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MODELING OF OPTIONS TO ADDRESS ENTRAINMENT AND IMPINGEMENT REDUCTIONS AT BAY SHORE

Kinectrics Report: 409025-001-RA-0001-R00

January, 2010

Xiude Lin and Paul Patrick
Civil and Environmental Solutions

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EXECUTIVE SUMMARY

A preliminary evaluation of various mitigation options for reducing fish entrainment and impingement at Bay Shore Power Plant was conducted by Kinectrics in 2008 (Kinectrics Report No. 014297-001-RA-0002-R00, December 2008). None of the options considered provided substantial reductions in entrainment (the only exception being a fine mesh screen in the screenhouse). A louver system with culvert bypass offered maximum predicted reduction. For impingement, the modeling results suggested that a louver array at 27 degrees with a slat angle of 90 degrees was the most effective diverter.

Additional modeling work was proposed to aid in the development of a pilot project involving a louver system with a culvert bypass. Proposed modeling was to consider three different options to address both entrainment and impingement reductions as follows:

- Reversed louver with fine mesh screening panels behind louver array (the fish mesh screening will address entrainment and is expected to be only in place primarily during the spring period- April, May and June; see Kinectrics Report No. 112026-005-RA-0004-R00, December 2007).

- Reversed louver without fine mesh screening panels behind louver array.

- Complete covering of entire intake mouth with fine mesh screening system.

Performance of a louver is dependent on many variables some of which are related to engineering design of the array whereas others are biological in nature and focus on fish attributes such as size, life history stage, and response to stimuli such as turbulent flows. Relevant factors for consideration for the proposed pilot project at Bay Shore Power Plant are given in the text. A summary of estimated swimming speeds indicated that the dominant species (>90%) that impinge at Bay Shore have estimated sustained swimming speeds that exceed the ambient flows in the intake channel at 11-12 cm/s. This will allow fish sufficient time to display an avoidance response to the louver array without becoming excessively fatigued.

The proposed pilot study at Bay Shore will include a unique fish diversion system which will incorporate features such as a reversed louver, an impermeable guiding wall (bottom overlay), and other design features that focus on slat spacing, slat length and frame angle. The primary

function of these components is to divert impinged fish as well as debris, and some entrainment. A fine mesh screen system is also proposed to be placed behind the louver array to divert entrained organisms.

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MODELING OF OPTIONS TO ADDRESS ENTRAINMENT AND IMPINGEMENT REDUCTIONS AT BAY SHORE

1.0 INTRODUCTION

1.1 Site Location

The Bay Shore Power Plant is located on the southern shore of Maumee Bay, near the mouth of the Maumee River, at the western end of Lake Erie, near Oregon, Ohio. Cooling water for Bay Shore is obtained from the Maumee River via an open intake channel and after traversing the condensers, is discharged to Maumee Bay (Figure 1).

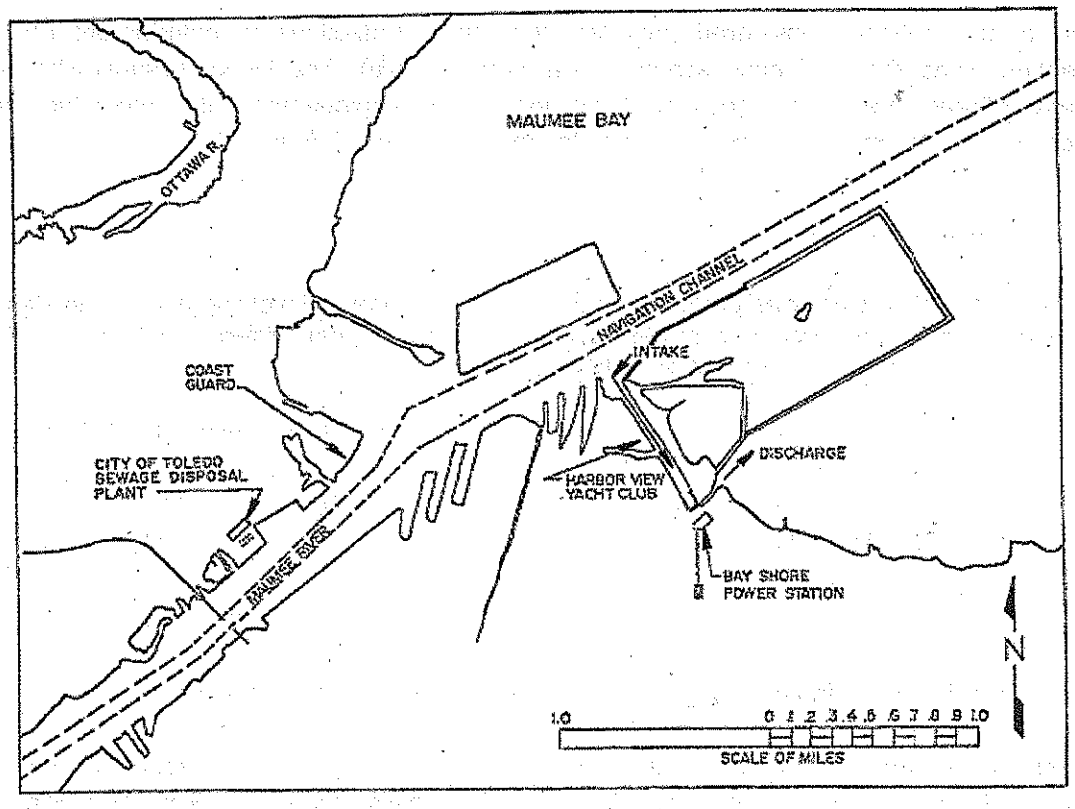


Figure 1. General Area Near the Bay Shore Power Plant

1.2 Options for Reducing Fish Entrainment and Impingement

An earlier modeling study was conducted by Kinectrics, and involved a preliminary evaluation of various mitigation options for reducing fish entrainment and impingement at Bay Shore (Kinectrics Report No. 014297-001-RA-0002-R00, December 2008). These options included the following:

1. Dredging part of the existing intake channel to achieve velocity reductions.
2. Installation of a diversion device (acoustics, louvers) at the mouth of the intake channel.
3. Installation of louvers part way down the intake channel to divert juvenile and adult fish with a culvert bypass to the discharge side.
4. Installation of louvers at the mouth of the intake channel
5. Installation of louvers part way down the intake channel with a culvert bypass plus a fish return pipe off the traveling screens to divert eggs and larvae to the culvert bypass instead of the existing discharge channel.

Hydraulic conditions and the transport of passive organisms within the Maumee River and intake channel were predicted using a three-dimensional computational fluid dynamics model (ANSYS/CFX).

None of the options considered provided substantial reductions in entrainment (the only exception being the fine mesh screen in the screenhouse). The louver system with culvert bypass offered maximum predicted reduction. For impingement, the modeling results suggested that an angle of 90 degrees was the most effective diverter.

2.0 SCOPE OF WORK

Additional modeling work was proposed to develop a pilot project involving a louver system with a culvert bypass. The proposed modeling was to consider three different options to address both entrainment and impingement reductions as follows:

- Reversed louver with fine mesh screening panels behind louver array (the fish mesh screening will address entrainment and is expected to be only in place primarily during the spring period- April, May and June; see Kinectrics Report No. 112026-005-RA-0004-R00 December 2007).
- Reversed louver without fine mesh screening panels behind louver array.
- Complete covering of entire intake mouth with fine mesh screening system.

In addition, the various design parameters required for fish diversion was prepared as well as some details concerning the proposed pilot project for consideration at the Bay Shore Plant. The pilot project design incorporated information from the modeling results as well as other literature.

3.0 METHODS

3.1 Computational Fluid Dyanamics (CFD) Analysis

A three-dimensional computational fluid dynamics model (ANSYS/CFX) was used to study flow patterns in the intake channel and adjacent shipping channel area and to predict changes in flow patterns associated with the proposed fish diversion options. The modeling domain for this study is outlined in Figure 2 and contains the intake channel and adjacent shipping channel area. Geographically, the model domain stretches 17.7 km from the West to the East and 16.2 km from the South to the North.

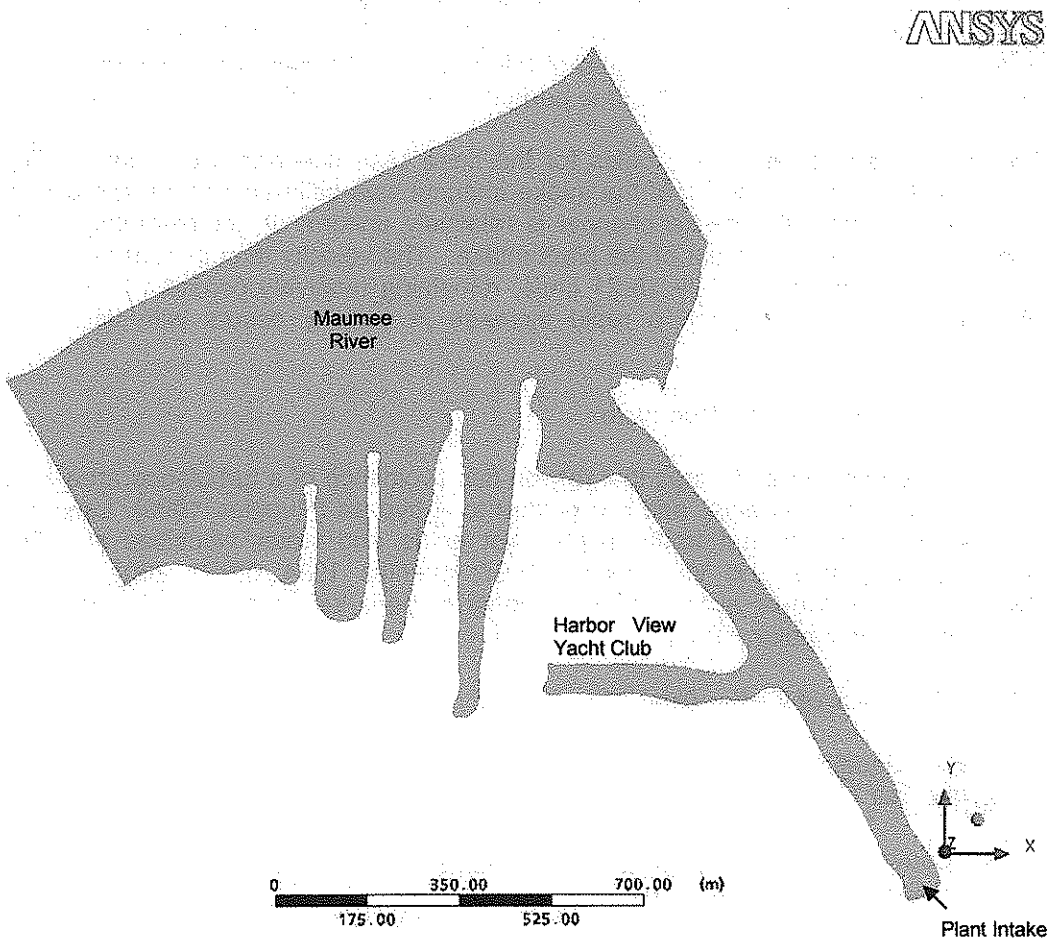


Figure 2. Top View of CFX Modeling Domain

3.2 Model Validation

The first step in the modeling process is to generate and validate a baseline model. This was done by creating a model scenario that incorporates existing bathymetry and flow data. Results of the model validation are provided in an earlier report (Kinectrics Report No. 014297-001-RA-0002-R00, December 2008).

4.0 RESULTS

4.1 Base Case Scenario

The flow rate of the Maumee River demonstrates substantial variation on a month-to-month basis and has ranged from values as low as 3 m^3/s (October 1963) to values as high as 1,081 m^3/s (March 1982). For the purpose of this analysis, the base case scenario is based on the monthly average flow rate for the time period of peak entrainment (June, 125 m/s).

The velocity and streamline profiles for the base case scenario are shown in Figure 3. The current velocity at the mouth of the intake channel was estimated to be approximately 8 cm/s. The velocity within the intake channel is relatively uniform at approximately 11-14 cm/s until approximately 200 m in front of the plant intake. The velocity then increases slightly, as shown in Figure 4, to approximately 18-21 cm/s, remaining relatively constant to within 25 m of the plant intake. At this point, a rapid increase in velocity occurs with the intake velocities approaching 34 cm/s.

4.2 Reversed Louver Scenario

Louvers are behavioral devices that rely on fish avoidance of a turbulence area created by slats as they move downstream, and are guided to a bypass (Ruggles 1990). Laboratory and field studies have shown that frame angle, slot angle and water velocities all influence louver performance (Bates and Vinsonhaler, 1957; Griffiths 1984; EPRI, 2001). The height or thickness of the louver slats does not appear to be a key factor in efficiency for guiding fish (Bates and Vinsonhaler, 1957).

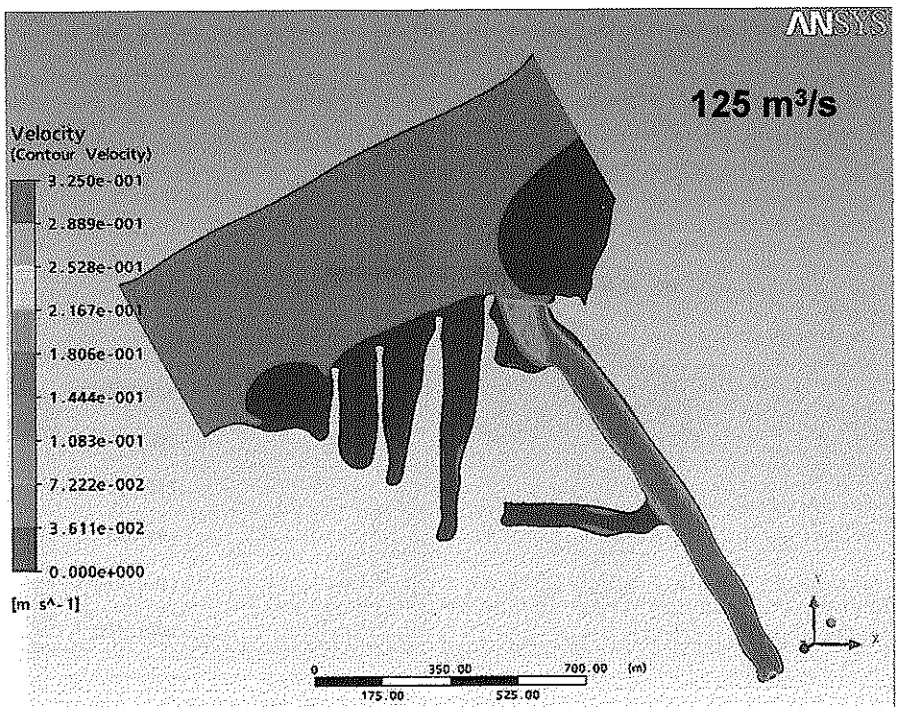
4.2.1 Overview of Earlier Analysis

An earlier modeling study (Kinectrics Report No. 014297-001-RA-0002-R00, December 2008) evaluated four (4) louver system scenarios:

1. Louver system at 45° (100 m total length) with slats 60° to flow
2. Louver system at 45° (100 m total length) with slats 90° to flow
3. Louver system at 27° (200 m total length) with slats 60° to flow
4. Louver system at 27° (200 m total length) with slats 90° to flow

For all scenarios, the slat spacing was 6" and the slat length was 24". None of the options considered provided substantial reductions in entrainment. For impingement, the modeling results suggested that a louver system at 27° (200m total length) with slats 90° to flow was the most effective diverter. For this scenario, the impinging velocity was estimated to be 0.16 m/s with an associated sweeping velocity of 0.32 m/s. However, due to model limitations at the time of this earlier assessment, these velocity estimates were derived by modeling a subsection of the entire louver system (Figure 5).

Figure 3. Velocity and Streamline Profiles for Base Case Scenario



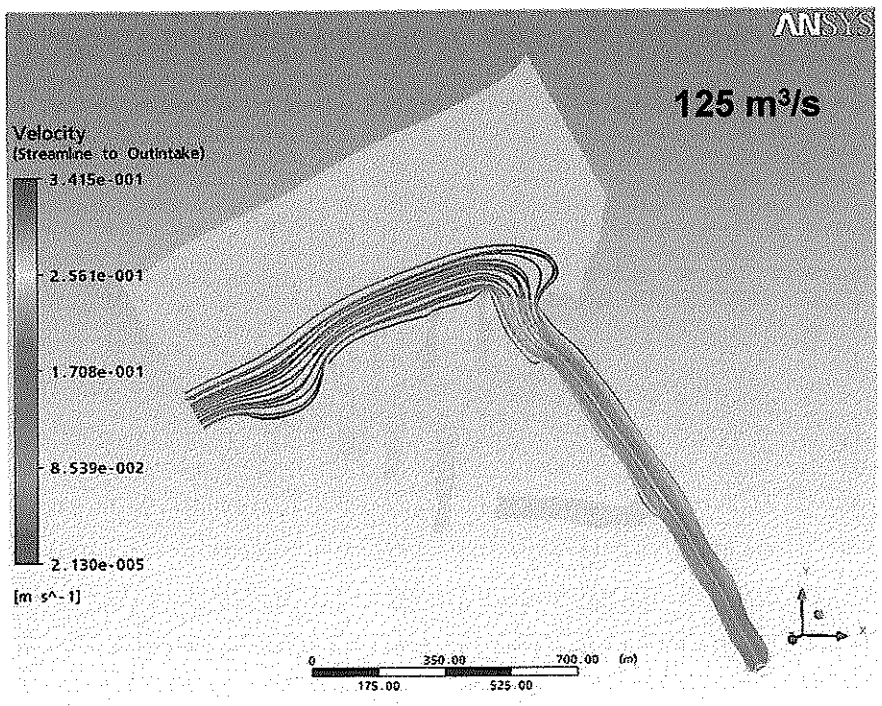


Figure 4. Velocity Profile in Vicinity of Plant Intake

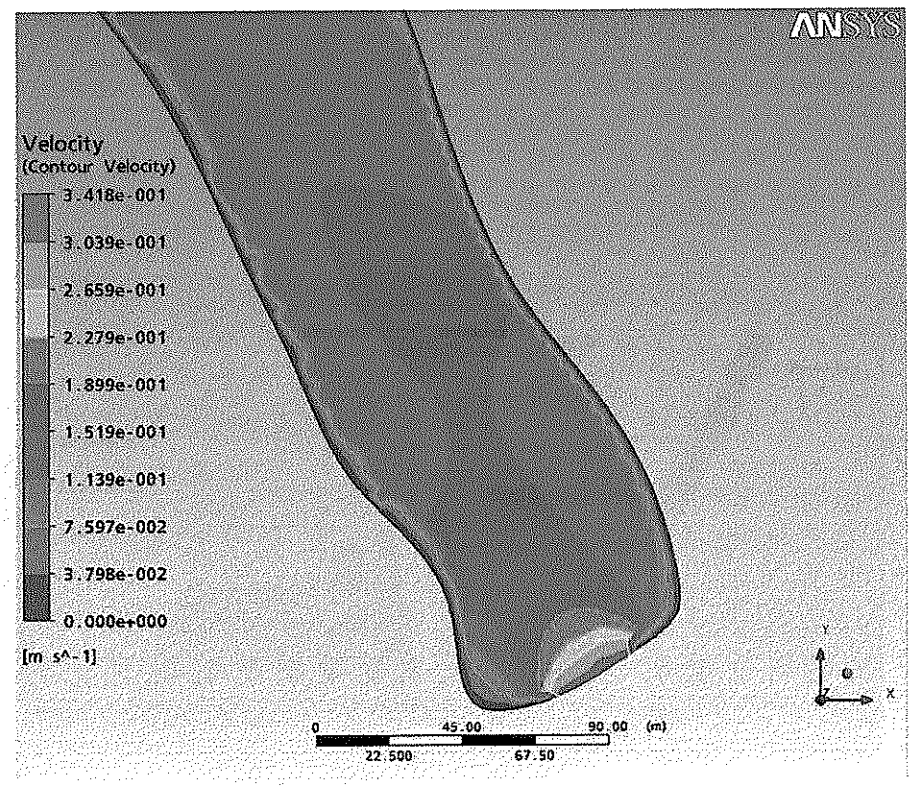
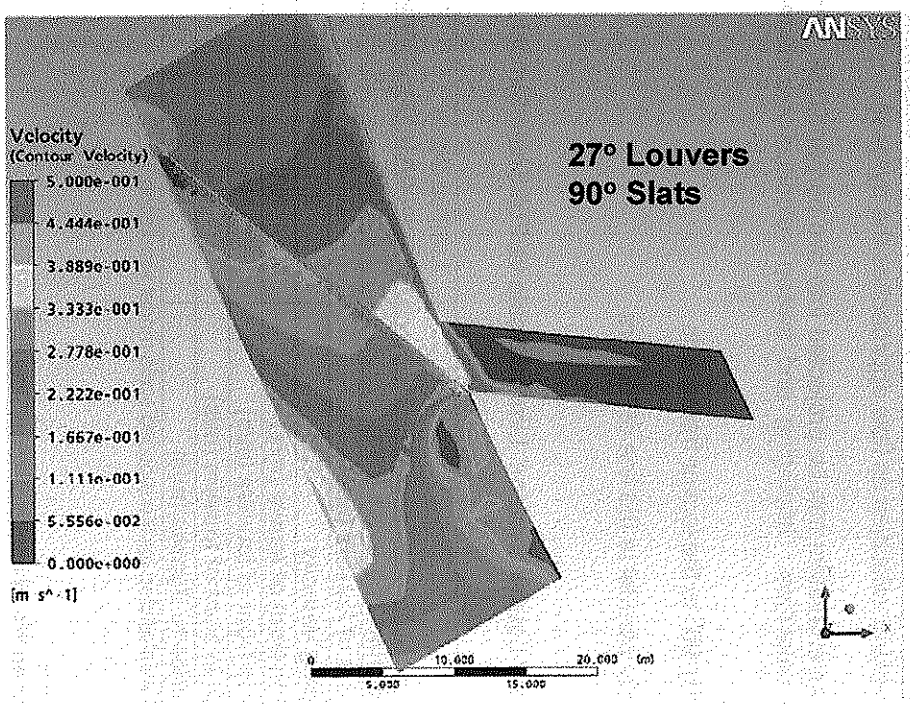
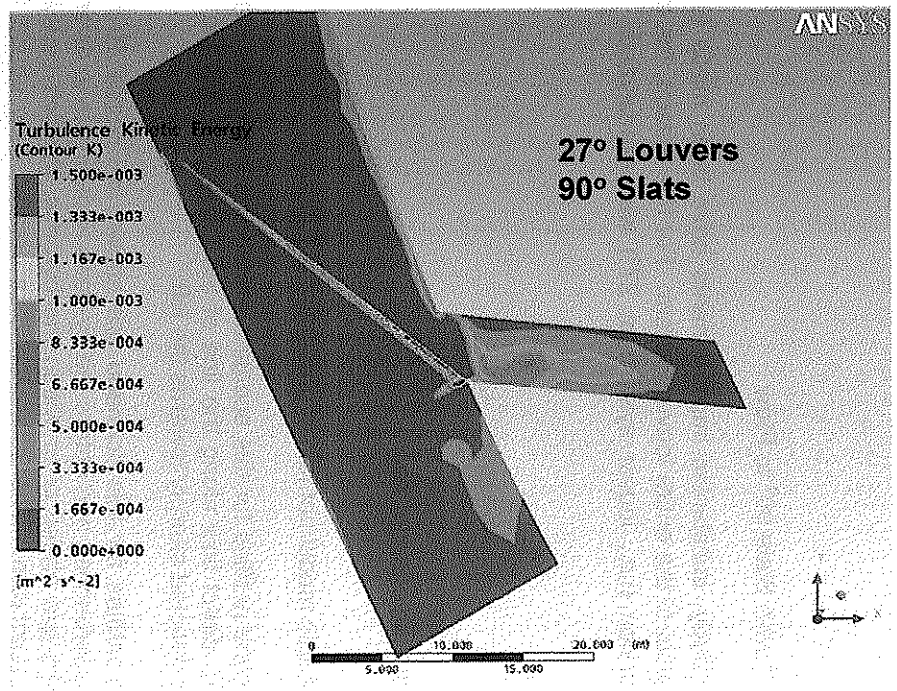


Figure 5. Velocity and Turbulence Profiles for 27° Louvers with Slats 90° to Flow: Limited Scale Simulation (6" Slat Spacing)





4.2.2 Louver System at 27° with Slats 90° to Flow

Since the earlier modeling study, substantial improvements have been made to the model to enable a more detailed analysis of the entire louver system. For this reason, the louver scenario predicting the greatest diversion (i.e., louver system at 27°) was reanalyzed. The following parameters were assumed:

- slat spacing = 6"
- slat length = 24"
- slat angle 90° to flow
- bypass flow = 3% of intake channel flow[1]

The resolution of the microscopic model domain is presented in Figure 6.

Streamline Profile: Streamline profiles for this scenario are shown in Figures 7-9. The reverse louver system is designed to direct flow along the line of the louver towards the bypass. Flow through the louver system is directed sharply towards the left.

Velocity Profile: Velocity profiles for this scenario are shown in Figures 10-11. A gradual increase in velocity as flow approaches and enters the by-pass is desirable in diversion of fish. If a reduction in velocity occurs just ahead of or within the by-pass, the fish usually stall in their movement and swim back upstream. The confusion thus created may cause them to move between the louver slats rather than through the bypass (Bates and Vinsonhaler, 1957). The velocity profile reveals increasing velocities as flow approaches the by-pass.

Velocity approaching the louver system can be projected into two perpendicular components, i.e., the impinging and sweep velocities. Impinging and sweep velocities are defined below and summarized in Table 1.

Vi = Impinging velocity 90° to the louver frame axis

Vs = Sweeping velocity parallel to the line of louvers

Table 1. Flow Parameters for Louver System: Limited Scale vs Full Scale Simulations

Velocity Profile	Limited Scale Simulation (m/s)	Full Scale Simulation (m/s)
Impinging Velocity - 1ft in front of louvers (m/s)	0.16	0.05
Sweep Velocity - 1ft in front of louvers (m/s)	0.34	0.19
Ratio of Sweep to Impinging Velocity	2.1	3.7
Approach Velocity - 20m in front of louver (m/s)	NA	0.16
Approach Velocity - 50m in front of louvers (m/s)	NA	0.15
Approach Velocity - 100m in front of louvers (m/s)	NA	0.12
Average Velocity at Entrance to Bypass (m/s)	NA	0.34

NA = not available, could not be calculated for the reduced scale model simulation.

[1] Bypass flow was assumed to be 3% of intake channel flow.

Figure 6. Resolution of the Microscopic Model Domain for the Louver Array

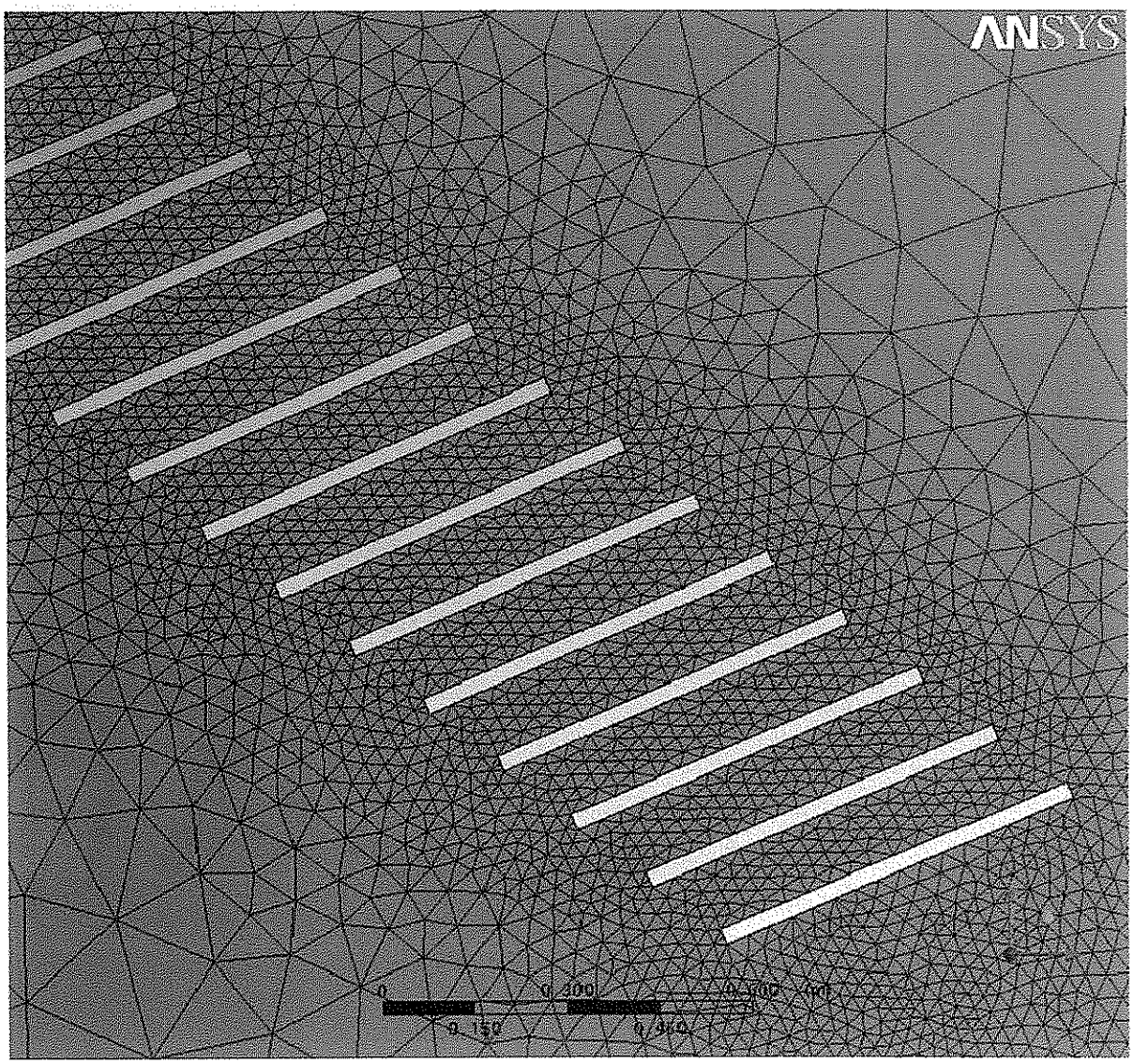


Figure 7. Streamline Profile for 27° Louvers with Slats 90° to Flow: Full-Scale Simulation (View #1 - Full Modeling Domain)

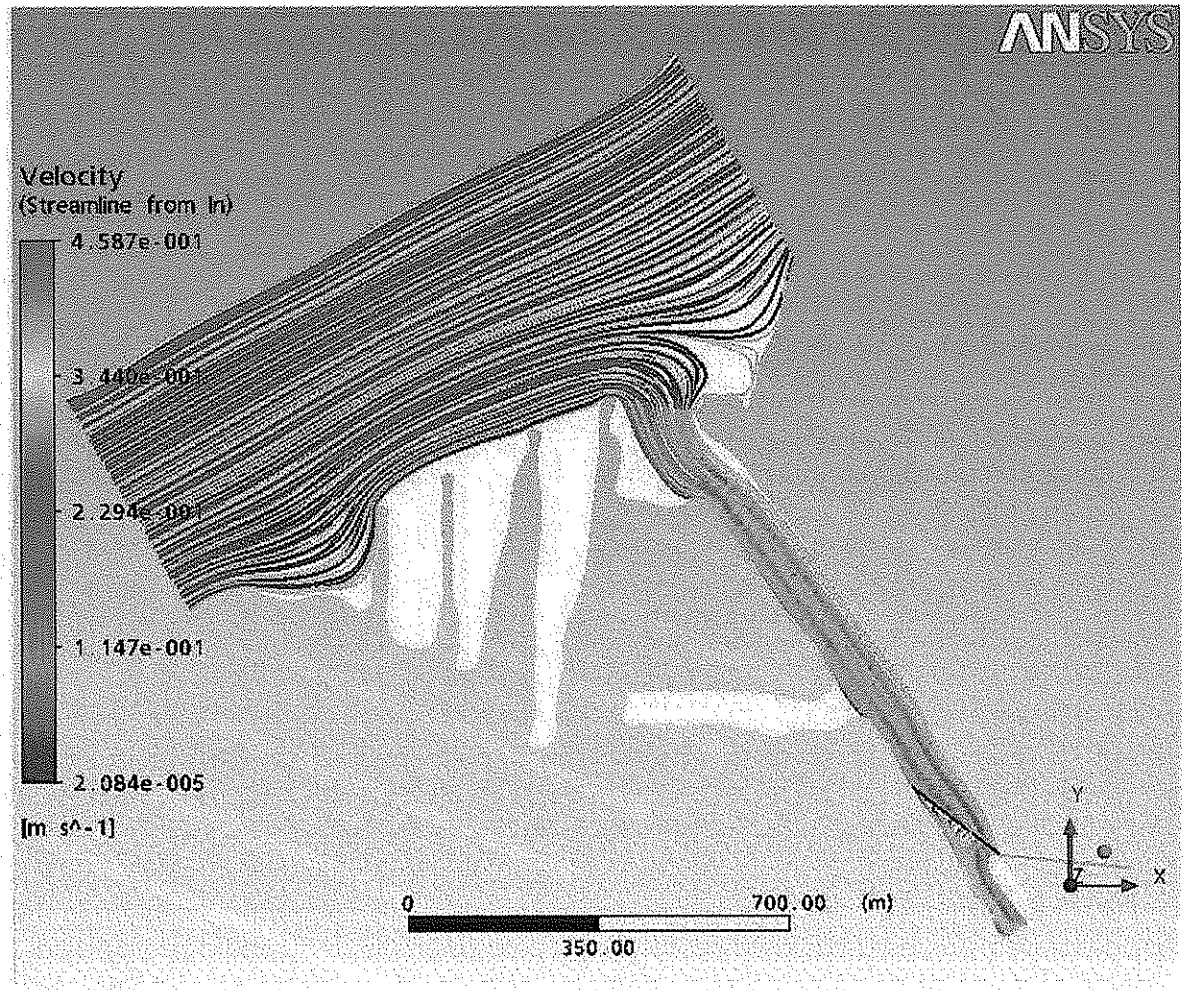


Figure 8. Streamline Profile for 27° Louvers with Slats 90° to Flow: Full-Scale Simulation (View #2 - Near Vicinity of Louver System)

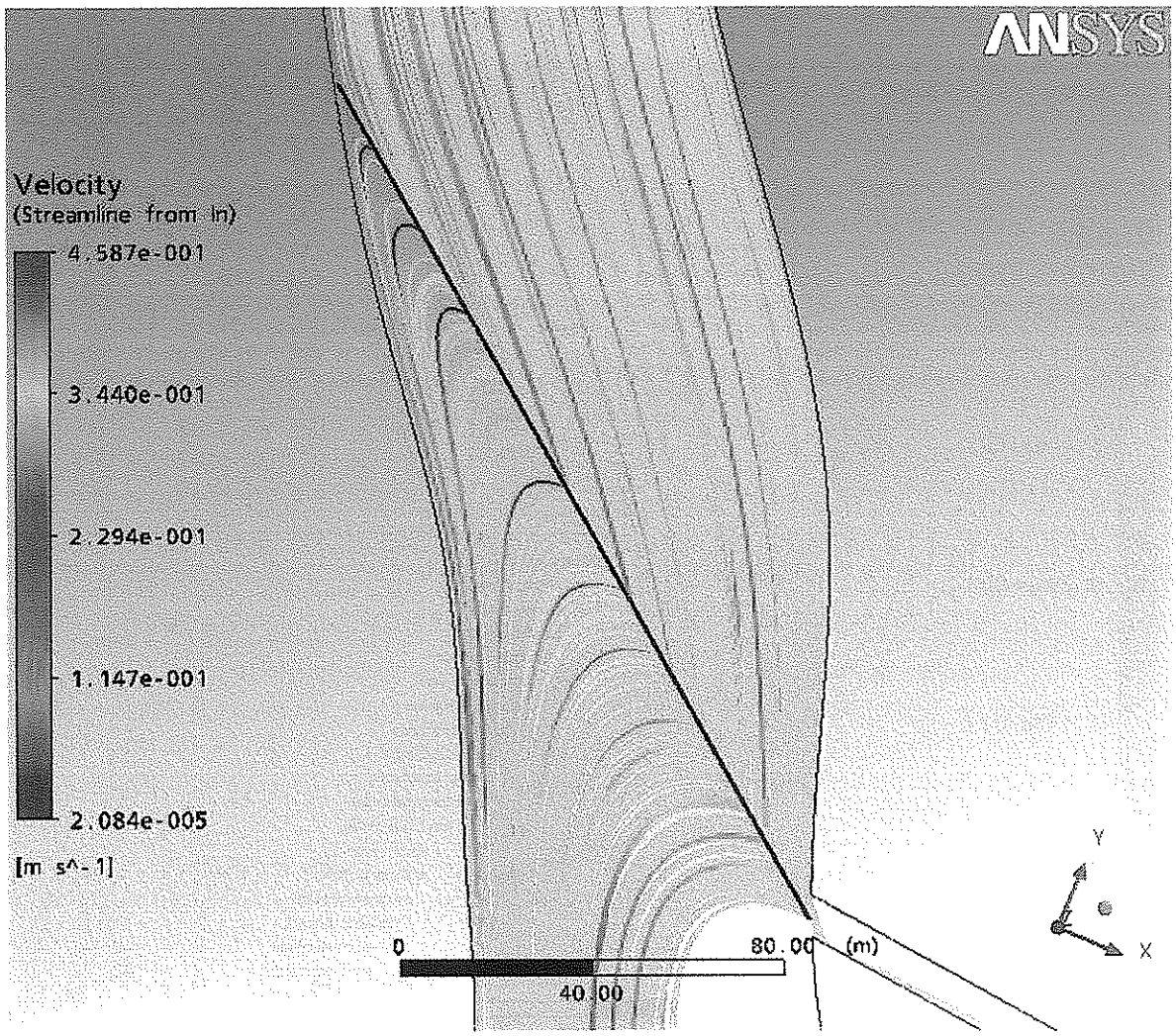


Figure 9. Streamline Profile for 27° Louvers with Slats 90° to Flow: Full-Scale Simulation

(View #3 - Near Vicinity of Individual Louver Slats)

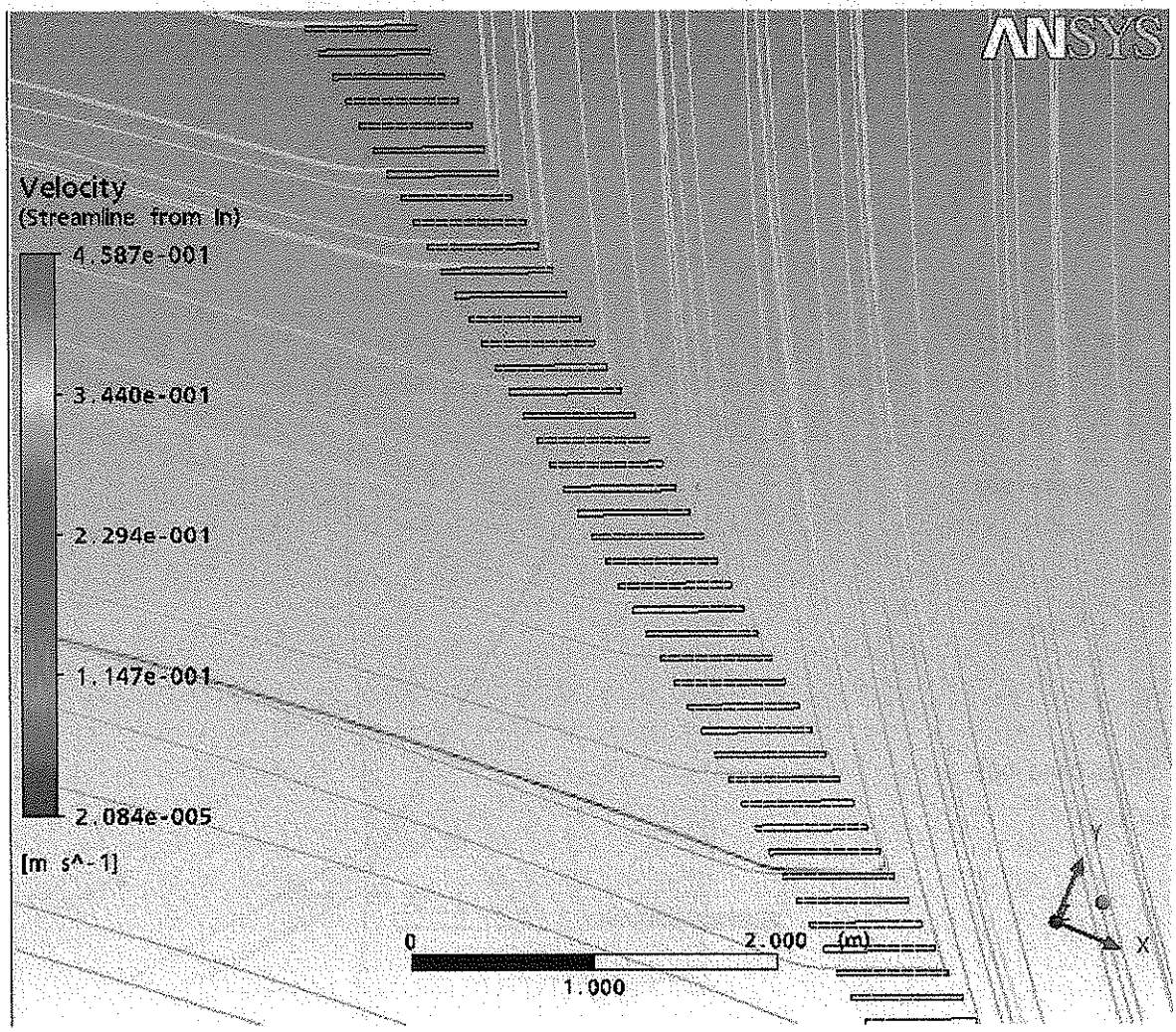
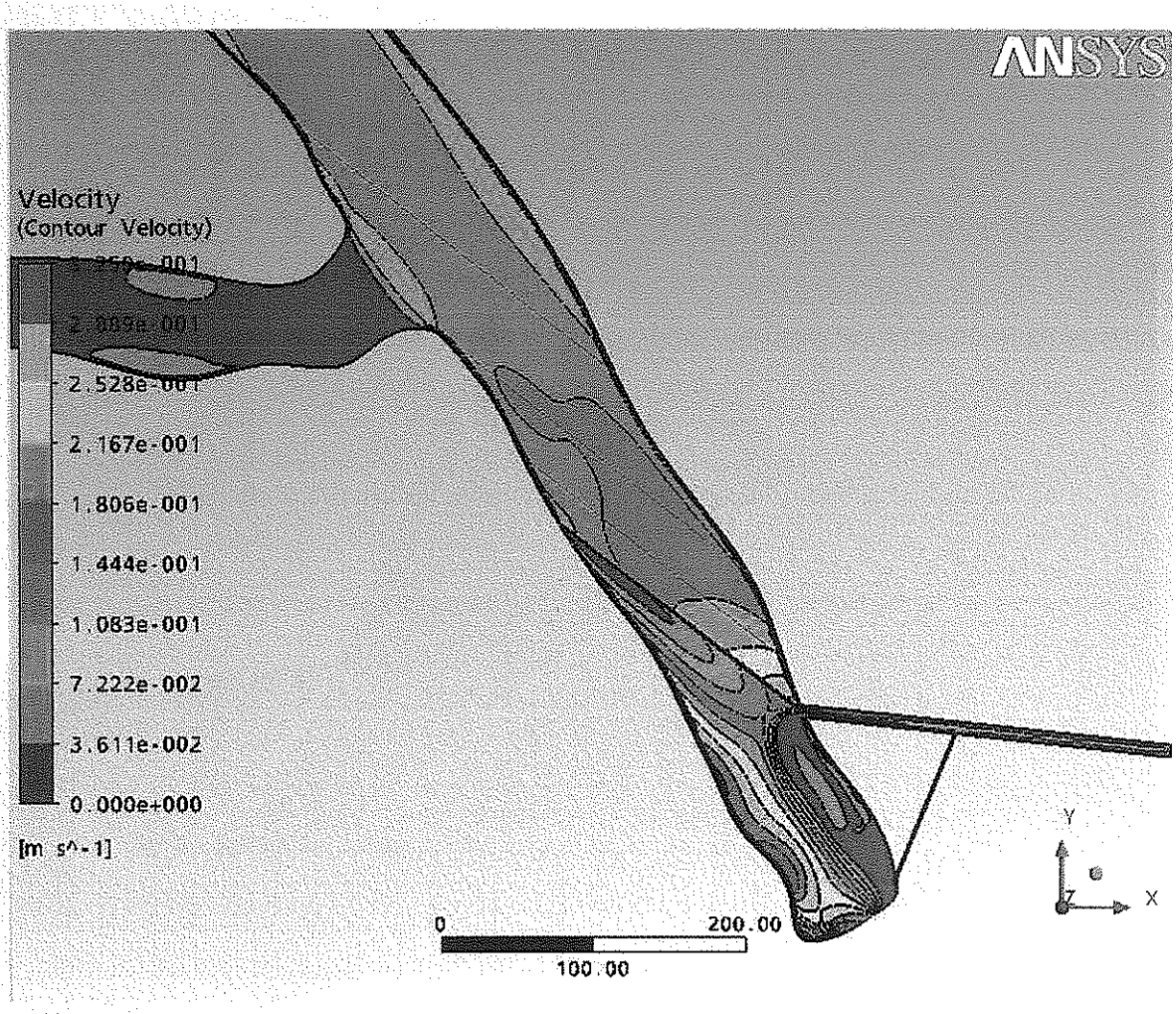
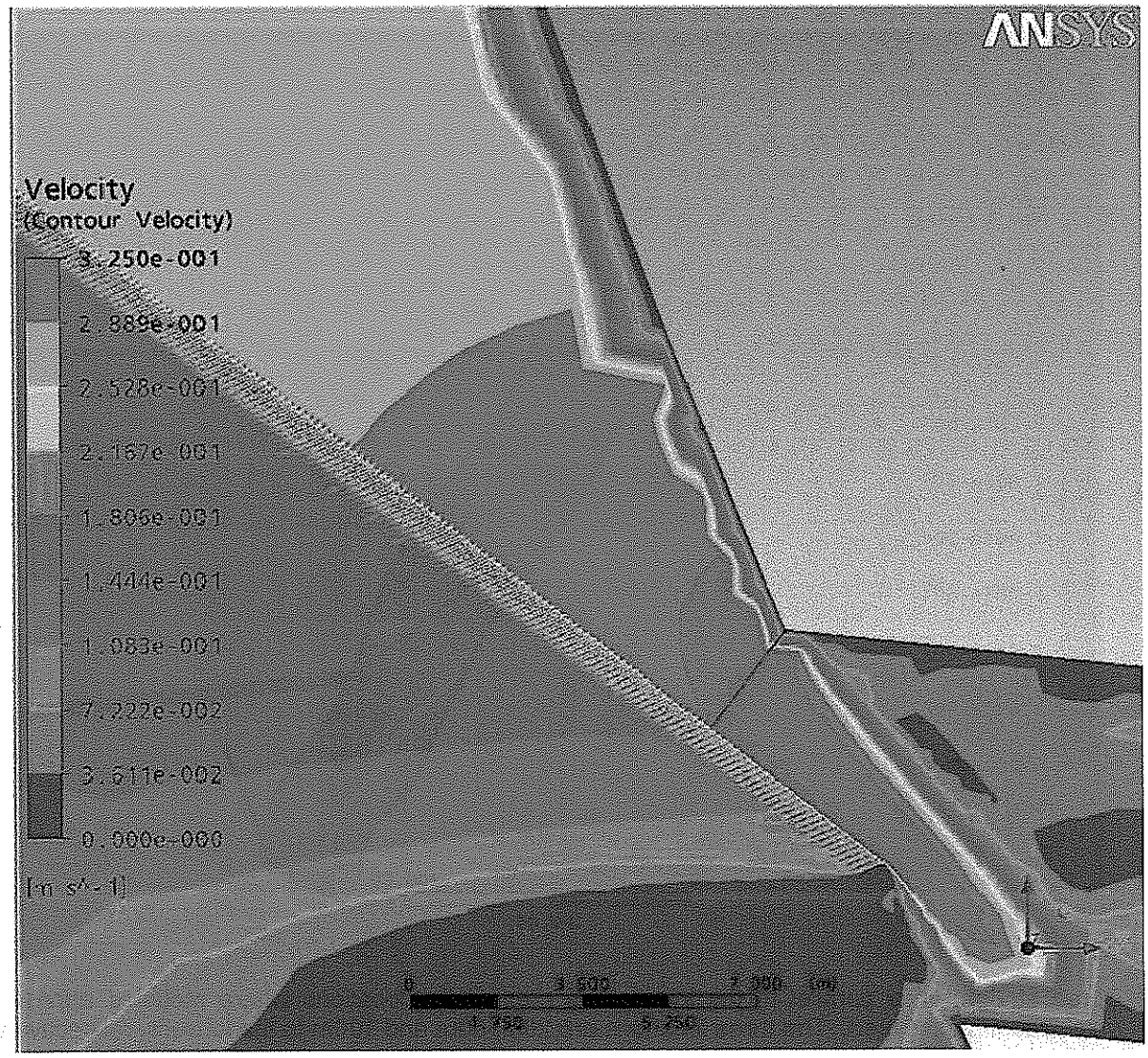


Figure 10. Velocity Profile with Reversed Louver System



Three straight lines parallel to the louver axis present the locations where modeled approach velocities are assessed. The three locations are 20m, 50m and 100m to the louvers, respectively.

Figure 11. Velocity Profile with Reversed Louver System in Vicinity of Bypass Channel



The black line indicates the horizontal location of the vertical cross-section where average velocity is calculated as presented in Table 1.

Impinging and sweep velocities predicted using the full scale simulation are lower than those developed using the limited scale simulation (Figure 5). This is to be expected since velocities for the limited scale simulation were determined for a segment of the louver closest to the bypass. As noted earlier, the velocity profile (Figure 10) reveals increasing velocities as flow approaches the by-pass.

A key observation from this assessment is that the full scale simulation provides a substantial improvement to the ratio of the sweep velocity to impinging velocity. This ratio has increased from an estimated value of 2.1 to 3.7.

Passive Diversion: To predict whether or not placement of a louver system in the intake channel would affect the entrainment of fish eggs or "non-motile" larvae at Bay Shore Power Plant, the path of 5,000 particles (1.0 cm diameter) was modeled following release upstream of the louver system. This analysis assumes that fish eggs and larvae are non-motile and not capable of sustained swimming. The annual effectiveness for the louver system was estimated to be approximately 3.9%. Overall, placement of a louver system within the intake channel is expected to provide only a minimal benefit for entrainment at Bay Shore Power Plant.

4.2.3 Fine Mesh Screening System Behind the Louver Array

As discussed above, placement of a louver system within the intake channel is not expected to provide substantial benefit for entrainment at Bay Shore Power Plant. One approach to increase the diversion efficiency of fish eggs and larvae is to place fine mesh screening behind the louver array.

This scenario was analyzed using ANSYS/CFX. During the model simulation, it was determined that fine-mesh screens are best analyzed using a *macroscopic* modeling approach, i.e. treating the screens as "porous media". However, macroscopic modeling of the combined system could not provide accurate estimates of passive diversion (deflection), because particles pass through the porous media. Based on model results, passive diversion rates for any combination of louver array and fine-mesh screen appeared to be related only to the function of the louver array. On this basis, it was not possible to adequately model passive diversion for this scenario.

While the macroscopic model could not adequately predict passive diversion for the combined louver/screen system, it was possible to assess the potential influence of back pressure created by the presence of the fine mesh screen. For this analysis, the screen (2mm) was placed at distances of 2.5m. 5.0m and 7.5m downstream of the louver array. Model results are summarized in Table 2. Key findings include the following:

1. The presence of a screen reduces the ratio of sweep velocity to impinging velocity. The overall impact to this ratio becomes smaller with increasing distance between the two components as well as the size of the screen opening (porosity).

2. The presence of a screen reduces the turbulence kinetic energy of the louver system. The overall impact decreases with increasing distance between the two components as well as the size of the screen opening (porosity).

Table 2. Flow Parameters for Combined Louver/Screen System

Velocity Profile	Louvers Only	Louvers with 2mm Screen (2.5m)	Louvers with 2mm Screen (5.0m)	Louvers with 2mm Screen (7.5m)	Louvers with 10mm Screen (2.5m)	Louvers with 10mm Screen (5.0m)	Louvers with 10mm Screen (7.5m)
Impinging Velocity: 1ft in front of louvers (m/s)	0.051	0.050	0.050	0.051	0.050	0.051	0.051
Sweep Velocity: 1ft in front of louvers (m/s)	0.188	0.171	0.172	0.173	0.175	0.173	0.177
Ratio of Sweep to Impinging Velocity	3.72	3.40	3.40	3.43	3.47	3.47	3.50
Turbulence Kinetic Energy at Louvers (m^2/s^2)	7.9E-04	6.5E-04	6.5E-04	6.6E-04	6.8E-04	6.8E-04	6.9E-04

4.2.4 Fine Mesh Screening System at Mouth of Intake Canal

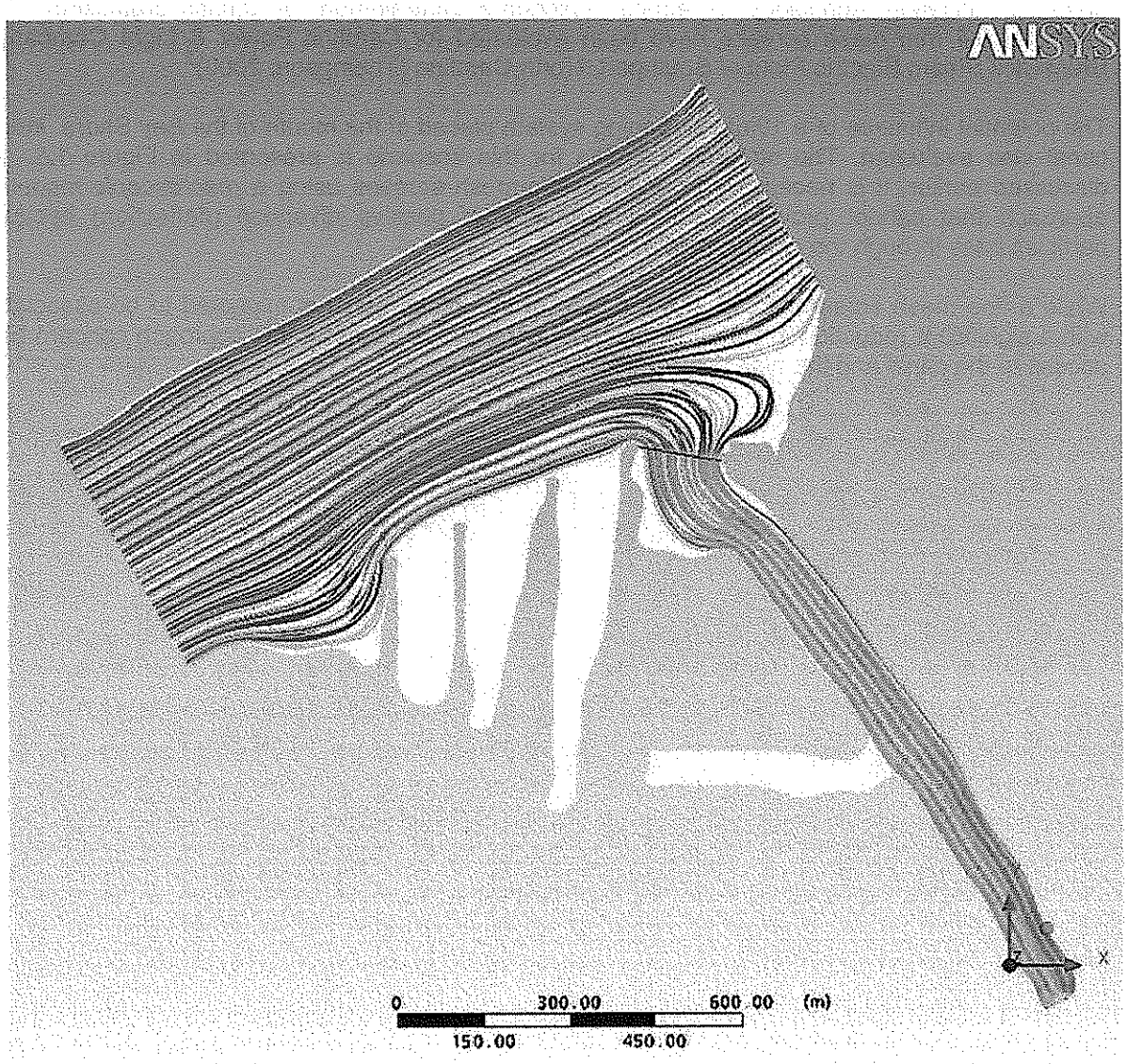
A fine mesh screen diversion structure placed at the mouth of an intake canal represents a potential mitigation technology to reduce impingement/entrainment of aquatic organisms. For example, 9.4 mm mesh screens have been evaluated for Carolina Power & Light Company's Brunswick Steam Electric Plant at Southport, North Carolina (Thompson, 2000)[2].

The potential influence of a 10mm screening system placed at the mouth of the Bay Shore intake canal was evaluated. The streamline profile for this scenario is presented in Figure 12. As discussed earlier, it is necessary to analyze fine-mesh screens using a *macroscopic* modeling approach that cannot provide accurate estimates of passive diversion (deflection) because particles pass through the porous media.

While a fine mesh screen placed at the mouth of the intake canal is expected to be associated with a significant reduction in fish impingement, key disadvantages of this approach concern boat access to the canal and the high potent ial for biofouling.

[2] Thomas Thompson (2000). Intake modifications to reduce entrainment and impingement at Carolina Power & Light Company's Brunswick Steam Electric Plant, Southport, North Carolina.

Figure 12. Streamline Profile for 10mm Screening System at Mouth of Intake Canal



5.0 PREDICTING THE EFFECTIVENESS OF A LOUVER ARRAY IN DIVERTING FISH

Performance of a louver is dependent on many variables some of which are related to engineering design of the array whereas others are biological in nature and focus on fish attributes such as size, life history stage, and response to stimuli such as turbulent flows. Relevant factors for consideration for the proposed pilot project at Bay Shore Power Plant will likely include the following:

5.1 Biological Attributes

- **Species** (predator/prey, pelagic/ demersal). Species specific responses will occur with some species showing much greater diversion than others. This is a typical feature of any behavioral system (e.g. Patrick et al. 1985, Patrick and Poulton 2001), and the design must consider the behavior of the target species (i.e. dominant species impinged and/or entrained).

- **Life History Stage** (YOY, juvenile, adult). Differences in response to a louver array can occur for life history stage even within the same species. Diversion efficiencies will vary not only in relation to differences in life history behavior (e.g. attraction or avoidance to flow) but also swim speed capabilities (which is a function of size and life history, see Table 3).

- **Swimming Abilities of Specific Fish:** Both sustained and burst speeds need to be considered (e.g. Table 1). Burst speed can be metabolically demanding for fish, and distance travelled may be relatively small relative to the size of the diversion bypass (Scruton and McKinley 1998). Hence, fish become fatigued and would be vulnerable to passage through the louver slats.

- **Schooling Behavior vs Individual Responses.** Improved effectiveness will be expected for fish approaching as a school as opposed to individuals or small groups. High fish impingement usually involves schooling species with large numbers.

5.2 Design Considerations for Fish Passage

- **Approach Velocity:** Average water velocity measured a few meters in front of the intake screen taken in the same direction as the general flow. The approach velocity should be low as possible (optimal at 0.15 cm/s or lower to allow fish sufficient time to elicit an avoidance response).

- **Sweep or Bypass Velocity:** Average velocity that sweeps along the louver array. This velocity should be directed towards some sort of bypass and should exceed approach velocity for passive diversion to occur.

- **Slat Velocity:** Slat velocity is the average velocity that passes through the louver slats. This velocity may exceed the sustained swimming velocities of the fish species (Table 3) but not always the burst speed of fish. The higher the slat velocity, the more difficult it will be for fish to bypass especially if approach velocities are high, and fish become fatigued.

- **Slat Angle:** This is the angle that the slat is attached to the frame, and is measured either relative to the frame or flow. It is well documented that slat angle can affect performance of the louver system (Griffith 1981, EPRI 2001).

- **Slat Spacing:** Louver spacing is the "clear" opening area of a louver array, and will typically vary from 5 to 30 cm. It is well documented that slat spacing will affect performance of the louver system (Griffith 1981, EPRI 2001).

- **Current Velocity:** Velocities will vary substantially at each power plant especially hydroelectric facilities (Odeh and Orvis 1998). If velocities far exceed the sustained swimming capabilities of the fish a low performance of the louver may be expected.

- **Frame Angle:** Louver frame angle is the angle of the louver array to the flow. It can be important in determining sweep velocity along the louver array.

- **Pressure Gradient:** Fish have ability to detect small pressure gradients which are required for a fish avoidance response.

- **Turbulence:** An area of turbulence should be created. However, the turbulence created should exceed the "attraction flow" to fish (Coutant 2001) and cause an avoidance response. Attraction flow should be considered at the bypass not through the louver slats.

- **Space Perception Cues:** In addition to flow, visual and/or space perception cues should be provided to maximize diversion effectiveness. The intent is to develop a multi-sensory approach whereas fish would be able to respond to more than stimuli (in this case, flow and visual). Maximizing the length of the louver slat is one approach to create a space perception cue.

- **Water Temperature:** Fish swim speed capabilities and behavioral responses are temperature dependent (discussed further below).

- **Bypass Design:** The bypass design is also critical in the louver design. Factors considered important include location, type (surface vs full depth), size, sweep velocity along louver to bypass, attraction velocity (at bypass), and quantity of flow.

Swimming speed varies primarily by fish size and water temperature, with small fish and those at cold temperatures performing most poorly. Overall, a fish's ability to avoid impingement depends on its swimming ability relative to the velocities in the flow field and the distance it needs to swim to reach a safe area (EPRI, 2000).

Blaxter (1969) concluded that the cruising speed for most fish is between 2 to 3 body lengths per second (BL/s). Sustained swimming speeds for fish species impinged at Bay Shore Power Plant were estimated based on the mean body length of impinged specimens. A summary of estimated swimming speeds is presented in Table 3. It is noteworthy that the dominant species (>90%) that impinge at Bay Shore have estimated sustained swimming speeds that exceed the ambient flows in the intake channel at 11-12 cm/s (emerald shiner-13 cm/s; white perch 20 cm/s; gizzard shad 21 cm/s; white bass 20 cm/s, Table 3). This will allow fish time to display an avoidance response to the louver array without becoming excessively fatigued.

Table 3. Estimated Swimming Speed of Fish Impinged at Bay Shore Power Plant

Species	# Impinged Annually	Mean Length (mm)	Sustained Swimming Speed (cm/s) [1]
Channel darter	281	30	6
Lepomis spp.	152	37	7
Fathead minnow	815	38	8
Western banded killifish	130	41	8
Sand shiner	23,103	44	9
Orangespotted sunfish	1,315	51	10
Northern redfin shiner	171	53	11
Round goby	93,918	55	11
Bluegill	32,112	56	11
Bluntnose minnow	2,357	56	11
Rainbow smelt	11,472	57	11
Golden shiner	384	60	12
Tadpole madtom	995	60	12
Green sunfish	421	61	12
Emerald shiner	24,080,877	66	13
Black crappie	741	66	13
Logperch	51,547	67	13
Brook silverside	20,538	69	14
Spotfin shiner	545	69	14
White crappie	1,430	75	15
Spottail shiner	313,326	77	15
Bigmouth buffalo	270	80	16
Black darter	296	80	16
Trout-perch	123,405	80	16
Yellow bullhead	826	92	18
Channel catfish	77,812	96	19
White perch	4,769,163	100	20
Flathead catfish	130	100	20
Pumpkinseed	3,031	103	21
Gizzard shad	14,313,113	106	21
Creek chub	171	108	22
Largemouth bass	3,333	108	22
Common carp	8,673	110	22
Smallmouth bass	4,571	112	22
Stonecat madtom	342	116	23
Brown bullhead	7,448	126	25
Central stoneroller	1,249	132	26
Quillback	1,306	132	26
Silver chub	10,703	132	26
Goldfish	4,445	133	27
Black bullhead	458	145	29
White bass	1,593,199	149	30
Freshwater drum	225,706	158	32
Yellow perch	159,379	159	32
Rainbow trout	93	160	32
White sucker	1,172	223	45
Redhorse	1,555	266	53
Walleye	77,469	333	67
Silver lamprey	128	357	71
Northern pike	416	423	85

[1] Swimming speed estimated as 2 x body length.

6.0 TRADITIONAL LOUVER SYSTEMS

Louvers are behavioral devices that rely on fish avoidance of a turbulence area created by slats as they move downstream and are guided to a bypass (Ruggles 1990). They have proven effective in many instances but their application has been primarily at hydroelectric facilities where their function is to divert fish from passing through turbines.

EPRI conducted a 2-year laboratory study on evaluating both angled bar racks and louvers for guiding fish at water intakes (EPRI 2001). Resource agencies increasingly require angled bar racks and louvers as fish protection technology at various water resource projects. In their testing both 15 and 45 degree slat angles were used, and both the slat length (10 cm) and clear opening (50 mm) were quite small. Conclusions were as follows:

- All bar rack and louver configurations created velocity and pressure gradients that could elicit a directional avoidance response by fish.
- The magnitude and related influence of the flow separation between consecutive louver or bar slats was the most distinctive difference between the configurations simulated.
- Results indicated marked deflection exceeding 90% in many scenarios, but this varied with species. The 15-degree structure was found to be the most effective and was considered to have considerable potential for diverting fish to a bypass. In these studies, the bypass received approximately 10% of the total flow.
- Louver and bar rack performance varied with species and performance for some species such as American eel was improved significantly with the addition of a bottom overlay. Performance of both louver and bar rack diversion systems had increased an additional 30% to over 90% in some instances.

For a more detailed review of louver systems consult Ruggles (1990) and Odeh and Orvis (1998). The concept of a bottom overlay is discussed in more detail below and will likely be incorporated into the louver array design proposed for Bay Shore.

7.0 NEW CONCEPT – REVERSED LOUVER – LABORATORY STUDIES

A comprehensive study involving 81 treatment combinations of slat angles, angle of flow, spacing and flow velocity was conducted using a louver system in a "reversed mode" (Patrick et al. 2005). In this design, flow is diverted towards the louver bypass channel whereas in more traditional louver arrangements, slats are placed perpendicular to support frames which would divert flow through louver slats for active diversion but would yield very low passive diversion. The advantage of this approach is that diversion of debris and/or semi-moribound/ dead fish can occur which is referred to as "passive" diversion. In contrast, "active" diversion refers to diversion by healthy fish based on their behavioral responses and swimming speed capabilities. In the lab study, slat angle was considered in relation to flow direction, and ranged from 90^0 to oblique angles (30^0). A summary of the different parameter tested are as follows:

- Angle of louver array to flow (14, 26, 45 degrees)
- Slat angle (30, 45, 67.5, 90 degrees)
- Slat opening (10, 20, 30 cm)
- Velocities (10,20,30 cm/s)

Results suggested that slat spacing and slat angle were the most important factors in diversion, both active and passive (Figures 13 to 15). Diversion increased linearly from 81% for 90^0 slat angles to 95% for a 30^0 slat angle. High passage results appeared to be related to lower slat angles which promoted passive diversion. Diversion also increased linearly with decreased spacing from 78% with 30 cm (12 in) spacing to 93% with 10 cm (4 in) slat spacing. Current velocity had a minor effect on active diversion but was more important for passive diversion. The system was also able to passively divert moribund or unhealthy fish. Overall all test conditions examined, the reversed louver effectiveness was about 10% lower for passive diversion than active diversion. For further details consult Griffiths (1984).

The reversed louver concept will be used in the proposed pilot project at Bay Shore, and is discussed in more detail in Section 10.

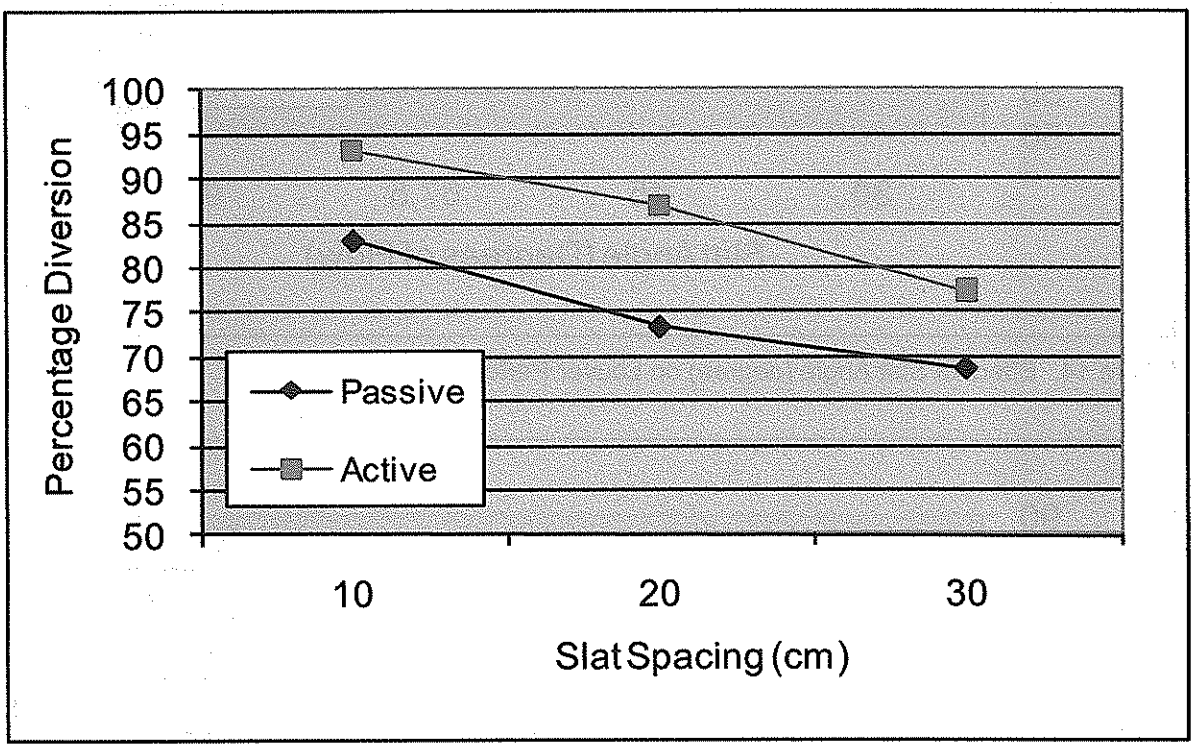


Figure 13. Effect of Slat Spacing (cm) on Louver Performance

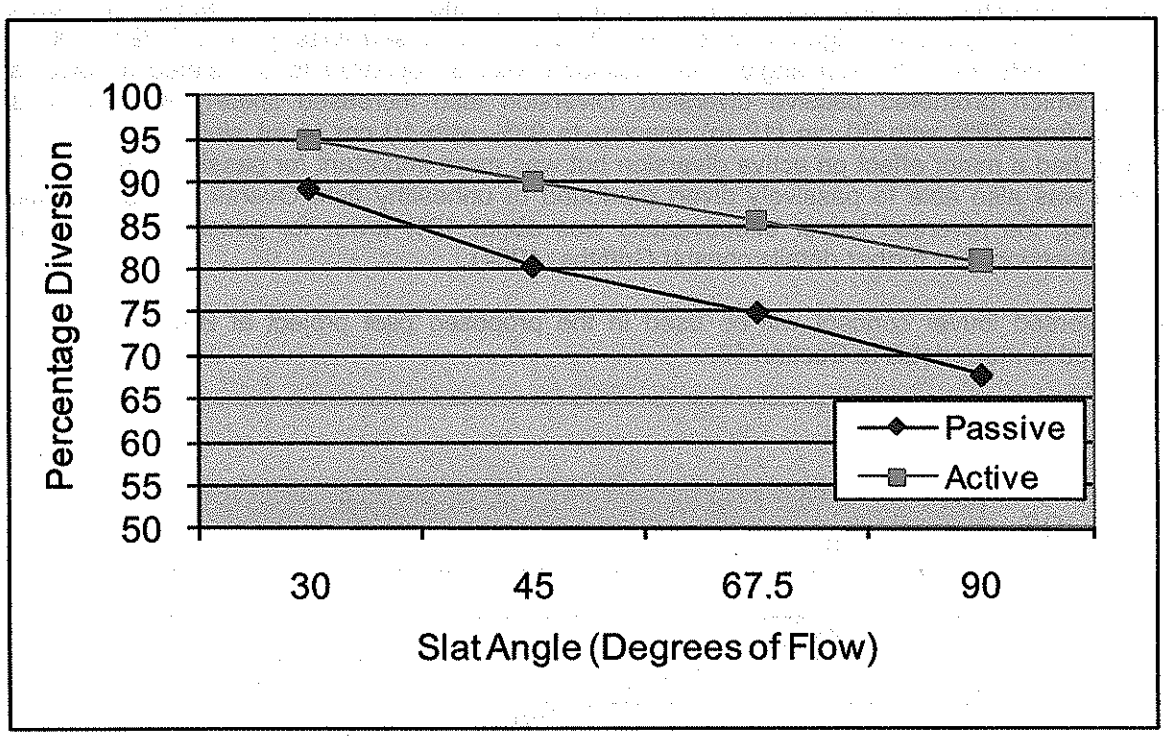


Figure 14. Effect of Slat Angle (degree) on Louver Performance

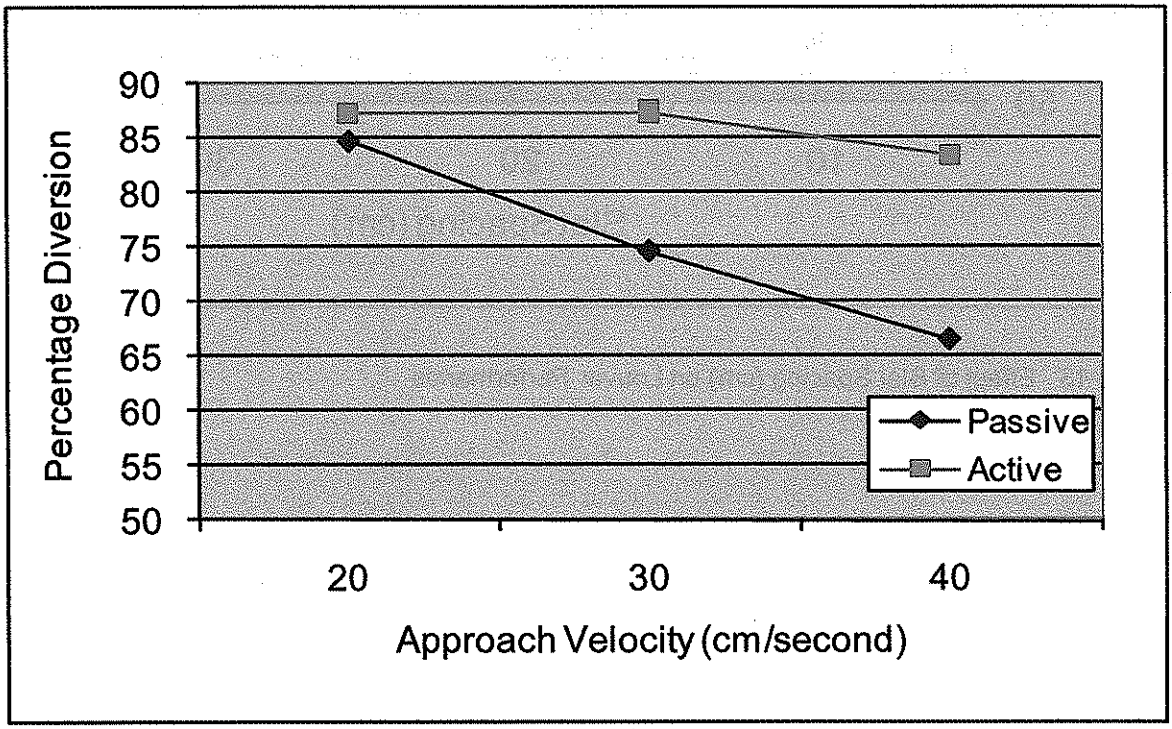


Figure 15. Effect of Approach Velocity (cm/s) on Louver Performance

8.0 GUIDE WALLS FOR DIVERTING FISH

Guide walls involve the use of an impermeable barrier that introduces a strong downstream current in the direction of the bypass channel (Oden and Orvis 1998). They are solid obstructions in the flow field which cover only a portion of the water column, and are angled similar to a louver array. Conceptually, it is somewhat similar to the bottom overlay described in the EPRI 2001 studies; however, for smolt diversion it is usually placed in the upper part of the water column.

Guidance is provided by several factors including the following:

- A downstream angled flow approach
- Adequately deep barrier with low flows velocities either above or below the wall (depending on design)
- Strong downstream current at the end of the structure into the entrance of the conveyance mechanism

Evaluation studies at Bellow Falls power station indicated that the guide wall to be very efficient in guiding fish to the sluice gate with an estimated effectiveness of 84% (Oden and Orvis 1998).

The guide wall/bottom overlay concept will also be incorporated into the pilot project louver design at Bay Shore to improve performance of the system in diverting fish as well as diverting some proportion of fish eggs and larval (see Section 10).

9.0 FINE MESH ANGLED SCREENS AND MODULAR INCLINED SCREENS

Fine mesh screens are typically used to address entrainment with mesh sizes ranging from 1 to 10 mm. Detailed reviews of this technology are given elsewhere and only a few lab and field studies are highlighted in this section. It is proposed to have a secondary fine mesh system behind the louver array to address entrainment.

A fine mesh screen diversion structure placed at the mouth of an intake canal represents a potential mitigation technology to reduce impingement/entrainment of aquatic organisms. For example, 9.4 mm mesh screens have been evaluated for Carolina Power & Light Company's Brunswick Steam Electric Plant at Southport, North Carolina (Thompson 2000). With the fine-mesh screen in place, entrainment was reduced as much as 80%.

Laboratory studies are also available for a modular inclined fine mesh screen which is typically used at high approach velocities since the application is for hydroelectric facilities. In these experiments, the fine mesh screen was angled similar to a typical louver array. The mesh size in these experiments was 2 mm, and the flows ranged from 2 to 10 feet/s. Performance of the angled system averaged about 90% and higher for most species tested over a 2 yr period (Table 4).

Table 4. Net Passage Survival (%) – Lab (1992-93)

Data provided by Alden Labs (Black to Patrick, 2009)

Species	Mean Length (mm)	2 ft/s	4 ft/s	6 ft/s	8 ft/s	10 ft/s	Combined
				1992			
Bluegill	47.0	85.8	99.2	90.7	78.0	-	88.9
Walleye	86.0	95.7	89.4	86.1	90.8	-	90.0
rainbow trout fry	48.0	92.6	100.0	100.0	95.2	91.9	96.8
rainbow trout juveniles	66.0	100.0	99.2	100.0	98.9	89.9	97.4
channel catfish	88.0	99.2	100.0	100.0	99.4	98.6	99.5
				1993			
coho salmon	49.0	94.1	100.0	98.6	98.2	95.3	98.0
Chinook salmon	53.0	100.0	100.0	99.3	98.0	93.8	97.2
golden shiner	76.0	99.1	98.7	95.1	93.2	94.7	95.5
Atlantic salmon smolts	169.0	100.0	100.0	100.0	100.0	100.0	100.0
brown trout	60.0	93.6	100.0	99.8	98.8	98.6	99.1

An angled fine mesh screen option is being considered for placement behind the louver array to address primarily entrainment. The proposed installation period would be only temporally to address the period when egg and larval fish are entrained, typically April, May and June periods (Ager et al. 2007). Given the short period when the screen is installed, there should be minimal concern with biofouling, especially zebra mussels. Mussel reproduction is largely a function of temperature, and may not start until late April or early May in a typical year. The larval stage of *Dreissena* alone usually takes about 18-30 days to complete (Mackie and Claudi 2010) even before the pediveliger stage occurs, after which the mussel enters the benthic (attached) stage. Growth of the mussel is temperature and food dependant but the rate of growth is typically only 1 mm/week. By June, only limited biofouling from mussels is expected. The screen will be removed at the end of June and cleaned after use.

10.0 INTEGRATED SYSTEM FOR CONSIDERATION AT BAY SHORE

The proposed pilot study at Bay Shore will include a unique fish diversion system which will incorporate features such as a reversed louver, an impermeable guiding wall (bottom overlay), and other design features as listed below. The primary function of these components is to divert impinged fish as well as debris, and some entrained organisms. A fine mesh screen system is also proposed to be placed behind the louver array to divert entrained organisms. Design features are as follows:

- **Reverse Louver:** The louver configuration will operate in a more "reversed" mode which will act better as a debris diverter as well as dead and/or semi-moribound fish. Studies conducted earlier by Kinectrics suggest that efficiencies as high as 90-95% can occur with

a 30 degree spacing (in a reversed mode). The optimal slat angle for the Bay Shore pilot project has not yet been determined but likely will be around 30 degrees (120 degrees to flow)..

- **Slat Spacing:** A 10 cm spacing is proposed to ensure high impingement diversion. There will be some concern with clogging from zebra mussels and other biofouling organisms. The maximum fouling of mussels on a structure without any biofouling protection is expected to be about 5-6 cm. Therfore, a proven silicon based coating is recommended to be applied to the upper section of the louver array to prevent mussel attachment (bottom overlay will not be coated). This unique coating has proven effective in deterring biofouling at some power plants for over a decade.

- **Slat Length:** The slat length will be at least 24 cm to create a "space perception" cue which should result in improved performance for fish diversion. Earlier studies have shown that certain species of fish tend to avoid close openings (space perception and visual cues) especially when approaching in schools as opposed to individual responses (Patrick and Rkman-Filopovic 2004).

- **Frame Angle:** The frame angle will be 27 degrees based on modeling results. This should allow sufficient sweep velocities along the louver array.

- **Bottom Overlay/Guiding Wall:** The bottom section of the louver array will be impermeable or solid; however, conceptually similar to the bottom overlay used in the EPRI studies. It is expected that the bottom ¼ of the louver array will be solid. A preliminary assessment of egg and larval distribution in the water column of the intake channel has suggested the preference for the bottom for some species such as freshwater drum (as much as 80%). This species alone contributes most of the egg entrainment at Bay Shore (Ager et al. 2007).

- **Bypass Design**: The pilot project will not consider a bypass design since the pilot involves only a section of louver to be tested.

- **Fine Mesh Angled Screen**: This screen will be placed behind the louver array and will have a mesh size of 7-10 mm (to be determined later). As mentioned above, the screen will only be used during the key entrainment periods typically May to June (Ager et al. 2007).

An option currently being considered for the pilot study is presented in Figures 16-17. The study will employ a louver system that covers a small portion of the intake canal. The bottom section of the louver array will be impermeable or solid. It is expected that the bottom ¼ of the louver array will be solid. A fine mesh angled screen will be placed behind the louver array and will have a mesh size of 7-10 mm (to be determined later). Full details for the pilot study will be provided in a separate document.

Figure 16. Proposed Pilot Trial Layout

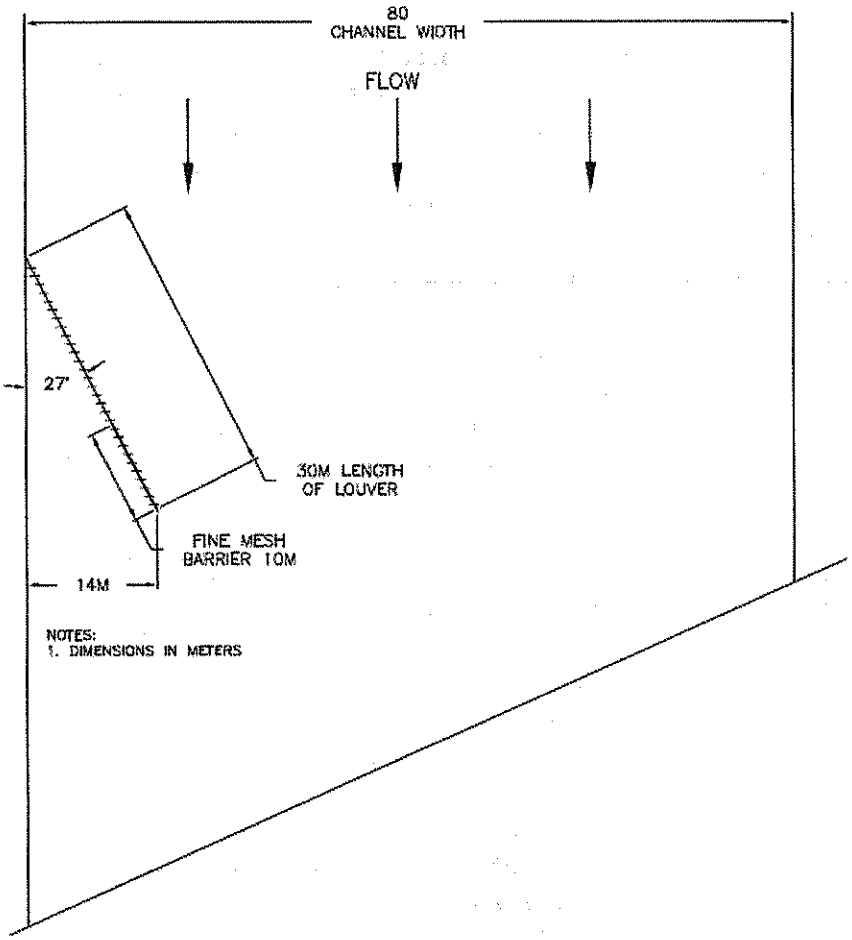
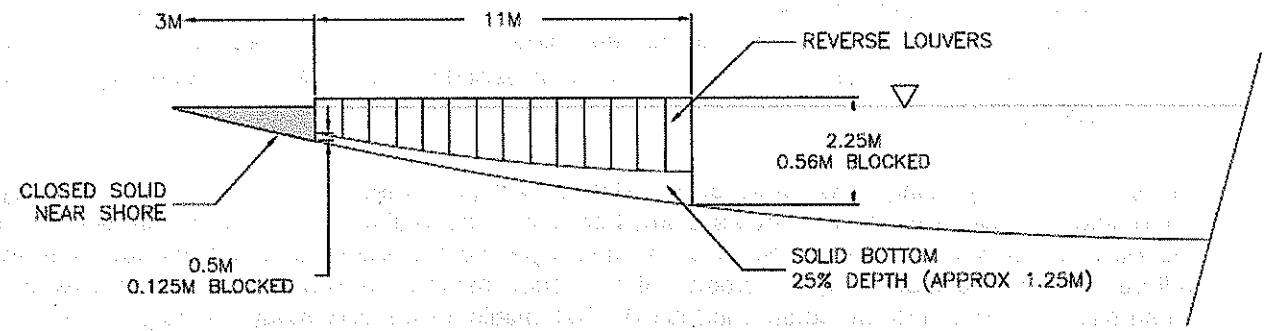


Figure 17. Proposed Pilot Trial – Side View



NOTES:
1. DIMENSIONS IN METERS
2. LOUVER SPACING NOT TO SCALE

11.0 CONCLUSIONS

- The modeling results have suggested that the frame angle should be 27 degrees which should allow an adequate sweep velocity. For a 15 cm spaced louver at 90 degrees angled to flow, an estimated sweep velocity should be 0.19 m/s (but likely will increase with a reduced slat spacing to 10 cm).

- Performance of a louver is dependent on many variables some of which are related to engineering design of the array whereas others are biological in nature and focus on fish attributes such as size, life history stage, and response to stimuli such as turbulent flows. Relevant factors for consideration for the proposed pilot project at Bay Shore Power Plant are given in the text. A summary of estimated swimming speeds indicated that the dominant species (>90%) that impinge at Bay Shore have estimated sustained swimming speeds that exceed the ambient flows in the intake channel at 11-12 cm/s. This will allow fish sufficient time to display an avoidance response to the louver array without becoming excessively fatigued.

- The proposed pilot study at Bay Shore will include a unique fish diversion system which will incorporate features such as a reversed louver, an impermeable guiding wall (bottom overlay), and other design features that focus on slat spacing, slat length and frame angle. The primary function of these components is to divert impinged fish as well as debris, and some entrained organisms. A fine mesh screen system is also proposed to be placed behind the louver array to divert entrained organisms.