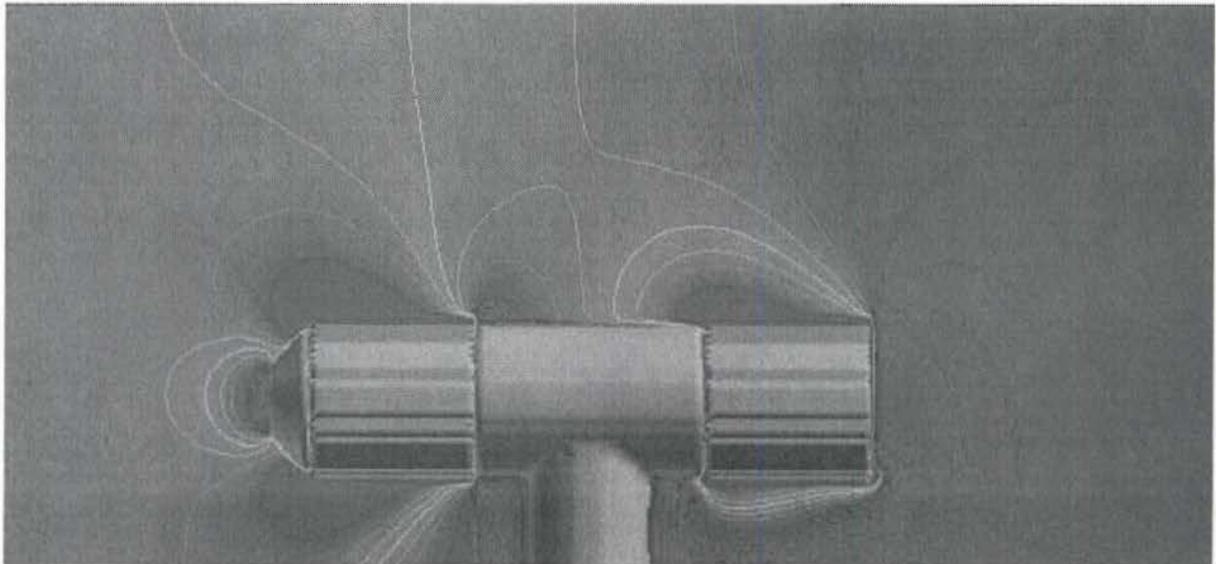# Laboratory Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes

*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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# CITATIONS

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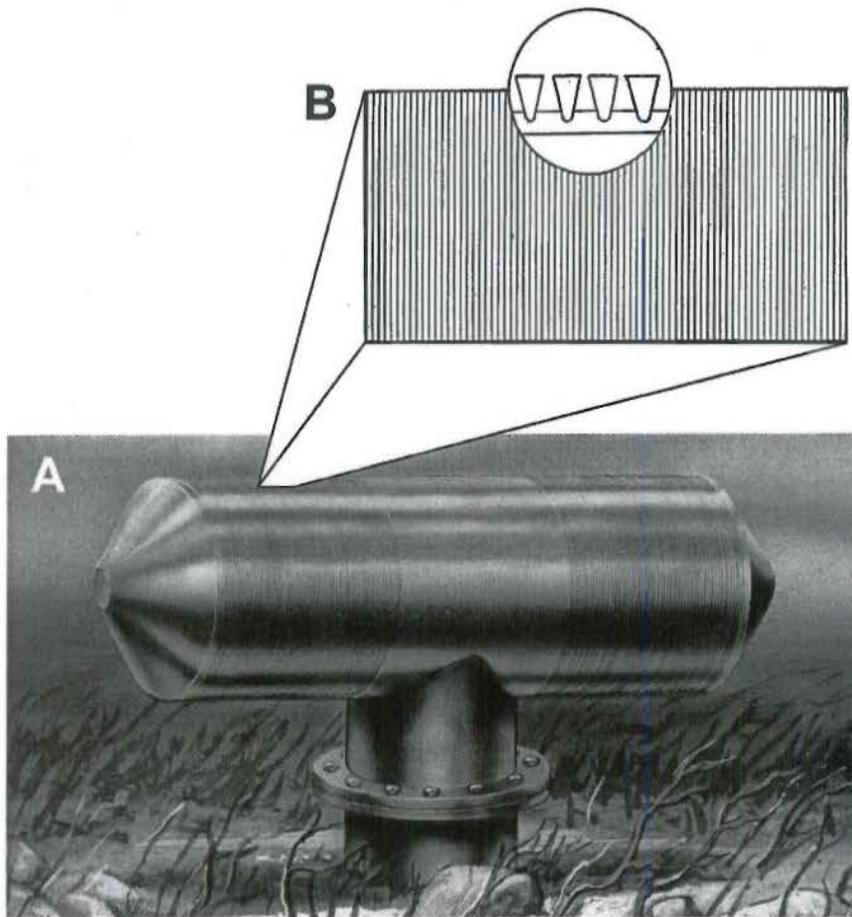
**Figure 1-1**
**Depiction of a Cylindrical Wedgewire Screen Installation (A) and Close-up of Slotted Wedgewire Elements (B) (Modified from Hanson 1978 and EPRI 1999).**

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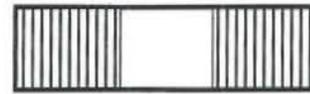
**Figure 1-2**
**Schematic of Wedgewire Screens (Plan View) Oriented Perpendicular and Parallel to Ambient Flow Direction**

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.
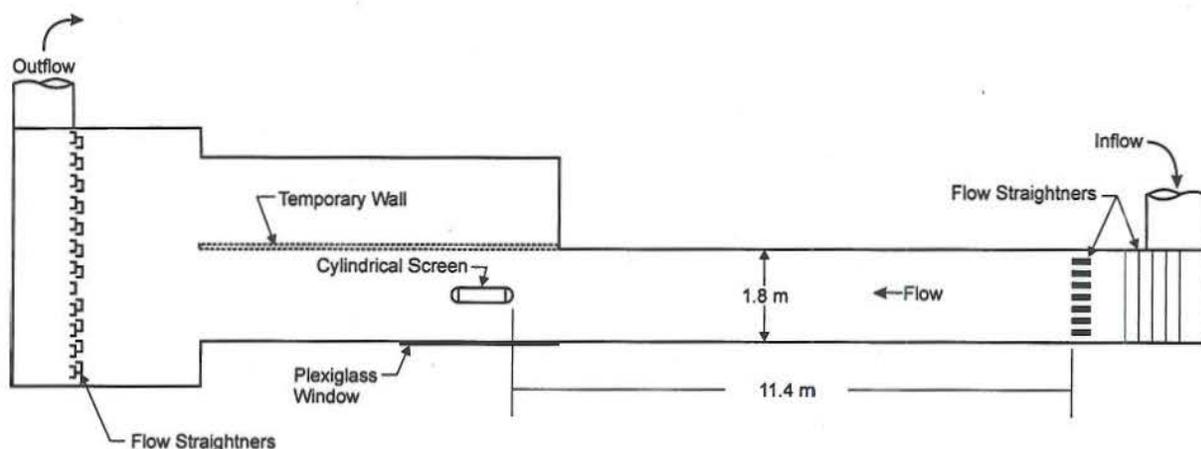


**Figure 2-1**
**Fish Testing Facility and Approximate Location of Cylindrical Wedgewire Screens**

**A**

1.3 m

25°

0.55 m

0.6 m

← Flow

To entrainment
collection net

Inclined collection screen

V-wire T-screen
(0.3 m in diameter by
1.3 m in length; plan
section depicts screen
oriented parallel and
perpendicular to flow)

Fish and egg
release system
(supported by a
moveable platform)

**B**

1.7 m

← Flow
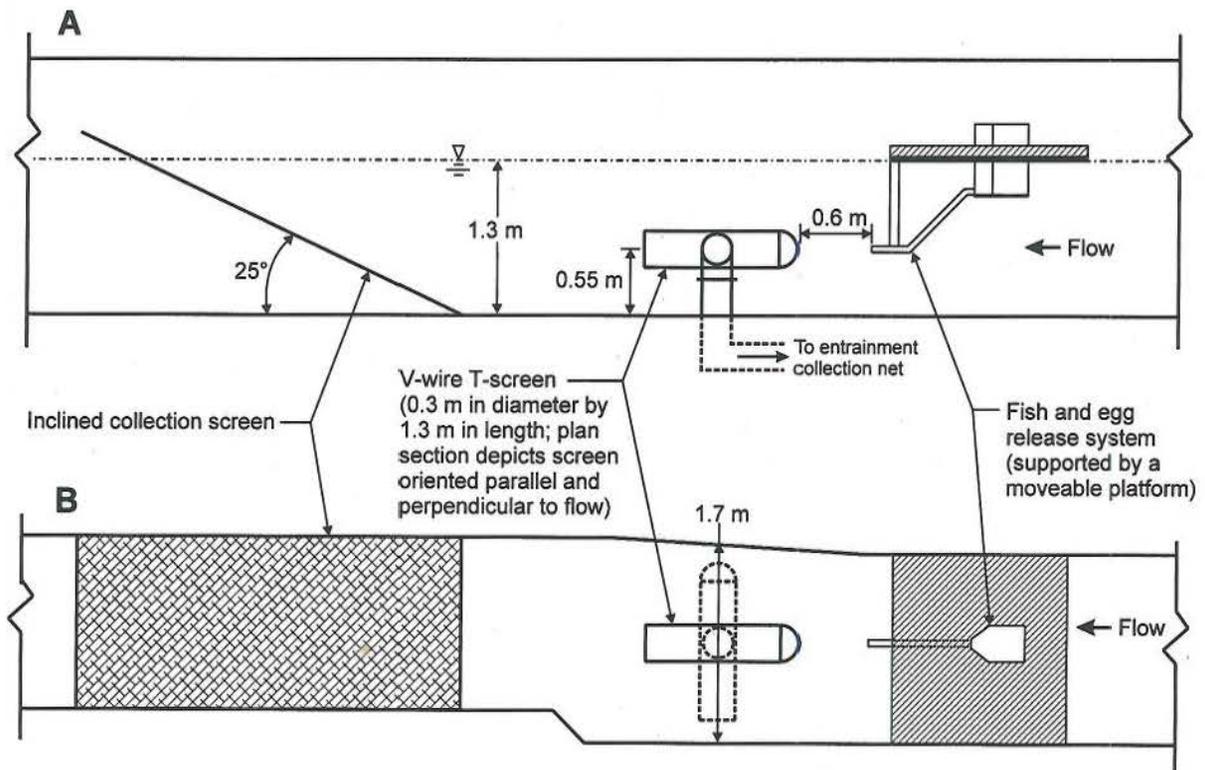
**Figure 2-2**
**2001 Wedgewire Screen Test Facility**
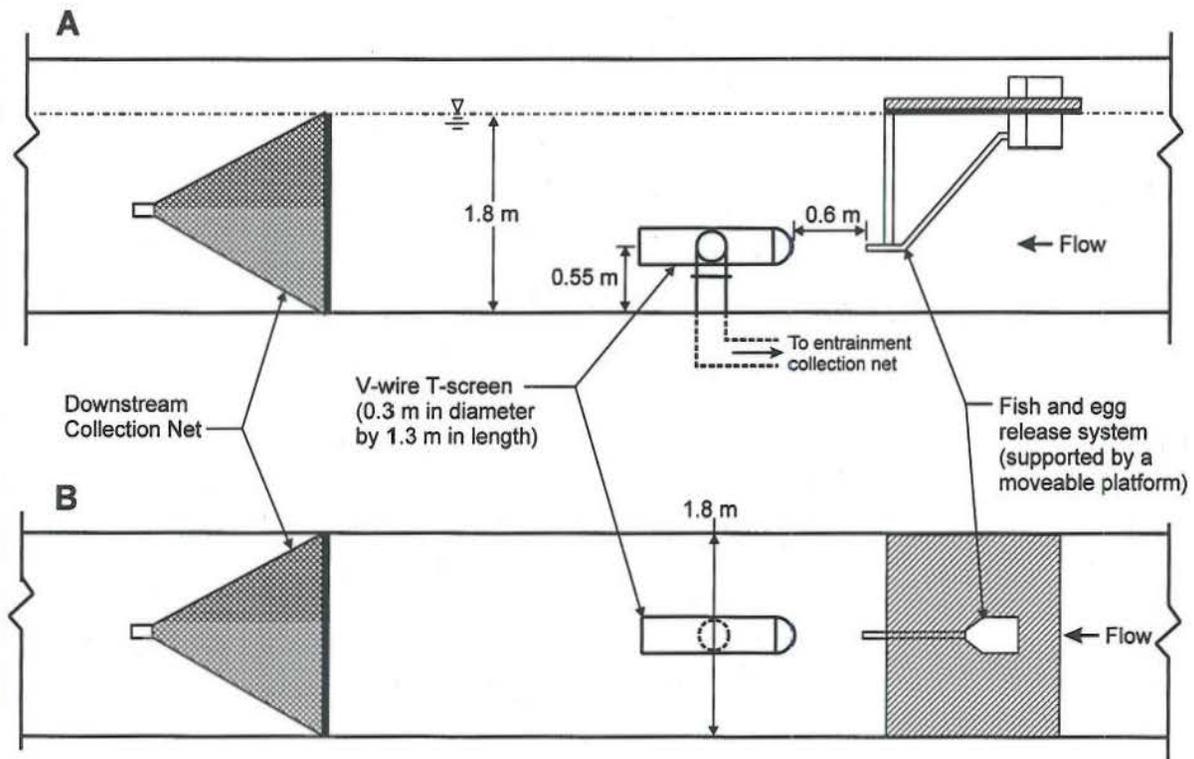
**Figure 2-3**
**2002 Wedgewire Screen Test Facility**

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.
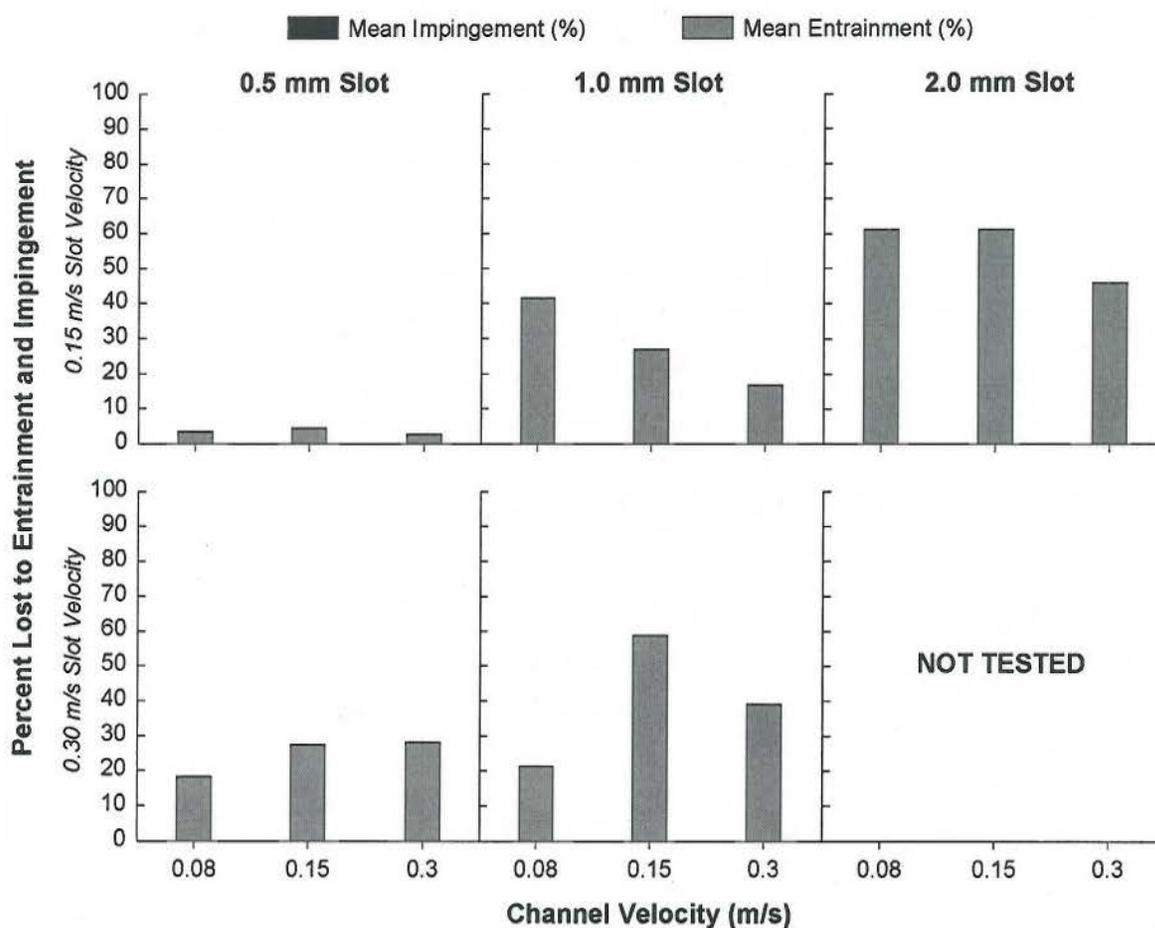
**Figure 3-4**
**Mean Percent of Striped Bass Larvae Lost to Impingement and Entrainment During Tests with the Screens Oriented Parallel to the Flow**
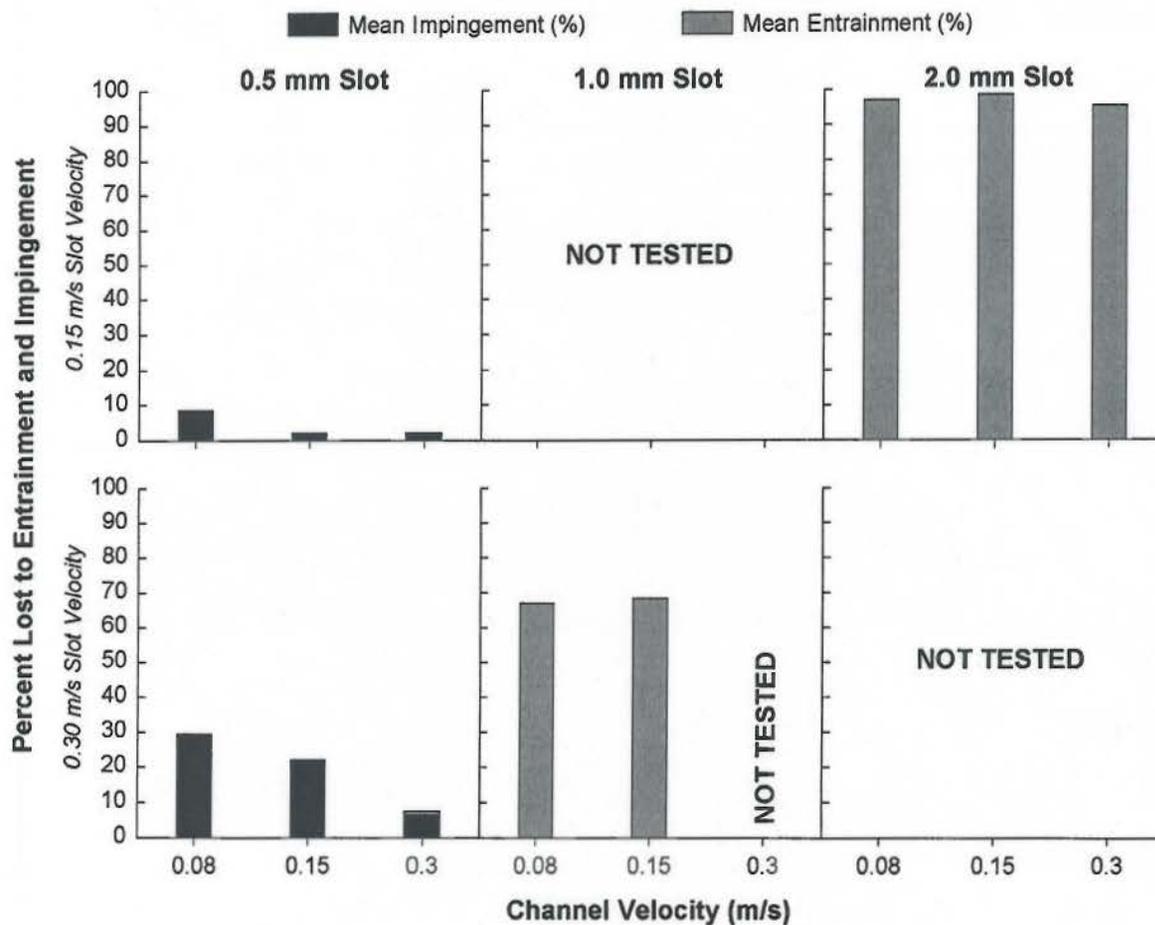
**Figure 3-5**
**Mean Percent of Striped Bass Larvae Lost to Impingement and Entrainment During Tests with the Screens Oriented Perpendicular to the Flow**

## 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 m³ | 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.
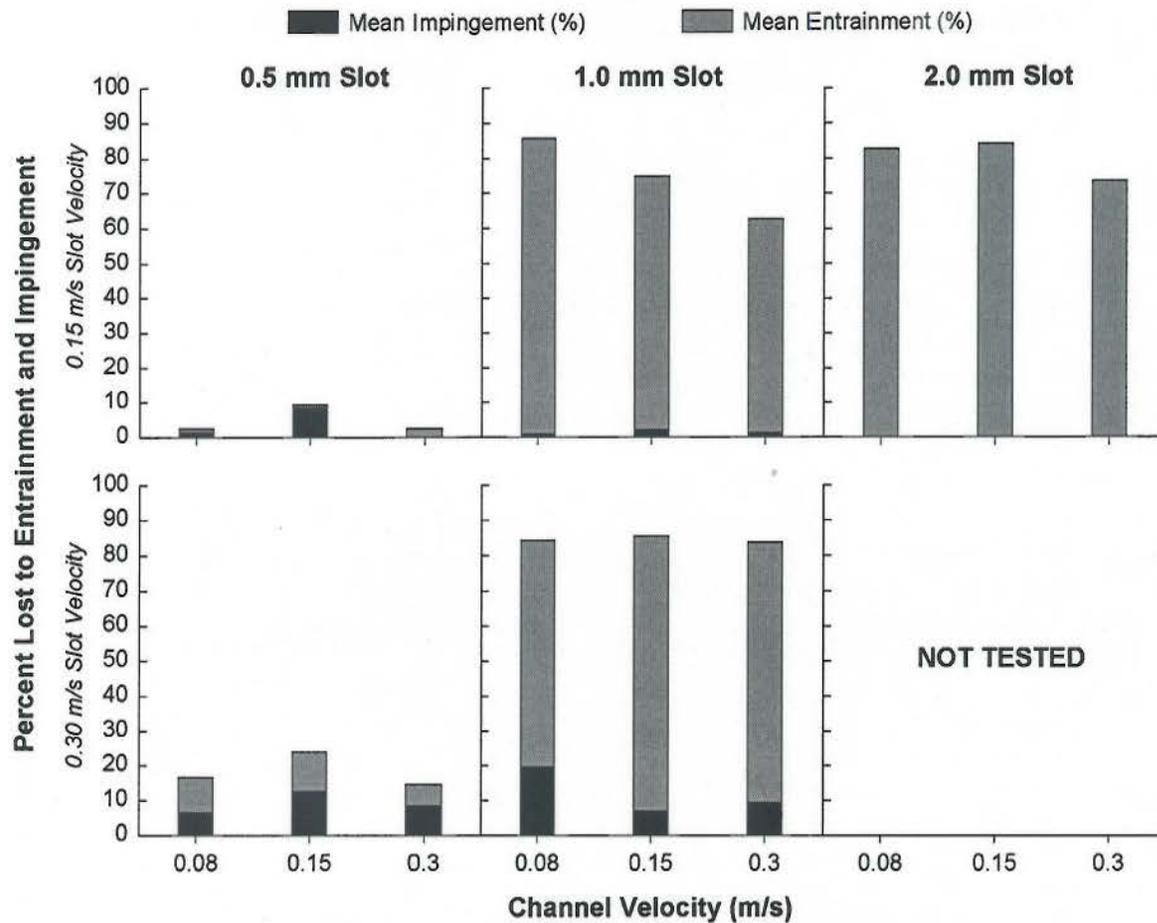
**Figure 3-6**
**Mean Percent of Winter Flounder Larvae Lost to Impingement and Entrainment**

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 m³ | 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.
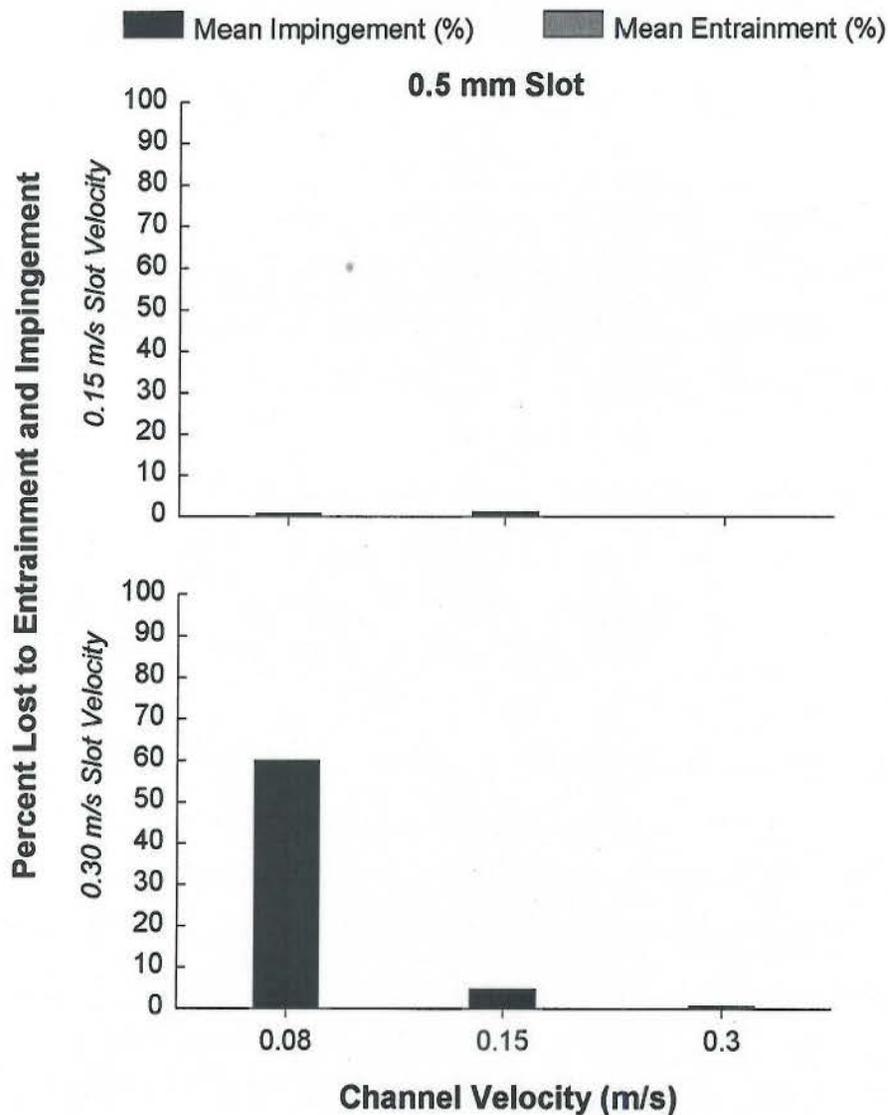
**Figure 3-7**
**Mean Percent of White Sucker eggs Lost to Impingement and Entrainment**

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 m³ | 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).
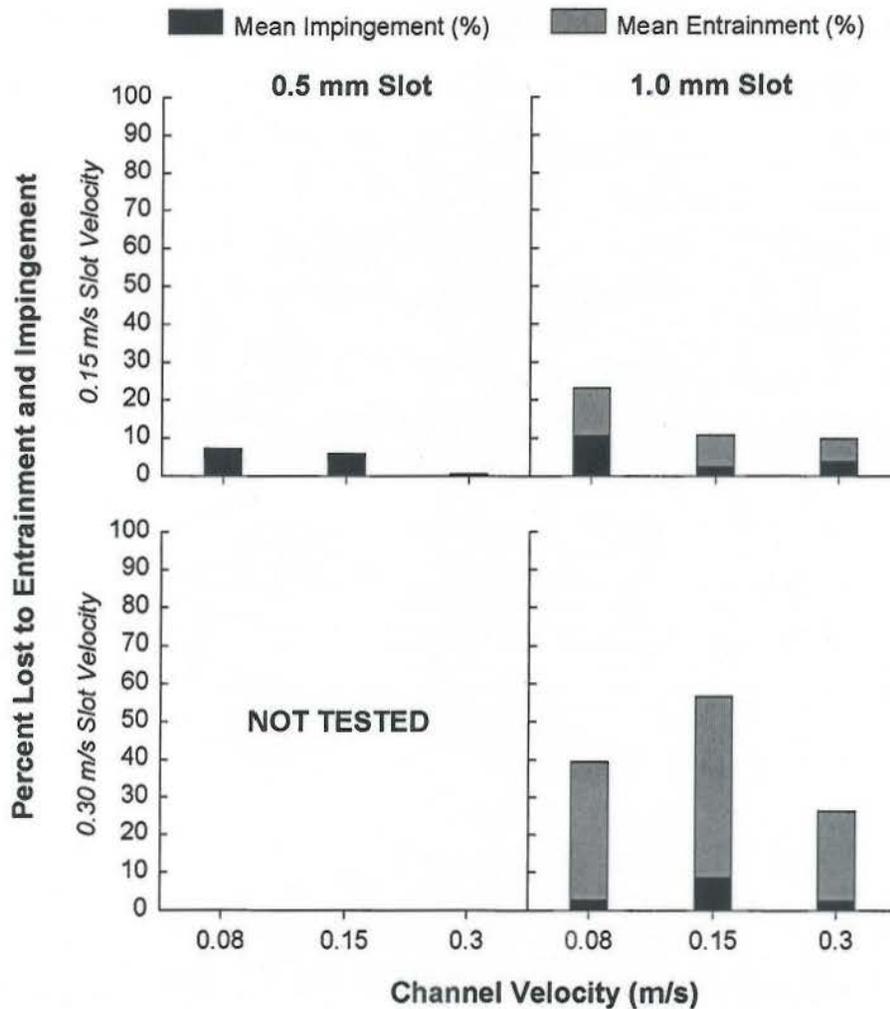
**Figure 3-8**
**Mean Percent of White Sucker Larvae Lost to Impingement and Entrainment**

## 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 m³ | 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 m³ | 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.
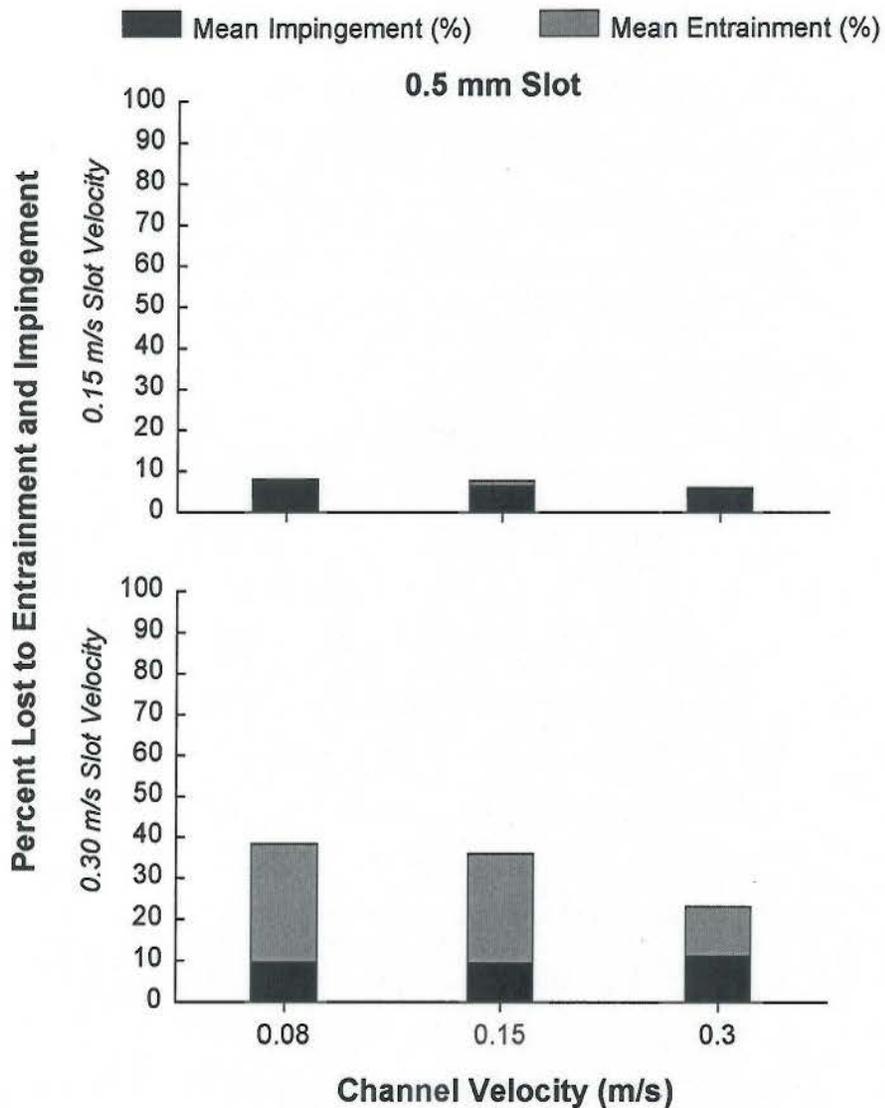
**Figure 3-9**
**Mean Percent of Yellow Perch Larvae Lost to Impingement and Entrainment**

## 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 m³ | 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 ($P < 0.05$).
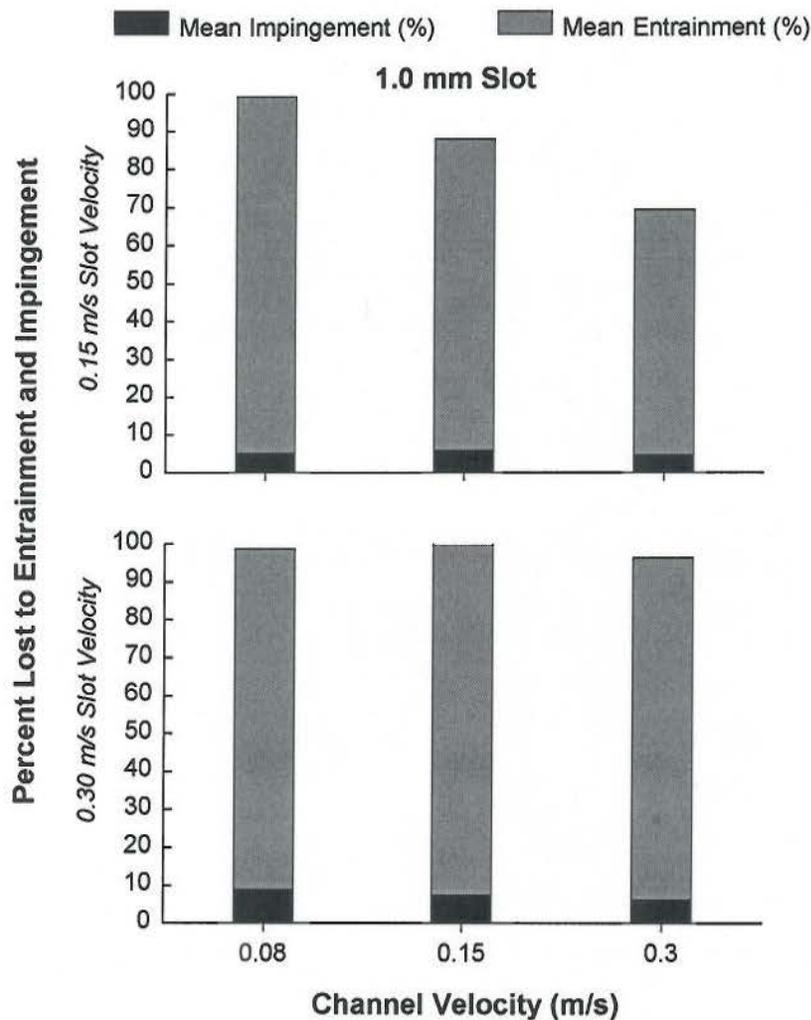
**Figure 3-10
Mean Percent of Common Carp Larvae Lost to Impingement and Entrainment**

## 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 m³ | 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.
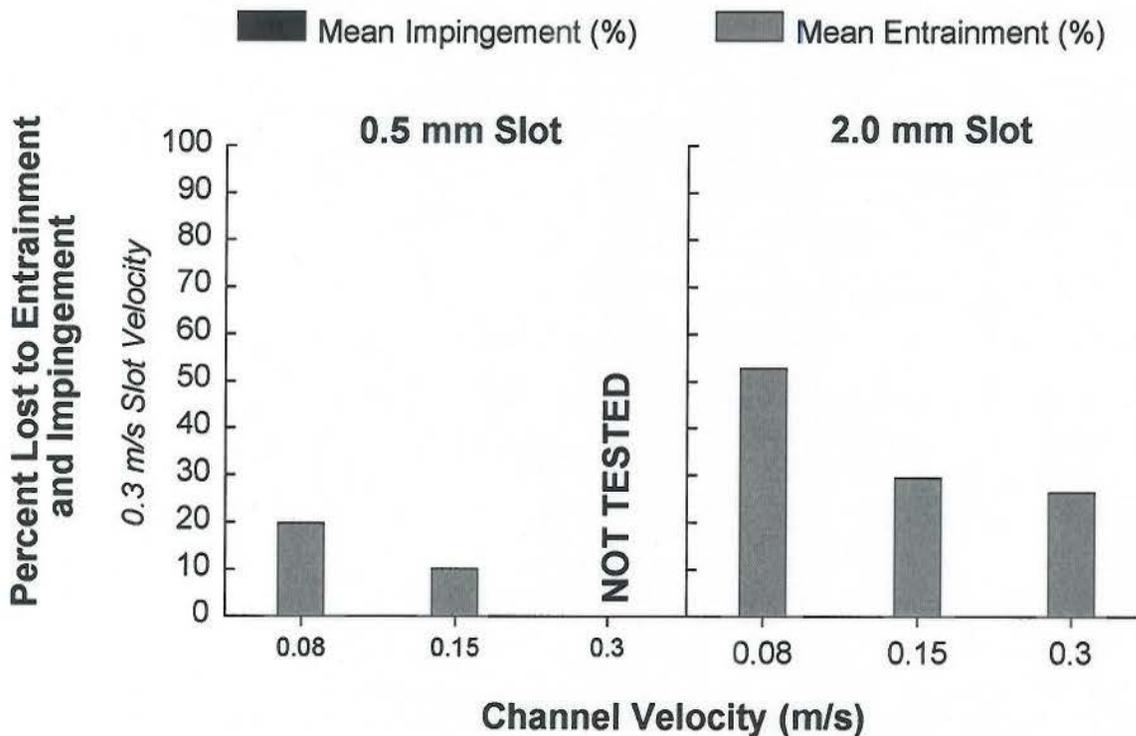


Figure 3-11
Mean Percent of Alewife Eggs Lost to Impingement and Entrainment

## 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 m³ | 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.
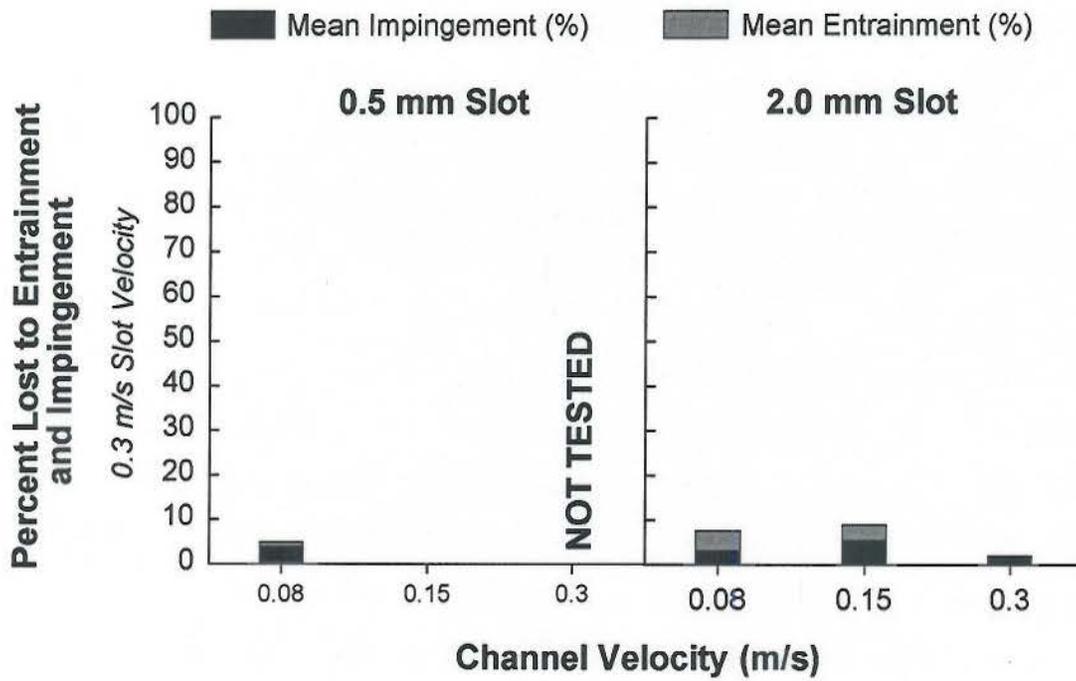
Figure 3-12
Mean Percent of Bluegill Larvae Lost to Impingement and Entrainment

# 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.
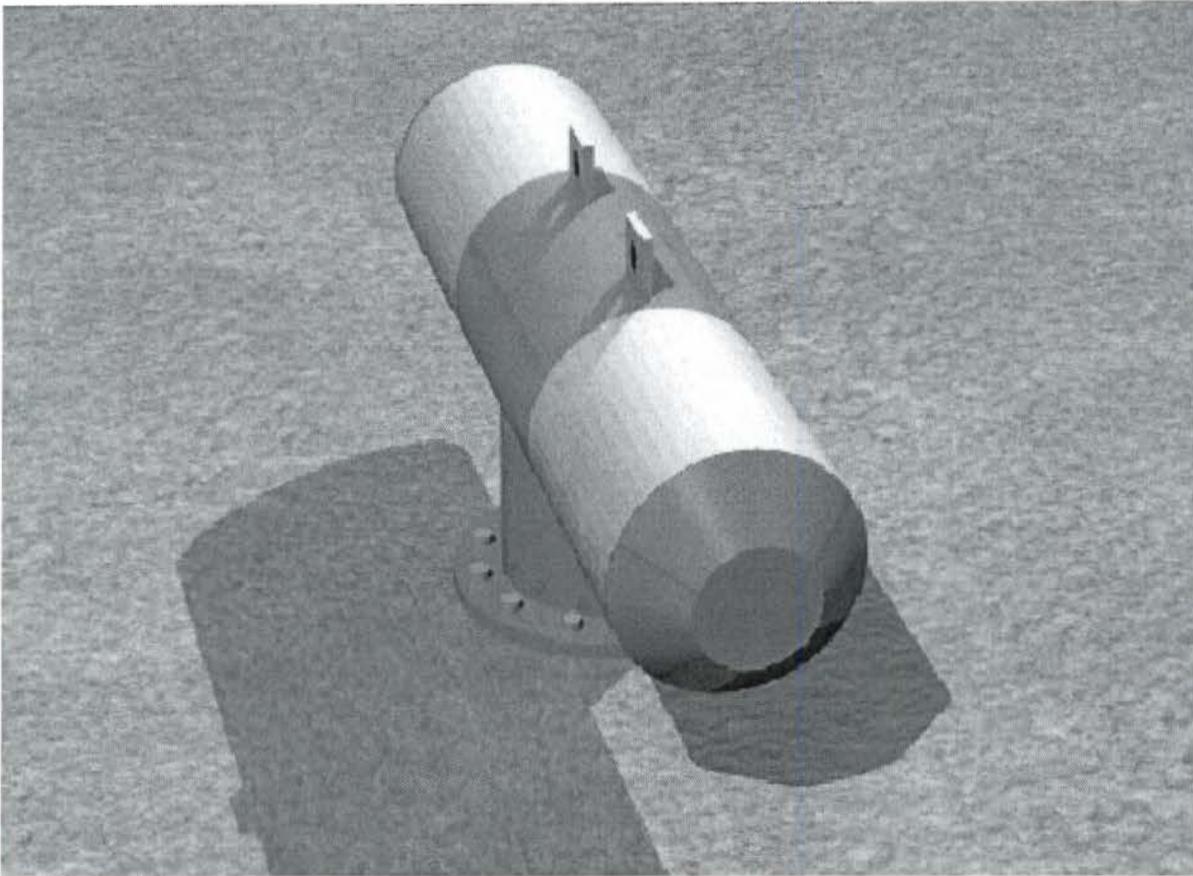
**Figure 4-1**
**Cylindrical Wedgewire Screen (CAD Model)**

## 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

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[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** (Fractional-Area-Volume-Obstacle-Representation) 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.

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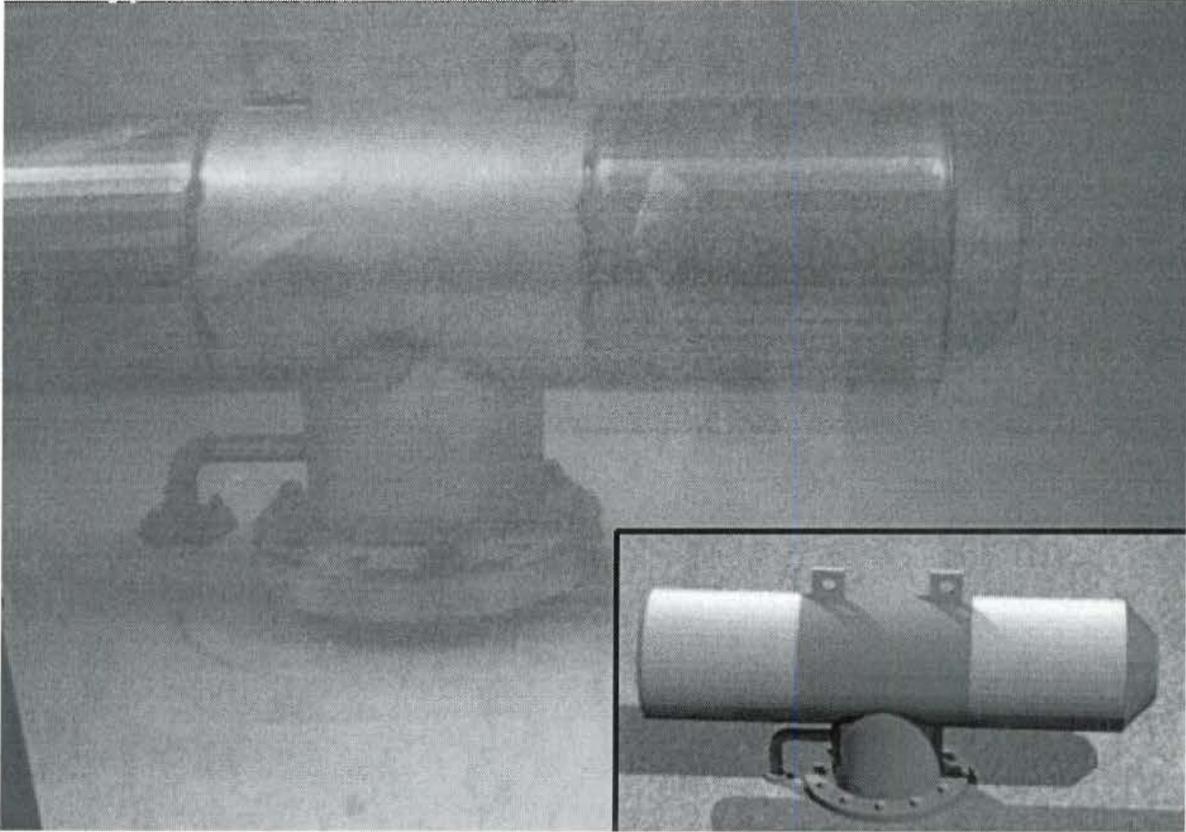
**Figure 4-2**
**T12 Screen (Photograph and CAD Model)**

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.
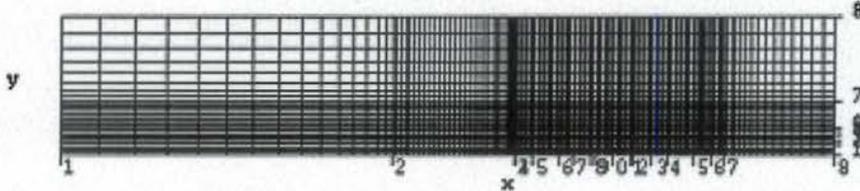
**Figure 4-3**
**Computational Mesh: X-Y grid**
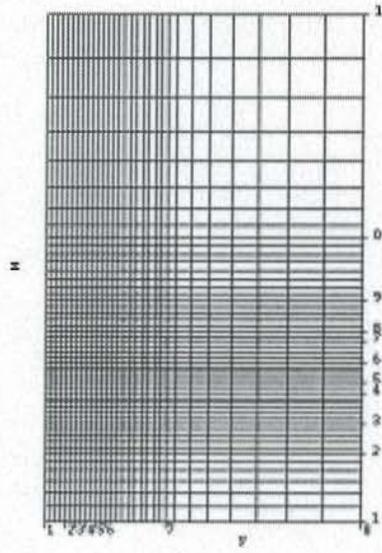


**Figure 4-4**
**Computational Mesh: X-Z grid**
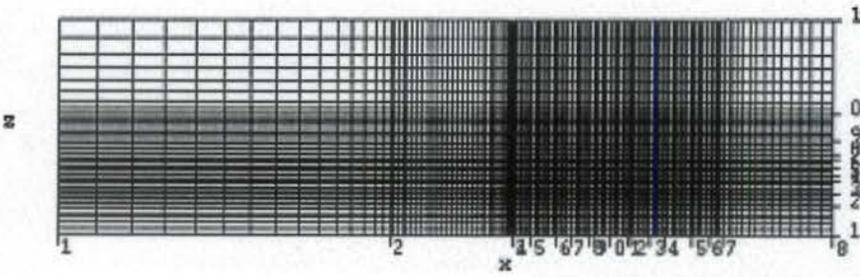


**Figure 4-5**
**Computational Mesh: Y-Z grid**

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.
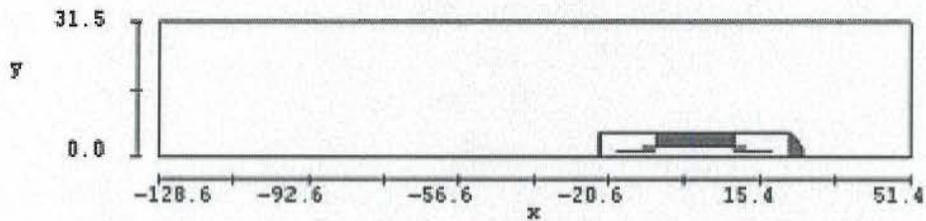


**Figure 4-6**
**Obstacle Plot – Calibration Exercise: X-Y Plane**
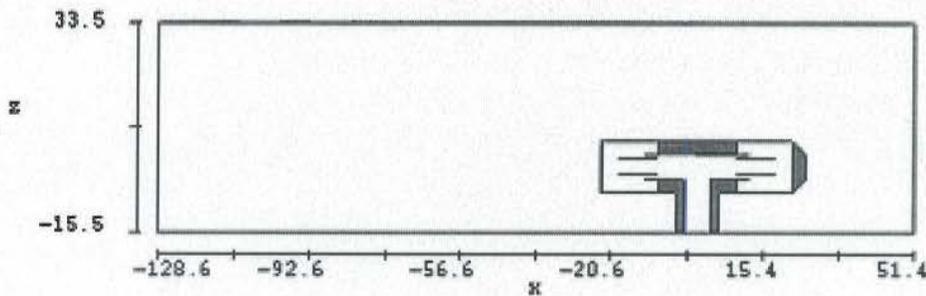


**Figure 4-7**
**Obstacle Plot – Calibration Exercise: X-Z Plane**
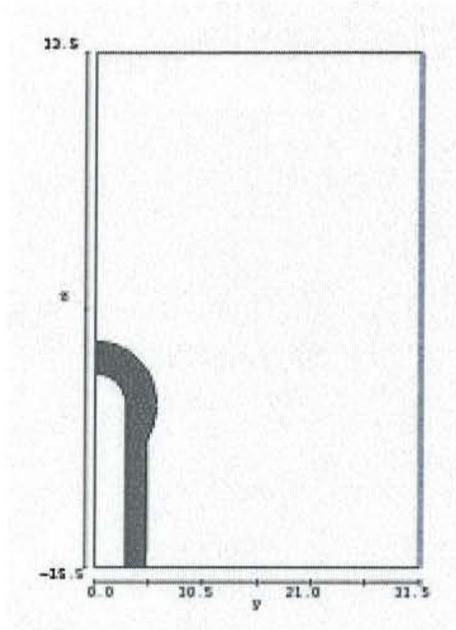
**Figure 4-8**
**Obstacle Plot – Calibration Exercise: Y-Z Plane**

*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.
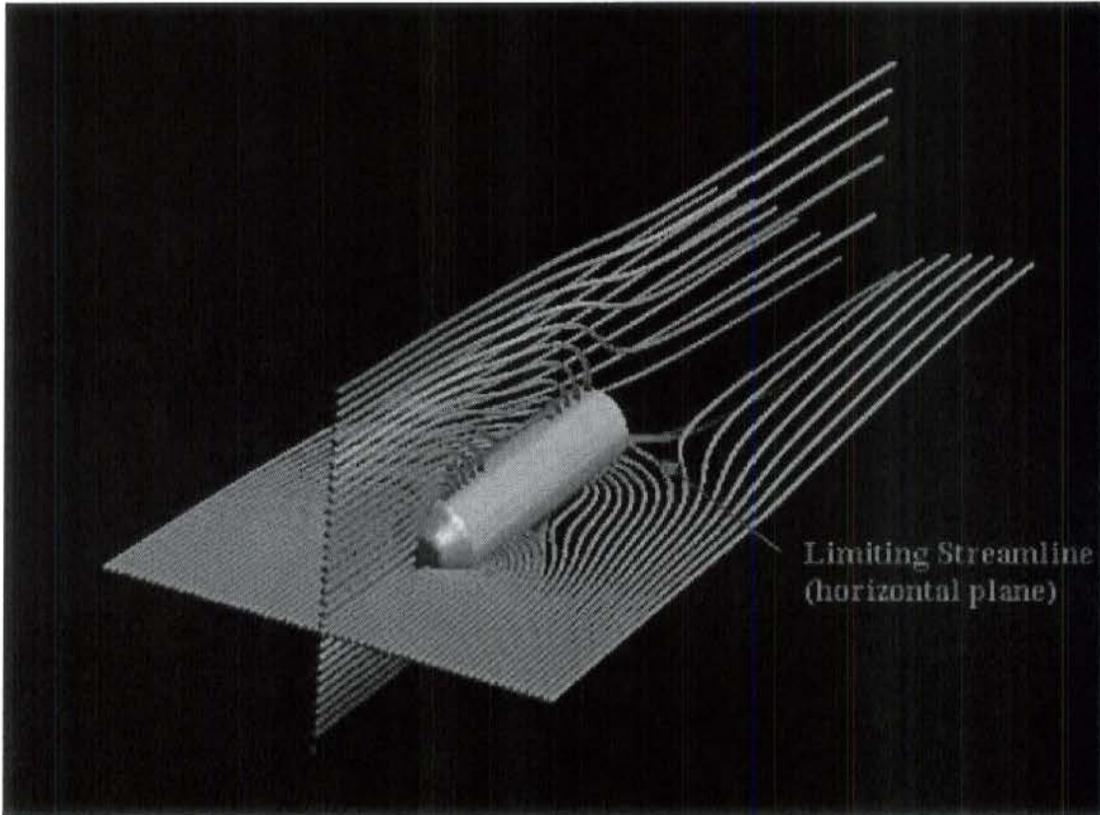


**Figure 4-9**
**Streamlines of flow (colored by elevation)**
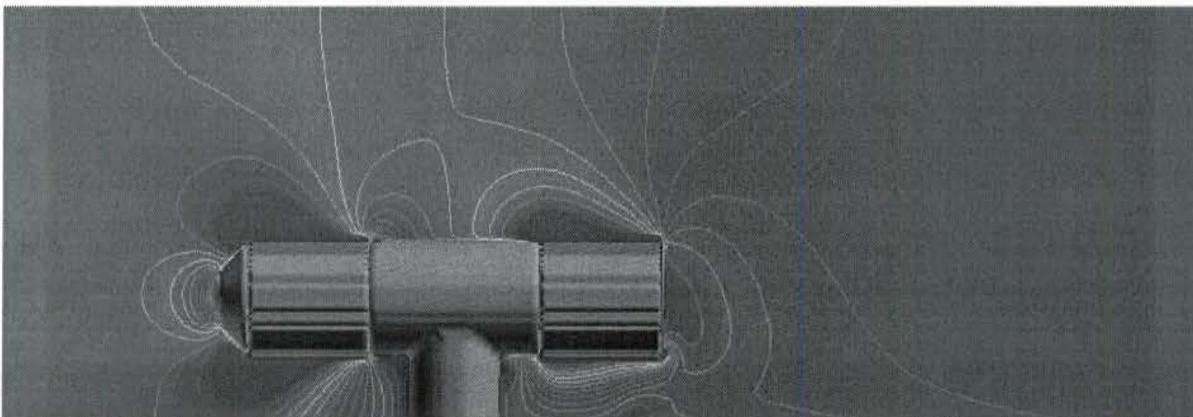


**Figure 4-10**
**Flow Distribution (colored by speed, flow is from left to right)**

## 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 m³/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]).

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[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.
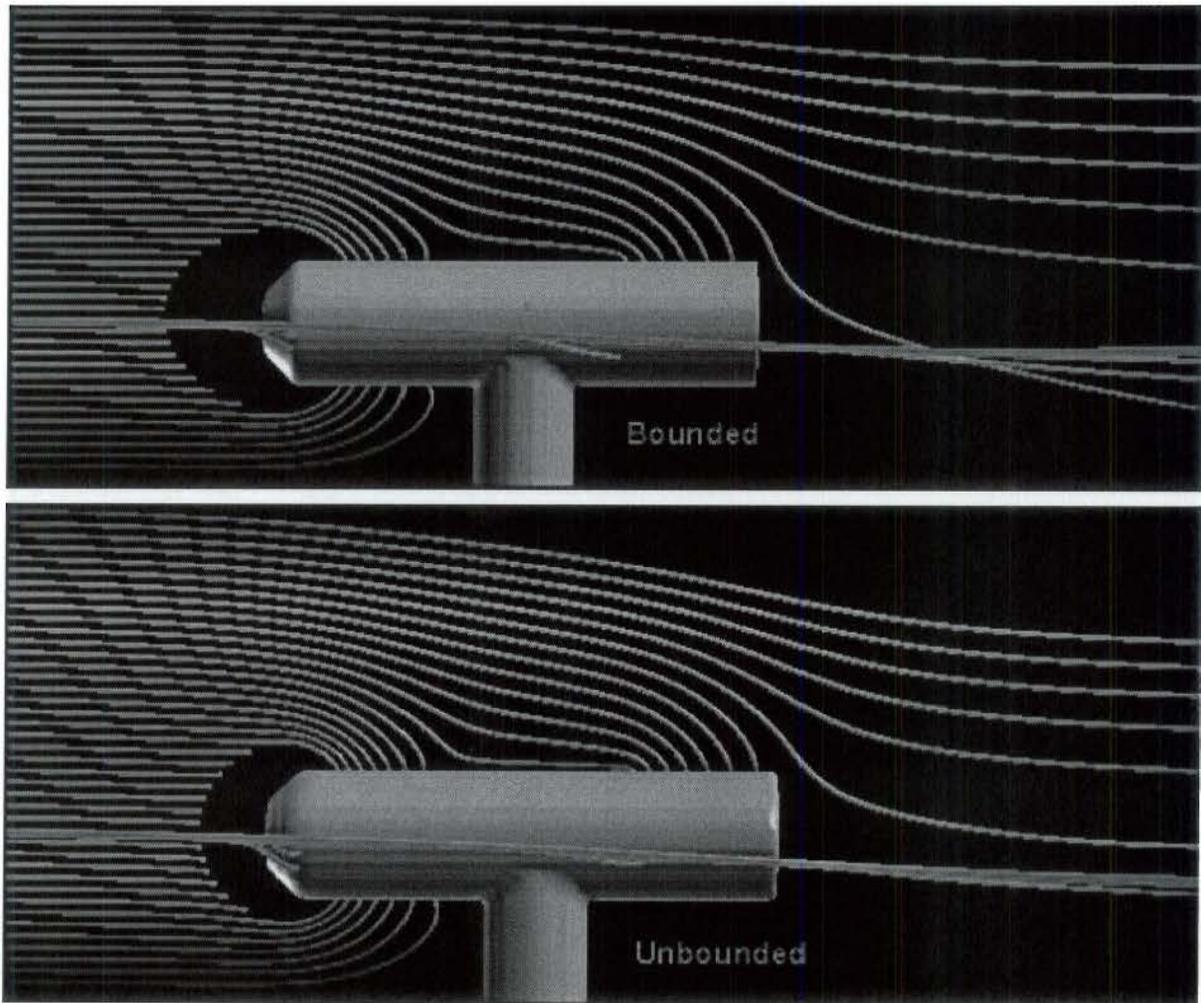
**Figure 4-12**
**Computed Results (colored by elevation)**

**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 (m³/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 m³/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.
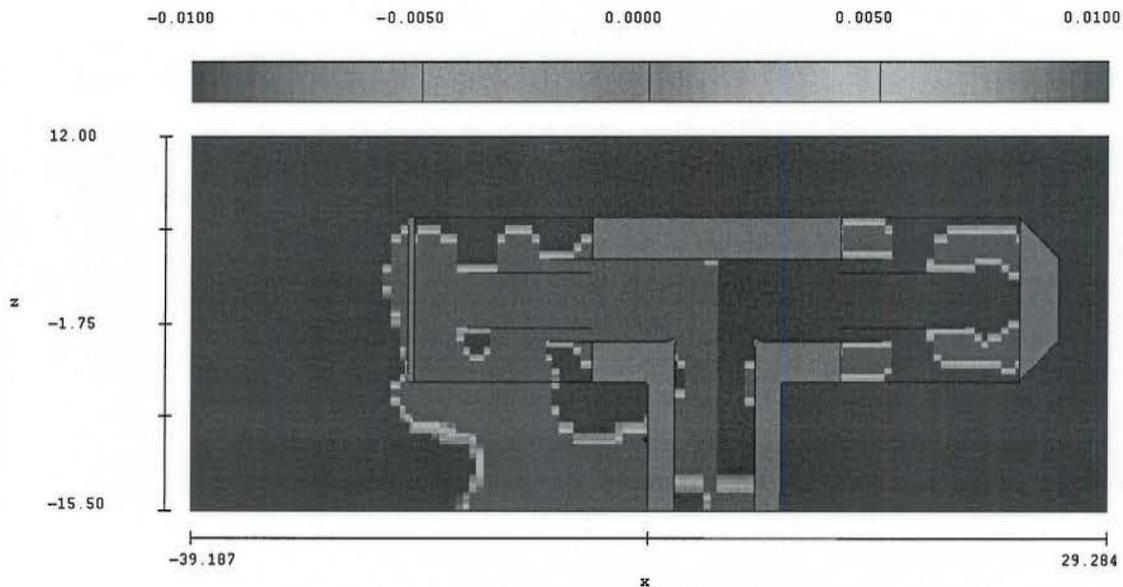


**Figure 4-13**
**Case 1 – Bounded Flow - Direction of flow along vertical center plane (blue – downstream, red – upstream). Flow moves from right to left**
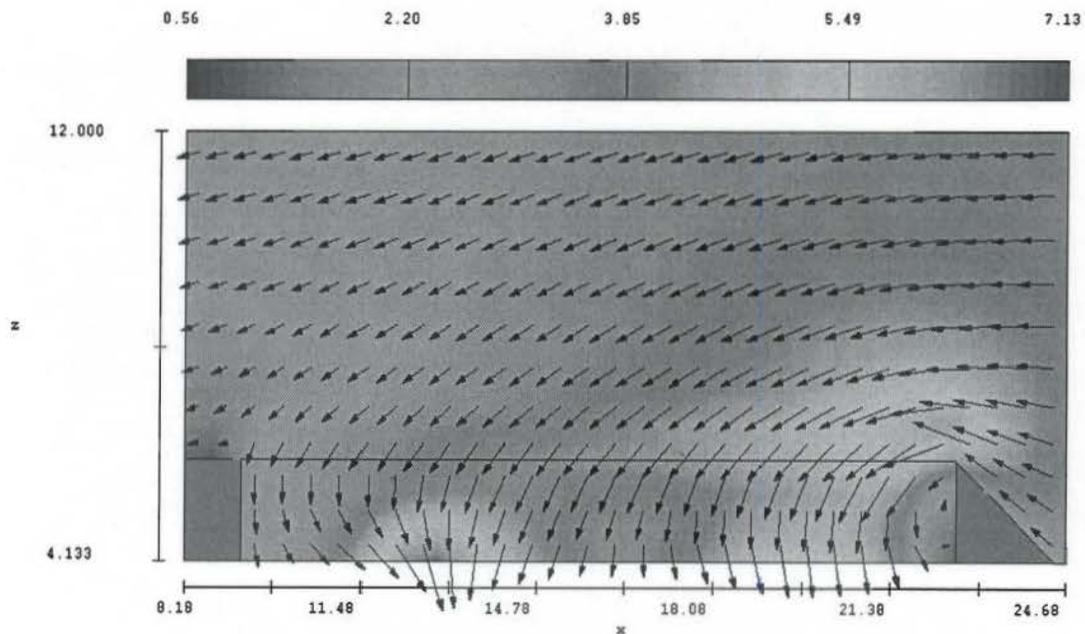
**Figure 4-14**
**Case 1 – Bounded Flow - Upstream Screen (Top) - vectors colored by speed (inches/second). Flow moves from right to left**
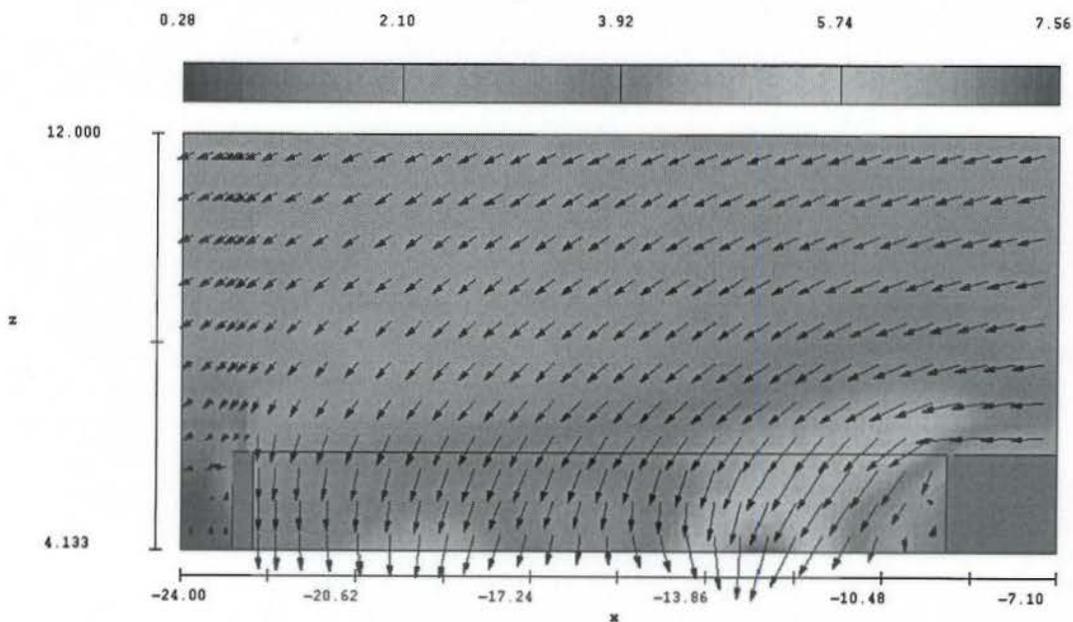


**Figure 4-15**
**Case 1 – Bounded Flow - Downstream Screen (Top) – vectors colored by speed (inches/second). Flow moves from right to left**
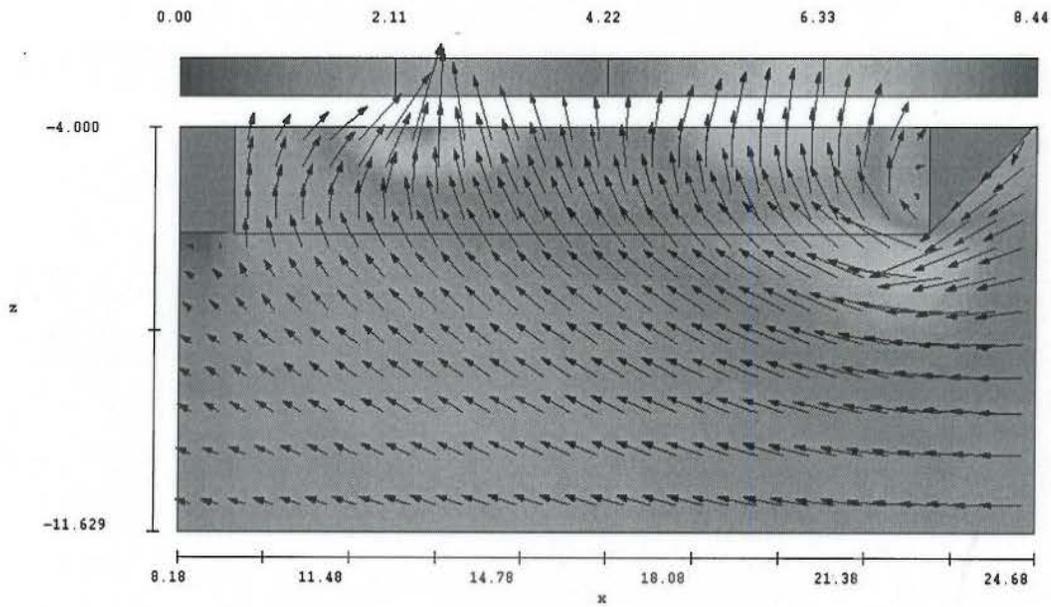
**Figure 4-16**
**Case 1 – Bounded Flow - Upstream Screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**
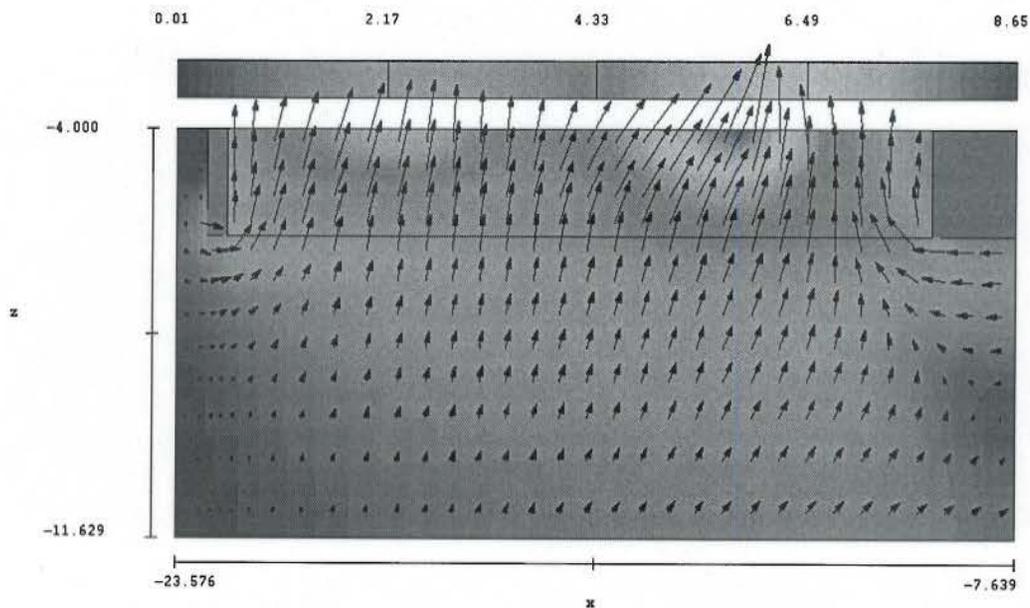


**Figure 4-17**
**Case 1 – Bounded Flow - Downstream Screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**
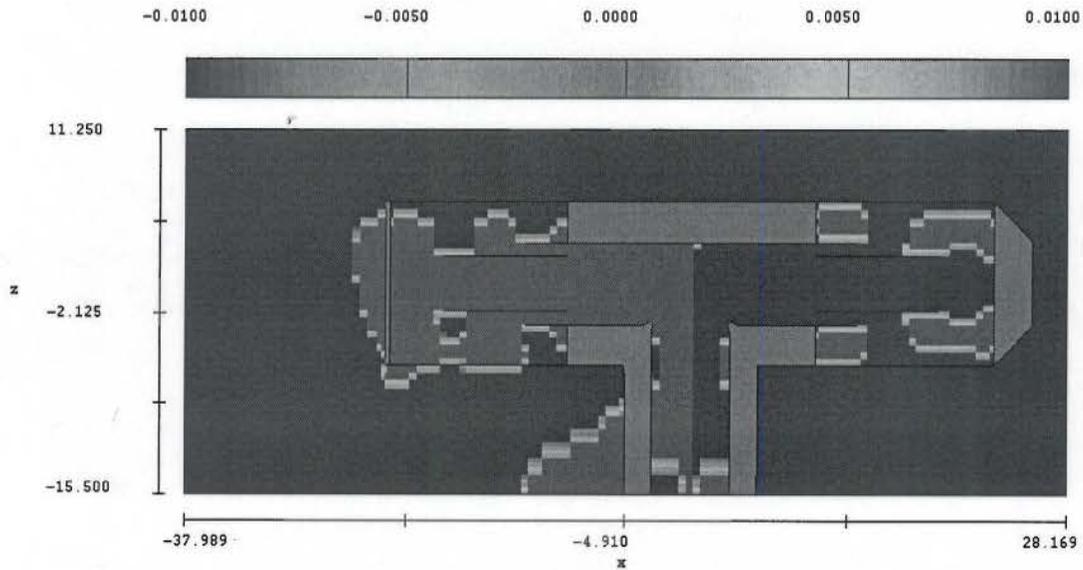
**Figure 4-18**
Case 1 – Unbounded Flow – Direction of flow along vertical center plane [blue – downstream; red – upstream]. Flow moves from right to left
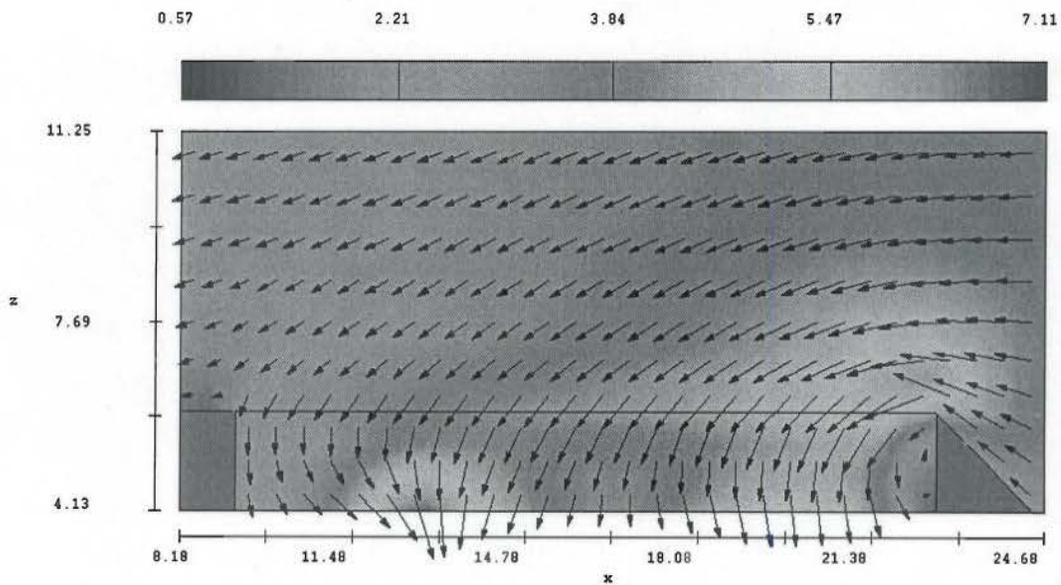


**Figure 4-19**
Case 1 – Unbounded Flow – Upstream screen (Top) – vectors colored by speed (inches/second). Flow moves from right to left
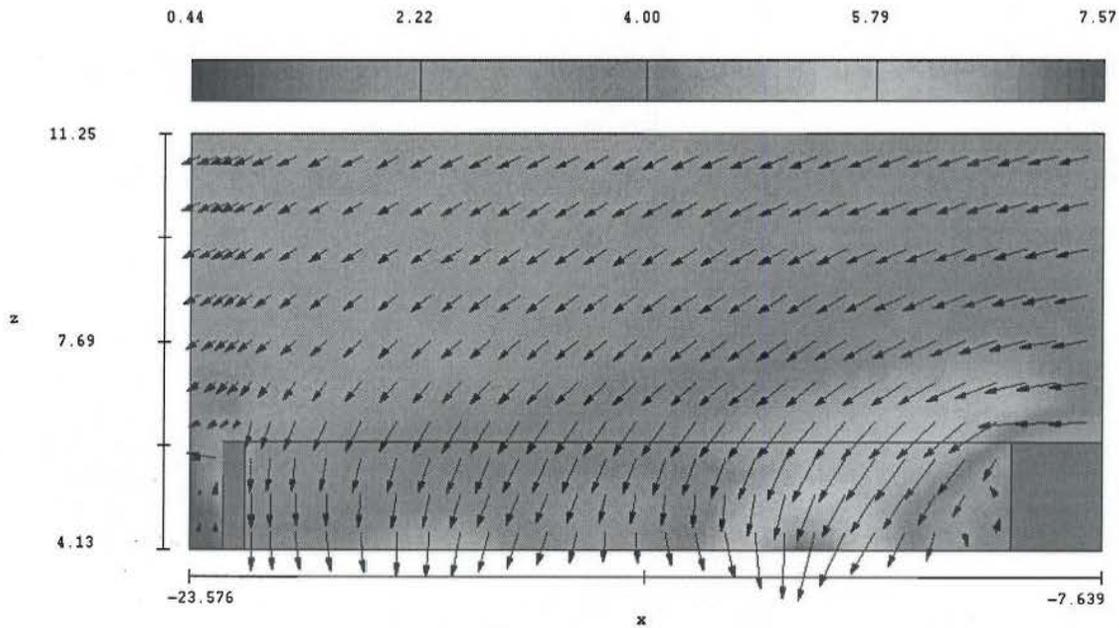
**Figure 4-20**
**Case 1 – Unbounded Flow – Downstream screen (Top) – vectors colored by speed (inches/second). Flow moves from right to left**
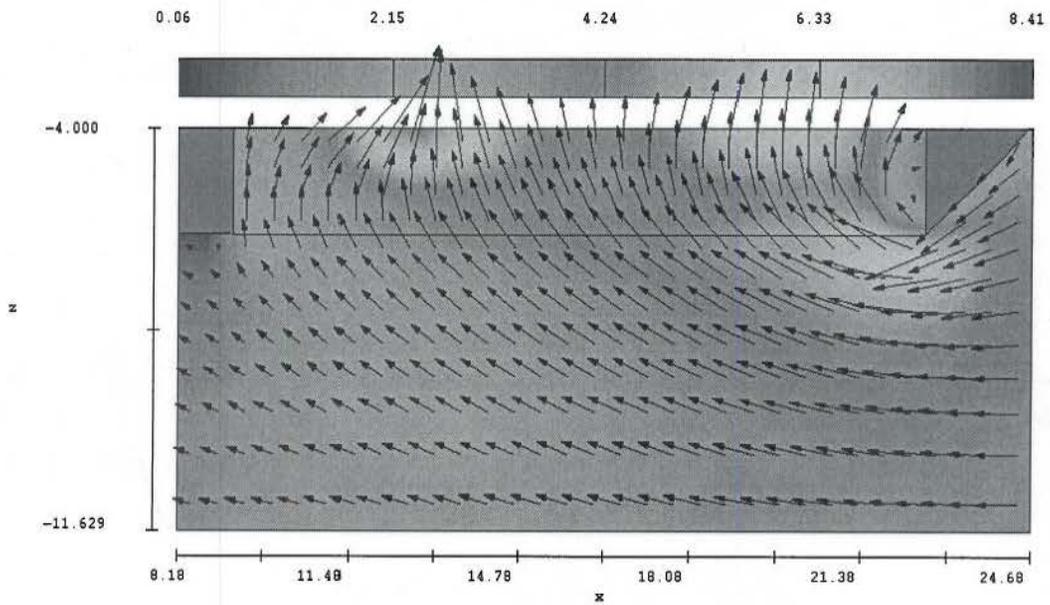


**Figure 4-21**
**Case 1 – Unbounded Flow – Upstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**
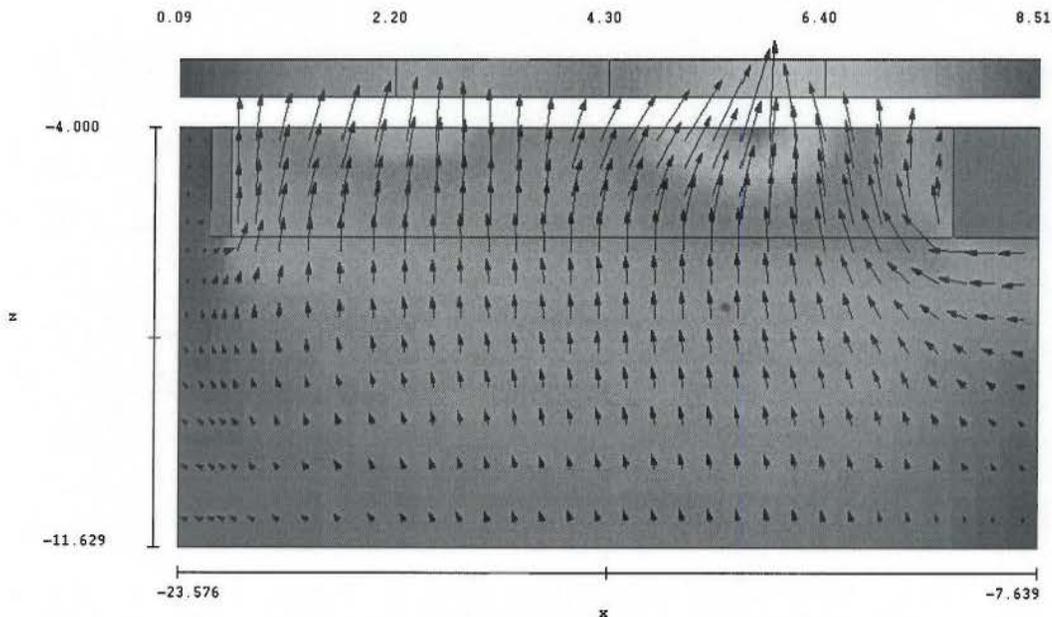
**Figure 4-22**
**Case 1 – Unbounded Flow – Downstream screen (Bottom) – vectors colored by speed (inches/second).  Flow moves from right to left**

## Test Case 2 (L/H)

A low approach velocity (7.6 cm/s) and a high withdrawal rate ($0.1 \text{ m}^3/\text{s}$) 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.
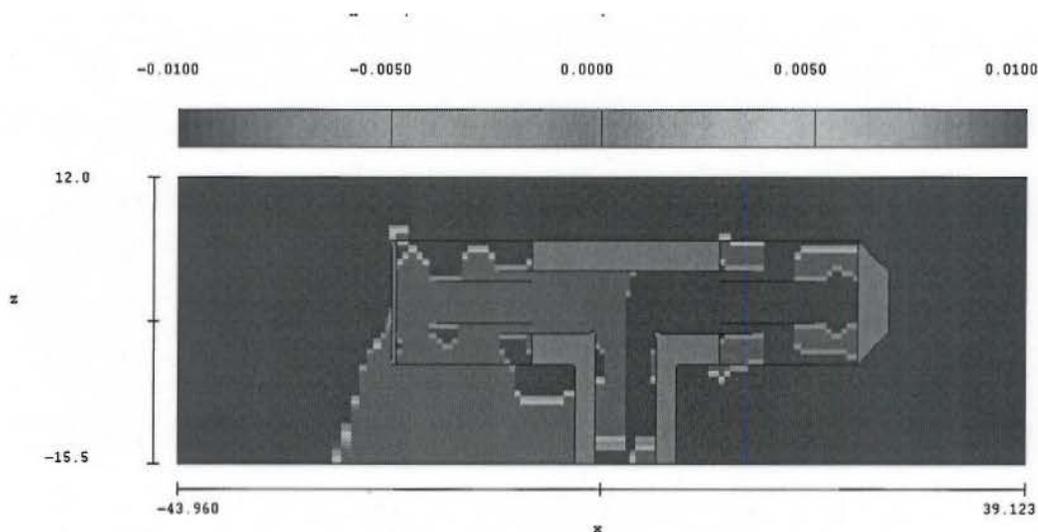


**Figure 4-23**
**Case 2 – Bounded Flow - Direction of flow along vertical center plane [blue – downstream, red – upstream]. Flow moves from right to left.**
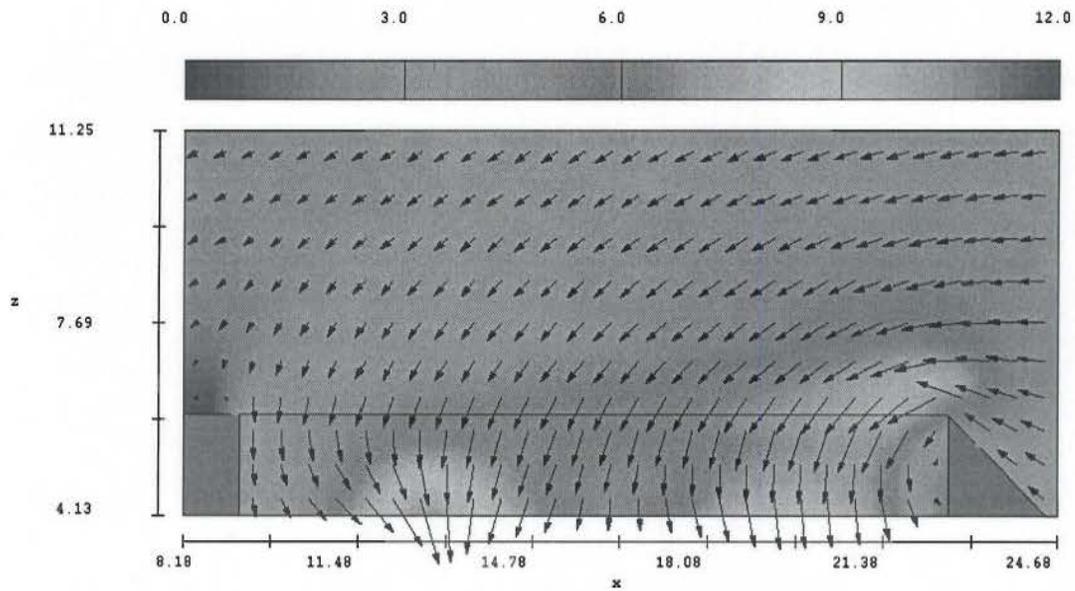
**Figure 4-24**
**Case 2 – Bounded Flow– Upstream Screen (Top) – Vectors colored by speed (inches/second).  Flow moves from right to left in all frames.**
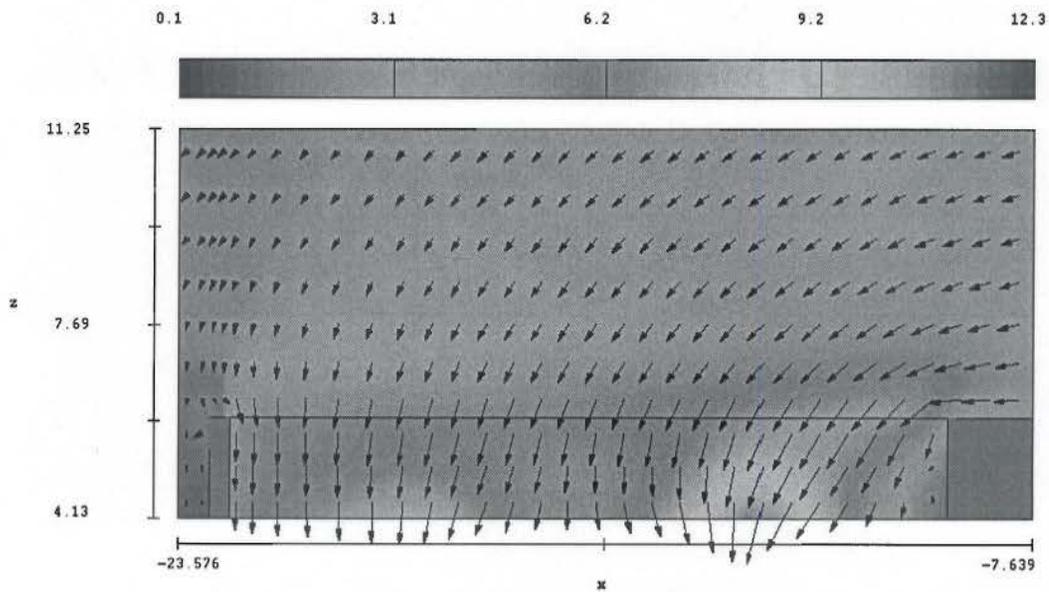


**Figure 4-25**
**Case 2 – Bounded Flow – Downstream Screen (Top) – vectors colored by speed (inches/second).  Flow moved from right to left in all frames.**
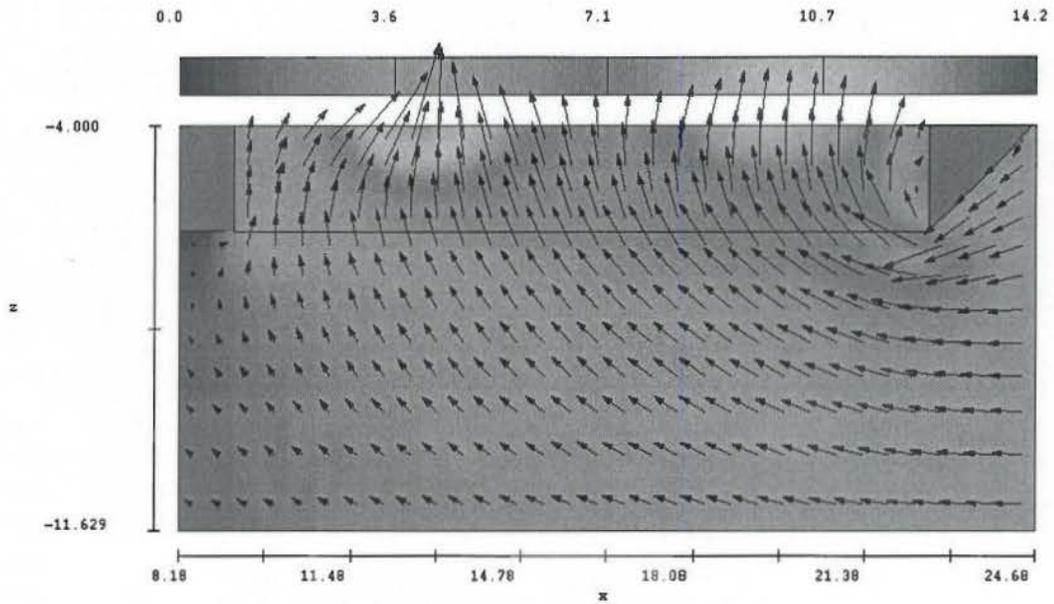
**Figure 4-26**
**Case 2 – Bounded Flow – Upstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**
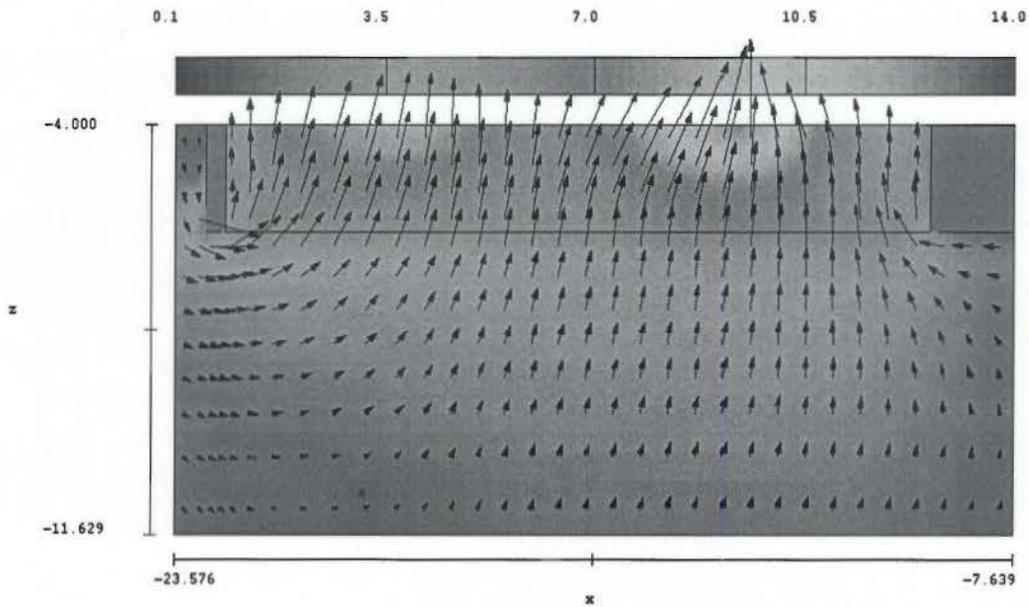


**Figure 4-27**
**Case 2 – Bounded Flow – Downstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**
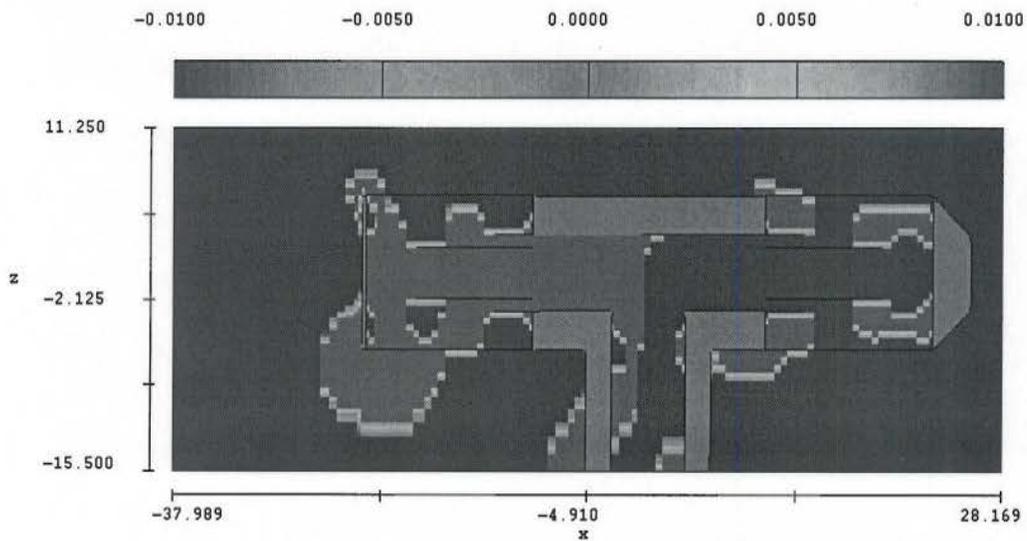
**Figure 4-28**
**Case 2 – Unbounded Flow - Direction of flow along vertical center plane [blue – downstream, red – upstream]. Flow moves from right to left.**
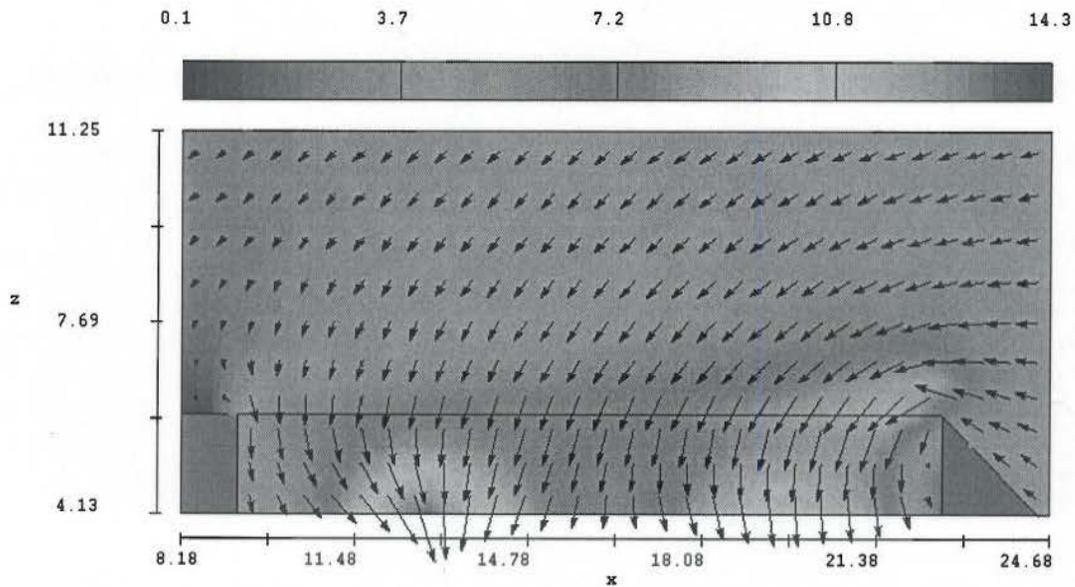


**Figure 4-29**
**Case 2 – Unbounded Flow – Upstream Screen (Top)– Vectors colored by speed (inches/second). Flow moves from right to left in all frames.**
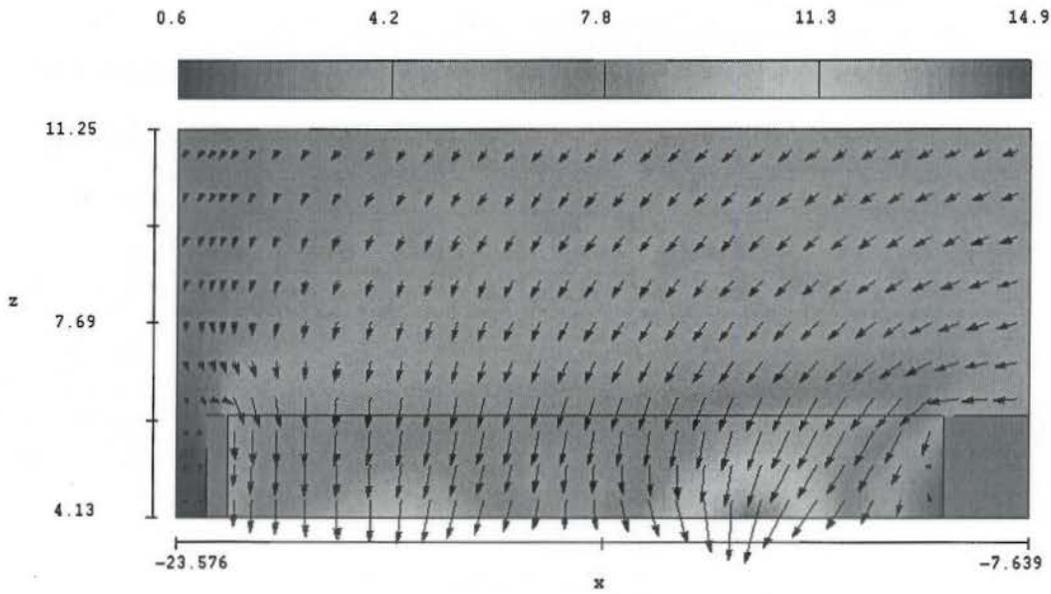
**Figure 4-30**
**Case 2 – Unbounded Flow – Downstream Screen (Top)– vectors colored by speed (inches/second). Flow moved from right to left in all frames.**
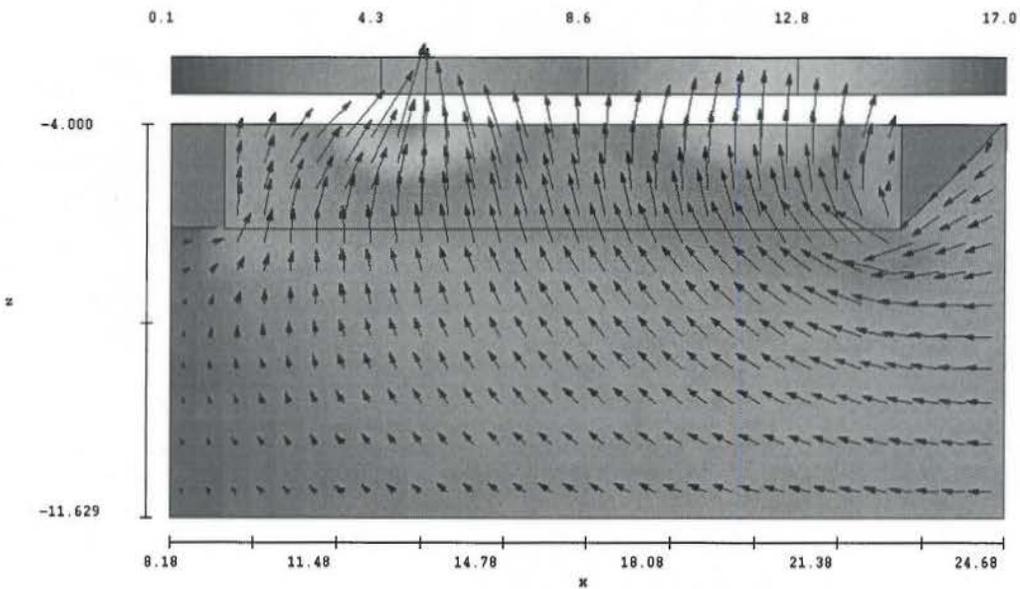


**Figure 4-31**
**Case 2 – Unbounded Flow – Upstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**

4-27
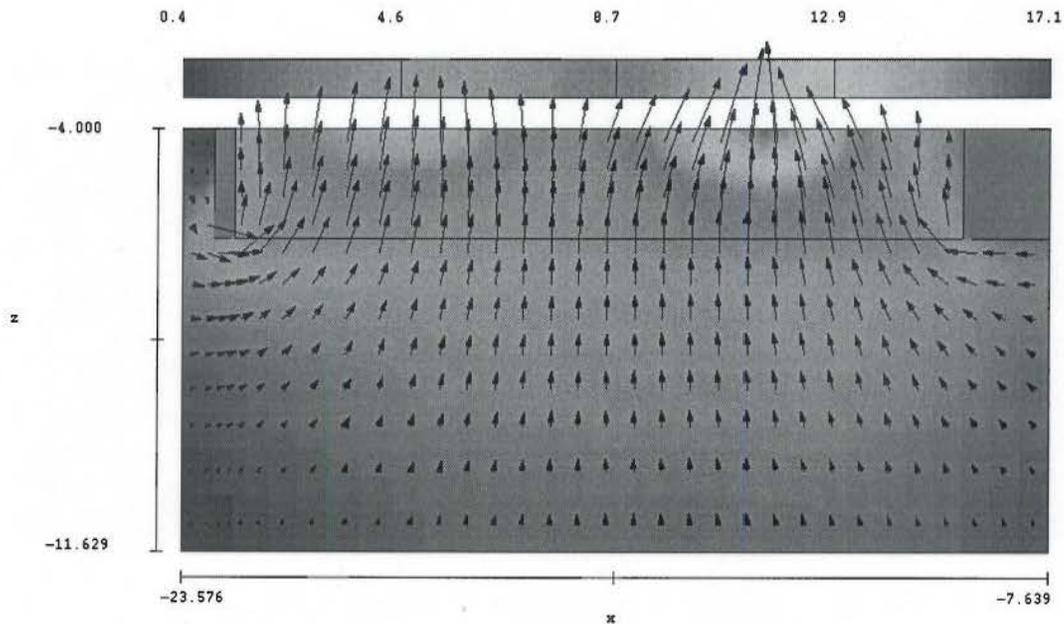
**Figure 4-32**
**Case 2 – Unbounded Flow – Downstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**

## Test Case 3 (H/H)

A high approach velocity (15.2 cm/s) and a high withdrawal rate (0.1 m³/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.
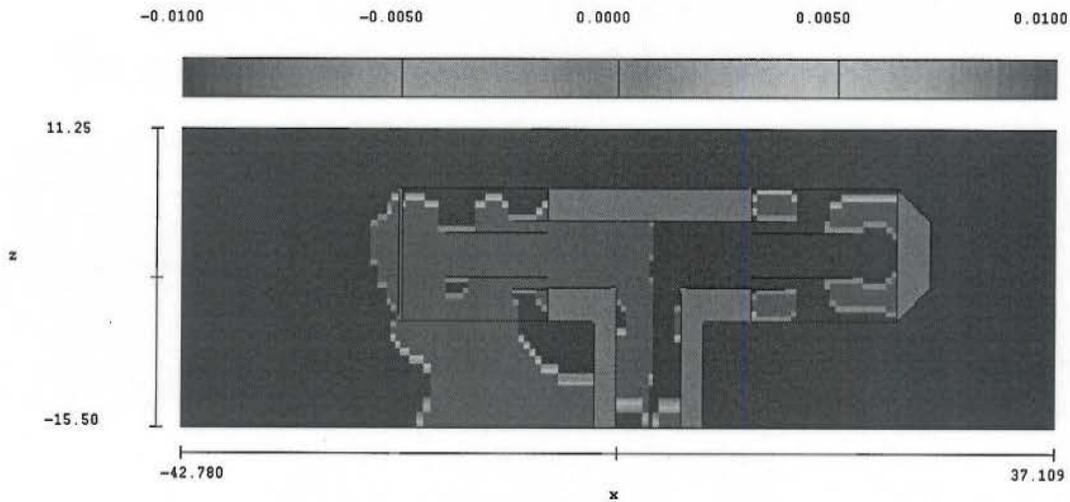


**Figure 4-33**
**Case 3 – Bounded Flow - Direction of flow along vertical center plane [blue – downstream, red – upstream]. Flow moves from right to left.**
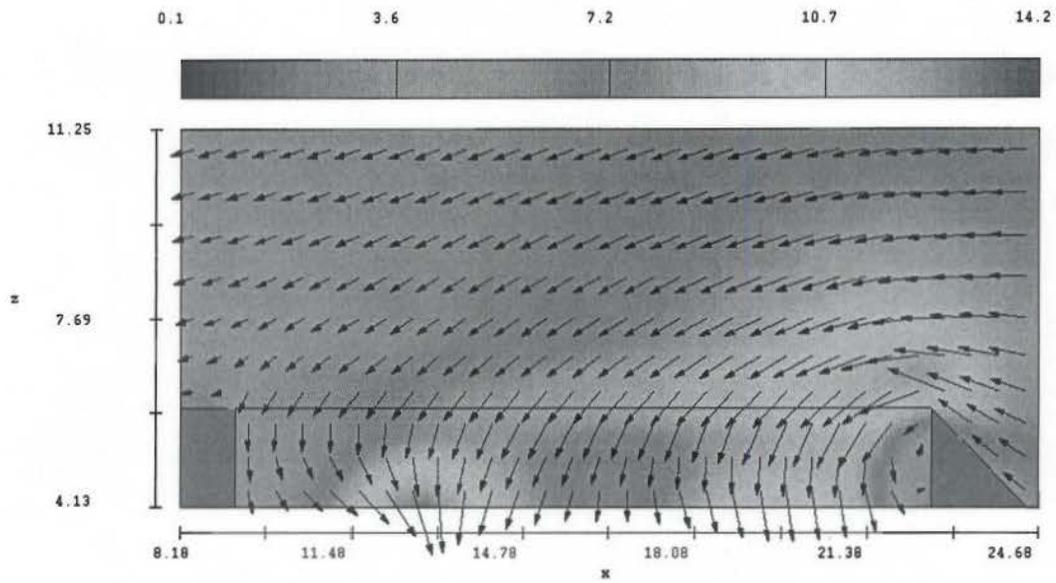
**Figure 4-34**
**Case 3 – Bounded Flow – Upstream Screen (Top) – Vectors colored by speed (inches/second). Flow moves from right to left in all frames.**
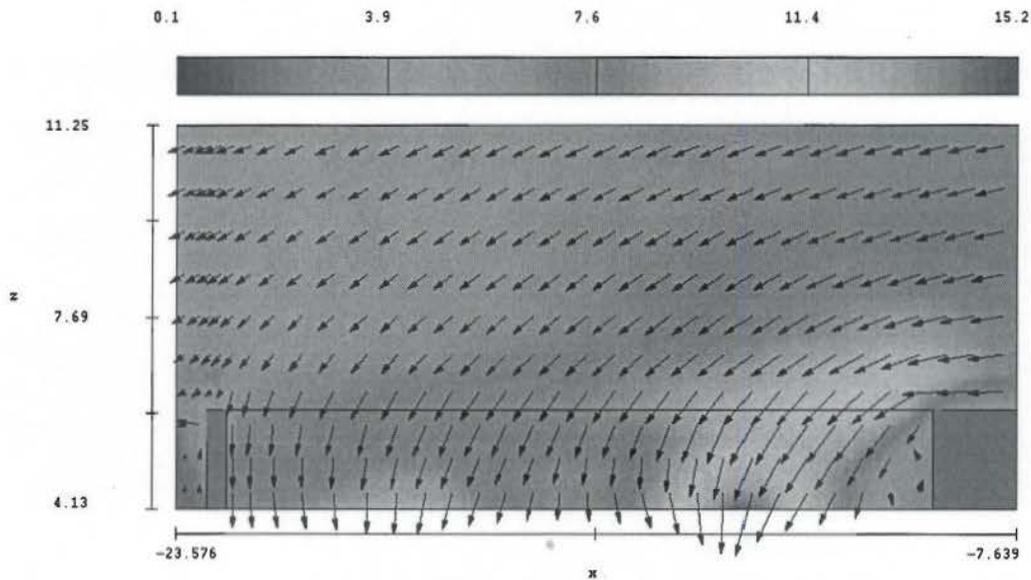


**Figure 4-35**
**Case 3 – Bounded Flow – Downstream Screen (Top) – vectors colored by speed (inches/second). Flow moved from right to left in all frames.**
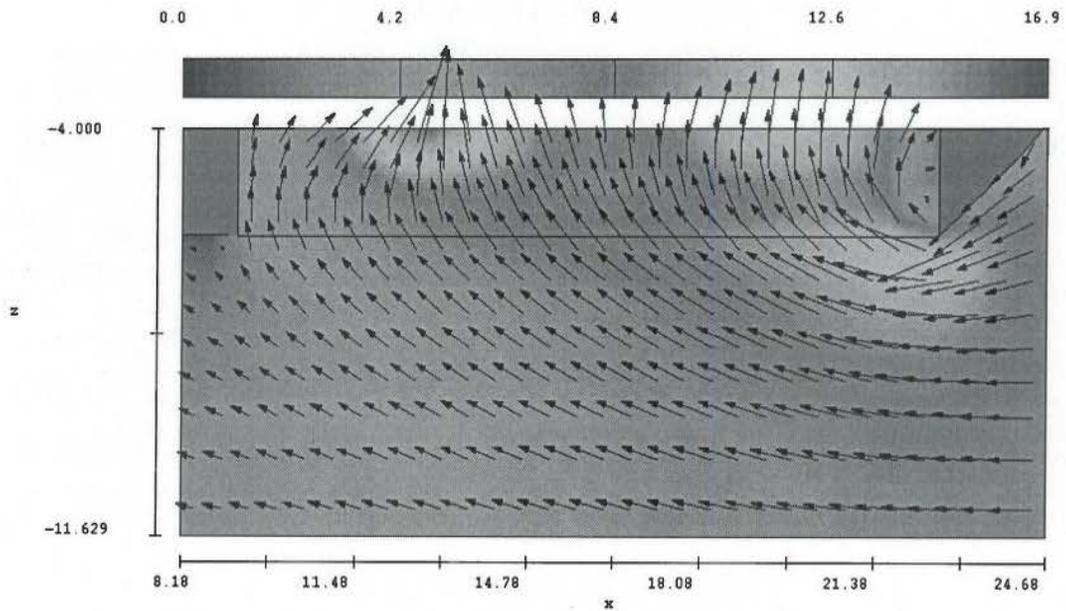
**Figure 4-36**
**Case 3 – Bounded Flow – Upstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**
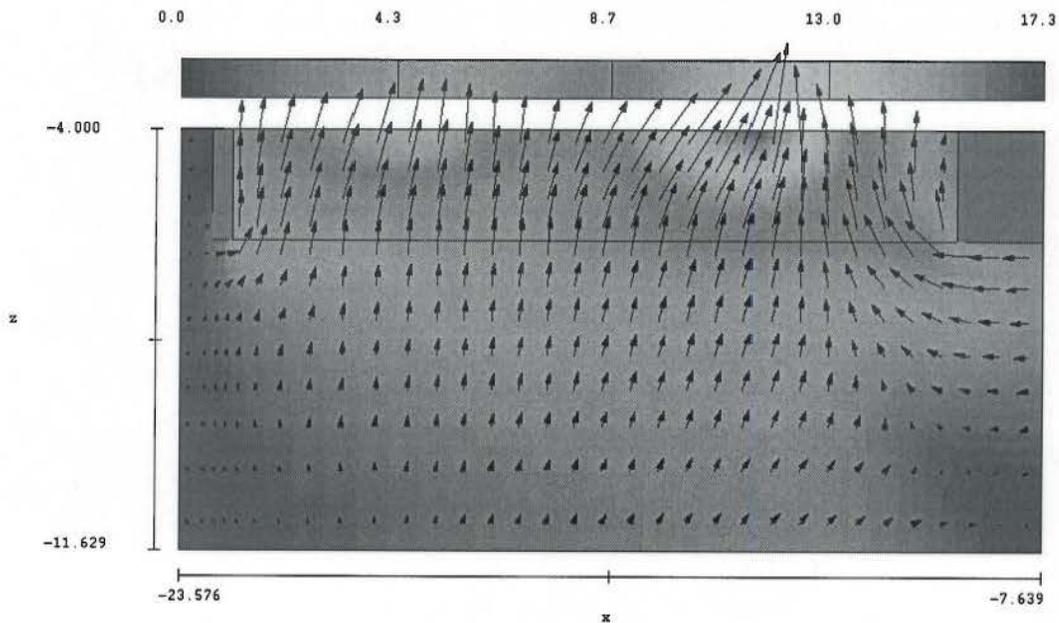


**Figure 4-37**
**Case 3 – Bounded Flow – Downstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**

4-31
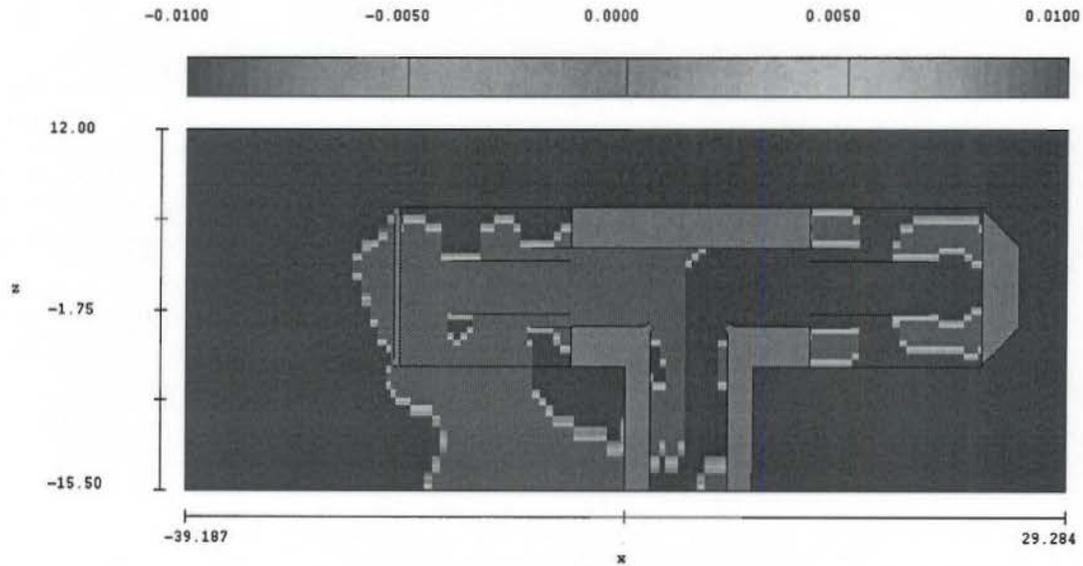
**Figure 4-38**
**Case 3 – Unbounded Flow - Direction of flow along vertical center plane [blue –
downstream, red – upstream]. Flow moves from right to left.**
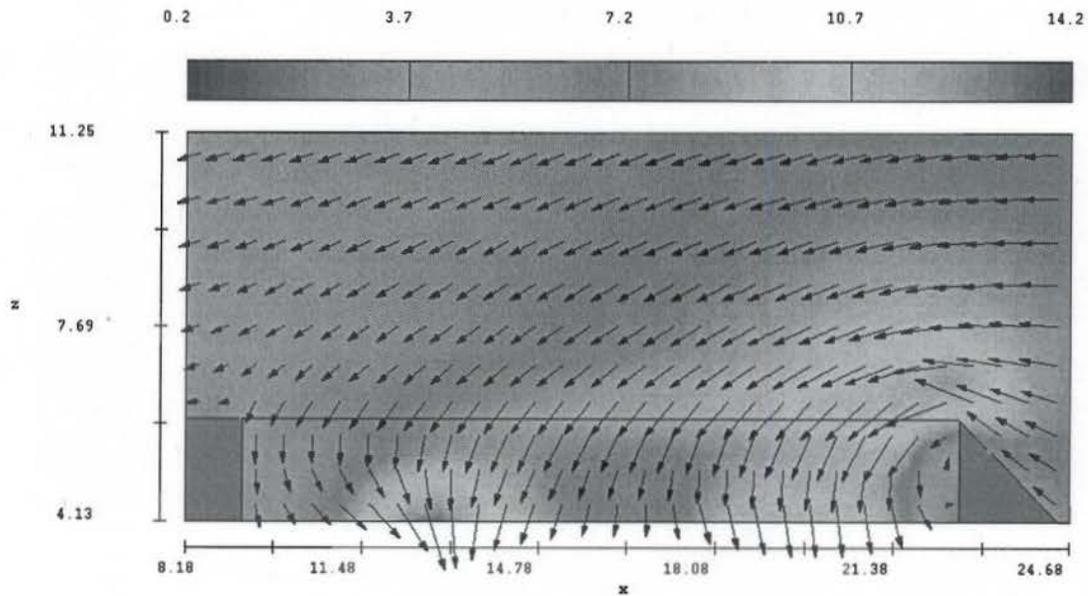


**Figure 4-39**
**Case 3 – Unbounded Flow – Upstream Screen (Top)– Vectors colored by speed
(inches/second). Flow moves from right to left in all frames.**
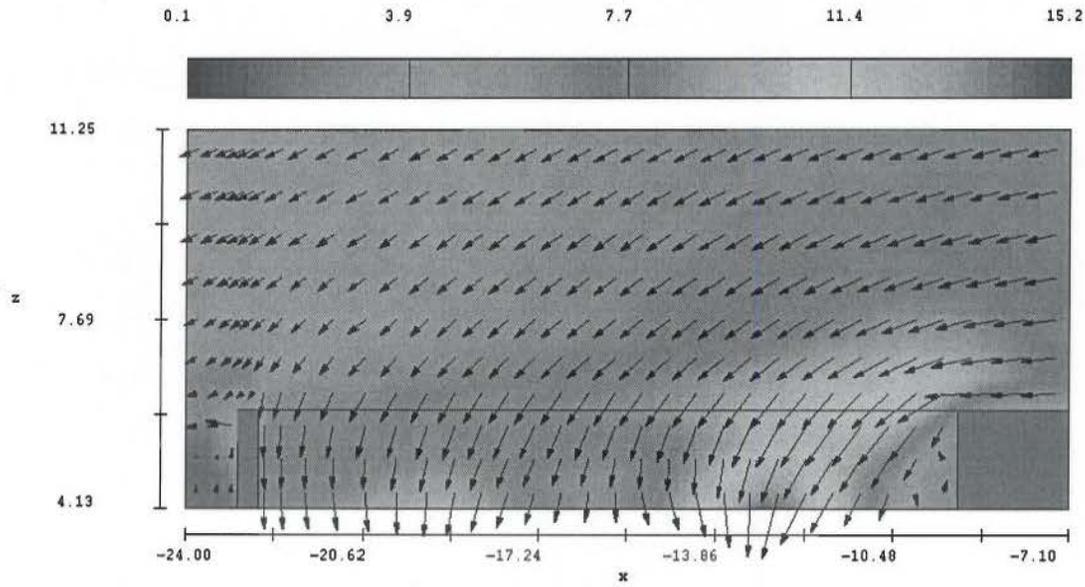
**Figure 4-40**
**Case 3 – Unbounded Flow – Downstream Screen (Top) – vectors colored by speed (inches/second). Flow moved from right to left in all frames.**
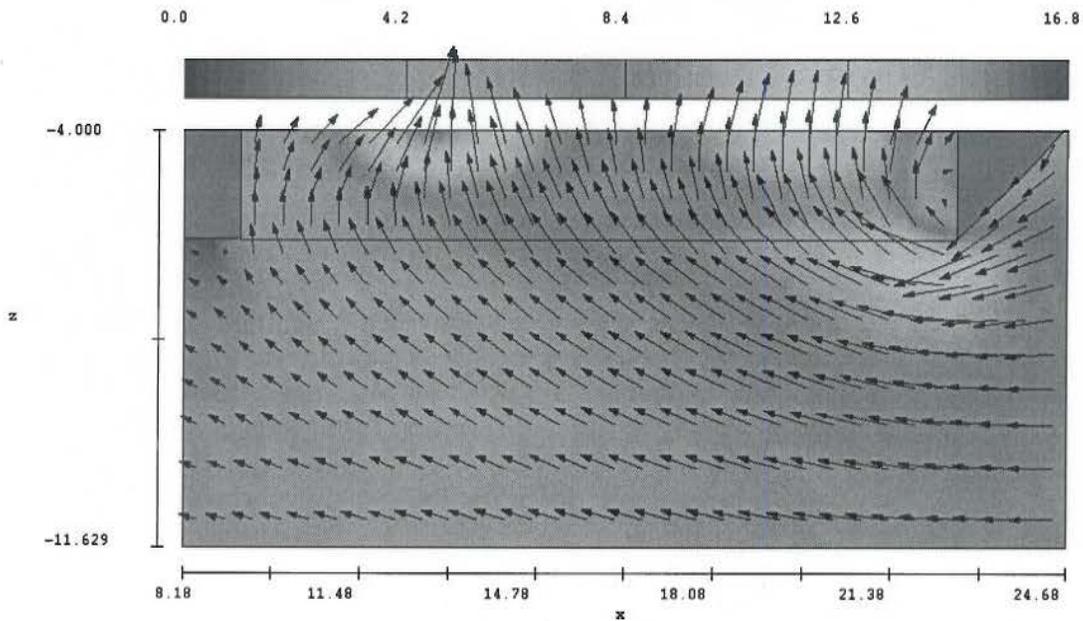


**Figure 4-41**
**Case 2 – Unbounded Flow – Upstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**
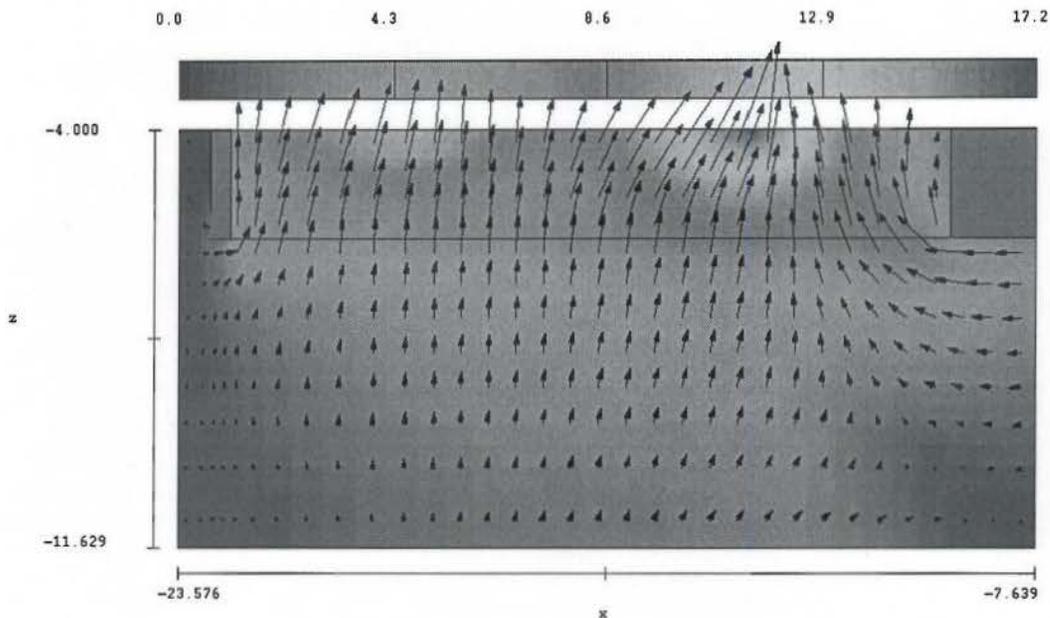
**Figure 4-42**
**Case 2 – Unbounded Flow – Downstream screen (Bottom) – vectors colored by speed (inches/second). Flow moves from right to left**

## 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
# REFERENCES

Boreman, J. 1977. Impacts of Power Plant Intake Velocities on Fish. U.S. Fish & Wildlife Service FWS/OBS-76/20.1.

Browne, M. E. 1979. Preliminary Engineering and Environmental Evaluation of Fine-Mesh Profile Wire as Powerplant Intake Screening. In Passive Intake Screen Workshop, Chicago, IL, December 1979.

Cook, L. E. 1978. The Johnson Screen for Cooling Water Intakes. In: Larval Exclusion Systems for Power Plant Cooling Water Intakes. Argonne National Laboratory Report ANL/ES-66. Sharma, R. K. and J. B. Palmer (Eds.)

EA Science and Technology. 1986. Results of Entrainment and Impingement Monitoring Study at the Westchester RESCO Facility, Peekskill, NY. RUS 41A

Ehrler, C. and C. Raifsnider. 1999. Evaluation of the Effectiveness of Intake Wedgewire Screens. In: Power Impacts on Aquatic Resources Conference, Atlanta, GA, April 12-15, 1999. Sponsored by Electric Power Research Institute (EPRI).

EPRI (Electric Power Research Institute). 1999. Fish Protection at Cooling Water Intakes. Prepared by Alden Research Laboratory, Inc., EPRI Report No. TR-114013.

Govindarajulu, Z. 2001. Statistical Techniques in Bioassay. Second edition, Karger, New York.

Gulvas, J. A. and I. H. Zeitoun. 1979. Cylindrical Wedge-Wire Screen Investigations in Offshore Lake Michigan for the J. H. Campbell Plant, 1979. In: Passive Intake Screen Systems Workshop, Chicago, IL, December 1979.

Hanson, B. N., W. H. Bason, B. E. Beitz, and K. E. Charles. 1978. A Practical Intake Screen which Substantially Reduces Entrainment. In: Fourth National Workshop on Entrainment and Impingement, Chicago, IL, December 5, 1977. Sponsored by Ecological Analysts. L. D. Johnson (Ed.)

Hanson, B. N. 1981. Studies of Larval Striped Bass (Morone saxatilis) and Yellow Perch (Perca Flavescens) Exposed to a 1 mm Slot Profile-Wire Screen Model Intake. In: Proceedings of the Workshop on Advanced Intake Technology, San Diego, CA, April 1981. P. B. Dorn and J. T. Larson (Eds.)

Heuer, J. H. and D. A. Tomljanovich. 1978. A Study on the Protection of Fish Larvae at Water Intakes Using Wedge-Wire Screening. TVA Technical Note B26.

Lifton, W. 1979. Biological Aspects of Screen Testing on the St. Johns River, Palatka, Florida. In: Passive Intake Screen Systems Workshop, Chicago, IL, December 1979.

Milliken, G. A. and D. E. Johnson. 1984. Analysis of Messy Data. Volume 1: Designed Experiments. Van Nostrand Reinhold, New York.

Otto, R. G., T. I. Hiebert and V. R. Kranz. 1981. The Effectiveness of a Remote Profile-Wire Screen Intake Module in Reducing the Entrainment of Fish Eggs and Larvae. In: Proceedings of the Workshop on Advanced Intake Technology, San Diego, CA, April 1981. P. B. Dorn and J. T. Larson (Eds.).

SAS Institute, Inc. 1989. SAS/STAT User's Guide, Version 6, Fourth Edition, Volume 2. SAS Institute, Cary, NC.

SAS Institute, Inc. 1990. SAS Procedures Guide: Usage and Reference, Version 6, Third Edition. SAS Institute, Cary, NC.

SAS Institute, Inc. 1996. SAS/STAT Software: Changes and Enhancements through Release 6.11. SAS Institute, Cary, NC.

Schneeberger, P. J., and D. J. Jude. 1981. Use of Fish Larva Morphometry to Predict Exclusion Capabilities of Small-Mesh Screens at Cooling-Water Intakes. Transactions of the American Fisheries Society 110:246-252.

Weisberg, S. B., W. H. Burton, E. A. Ross, and F. Jacobs. 1984. The Effects of Screen Slot Size, Screen Diameter, and Through-Slot Velocity on Entrainment of Estuarine Ichthyoplankton through Wedge-Wire Screens.

Weisberg, S. B., W. H. Burton, F. Jacobs and E. A. Ross. 1987. Reductions in Ichthyoplankton Entrainment with Fine-Mesh, Wedge-Wire Screens. North American Journal of Fisheries Management 7: 386-393.

Zeitoun, I. H., J. A. Gulvas, and D. B. Roarabaugh. 1981a. Effectiveness of Fine Mesh Cylindrical Wedge-Wire Screens in Reducing Entrainment of Lake Michigan Ichthyoplankton. Canadian Journal of Fisheries and Aquatic Science 38: 120-125.

Zeitoun, I. H., J. A. Gulvas and J. Z. Reynolds. 1981b. Effectiveness of Small Mesh Cylindrical Wedge-Wire Screens in Reducing Fish Larvae Entrainment at an Offshore and an Onshore Location of Lake Michigan. In: Proceedings of the Workshop on Advanced Intake Technology, San Diego, CA, April 1981. P. B. Dorn and J. T. Larson (Eds.)

# 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 |

*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) |
|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

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| 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 |

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| 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 |

# D
# 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 |

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| 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 |

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| 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 (m³) | No. entrainment adjusted for CE/m³ | % 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 |

*Program:*
Section 316 (a) and (b) Fish Protection Issues

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