.6	7	0	0	95	105
5/17/2002	10:15	3	11.00	0.9	9.75	7	3	0.0057	76	136
5/17/2002	10:15	7	12.20	0.7	9.61	6.5	0	0	85	108
5/20/2002	7:51	4	11.20	1	10.06	7	3	0.0057	63	143
5/20/2002	8:08	6	11.50	0.7	9.62	7	0	0	70	107
5/21/2002	13:16	4	11.20	1.2	9.8	7	3	0.0057	80	150
5/21/2002	13:40	7	12.40	1	9.27	6.5	0	0	57	130
5/22/2002	13:11	1	11.20	1.2	9.7	6.5	0	0	68	140
5/22/2002	13:39	9	12.40	1.1	9.36	7	0	0	50	120

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
5/23/2002	11:40	3	11.20	1.3	9.89		3	0.0057	64	132
5/23/2002	11:40	8	12.20	1.1	9.56		0.2	0.0003	40	120
5/24/2002	13:19	6	12.50	1.2	9.4		0.2	0.0003	45	129
5/24/2002	13:23	2	11.10	1.3	9.66		3	0.0057	49	148
5/26/2002	14:42	4	11.00	1.5	9.84		2	0.0038	55	145
5/26/2002	14:57	7	12.50	1.3	9.38		0	0	40	137
5/27/2002	9:15	4	11.10	1.5	9.73		2.5	0.0047	40	136
5/27/2002	9:15	7	12.40	1.3	9.55		0.2	0.0003	36	120
5/28/2002	8:20	1	11.40	1.5	9.43	7	2	0.0038	43	130
5/28/2002	8:30	8	12.30	1.3	9.02	7	0.2	0.0003	30	140
5/29/2002	8:15	2	11.20	1.4	9.41	6.5	1.5	0.0028	50	155
5/29/2002	10:30	6	12.60	1.2	9.13	6.5	0.2	0.0003	70	115
5/30/2002	13:29	7	13.00	1.2	9	7	0	0	69	148
5/30/2002	13:34	1	11.40	1.2	9.26	7	0.9	0.0017	42	172
5/31/2002	14:32	1	11.50	1.1	9.2	6.5	0.8	0.0015	40	148
6/1/2002	11:00	4	11.10	1.1	9.26	6.5	0.2	0.0003	35	150
6/3/2002	8:15	4	11.10	1.7	9.5	7	0.2	0.0003	42	200
6/3/2002	13:20	FLUME	18.00	0.2	6.4	6.5	0	0	32	58
6/4/2002	8:20	4	11.30	1.7	9.48	7	0.2	0.0003	85	250
6/5/2002	8:15	1	17.80	1.7	7.9	7	0.2	0.0008	80	223
6/5/2002	8:45	FLUME	17.20	0.2	7.4					
6/6/2002	8:25	4	18.40	1.6	7.79	7	0.2	0.0008	70	220
6/6/2002	8:45	FLUME	17.70	0.2	7.33					
6/7/2002	8:20	4	10.90	1.5	9.51	6.7	0.2	0.0003	75	220
6/7/2002	8:30	FLUME	17.00	0.2	7.45					
6/9/2002	15:30	4	14.90	1.5	8.54	6.7	0.2	0.0005	78	220
6/10/2002	8:23	4	15.30	1.5	8.52	6.7	0.2	0.0005	78	217

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
6/10/2002	8:35	FLUME	16.40	0.2	7.06					
6/11/2002	13:47	4	16.90	1.5	8.12					
6/12/2002	10:30	4	16.30	1.5	8.22	6.7	0.2	0.0005	70	
6/13/2002	11:00	4	14.80	1.5	8.5	6.7	0.2	0.0005	80	
6/14/2002	8:18	4	15.30	1.5	8.49	6.7	0.2	0.0005	80	
6/16/2002	12:10	4	14.50	1.5	8.47	6.5	0.2	0.0005	80	
6/17/2002	11:40	1	12.30	1.5	8.23	6.7	0.2	0.0005	80	
6/18/2002	15:30	4	16.30	1.5	8.24					
6/19/2002	10:27	4	13.90	1.5	9.01	6.7	0.2	0.00025	70	
6/20/2002	13:45	4	14.30	1.5	8.98	6.7	0.2	0.00025	75	
6/21/2002	9:05	4	17.00	1.5	8.33	6.7	0.2	0.00031	75	
6/21/2002	9:27	6	19.20	1.8	7.73	6.8	0	0	70	
6/22/2002	8:30	3	20.00	1.5	8.02					
6/23/2002	17:30	3	16.10	1.6	8.16	6.8			73	
6/24/2002	8:36	3	16.80	1.7	7.87	6.8	0	0	62	
6/25/2002	8:20	4	17.40	1.9	8.04	6.8	0	0	60	
6/25/2002	10:45	7	12.60	2	8.87	6.8	0	0	80	
6/26/2002	8:58	3	17.40	1.9	7.88	6.8	0	0	48	160
6/26/2002	9:16	7	15.10	2	8.19	7	0	0	60	124
6/27/2002	10:30	3	17.40	1.9	7.84	6.8	0	0	48	144
6/27/2002	10:46	7	18.80	2	7.23	6.8	0.2		52	120
6/27/2002	11:19	FLUME	21.30	0.2	6.5					
6/28/2002	10:07	3	17.50	1.9	7.86	6.8	0	0	50	150
6/28/2002	10:46	7	16.30	1.9	8.11	6.3	0.2	0.00012	24	130
6/29/2002	13:00	4	17.20	2.2	7.83					
6/30/2002	14:00	4	17.40	1.5	8.04	6.8	0	0	20	132
6/30/2002	14:00	7	15.80	2	8.42	6.2	0.2	0.00009	20	148

Date	Time	Tank#	Temp (C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Ammonia (Total; ppm)	Ammonia (NH3; ppm)	Alkalinity (ppm)	Hardness (ppm)
7/1/2002	8:25	4	17.30	2.1	8.19	6.8	0.2	0.0004	40	150
7/1/2002	8:35	6	16.00	2	8.56	5.8	1		16	130
7/2/2002	9:11	6	16.80	1.9	8.25	6.8	1.5		44	136

C
2001 ENTRAINMENT AND IMPINGEMENT DATA

Species	Orientation	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m3)	No. entrainment adjusted for CE/m3	% Loss (entrainment + impingement)
STB	0	0.5	0.15	0.08	egg	100	9.0	9.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	9.00
STB	0	0.5	0.15	0.08	egg	100	25.0	25.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	25.00
STB	0	0.5	0.15	0.08	egg	100	5.0	5.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	5.00
STB	0	0.5	0.15	0.15	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	0	0.5	0.15	0.15	egg	100	2.0	2.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	2.00
STB	0	0.5	0.15	0.15	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	0	0.5	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	0	0.5	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	0	0.5	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	0	0.5	0.30	0.08	egg	100	100.0	100.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	100.00
STB	0	0.5	0.30	0.08	egg	100	96.0	96.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	96.00
STB	0	0.5	0.30	0.08	egg	100	96.0	96.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	96.00
STB	0	0.5	0.30	0.15	egg	100	40.0	40.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	40.00
STB	0	0.5	0.30	0.15	egg	100	8.0	8.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	8.00
STB	0	0.5	0.30	0.15	egg	100	16.0	16.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	16.00
STB	0	0.5	0.30	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	0.00
STB	0	0.5	0.30	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	0.00
STB	0	0.5	0.30	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	0.00
STB	0	1.0	0.15	0.08	egg	100	100.0	100.0	0.00	1.000	0.0	0.0	1.30	22.03	0.00	100.00
STB	0	1.0	0.15	0.08	egg	100	99.0	99.0	0.00	1.000	0.0	0.0	1.30	22.03	0.00	99.00
STB	0	1.0	0.15	0.08	egg	100	74.0	74.0	0.00	1.000	0.0	0.0	1.30	22.03	0.00	74.00
STB	0	1.0	0.15	0.15	egg	100	1.0	1.0	0.00	1.000	0.0	0.0	1.30	22.03	0.00	1.00
STB	0	1.0	0.15	0.15	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.30	22.03	0.00	0.00
STB	0	1.0	0.15	0.15	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.30	22.03	0.00	0.00
STB	0	1.0	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.30	22.03	0.00	0.00
STB	0	1.0	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.30	22.03	0.00	0.00
STB	0	1.0	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.30	22.03	0.00	0.00

Species	Orientation	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m3)	No. entrainment adjusted for CE/m3	% Loss (entrainment + impingement)
STB	0	1.0	0.30	0.08	egg	100	98.0	98.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	98.00
STB	0	1.0	0.30	0.08	egg	100	100.0	100.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	100.00
STB	0	1.0	0.30	0.08	egg	100	98.0	98.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	98.00
STB	0	1.0	0.30	0.15	egg	100	89.0	89.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	89.00
STB	0	1.0	0.30	0.15	egg	100	85.0	85.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	85.00
STB	0	1.0	0.30	0.15	egg	100	92.0	92.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	92.00
STB	0	1.0	0.30	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	0.00
STB	0	1.0	0.30	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	0.00
STB	0	1.0	0.30	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	0.00
STB	0	2.0	0.15	0.08	egg	100	96.0	96.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	96.00
STB	0	2.0	0.15	0.08	egg	100	97.0	97.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	97.00
STB	0	2.0	0.15	0.08	egg	100	88.0	88.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	88.00
STB	0	2.0	0.15	0.15	egg	100	1.0	1.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	1.00
STB	0	2.0	0.15	0.15	egg	100	6.0	6.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	6.00
STB	0	2.0	0.15	0.15	egg	100	7.0	7.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	7.00
STB	0	2.0	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	0.00
STB	0	2.0	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	0.00
STB	0	2.0	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	0.00
STB	0	0.5	0.15	0.08	larvae	100	0.0	0.0	2.00	0.878	2.3	2.3	0.81	13.74	1.66	2.00
STB	0	0.5	0.15	0.08	larvae	100	0.0	0.0	8.00	0.878	9.1	9.1	0.81	13.74	6.63	8.00
STB	0	0.5	0.15	0.08	larvae	100	0.0	0.0	1.00	0.878	1.1	1.1	0.81	13.74	0.83	1.00
STB	0	0.5	0.15	0.08	larvae	100	0.0	0.0	1.00	0.878	1.1	1.1	0.81	13.74	0.83	1.00
STB	0	0.5	0.15	0.15	larvae	100	0.0	0.0	14.00	0.878	15.9	15.9	0.81	13.74	11.60	14.00
STB	0	0.5	0.15	0.15	larvae	100	0.0	0.0	1.00	0.878	1.1	1.1	0.81	13.74	0.83	1.00
STB	0	0.5	0.15	0.15	larvae	100	0.0	0.0	1.00	0.878	1.1	1.1	0.81	13.74	0.83	1.00
STB	0	0.5	0.15	0.15	larvae	100	0.0	0.0	0.00	0.878	0.0	0.0	0.81	13.74	0.00	0.00
STB	0	0.5	0.15	0.30	larvae	100	0.0	0.0	4.00	0.878	4.6	4.6	0.81	13.74	3.32	4.00

Species	Orientation	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m3)	No. entrainment adjusted for CE/m3	% Loss (entrainment + impingement)
STB	0	0.5	0.15	0.30	larvae	100	0.0	0.0	3.00	0.878	3.4	3.4	0.81	13.74	2.49	3.00
STB	0	0.5	0.15	0.30	larvae	100	0.0	0.0	0.00	0.878	0.0	0.0	0.81	13.74	0.00	0.00
STB	0	0.5	0.30	0.08	larvae	100	0.0	0.0	17.00	0.878	19.4	19.4	1.62	27.48	7.05	17.00
STB	0	0.5	0.30	0.08	larvae	100	0.0	0.0	21.00	0.878	23.9	23.9	1.62	27.48	8.70	21.00
STB	0	0.5	0.30	0.08	larvae	100	0.0	0.0	10.00	0.878	11.4	11.4	1.62	27.48	4.14	10.00
STB	0	0.5	0.30	0.15	larvae	100	0.0	0.0	28.00	0.878	31.9	31.9	1.62	27.48	11.60	28.00
STB	0	0.5	0.30	0.15	larvae	100	0.0	0.0	34.00	0.878	38.7	38.7	1.62	27.48	14.09	34.00
STB	0	0.5	0.30	0.15	larvae	100	0.0	0.0	10.00	0.878	11.4	11.4	1.62	27.48	4.14	10.00
STB	0	0.5	0.30	0.30	larvae	100	0.0	0.0	17.00	0.878	19.4	19.4	1.62	27.48	7.05	17.00
STB	0	0.5	0.30	0.30	larvae	100	0.0	0.0	40.00	0.878	45.6	45.6	1.62	27.48	16.58	40.00
STB	0	0.5	0.30	0.30	larvae	100	0.0	0.0	39.00	0.878	44.4	44.4	1.62	27.48	16.16	39.00
STB	0	0.5	0.30	0.30	larvae	100	0.0	0.0	3.00	0.878	3.4	3.4	1.62	27.48	1.24	3.00
STB	0	1.0	0.15	0.08	larvae	100	0.0	0.0	26.00	0.878	29.6	29.6	1.30	22.03	13.44	26.00
STB	0	1.0	0.15	0.08	larvae	100	0.0	0.0	43.00	0.878	49.0	49.0	1.30	22.03	22.23	43.00
STB	0	1.0	0.15	0.08	larvae	100	0.0	0.0	40.00	0.878	45.6	45.6	1.30	22.03	20.68	40.00
STB	0	1.0	0.15	0.15	larvae	100	0.0	0.0	20.00	0.878	22.8	22.8	1.30	22.03	10.34	20.00
STB	0	1.0	0.15	0.15	larvae	100	0.0	0.0	22.00	0.878	25.1	25.1	1.30	22.03	11.37	22.00
STB	0	1.0	0.15	0.15	larvae	100	0.0	0.0	29.00	0.878	33.0	33.0	1.30	22.03	14.99	29.00
STB	0	1.0	0.15	0.30	larvae	100	0.0	0.0	12.00	0.878	13.7	13.7	1.30	22.03	6.20	12.00
STB	0	1.0	0.15	0.30	larvae	100	0.0	0.0	18.00	0.878	20.5	20.5	1.30	22.03	9.31	18.00
STB	0	1.0	0.15	0.30	larvae	100	0.0	0.0	14.00	0.878	15.9	15.9	1.30	22.03	7.24	14.00
STB	0	1.0	0.30	0.08	larvae	100	0.0	0.0	17.00	0.878	19.4	19.4	2.59	44.06	4.39	17.00
STB	0	1.0	0.30	0.08	larvae	100	0.0	0.0	21.00	0.878	23.9	23.9	2.59	44.06	5.43	21.00
STB	0	1.0	0.30	0.08	larvae	100	0.0	0.0	18.00	0.878	20.5	20.5	2.59	44.06	4.65	18.00
STB	0	1.0	0.30	0.15	larvae	100	0.0	0.0	73.00	0.878	83.1	83.1	2.59	44.06	18.87	73.00
STB	0	1.0	0.30	0.15	larvae	100	0.0	0.0	56.00	0.878	63.8	63.8	2.59	44.06	14.48	56.00
STB	0	1.0	0.30	0.15	larvae	100	0.0	0.0	26.00	0.878	29.6	29.6	2.59	44.06	6.72	26.00

Species	Orientation	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m3)	No. entrainment adjusted for CE/m3	% Loss (entrainment + impingement)
STB	0	1.0	0.30	0.30	larvae	100	0.0	0.0	38.00	0.878	43.3	43.3	2.59	44.06	9.82	38.00
STB	0	1.0	0.30	0.30	larvae	100	0.0	0.0	31.00	0.878	35.3	35.3	2.59	44.06	8.01	31.00
STB	0	1.0	0.30	0.30	larvae	100	0.0	0.0	34.00	0.878	38.7	38.7	2.59	44.06	8.79	34.00
STB	0	2.0	0.15	0.08	larvae	100	0.0	0.0	84.00	0.878	95.7	95.7	1.86	31.57	30.30	84.00
STB	0	2.0	0.15	0.08	larvae	100	0.0	0.0	30.00	0.878	34.2	34.2	1.86	31.57	10.82	30.00
STB	0	2.0	0.15	0.08	larvae	100	0.0	0.0	47.00	0.878	53.5	53.5	1.86	31.57	16.96	47.00
STB	0	2.0	0.15	0.15	larvae	100	0.0	0.0	48.00	0.878	54.7	54.7	1.86	31.57	17.32	48.00
STB	0	2.0	0.15	0.15	larvae	100	0.0	0.0	61.00	0.878	69.5	69.5	1.86	31.57	22.01	61.00
STB	0	2.0	0.15	0.15	larvae	100	0.0	0.0	52.00	0.878	59.2	59.2	1.86	31.57	18.76	52.00
STB	0	2.0	0.15	0.30	larvae	100	0.0	0.0	33.00	0.878	37.6	37.6	1.86	31.57	11.91	33.00
STB	0	2.0	0.15	0.30	larvae	100	0.0	0.0	37.00	0.878	42.1	42.1	1.86	31.57	13.35	37.00
STB	0	2.0	0.15	0.30	larvae	100	0.0	0.0	51.00	0.878	58.1	58.1	1.86	31.57	18.40	51.00
STB	90	0.5	0.15	0.08	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	90	0.5	0.15	0.08	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	90	0.5	0.15	0.08	egg	100	1.0	1.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	1.00
STB	90	0.5	0.15	0.15	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	90	0.5	0.15	0.15	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	90	0.5	0.15	0.15	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	90	0.5	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	90	0.5	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	90	0.5	0.15	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	0.81	13.74	0.00	0.00
STB	90	0.5	0.30	0.08	egg	100	40.0	40.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	40.00
STB	90	0.5	0.30	0.08	egg	100	50.0	50.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	50.00
STB	90	0.5	0.30	0.08	egg	100	50.0	50.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	50.00
STB	90	0.5	0.30	0.15	egg	100	1.0	1.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	1.00
STB	90	0.5	0.30	0.15	egg	100	1.0	1.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	1.00
STB	90	0.5	0.30	0.15	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	0.00

Species	Orientation	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m3)	No. entrainment adjusted for CE/m3	% Loss (entrainment + impingement)
STB	90	0.5	0.30	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	0.00
STB	90	0.5	0.30	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	0.00
STB	90	0.5	0.30	0.30	egg	100	0.0	0.0	0.00	1.000	0.0	0.0	1.62	27.48	0.00	0.00
STB	90	1.0	0.30	0.08	egg	100	48.0	48.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	48.00
STB	90	1.0	0.30	0.08	egg	100	42.0	42.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	42.00
STB	90	1.0	0.30	0.08	egg	100	43.0	43.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	43.00
STB	90	1.0	0.30	0.15	egg	100	22.0	22.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	22.00
STB	90	1.0	0.30	0.15	egg	100	51.0	51.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	51.00
STB	90	1.0	0.30	0.15	egg	100	45.0	45.0	0.00	1.000	0.0	0.0	2.59	44.06	0.00	45.00
STB	90	2.0	0.15	0.08	egg	100	18.0	18.0	3.00	1.000	3.0	3.0	1.86	31.57	0.95	21.00
STB	90	2.0	0.15	0.08	egg	100	11.0	11.0	5.00	1.000	5.0	5.0	1.86	31.57	1.58	16.00
STB	90	2.0	0.15	0.08	egg	100	56.0	56.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	56.00
STB	90	2.0	0.15	0.15	egg	100	10.0	10.0	4.00	1.000	4.0	4.0	1.86	31.57	1.27	14.00
STB	90	2.0	0.15	0.15	egg	100	11.0	11.0	4.00	1.000	4.0	4.0	1.86	31.57	1.27	15.00
STB	90	2.0	0.15	0.15	egg	100	28.0	28.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	28.00
STB	90	2.0	0.15	0.30	egg	100	4.0	4.0	2.00	1.000	2.0	2.0	1.86	31.57	0.63	6.00
STB	90	2.0	0.15	0.30	egg	100	0.0	0.0	3.00	1.000	3.0	3.0	1.86	31.57	0.95	3.00
STB	90	2.0	0.15	0.30	egg	100	7.0	7.0	0.00	1.000	0.0	0.0	1.86	31.57	0.00	7.00
STB	90	0.5	0.15	0.08	larvae	100	15.0	15.0	0.00	0.878	0.0	0.0	0.81	13.74	0.00	15.00
STB	90	0.5	0.15	0.08	larvae	100	5.0	5.0	0.00	0.878	0.0	0.0	0.81	13.74	0.00	5.00
STB	90	0.5	0.15	0.08	larvae	100	5.0	5.0	0.00	0.878	0.0	0.0	0.81	13.74	0.00	5.00
STB	90	0.5	0.15	0.15	larvae	100	0.0	0.0	1.00	0.878	1.1	1.1	0.81	13.74	0.83	1.00
STB	90	0.5	0.15	0.15	larvae	100	3.0	3.0	0.00	0.878	0.0	0.0	0.81	13.74	0.00	3.00
STB	90	0.5	0.15	0.15	larvae	100	2.0	2.0	0.00	0.878	0.0	0.0	0.81	13.74	0.00	2.00
STB	90	0.5	0.15	0.30	larvae	100	1.0	1.0	0.00	0.878	0.0	0.0	0.81	13.74	0.00	1.00
STB	90	0.5	0.15	0.30	larvae	100	1.0	1.0	1.00	0.878	1.1	1.1	0.81	13.74	0.83	2.00
STB	90	0.5	0.15	0.30	larvae	100	3.0	3.0	0.00	0.878	0.0	0.0	0.81	13.74	0.00	3.00

Species	Orientation	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m3)	No. entrainment adjusted for CE/m3	% Loss (entrainment + impingement)
STB	90	0.5	0.30	0.08	larvae	100	15.0	15.0	0.00	0.878	0.0	0.0	1.62	27.48	0.00	15.00
STB	90	0.5	0.30	0.08	larvae	100	30.0	30.0	0.00	0.878	0.0	0.0	1.62	27.48	0.00	30.00
STB	90	0.5	0.30	0.08	larvae	100	43.0	43.0	0.00	0.878	0.0	0.0	1.62	27.48	0.00	43.00
STB	90	0.5	0.30	0.15	larvae	100	4.0	4.0	0.00	0.878	0.0	0.0	1.62	27.48	0.00	4.00
STB	90	0.5	0.30	0.15	larvae	100	24.0	24.0	0.00	0.878	0.0	0.0	1.62	27.48	0.00	24.00
STB	90	0.5	0.30	0.15	larvae	100	38.0	38.0	0.00	0.878	0.0	0.0	1.62	27.48	0.00	38.00
STB	90	0.5	0.30	0.30	larvae	100	3.0	3.0	1.00	0.878	1.1	1.1	1.62	27.48	0.41	4.00
STB	90	0.5	0.30	0.30	larvae	100	11.0	11.0	0.00	0.878	0.0	0.0	1.62	27.48	0.00	11.00
STB	90	0.5	0.30	0.30	larvae	100	6.0	6.0	1.00	0.878	1.1	1.1	1.62	27.48	0.41	7.00
STB	90	1.0	0.30	0.08	larvae	75	0.0	0.0	41.00	0.878	46.7	62.3	2.59	44.06	14.13	54.67
STB	90	1.0	0.30	0.08	larvae	75	0.0	0.0	44.00	0.878	50.1	66.8	2.59	44.06	15.16	58.67
STB	90	1.0	0.30	0.08	larvae	75	0.0	0.0	47.00	0.878	53.5	71.4	2.59	44.06	16.20	62.67
STB	90	1.0	0.30	0.15	larvae	75	0.0	0.0	49.00	0.878	55.8	74.4	2.59	44.06	16.89	65.33
STB	90	1.0	0.30	0.15	larvae	75	0.0	0.0	38.00	0.878	43.3	57.7	2.59	44.06	13.10	50.67
STB	90	1.0	0.30	0.15	larvae	75	0.0	0.0	48.00	0.878	54.7	72.9	2.59	44.06	16.54	64.00
STB	90	2.0	0.15	0.08	larvae	100	0.0	0.0	80.00	0.878	91.1	91.1	1.86	31.57	28.86	80.00
STB	90	2.0	0.15	0.08	larvae	100	0.0	0.0	90.00	0.878	100.0	100.0	1.86	31.57	31.68	90.00
STB	90	2.0	0.15	0.08	larvae	100	0.0	0.0	95.00	0.878	100.0	100.0	1.86	31.57	31.68	95.00
STB	90	2.0	0.15	0.15	larvae	100	0.0	0.0	84.00	0.878	95.7	95.7	1.86	31.57	30.30	84.00
STB	90	2.0	0.15	0.15	larvae	100	0.0	0.0	95.00	0.878	100.0	100.0	1.86	31.57	31.68	95.00
STB	90	2.0	0.15	0.15	larvae	100	0.0	0.0	93.00	0.878	100.0	100.0	1.86	31.57	31.68	93.00
STB	90	2.0	0.15	0.30	larvae	100	0.0	0.0	81.00	0.878	92.3	92.3	1.86	31.57	29.22	81.00
STB	90	2.0	0.15	0.30	larvae	100	0.0	0.0	87.00	0.878	99.1	99.1	1.86	31.57	31.39	87.00
STB	90	2.0	0.15	0.30	larvae	100	0.0	0.0	83.00	0.878	94.5	94.5	1.86	31.57	29.94	83.00

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2002 ENTRAINMENT AND IMPINGEMENT DATA

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
ALW	0.50	0.30	0.08	Egg	75	0	0.0	10	0.596	16.8	22.4	1.617	27.47	0.81	22.37
ALW	0.50	0.30	0.08	Egg	75	0	0.0	5	0.596	8.4	11.2	1.617	27.47	0.41	11.19
ALW	0.50	0.30	0.08	Egg	75	0	0.0	10	0.596	16.8	22.4	1.617	27.47	0.81	22.37
ALW	0.50	0.30	0.08	Egg	75	0	0.0	5	0.596	8.4	11.2	1.617	27.47	0.41	11.19
ALW	0.50	0.30	0.08	Egg	75	0	0.0	14	0.596	23.5	31.3	1.617	27.47	1.14	31.32
ALW	0.50	0.30	0.15	Egg	50	0	0.0	11	0.596	18.5	36.9	1.617	27.47	1.34	36.91
ALW	0.50	0.30	0.15	Egg	50	0	0.0	0	0.596	0.0	0.0	1.617	27.47	0.00	0.00
ALW	0.50	0.30	0.15	Egg	50	0	0.0	1	0.596	1.7	3.4	1.617	27.47	0.12	3.36
ALW	0.50	0.30	0.15	Egg	50	0	0.0	2	0.596	3.4	6.7	1.617	27.47	0.24	6.71
ALW	0.50	0.30	0.15	Egg	50	0	0.0	1	0.596	1.7	3.4	1.617	27.47	0.12	3.36
ALW	2.00	0.30	0.08	Egg	75	0	0.0	21	0.596	35.2	47.0	3.715	63.12	0.74	46.98
ALW	2.00	0.30	0.08	Egg	75	0	0.0	16	0.596	26.8	35.8	3.715	63.12	0.57	35.79
ALW	2.00	0.30	0.08	Egg	75	0	0.0	7	0.596	11.7	15.7	3.715	63.12	0.25	15.66
ALW	2.00	0.30	0.08	Egg	75	0	0.0	30	0.596	50.3	67.1	3.715	63.12	1.06	67.11
ALW	2.00	0.30	0.08	Egg	75	0	0.0	44	0.596	73.8	98.4	3.715	63.12	1.56	98.43
ALW	2.00	0.30	0.15	Egg	75	0	0.0	6	0.596	10.1	13.4	3.715	63.12	0.21	13.42
ALW	2.00	0.30	0.15	Egg	75	0	0.0	2	0.596	3.4	4.5	3.715	63.12	0.07	4.47
ALW	2.00	0.30	0.15	Egg	75	0	0.0	5	0.596	8.4	11.2	3.715	63.12	0.18	11.19
ALW	2.00	0.30	0.15	Egg	75	0	0.0	45	0.596	75.5	100.7	3.715	63.12	1.59	100.67
ALW	2.00	0.30	0.15	Egg	75	0	0.0	8	0.596	13.4	17.9	3.715	63.12	0.28	17.90
ALW	2.00	0.30	0.30	Egg	75	0	0.0	15	0.596	25.2	33.6	3.715	63.12	0.53	33.56
ALW	2.00	0.30	0.30	Egg	75	0	0.0	8	0.596	13.4	17.9	3.715	63.12	0.28	17.90
ALW	2.00	0.30	0.30	Egg	75	0	0.0	19	0.596	31.9	42.5	3.715	63.12	0.67	42.51
ALW	2.00	0.30	0.30	Egg	75	0	0.0	7	0.596	11.7	15.7	3.715	63.12	0.25	15.66
ALW	2.00	0.30	0.30	Egg	75	0	0.0	10	0.596	16.8	22.4	3.715	63.12	0.35	22.37
WHS	0.50	0.15	0.08	Egg	75	1	1.3	0	0.985	0.0	0.0	0.808	13.73	0.00	1.33

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
WHS	0.50	0.15	0.08	Egg	75	1	1.3	0	0.985	0.0	0.0	0.808	13.73	0.00	1.33
WHS	0.50	0.15	0.08	Egg	75	0	0.0	0	0.985	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.08	Egg	72	0	0.0	0	0.985	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.08	Egg	75	0	0.0	0	0.985	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.15	Egg	75	1	1.3	0	0.985	0.0	0.0	0.808	13.73	0.00	1.33
WHS	0.50	0.15	0.15	Egg	75	1	1.3	0	0.985	0.0	0.0	0.808	13.73	0.00	1.33
WHS	0.50	0.15	0.15	Egg	75	2	2.7	0	0.985	0.0	0.0	0.808	13.73	0.00	2.67
WHS	0.50	0.15	0.15	Egg	75	0	0.0	0	0.985	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.15	Egg	75	0	0.0	0	0.985	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.30	Egg	75	0	0.0	0	0.985	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.30	Egg	75	0	0.0	0	0.985	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.30	Egg	75	0	0.0	0	0.985	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.30	Egg	75	0	0.0	0	0.985	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.30	Egg	75	0	0.0	0	0.985	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.30	0.08	Egg	72	49	68.1	0	0.985	0.0	0.0	1.617	27.47	0.00	68.06
WHS	0.50	0.30	0.08	Egg	68	20	29.4	0	0.985	0.0	0.0	1.617	27.47	0.00	29.41
WHS	0.50	0.30	0.08	Egg	75	70	93.3	0	0.985	0.0	0.0	1.617	27.47	0.00	93.33
WHS	0.50	0.30	0.08	Egg	75	31	41.3	1	0.985	1.0	1.4	1.617	27.47	0.05	42.69
WHS	0.50	0.30	0.08	Egg	75	50	66.7	0	0.985	0.0	0.0	1.617	27.47	0.00	66.67
WHS	0.50	0.30	0.15	Egg	75	6	8.0	0	0.985	0.0	0.0	1.617	27.47	0.00	8.00
WHS	0.50	0.30	0.15	Egg	75	5	6.7	0	0.985	0.0	0.0	1.617	27.47	0.00	6.67
WHS	0.50	0.30	0.15	Egg	75	1	1.3	0	0.985	0.0	0.0	1.617	27.47	0.00	1.33
WHS	0.50	0.30	0.15	Egg	75	2	2.7	0	0.985	0.0	0.0	1.617	27.47	0.00	2.67
WHS	0.50	0.30	0.15	Egg	75	4	5.3	0	0.985	0.0	0.0	1.617	27.47	0.00	5.33
WHS	0.50	0.30	0.30	Egg	72	0	0.0	0	0.985	0.0	0.0	1.617	27.47	0.00	0.00
WHS	0.50	0.30	0.30	Egg	75	0	0.0	0	0.985	0.0	0.0	1.617	27.47	0.00	0.00

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
WHS	0.50	0.30	0.30	Egg	75	0	0.0	0	0.985	0.0	0.0	1.617	27.47	0.00	0.00
WHS	0.50	0.30	0.30	Egg	75	0	0.0	0	0.985	0.0	0.0	1.617	27.47	0.00	0.00
WHS	0.50	0.30	0.30	Egg	75	2	2.7	0	0.985	0.0	0.0	1.617	27.47	0.00	2.67
BLG	2.00	0.30	0.30	Larvae	50	1	2.0	0	0.100	0.0	0.0	3.715	63.12	0.00	2.00
BLG	2.00	0.30	0.30	Larvae	50	0	0.0	0	0.100	0.0	0.0	3.715	63.12	0.00	0.00
BLG	2.00	0.30	0.30	Larvae	50	2	4.0	1	1.000	1.0	2.0	3.715	63.12	0.32	6.00
BLG	2.00	0.30	0.30	Larvae	50	1	2.0	0	1.000	0.0	0.0	3.715	63.12	0.00	2.00
BLG	2.00	0.30	0.30	Larvae	50	0	0.0	0	1.000	0.0	0.0	3.715	63.12	0.00	0.00
BLG	2.00	0.30	0.15	Larvae	50	4	8.0	3	1.000	3.0	6.0	3.715	63.12	0.10	14.00
BLG	2.00	0.30	0.15	Larvae	50	3	6.0	1	1.000	1.0	2.0	3.715	63.12	0.03	8.00
BLG	2.00	0.30	0.15	Larvae	50	1	2.0	2	1.000	2.0	4.0	3.715	63.12	0.06	6.00
BLG	2.00	0.30	0.15	Larvae	50	3	6.0	1	1.000	1.0	2.0	3.715	63.12	0.03	8.00
BLG	2.00	0.30	0.15	Larvae	50	3	6.0	1	1.000	1.0	2.0	3.715	63.12	0.03	8.00
BLG	2.00	0.30	0.08	Larvae	49	5	10.2	2	1.000	2.0	4.1	3.715	63.12	0.06	14.29
BLG	2.00	0.30	0.08	Larvae	50	0	0.0	3	1.000	3.0	6.0	3.715	63.12	0.10	6.00
BLG	2.00	0.30	0.08	Larvae	50	2	4.0	4	1.000	4.0	8.0	3.715	63.12	0.13	12.00
BLG	2.00	0.30	0.08	Larvae	50	1	2.0	0	1.000	0.0	0.0	3.715	63.12	0.00	2.00
BLG	2.00	0.30	0.08	Larvae	50	0	0.0	2	1.000	2.0	4.0	3.715	63.12	0.06	4.00
BLG	0.50	0.30	0.15	Larvae	50	0	0.0	0	1.000	0.0	0.0	1.617	27.47	0.00	0.00
BLG	0.50	0.30	0.08	Larvae	50	4	8.0	0	1.000	0.0	0.0	1.617	27.47	0.00	8.00
BLG	0.50	0.30	0.08	Larvae	50	2	4.0	0	1.000	0.0	0.0	1.617	27.47	0.00	4.00
BLG	0.50	0.30	0.08	Larvae	50	2	4.0	0	1.000	0.0	0.0	1.617	27.47	0.00	4.00
BLG	0.50	0.30	0.08	Larvae	50	1	2.0	0	1.000	0.0	0.0	1.617	27.47	0.00	2.00
BLG	0.50	0.30	0.08	Larvae	50	1	2.0	2	1.000	20.0	4.0	1.617	27.47	1.46	42.00
CRP	1.00	0.15	0.08	Larvae	50	3	6.0	50	0.992	50.4	100.8	1.297	22.04	4.57	106.81
CRP	1.00	0.15	0.08	Larvae	50	3	6.0	51	0.992	51.4	102.8	1.297	22.04	4.67	108.82

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
CRP	1.00	0.15	0.08	Larvae	50	4	8.0	46	0.992	46.4	92.7	1.297	22.04	4.21	100.74
CRP	1.00	0.15	0.08	Larvae	50	3	6.0	44	0.992	44.4	88.7	1.297	22.04	4.03	94.71
CRP	1.00	0.15	0.08	Larvae	50	0	0.0	42	0.992	42.3	84.7	1.297	22.04	3.84	84.68
CRP	1.00	0.15	0.15	Larvae	50	3	6.0	36	0.992	36.3	72.6	1.297	22.04	3.29	78.58
CRP	1.00	0.15	0.15	Larvae	50	5	10.0	42	0.992	42.3	84.7	1.297	22.04	3.84	94.68
CRP	1.00	0.15	0.15	Larvae	50	0	0.0	43	0.992	43.3	86.7	1.297	22.04	3.93	86.69
CRP	1.00	0.15	0.15	Larvae	50	4	8.0	38	0.992	38.3	76.6	1.297	22.04	3.48	84.61
CRP	1.00	0.15	0.15	Larvae	50	3	6.0	44	0.992	44.4	88.7	1.297	22.04	4.03	94.71
CRP	1.00	0.15	0.30	Larvae	50	4	8.0	28	0.992	28.2	56.5	1.297	22.04	2.56	64.45
CRP	1.00	0.15	0.30	Larvae	50	4	8.0	34	0.992	34.3	68.5	1.297	22.04	3.11	76.55
CRP	1.00	0.15	0.30	Larvae	50	1	2.0	32	0.992	32.3	64.5	1.297	22.04	2.93	66.52
CRP	1.00	0.15	0.30	Larvae	50	2	4.0	35	0.992	35.3	70.6	1.297	22.04	3.20	74.56
CRP	1.00	0.15	0.30	Larvae	50	1	2.0	31	0.992	31.3	62.5	1.297	22.04	2.84	64.50
CRP	1.00	0.30	0.08	Larvae	75	13	17.3	55	0.944	58.3	77.7	2.593	44.06	1.76	95.02
CRP	1.00	0.30	0.08	Larvae	75	4	5.3	68	0.944	72.0	96.0	2.593	44.06	2.18	101.38
CRP	1.00	0.30	0.08	Larvae	75	2	2.7	68	0.944	72.0	96.0	2.593	44.06	2.18	98.71
CRP	1.00	0.30	0.08	Larvae	50	5	10.0	40	0.944	42.4	84.7	2.593	44.06	1.92	94.75
CRP	1.00	0.30	0.08	Larvae	50	5	10.0	44	0.944	46.6	93.2	2.593	44.06	2.12	103.22
CRP	1.00	0.30	0.15	Larvae	50	4	8.0	45	0.944	47.7	95.3	2.593	44.06	2.16	103.34
CRP	1.00	0.30	0.15	Larvae	50	2	4.0	45	0.944	47.7	95.3	2.593	44.06	2.16	99.34
CRP	1.00	0.30	0.15	Larvae	50	5	10.0	43	0.944	45.6	91.1	2.593	44.06	2.07	101.10
CRP	1.00	0.30	0.15	Larvae	50	3	6.0	42	0.944	44.5	89.0	2.593	44.06	2.02	94.98
CRP	1.00	0.30	0.15	Larvae	50	5	10.0	48	0.944	50.8	101.7	2.593	44.06	2.31	111.69
CRP	1.00	0.30	0.30	Larvae	50	2	4.0	42	0.944	44.5	89.0	2.593	44.06	2.02	92.98
CRP	1.00	0.30	0.30	Larvae	50	4	8.0	40	0.944	42.4	84.7	2.593	44.06	1.92	92.75
CRP	1.00	0.30	0.30	Larvae	50	2	4.0	49	0.944	51.9	103.8	2.593	44.06	2.36	107.81

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
CRP	1.00	0.30	0.30	Larvae	50	4	8.0	43	0.944	45.6	91.1	2.593	44.06	2.07	99.10
CRP	1.00	0.30	0.30	Larvae	50	4	8.0	38	0.944	40.3	80.5	2.593	44.06	1.83	88.51
RBS	0.50	0.15	0.08	Larvae	75	0	0.0	57	0.800	71.3	95.0	0.808	13.73	6.92	95.00
RBS	0.50	0.15	0.08	Larvae	75	0	0.0	38	0.800	47.5	63.3	0.808	13.73	4.61	63.33
RBS	0.50	0.15	0.08	Larvae	75	0	0.0	62	0.800	77.5	103.3	0.808	13.73	7.53	103.33
RBS	0.50	0.15	0.08	Larvae	75	0	0.0	40	0.800	50.0	66.7	0.808	13.73	4.86	66.67
RBS	0.50	0.15	0.08	Larvae	75	0	0.0	28	0.800	35.0	46.7	0.808	13.73	3.40	46.67
RBS	0.50	0.15	0.15	Larvae	75	0	0.0	34	0.800	42.5	56.7	0.808	13.73	4.13	56.67
RBS	0.50	0.15	0.15	Larvae	75	0	0.0	36	0.800	45.0	60.0	0.808	13.73	4.37	60.00
RBS	0.50	0.15	0.15	Larvae	75	0	0.0	21	0.800	26.3	35.0	0.808	13.73	2.55	35.00
RBS	0.50	0.15	0.15	Larvae	75	0	0.0	44	0.800	55.0	73.3	0.808	13.73	5.34	73.33
RBS	0.50	0.15	0.15	Larvae	75	1	1.3	67	0.800	83.8	111.7	0.808	13.73	8.13	113.00
RBS	0.50	0.15	0.30	Larvae	75	0	0.0	22	0.800	27.5	36.7	0.808	13.73	2.67	36.67
RBS	0.50	0.15	0.30	Larvae	75	0	0.0	4	0.800	5.0	6.7	0.808	13.73	0.49	6.67
RBS	0.50	0.15	0.30	Larvae	75	0	0.0	7	0.800	8.8	11.7	0.808	13.73	0.85	11.67
RBS	0.50	0.15	0.30	Larvae	75	0	0.0	19	0.800	23.8	31.7	0.808	13.73	2.31	31.67
RBS	0.50	0.15	0.30	Larvae	75	0	0.0	24	0.800	30.0	40.0	0.808	13.73	2.91	40.00
WFL	0.50	0.15	0.08	Larvae	75	3	4.0	0	0.98	0.0	0.0	0.808	13.73	0.00	4.00
WFL	0.50	0.15	0.08	Larvae	75	3	4.0	1	0.98	1.0	1.4	0.808	13.73	0.10	5.36
WFL	0.50	0.15	0.08	Larvae	75	0	0.0	0	0.98	0.0	0.0	0.808	13.73	0.00	0.00
WFL	0.50	0.15	0.08	Larvae	75	0	0.0	2	0.98	2.0	2.7	0.808	13.73	0.20	2.72
WFL	0.50	0.15	0.08	Larvae	75	0	0.0	0	0.98	0.0	0.0	0.808	13.73	0.00	0.00
WFL	0.50	0.15	0.15	Larvae	75	1	1.3	0	0.98	0.0	0.0	0.808	13.73	0.00	1.33
WFL	0.50	0.15	0.15	Larvae	75	32	42.7	0	0.98	0.0	0.0	0.808	13.73	0.00	42.67
WFL	0.50	0.15	0.15	Larvae	100	0	0.0	1	0.98	1.0	1.0	0.808	13.73	0.07	1.02
WFL	0.50	0.15	0.15	Larvae	75	0	0.0	1	0.98	1.0	1.4	0.808	13.73	0.10	1.36

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
WFL	0.50	0.15	0.15	Larvae	75	0	0.0	0	0.98	0.0	0.0	0.808	13.73	0.00	0.00
WFL	0.50	0.15	0.30	Larvae	99	0	0.0	6	0.98	6.1	6.2	0.808	13.73	0.45	6.18
WFL	0.50	0.15	0.30	Larvae	75	0	0.0	1	0.98	1.0	1.4	0.808	13.73	0.10	1.36
WFL	0.50	0.15	0.30	Larvae	75	0	0.0	3	0.98	3.1	4.1	0.808	13.73	0.30	4.08
WFL	0.50	0.15	0.30	Larvae	75	0	0.0	0	0.98	0.0	0.0	0.808	13.73	0.00	0.00
WFL	0.50	0.15	0.30	Larvae	100	0	0.0	1	0.98	1.0	1.0	0.808	13.73	0.07	1.02
WFL	0.50	0.30	0.08	Larvae	75	4	5.3	10	0.934	10.7	14.3	1.617	27.47	0.52	19.61
WFL	0.50	0.30	0.08	Larvae	75	0	0.0	2	0.934	2.1	2.9	1.617	27.47	0.10	2.86
WFL	0.50	0.30	0.08	Larvae	75	6	8.0	4	0.934	4.3	5.7	1.617	27.47	0.21	13.71
WFL	0.50	0.30	0.08	Larvae	75	10	13.3	0	0.934	0.0	0.0	1.617	27.47	0.00	13.33
WFL	0.50	0.30	0.08	Larvae	75			19	0.934	20.3	27.1	1.617	27.47	0.99	
WFL	0.50	0.30	0.15	Larvae	75	17	22.7	10	0.934	10.7	14.3	1.617	27.47	0.52	36.94
WFL	0.50	0.30	0.15	Larvae	75	6	8.0	1	0.934	1.1	1.4	1.617	27.47	0.05	9.43
WFL	0.50	0.30	0.15	Larvae	75	6	8.0	6	0.934	6.4	8.6	1.617	27.47	0.31	16.57
WFL	0.50	0.30	0.15	Larvae	75	4	5.3	13	0.934	13.9	18.6	1.617	27.47	0.68	23.89
WFL	0.50	0.30	0.15	Larvae	75	15	20.0	9	0.934	9.6	12.8	1.617	27.47	0.47	32.85
WFL	0.50	0.30	0.30	Larvae	75	9	12.0	2	0.934	2.1	2.9	1.617	27.47	0.10	14.86
WFL	0.50	0.30	0.30	Larvae	75	6	8.0	7	0.934	7.5	10.0	1.617	27.47	0.36	17.99
WFL	0.50	0.30	0.30	Larvae	75	5	6.7	4	0.934	4.3	5.7	1.617	27.47	0.21	12.38
WFL	0.50	0.30	0.30	Larvae	75	6	8.0	2	0.934	2.1	2.9	1.617	27.47	0.10	10.86
WFL	0.50	0.30	0.30	Larvae	75			6	0.934	6.4	8.6	1.617	27.47	0.31	
WFL	1.00	0.15	0.08	Larvae	75	0	0.0	56	0.983	57.0	76.0	1.297	22.04	3.45	75.96
WFL	1.00	0.15	0.08	Larvae	75	0	0.0	66	0.983	67.1	89.5	1.297	22.04	4.06	89.52
WFL	1.00	0.15	0.08	Larvae	75	0	0.0	66	0.983	67.1	89.5	1.297	22.04	4.06	89.52
WFL	1.00	0.15	0.08	Larvae	75	1	1.3	64	0.983	65.1	86.8	1.297	22.04	3.94	88.14
WFL	1.00	0.15	0.08	Larvae	75	3	4.0	60	0.983	61.0	81.4	1.297	22.04	3.69	85.38

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
WFL	1.00	0.15	0.15	Larvae	75	2	2.7	61	0.983	62.1	82.7	1.297	22.04	3.75	85.41
WFL	1.00	0.15	0.15	Larvae	75	2	2.7	43	0.983	43.7	58.3	1.297	22.04	2.65	60.99
WFL	1.00	0.15	0.15	Larvae	75	3	4.0	48	0.983	48.8	65.1	1.297	22.04	2.95	69.11
WFL	1.00	0.15	0.15	Larvae	75	1	1.3	66	0.983	67.1	89.5	1.297	22.04	4.06	90.86
WFL	1.00	0.15	0.15	Larvae	75	1	1.3	49	0.983	49.8	66.5	1.297	22.04	3.02	67.80
WFL	1.00	0.15	0.30	Larvae	75	0	0.0	44	0.983	44.8	59.7	1.297	22.04	2.71	59.68
WFL	1.00	0.15	0.30	Larvae	75	2	2.7	42	0.983	42.7	57.0	1.297	22.04	2.59	59.64
WFL	1.00	0.15	0.30	Larvae	75	1	1.3	44	0.983	44.8	59.7	1.297	22.04	2.71	61.01
WFL	1.00	0.15	0.30	Larvae	75	2	2.7	47	0.983	47.8	63.8	1.297	22.04	2.89	66.42
WFL	1.00	0.15	0.30	Larvae	75	0	0.0	49	0.983	49.8	66.5	1.297	22.04	3.02	66.46
WFL	1.00	0.30	0.08	Larvae	75	13	17.3	52	1	52.0	69.3	2.593	44.06	1.57	86.67
WFL	1.00	0.30	0.08	Larvae	75	10	13.3	57	1	57.0	76.0	2.593	44.06	1.73	89.33
WFL	1.00	0.30	0.08	Larvae	75	19	25.3	50	1	50.0	66.7	2.593	44.06	1.51	92.00
WFL	1.00	0.30	0.08	Larvae	73	11	15.1	34	1	34.0	46.6	2.593	44.06	1.06	61.64
WFL	1.00	0.30	0.08	Larvae	75	21	28.0	48	1	48.0	64.0	2.593	44.06	1.45	92.00
WFL	1.00	0.30	0.15	Larvae	75	2	2.7	71	1	71.0	94.7	2.593	44.06	2.15	97.33
WFL	1.00	0.30	0.15	Larvae	75	11	14.7	33	1	33.0	44.0	2.593	44.06	1.00	58.67
WFL	1.00	0.30	0.15	Larvae	75	2	2.7	71	1	71.0	94.7	2.593	44.06	2.15	97.33
WFL	1.00	0.30	0.15	Larvae	75	4	5.3	58	1	58.0	77.3	2.593	44.06	1.76	82.67
WFL	1.00	0.30	0.15	Larvae	75	8	10.7	61	1	61.0	81.3	2.593	44.06	1.85	92.00
WFL	1.00	0.30	0.30	Larvae	75	9	12.0	66	1.000	66.0	88.0	2.593	44.06	2.00	100.00
WFL	1.00	0.30	0.30	Larvae	75	9	12.0	54	1.000	54.0	72.0	2.593	44.06	1.63	84.00
WFL	1.00	0.30	0.30	Larvae	75	8	10.7	44	1.000	44.0	58.7	2.593	44.06	1.33	69.33
WFL	1.00	0.30	0.30	Larvae	75	8	10.7	45	1.000	45.0	60.0	2.593	44.06	1.36	70.67
WFL	1.00	0.30	0.30	Larvae	75	2	2.7	69	1.000	69.0	92.0	2.593	44.06	2.09	94.67
WFL	2.00	0.15	0.08	Larvae	75	0	0.0	64	0.983	65.1	86.8	1.857	31.55	2.75	86.81

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
WFL	2.00	0.15	0.08	Larvae	75	0	0.0	40	0.983	40.7	54.3	1.857	31.55	1.72	54.26
WFL	2.00	0.15	0.08	Larvae	75	0	0.0	64	0.983	65.1	86.8	1.857	31.55	2.75	86.81
WFL	2.00	0.15	0.08	Larvae	75	0	0.0	68	0.983	69.2	92.2	1.857	31.55	2.92	92.23
WFL	2.00	0.15	0.08	Larvae	75	0	0.0	69	0.983	70.2	93.6	1.857	31.55	2.97	93.59
WFL	2.00	0.15	0.15	Larvae	75	0	0.0	52	0.983	52.9	70.5	1.857	31.55	2.24	70.53
WFL	2.00	0.15	0.15	Larvae	75	0	0.0	64	0.983	65.1	86.8	1.857	31.55	2.75	86.81
WFL	2.00	0.15	0.15	Larvae	75	0	0.0	69	0.983	70.2	93.6	1.857	31.55	2.97	93.59
WFL	2.00	0.15	0.15	Larvae	75	0	0.0	61	0.983	62.1	82.7	1.857	31.55	2.62	82.74
WFL	2.00	0.15	0.15	Larvae	75	0	0.0	64	0.983	65.1	86.8	1.857	31.55	2.75	86.81
WFL	2.00	0.15	0.30	Larvae	75	0	0.0	51	0.983	51.9	69.2	1.857	31.55	2.19	69.18
WFL	2.00	0.15	0.30	Larvae	75	0	0.0	51	0.983	51.9	69.2	1.857	31.55	2.19	69.18
WFL	2.00	0.15	0.30	Larvae	75	0	0.0	58	0.983	59.0	78.7	1.857	31.55	2.49	78.67
WFL	2.00	0.15	0.30	Larvae	75	0	0.0	51	0.983	51.9	69.2	1.857	31.55	2.19	69.18
WFL	2.00	0.15	0.30	Larvae	75	1	1.3	59	0.983	60.0	80.0	1.857	31.55	2.54	81.36
WHS	0.50	0.15	0.08	Larvae	75	2	2.7	0	0.970	0.0	0.0	0.808	13.73	0.00	2.67
WHS	0.50	0.15	0.08	Larvae	75	6	8.0	0	0.970	0.0	0.0	0.808	13.73	0.00	8.00
WHS	0.50	0.15	0.08	Larvae	75	12	16.0	0	0.970	0.0	0.0	0.808	13.73	0.00	16.00
WHS	0.50	0.15	0.08	Larvae	75	5	6.7	0	0.970	0.0	0.0	0.808	13.73	0.00	6.67
WHS	0.50	0.15	0.08	Larvae	75	2	2.7	0	0.970	0.0	0.0	0.808	13.73	0.00	2.67
WHS	0.50	0.15	0.15	Larvae	75	8	10.7	0	0.970	0.0	0.0	0.808	13.73	0.00	10.67
WHS	0.50	0.15	0.15	Larvae	75	10	13.3	0	0.970	0.0	0.0	0.808	13.73	0.00	13.33
WHS	0.50	0.15	0.15	Larvae	73	1	1.4	0	0.970	0.0	0.0	0.808	13.73	0.00	1.37
WHS	0.50	0.15	0.15	Larvae	75	1	1.3	0	0.970	0.0	0.0	0.808	13.73	0.00	1.33
WHS	0.50	0.15	0.15	Larvae	74	2	2.7	0	0.970	0.0	0.0	0.808	13.73	0.00	2.70
WHS	0.50	0.15	0.30	Larvae	75	0	0.0	1	0.970	1.0	1.4	0.808	13.73	0.10	1.37
WHS	0.50	0.15	0.30	Larvae	75	0	0.0	0	0.970	0.0	0.0	0.808	13.73	0.00	0.00

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
WHS	0.50	0.15	0.30	Larvae	75	0	0.0	0	0.970	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.30	Larvae	75	0	0.0	0	0.970	0.0	0.0	0.808	13.73	0.00	0.00
WHS	0.50	0.15	0.30	Larvae	75	1	1.3	0	0.970	0.0	0.0	0.808	13.73	0.00	1.33
WHS	1.00	0.15	0.08	Larvae	50	7	14.0	16	0.970	16.5	33.0	1.297	22.04	1.50	46.99
WHS	1.00	0.15	0.08	Larvae	50	8	16.0	3	0.970	3.1	6.2	1.297	22.04	0.28	22.19
WHS	1.00	0.15	0.08	Larvae	50	5	10.0	3	0.970	3.1	6.2	1.297	22.04	0.28	16.19
WHS	1.00	0.15	0.08	Larvae	50	4	8.0	1	0.970	1.0	2.1	1.297	22.04	0.09	10.06
WHS	1.00	0.15	0.08	Larvae	50	3	6.0	7	0.970	7.2	14.4	1.297	22.04	0.65	20.43
WHS	1.00	0.15	0.15	Larvae	50	3	6.0	7	0.970	7.2	14.4	1.297	22.04	0.65	20.43
WHS	1.00	0.15	0.15	Larvae	50	1	2.0	3	0.970	3.1	6.2	1.297	22.04	0.28	8.19
WHS	1.00	0.15	0.15	Larvae	50	0	0.0	2	0.970	2.1	4.1	1.297	22.04	0.19	4.12
WHS	1.00	0.15	0.30	Larvae	50	2	4.0	4	0.970	4.1	8.2	1.297	22.04	0.37	12.25
WHS	1.00	0.15	0.30	Larvae	50	2	4.0	2	0.970	2.1	4.1	1.297	22.04	0.19	8.12
WHS	1.00	0.15	0.30	Larvae	50	1	2.0	2	0.970	2.1	4.1	1.297	22.04	0.19	6.12
WHS	1.00	0.15	0.30	Larvae	50	3	6.0	4	0.970	4.1	8.2	1.297	22.04	0.37	14.25
WHS	1.00	0.15	0.30	Larvae	50	2	4.0	2	0.970	2.1	4.1	1.297	22.04	0.19	8.12
WHS	1.00	0.30	0.08	Larvae	75	2	2.7	21	0.985	21.3	28.4	2.593	44.06	0.65	31.09
WHS	1.00	0.30	0.08	Larvae	75	0	0.0	23	0.985	23.4	31.1	2.593	44.06	0.71	31.13
WHS	1.00	0.30	0.08	Larvae	75	3	4.0	29	0.985	29.4	39.3	2.593	44.06	0.89	43.26
WHS	1.00	0.30	0.08	Larvae	50	0	0.0	8	0.985	8.1	16.2	2.593	44.06	0.37	16.24
WHS	1.00	0.30	0.08	Larvae	50	4	8.0	33	0.985	33.5	67.0	2.593	44.06	1.52	75.01
WHS	1.00	0.30	0.15	Larvae	50	2	4.0	17	0.985	17.3	34.5	2.593	44.06	0.78	38.52
WHS	1.00	0.30	0.15	Larvae	50	1	2.0	20	0.985	20.3	40.6	2.593	44.06	0.92	42.61
WHS	1.00	0.30	0.15	Larvae	50	6	12.0	31	0.985	31.5	62.9	2.593	44.06	1.43	74.94
WHS	1.00	0.30	0.15	Larvae	50	6	12.0	25	0.985	25.4	50.8	2.593	44.06	1.15	62.76
WHS	1.00	0.30	0.15	Larvae	50	7	14.0	25	0.985	25.4	50.8	2.593	44.06	1.15	64.76

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
WHS	1.00	0.30	0.30	Larvae	50	0	0.0	9	0.985	9.1	18.3	2.593	44.06	0.41	18.27
WHS	1.00	0.30	0.30	Larvae	50	0	0.0	8	0.985	8.1	16.2	2.593	44.06	0.37	16.24
WHS	1.00	0.30	0.30	Larvae	50	0	0.0	13	0.985	13.2	26.4	2.593	44.06	0.60	26.40
WHS	1.00	0.30	0.30	Larvae	50	1	2.0	20	0.985	20.3	40.6	2.593	44.06	0.92	42.61
WHS	1.00	0.30	0.30	Larvae	50	6	12.0	8	0.985	8.1	16.2	2.593	44.06	0.37	28.24
YLP	0.50	0.15	0.08	Larvae	75	4	5.3	0	0.878	0.0	0.0	0.808	13.73	0.00	5.33
YLP	0.50	0.15	0.08	Larvae	75	5	6.7	0	0.878	0.0	0.0	0.808	13.73	0.00	6.67
YLP	0.50	0.15	0.08	Larvae	75	4	5.3	0	0.878	0.0	0.0	0.808	13.73	0.00	5.33
YLP	0.50	0.15	0.08	Larvae	75	13	17.3	0	0.878	0.0	0.0	0.808	13.73	0.00	17.33
YLP	0.50	0.15	0.08	Larvae	75	4	5.3	0	0.878	0.0	0.0	0.808	13.73	0.00	5.33
YLP	0.50	0.15	0.15	Larvae	73	5	6.8	2	0.878	2.3	3.1	0.808	13.73	0.23	9.97
YLP	0.50	0.15	0.15	Larvae	75	3	4.0	1	0.878	1.1	1.5	0.808	13.73	0.11	5.52
YLP	0.50	0.15	0.15	Larvae	75	3	4.0	0	0.878	0.0	0.0	0.808	13.73	0.00	4.00
YLP	0.50	0.15	0.15	Larvae	75	6	8.0	0	0.878	0.0	0.0	0.808	13.73	0.00	8.00
YLP	0.50	0.15	0.15	Larvae	75	8	10.7	0	0.878	0.0	0.0	0.808	13.73	0.00	10.67
YLP	0.50	0.15	0.30	Larvae	72	5	6.9	0	0.878	0.0	0.0	0.808	13.73	0.00	6.94
YLP	0.50	0.15	0.30	Larvae	75	3	4.0	0	0.878	0.0	0.0	0.808	13.73	0.00	4.00
YLP	0.50	0.15	0.30	Larvae	75	2	2.7	0	0.878	0.0	0.0	0.808	13.73	0.00	2.67
YLP	0.50	0.15	0.30	Larvae	75	6	8.0	0	0.878	0.0	0.0	0.808	13.73	0.00	8.00
YLP	0.50	0.15	0.30	Larvae	75	6	8.0	0	0.878	0.0	0.0	0.808	13.73	0.00	8.00
YLP	0.50	0.30	0.08	Larvae	75	5	6.7	32	0.944	33.9	45.2	1.617	27.47	1.65	51.86
YLP	0.50	0.30	0.08	Larvae	75	5	6.7	29	0.944	30.7	41.0	1.617	27.47	1.49	47.63
YLP	0.50	0.30	0.08	Larvae	73	7	9.6	7	0.944	7.4	10.2	1.617	27.47	0.37	19.75
YLP	0.50	0.30	0.08	Larvae	75	7	9.3	23	0.944	24.4	32.5	1.617	27.47	1.18	41.82
YLP	0.50	0.30	0.08	Larvae	75	12	16.0	10	0.944	10.6	14.1	1.617	27.47	0.51	30.12
YLP	0.50	0.30	0.15	Larvae	75	12	16.0	22	0.944	23.3	31.1	1.617	27.47	1.13	47.07

Species	Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Life Stage	No. Released	No. Impinged	% Impinged	No. Entrained	Net Collection Efficiency (CE)	No. Entrained (adjusted for CE)	% Entrained (adjusted for CE)	Flow Rate (cfs)	Flow Volume (m^3)	No. entrainment adjusted for CE/m^3	% Loss (entrainment + impingement)
YLP	0.50	0.30	0.15	Larvae	75	8	10.7	24	0.944	25.4	33.9	1.617	27.47	1.23	44.56
YLP	0.50	0.30	0.15	Larvae	75	3	4.0	10	0.944	10.6	14.1	1.617	27.47	0.51	18.12
YLP	0.50	0.30	0.15	Larvae	75	10	13.3	22	0.944	23.3	31.1	1.617	27.47	1.13	44.41
YLP	0.50	0.30	0.15	Larvae	75	3	4.0	15	0.944	15.9	21.2	1.617	27.47	0.77	25.19
YLP	0.50	0.30	0.30	Larvae	75	5	6.7	5	0.944	5.3	7.1	1.617	27.47	0.26	13.73
YLP	0.50	0.30	0.30	Larvae	75	10	13.3	14	0.944	14.8	19.8	1.617	27.47	0.72	33.11
YLP	0.50	0.30	0.30	Larvae	75	6	8.0	12	0.944	12.7	16.9	1.617	27.47	0.62	24.95
YLP	0.50	0.30	0.30	Larvae	75	14	18.7	5	0.944	5.3	7.1	1.617	27.47	0.26	25.73
YLP	0.50	0.30	0.30	Larvae	75	7	9.3	6	0.944	6.4	8.5	1.617	27.47	0.31	17.81

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Section 316 (a) and (b) Fish Protection Issues

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