Jamaica Bay Long-Term Control Plan

Ribbed Mussel (*Geukensia demissa*) Project

Phase III - Mesocosm Scaling and CFD Modeling Report

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1 Introduction

The New York City Department of Environmental Protection (DEP) proposes to mitigate the influence of pathogens derived from combined sewer overflow (CSO) events by installing a community of ribbed mussels (*Geukensia demissa*) in two Jamaica Bay tributaries. This approach could be adopted in various waterbodies, however, the two areas this project will be targeting are Bergen and Thurston Basins. DEP has contracted with Hazen and Sawyer, and Cornell Cooperative Extension to conduct a literature review and an array of experiments with ribbed mussels to determine the feasibility of the project goal. The project has been broken up into several phases beginning with a literature review (Phase I), followed by laboratory-based microcosm trials (Phase II) that will scale up to mesocosm simulations (Phase III) and then field in-situ trials (Phase IV):

- Phase I – Literature Review and Preliminary Microcosm Experiments
- Phase II – Microcosm Experiments (laboratory bench-top experiments)
- Phase III – Mesocosm Experiment (scaled physical model)
- Phase IV – In-situ Pilot Study (deployment in Bergen and Thurston Basin)

The purpose of this report is to document the modeling completed to inform the design of the mesocosm and in-situ experiments. **Section 2** describes how the mesocosm experiment was scaled down based on real world conditions for Bergen Basin and assumptions made on representative in-situ design parameters for current velocity, deployment site dimensions, and basin depth. **Section 3** describes the CFD modeling conducted to inform the evaluation of spatial arrangements for the mesocosm experiments. Finally, **Section 4** describes the final experimental layout that was constructed for the mesocosm experiments.

2 Mesocosm Model Scaling

2.1 Model Scaling Theory

Hydraulic models involving a free surface are constructed using Froude similarity. The flow process is controlled by gravitational and inertial forces. The Froude number (F), representing the ratio of inertial to gravitational forces can be defined as:

$$F = \frac{V}{\sqrt{\mathrm{gL}}} \qquad \text{(Equation 1)}$$

where V is average velocity, g is gravitational acceleration, and L is a characteristic linear flow dimension such as depth.

For flow similarity, the Froude number is maintained equal between the mesocosm and in-situ model such that the ratio of the Froude numbers (F_r) is equal to 1:

$$F_r = \frac{F_{In-Situ}}{F_{Mesocosm}} = 1 \qquad \text{(Equation 2)}$$

If the mesocosm was scaled proportionally with respect to length, width, and depth, the proportional depths would only be a few inches deep, which would be too shallow to run the ribbed mussel experiments. Given that the mesocosm system would require a minimum depth threshold to contain ribbed mussels, a distorted model with Froude similitude was needed to distort the geometric scale in the z-axis. Utilizing a larger scaling ratio in the x-axis than the z-axis is typical for river models where the Froude number scaling ratio (F_r) is related to the vertical scale ratio (Z_r) and the velocity ratio (V_r) is expressed as (Chanson, 1999):

$$_r = \sqrt{\mathrm{Zr}} \qquad \text{(Equation 3)}$$

2.2 Assumptions on Representative In-Situ Design Parameters

2.2.1 Velocity

Velocity profiles for the typical year (2008) in Bergen basin were analyzed from the LTCP Hydrodynamic/Water Quality model. Velocity profiles were evaluated for the typical year and four representative storms. The average net velocity, average outflow, and average inflow velocities were characterized for the bottom, middle, and top layer of the modeled water column (**Appendix A**).

Average net velocity includes both incoming and outgoing tides during a storm event. Average outflow velocities are the confluence of CSO discharge with outgoing tides. Average inflow velocities occur when the incoming tide exceeds the CSO discharge velocity.

Positive velocities represent flow from Jamaica Bay toward the head-end of Bergen Basin and negative velocities are outflows from the head-end. The mesocosm model used the middle depth layer velocities as the representative conditions of the ribbed mussel bed.

Bergen Basin was modeled in 8 segments located in the following attainment zones **(Figure 2-1)**:

- 0-69% Enterococci Attainment: Model Segments 1 – 4
- 70-79% Enterococci Attainment: Model Segments 5 – 6
- 80-89% Enterococci Attainment: Model Segments 7 – 8

Model segments 1-4 are the location of low pathogen attainment and are closest to the head-end of Bergen Basin (**Figure 2-1**). Model segments 2-5 were used as the representative velocities to exclude velocities modeled directly at the head-end outfall (model segment 1). Model segments further from the head-end of Bergen Basin (models segments 6-8) had lower velocities which would translate to higher residence times. It is not anticipated at this time that ribbed mussels will be deployed closest to the outfall at model segment 1 and 4, so the remaining model segments within the low and medium attainment zones (0-69% and 70-79% attainment) were used for the representative velocities and provided a conservative estimate. **Table 2-1** provides the average net and outflow velocities for Bergen Basin model segments 2-5. Of note, surface layer velocities were the highest and outflowed from the head-end of Bergin Basin (negative velocities). The middle layer velocities were lower and fluctuated between negative and positive values depending on the storm and tidal conditions. For the sample storms, the average net velocity was 0.04 ft/s and the outflow velocity was -0.07 ft/s. For the typical year storms, the average net velocity was 0.06 ft/s and the outflow velocity was -0.06 ft/s.

The average outflow velocity of the sample storms (-0.07 ft/s) was used as representative model velocity as a conservative assumption that the CSO discharge flows through the mesocosm system and does not recirculate.

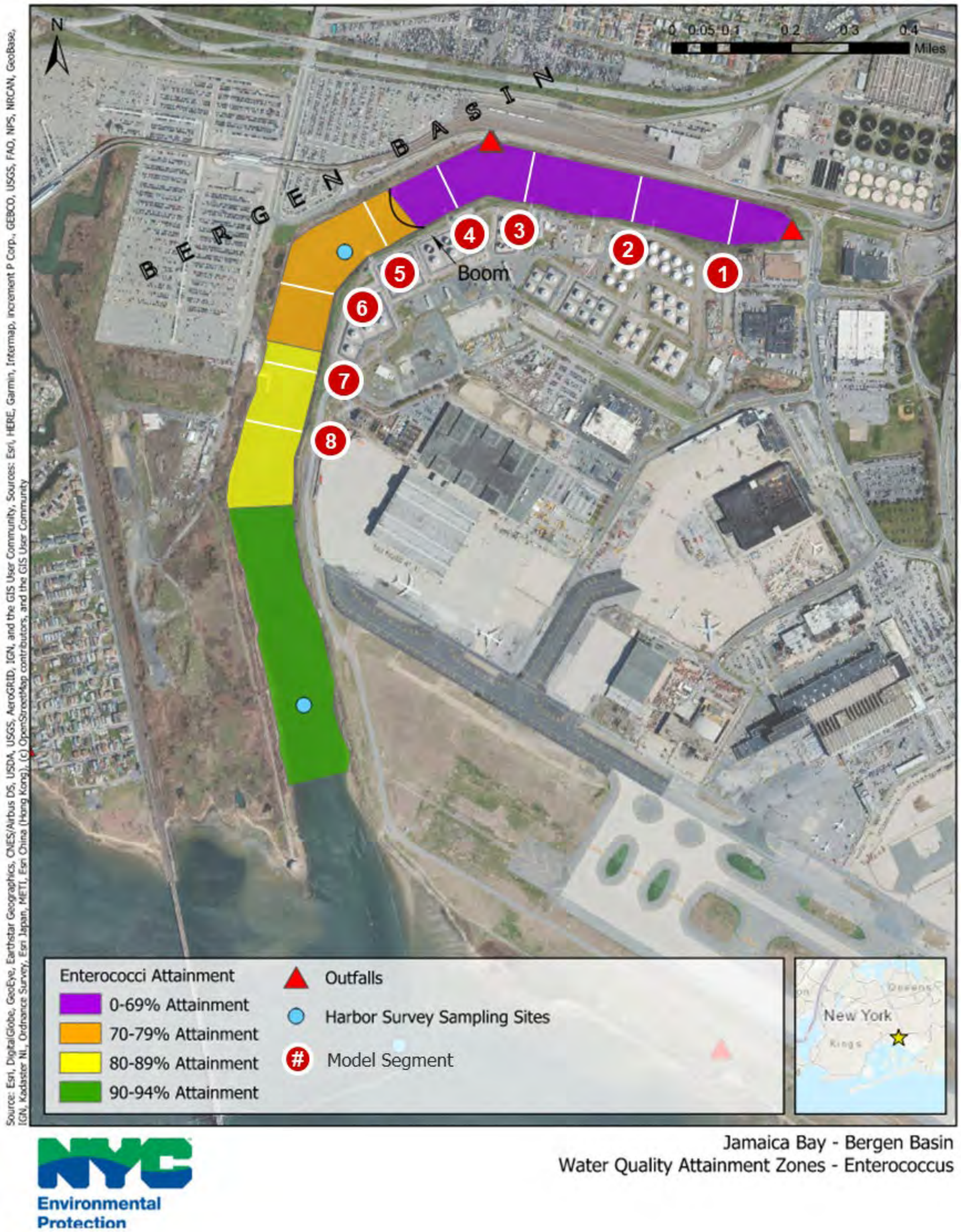


Figure 2-1: Model Segments and Water Quality Attainment Zones of Bergen Basin

Table 2-1: Summary of Average Net and Outflow Velocities for Bergen Basin Model Segments 2-5

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average of Model Segments: 2-5 Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	3/10/2008	1.68	-0.40	0.02	0.02	-0.49	-0.13	-0.06	0.13	0.11	0.07
7/22/2008	7/25/2008	0.44	-0.50	0.07	0.02	-0.47	-0.04	-0.06	0.17	0.09	0.06
9/5/2008	9/8/2008	0.85	-0.44	0.04	0.03	-0.37	-0.04	-0.05	0.08	0.09	0.04
11/30/2008	12/3/2008	0.78	-0.07	0.02	0.00	-0.41	-0.06	-0.05	0.10	0.09	0.05
Average (4 sample storms)			**-0.35**	**0.04**	**0.02**	**-0.44**	**-0.07**	**-0.05**	**0.12**	**0.10**	**0.05**
Average (all typical year storms)			**-0.22**	**0.06**	**0.01**	**-0.34**	**-0.06**	**-0.05**	**0.13**	**0.09**	**0.05**

2.2.2 Basin Channel Dimensions

A representative deployment site was assumed to establish length and width for the mesocosm system. The assumed dimensions inform the model size, but the actual in-situ installation location and dimensions will be further refined for the in-situ pilot (Phase IV).

As shown in **Figure 2-2,** the representative dimensions that were assumed for the mesocosm model scaling were a length of 360 ft and width of 80 ft. Bergen Basin has an average width of approximately 300 ft. The deployment site was assumed to be a third of the overall basin width assuming an unused shoreline buffer of 30 ft on either shore. The length of the site was determined to match the size proportions of the physical mesocosm tank. Channel depths were assumed from the Jamaica Bay and Rockaway Inlet NOAA Booklet Chart 12350. The average depth below Mean Lower Low Water in Bergen and Thurston Basin was 15 ft (**Figure 2-3**).

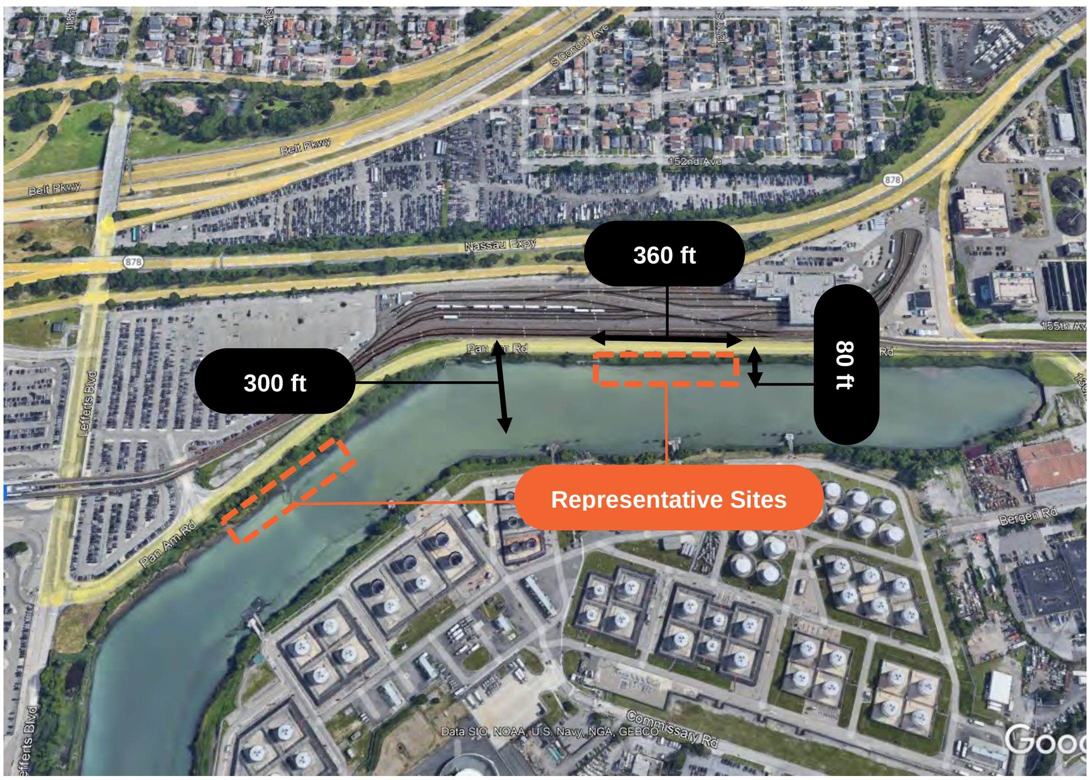


Figure 2-2: Representative Deployment Site Dimensions in Bergen Basin

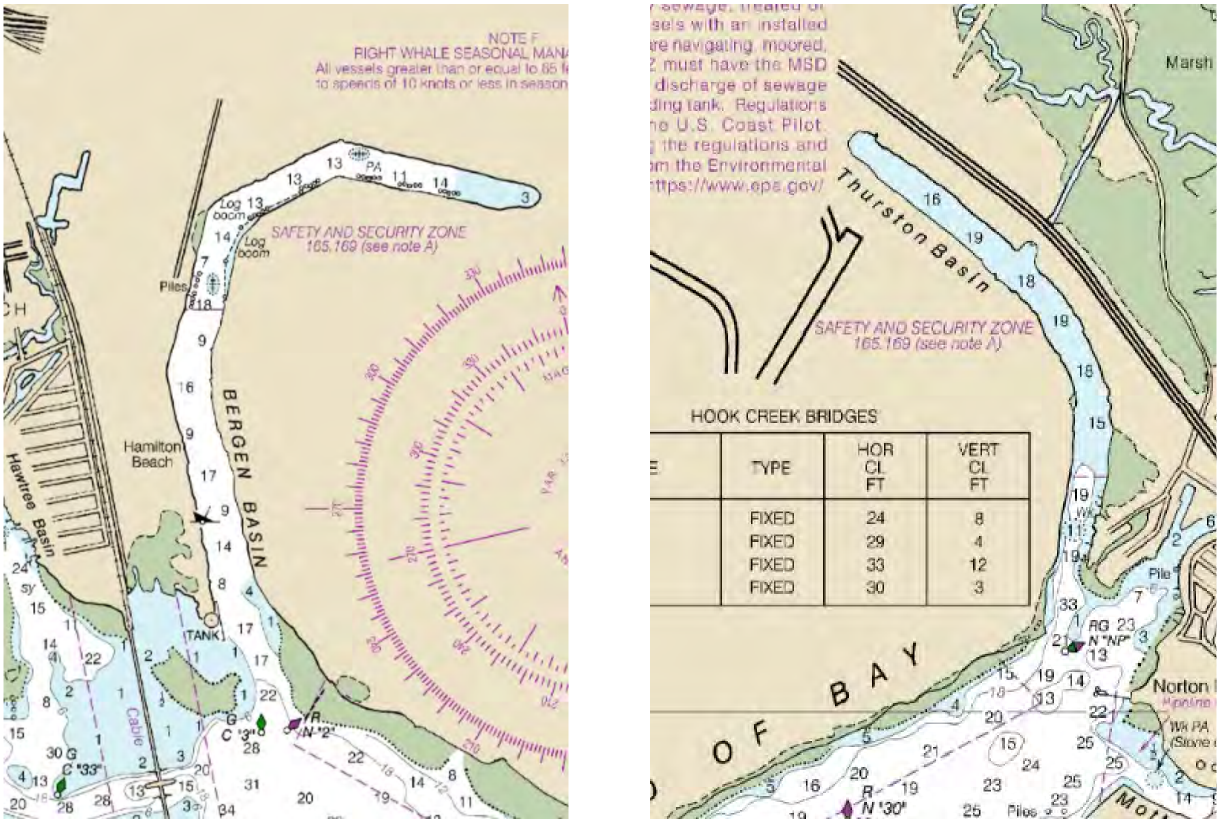


Figure 2-3: Excerpts from NOAA Booklet Chart 12350; Depths below Mean Lower Low Water in Bergen Basin (left) and Thurston Basin (right)

2.3 Selection of Model Scale

Table 2-2 provides a summary of the in-situ design parameters used to scale the mesocosm model and **Table 2-3** shows the mesocosm design parameters that were scaled from the in-situ design parameters. The scaled mesocosm model dimensions are 9 ft long x 2 ft wide x 1 ft deep, and the overall mesocosm tank dimensions are 10 ft long x 2 ft wide x 2 ft deep. The mesocosm tank dimensions were selected based on the model scaling and laboratory space capacity. The mesocosm model has a 15:1 scale to the in-situ design parameters. The mesocosm velocity (0.02 ft/s) and flow rate (16 gpm) were determined using the distorted vertical scaling factor from **Equation 3**.

The goal of the mesocosm experiments is to test how ribbed mussel clearance rates are influenced by mussel density and spatial arrangement under a flow-through condition. To estimate mussel density ranges to test in the mesocosm experiment, mussel populations were scaled based on the estimated flow rate that could be cleared hourly. The average ribbed mussel clearance rate measured during the Phase II microcosms exceeded 1 L/hr per mussel (Phase II Microcosm Experiments Final Report, dated June 30, 2021). At this clearance rate and a mesocosm flow rate of 16 gpm, 370 mussels would be needed to clear 10% of the flow, 740 mussels to clear 20% of the flow, and 1480 mussels to clear 40% of the flow. These mussel densities were used in the CFD model to evaluate how mussel density and spatial arrangement may limit flow characteristics.

Table 2-2: Summary of In-Situ Design Parameters

Parameter	Value	Notes
Velocity	-0.07 ft/s	Average outflow velocity in the middle layer of the 0 to 69% attainment zone in Bergen Basin
Length	360 ft	Assumed to maintain model proportionality with mesocosm tank
Width	80 ft	Assumed as one third of the navigable basin width
Depth	15 ft	Average from NOAA Booklet Chart 12350

Table 2-3: Summary of Mesocosm Design Parameters

Parameter	Value	Notes
Velocity	-0.02 ft/s	Calculated from **Equation 3** using distorted vertical scale
Length	9 ft	Maximum usable tank length in laboratory space
Width	2 ft	Scaled proportionally
Depth	1 ft	Minimum depth to contain ribbed mussels
Flow Rate	16 gpm	Calculated from mesocosm velocity and tank dimensions
Ribbed Mussels needed to provide a clearance rate equal to 20% of the flowrate	740 mussels	Calculated from flow rate using an average individual mussel clearance rate of 1 L/hr

3 CFD Modeling of Mesocosm Spatial Arrangements

A computational fluid dynamics (CFD) model was developed to screen whether potential mussel spatial arrangements will have undesirable flow characteristics such as internal short-circuiting, low mixing, or low travel time. The following five spatial arrangements were modeled based on potential configurations and mussel densities:

1. Uniform Distribution
2. Back-loaded Distribution
3. Front-loaded Distribution
4. Longitudinal Continuous Socking
5. Lateral Continuous Socking

Table 3-1 summarizes the insights from CFD modeling of the spatial arrangements. Additional spatial arrangement orientations such as streamlined or flat facing mussels were modeled to assess the flow conditions and mixing potential of these orientations. This will inform the optimal spatial arrangement for deployment of the mesocosm and potentially in-situ and full-scale application. However, as the ribbed mussel installations in the subject Basin mature the orientation will be governed by on-site environmental conditions such as tidal, flow, wind patterns, etc.

Based on the CFD modeling results, the uniform distribution (Spatial Arrangement #1) and back-loaded distribution (Spatial Arrangement #2) were selected for further evaluation during the mesocosm experiments. These spatial arrangements had the least internal short-circuiting and longest travel times.

The CFD model results for Spatial Arrangement #1: Uniform Distribution for the flat facing and streamlined orientations are shown in **Figure 3-1** and **Figure 3-2** respectively.

The CFD model results for Spatial Arrangement #2: Back-loaded Distribution for the flat facing and streamlined orientations are shown in **Figure 3-3** and **Figure 3-4** respectively.

Appendix B includes the CFD model results for all modeled spatial arrangements. These plots include travel times through the mesocosm tank and velocity contours in the mussel bed (Z = 6”), above the mussel bed (Z = 11”), and below the mussel bed (Z = 1”). Vertical short-circuiting can be observed when velocities are high above and below the mussel bed. Lateral short-circuiting can be observed when velocities are higher around the side of the mussel bed. Low mixing can be observed if velocity contours are parallel and move linearly through the mussel bed. Low travel times can be observed by the color of the flow pathlines, where low travel times at the end of the tank are shown in blues and greens.

Table 3-1: Summary of Results from CFD Modeling

ID	Arrangement	Vertical Short-Circuit	Lateral Short-Circuit	Low Mixing	Low Travel Time
#1a	Uniform Distribution, Flat Facings	•			
#1b	Uniform Distribution, Streamlined			•	
#1c	Uniform Distribution, Rows of 4 Streamlined, Rows of 3 Flat Facing	•	•		
#1d	Uniform Distribution, Rows of 4 Flat Facings, Rows of 3 Streamlined	•			
#2a	Back-loaded Distribution, Flat Facings	•			•
#2b	Back-loaded Distribution, Streamlined			•	
#2d	Back-loaded Distribution, Rows of 4 Flat Facings, Rows of 3 Streamlined	•			•
#3a	Front-loaded Distribution, Flat Facings	•			•
#3b	Front-loaded Distribution, Streamlined			•	
#4	Longitudinal Continuous Socking			•	
#5	Lateral Continuous Socking		•		

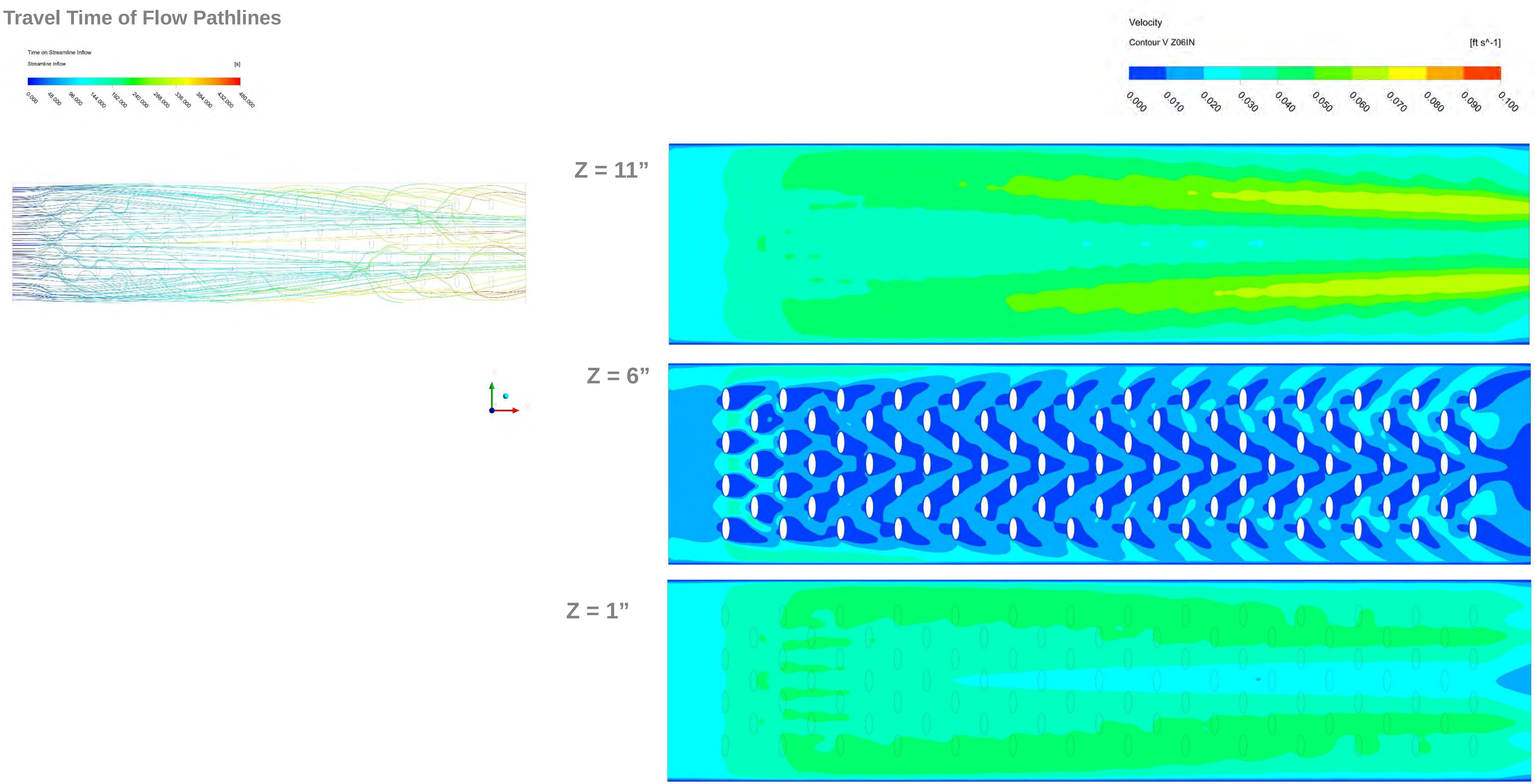
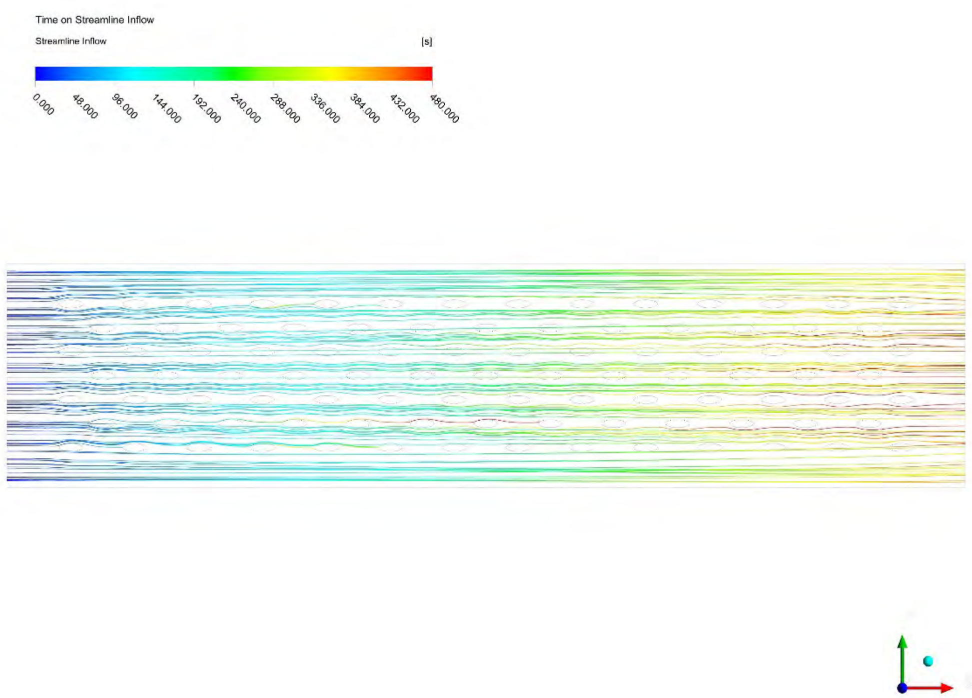


Figure 3-1: CFD Model Results for Spatial Arrangement #1a: Uniform Distribution, Flat Facings

Travel Time of Flow Pathlines



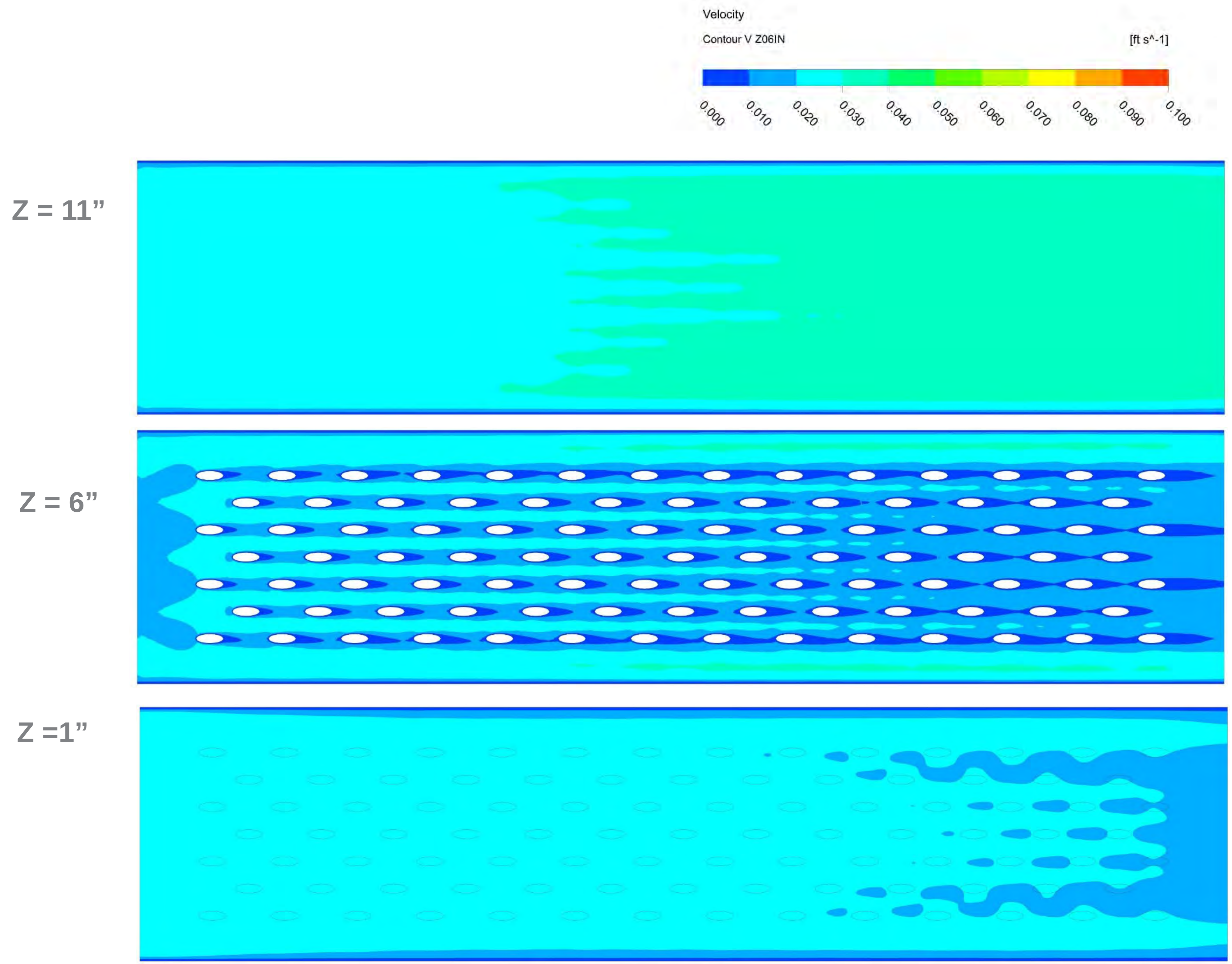


Figure 3-2: CFD Model Results for Spatial Arrangement #1b: Uniform Distribution, Streamlined

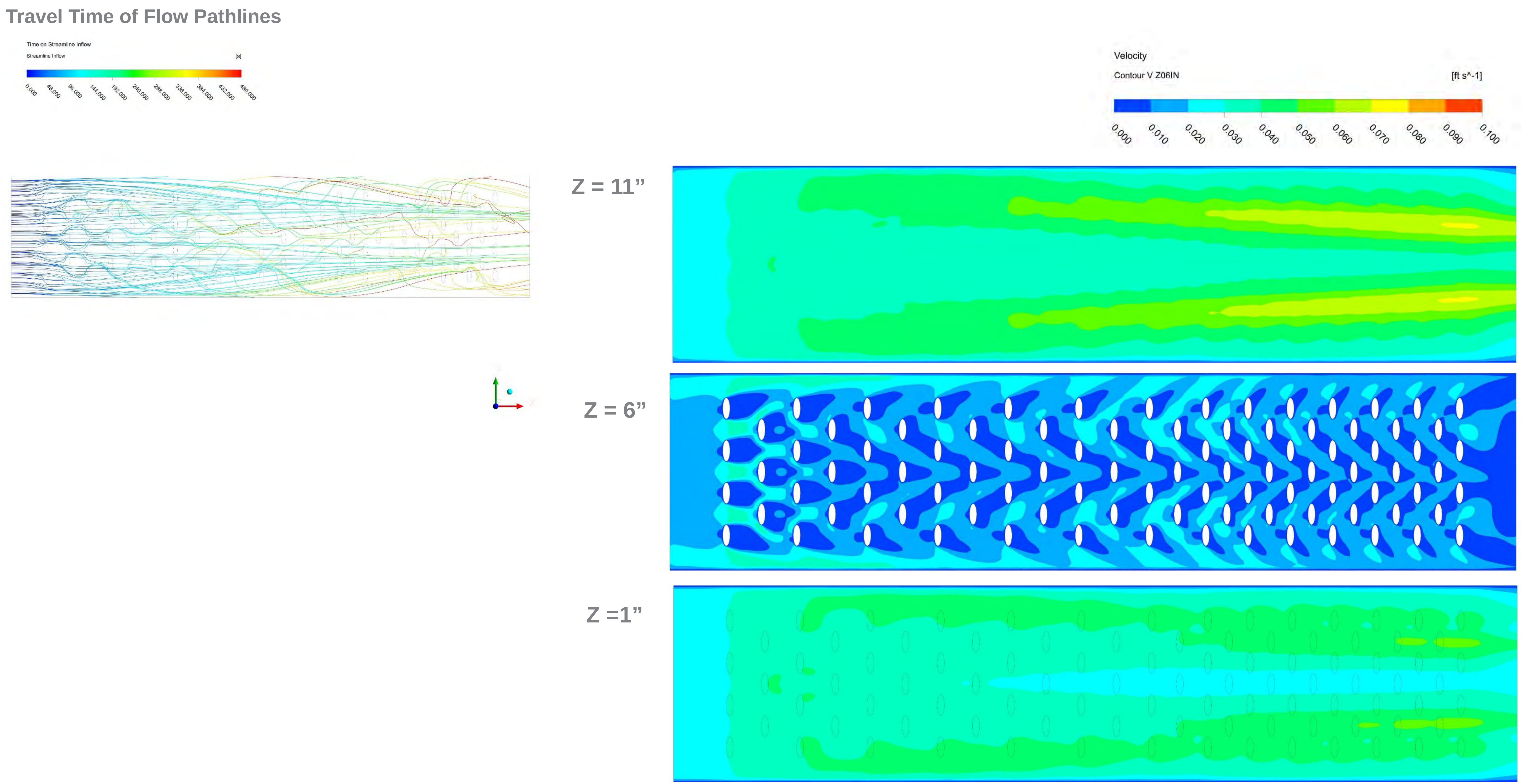


Figure 3-3: CFD Model Results for Spatial Arrangement #2a: Back-loaded Distribution, Flat Facings

Travel Time of Flow Pathlines

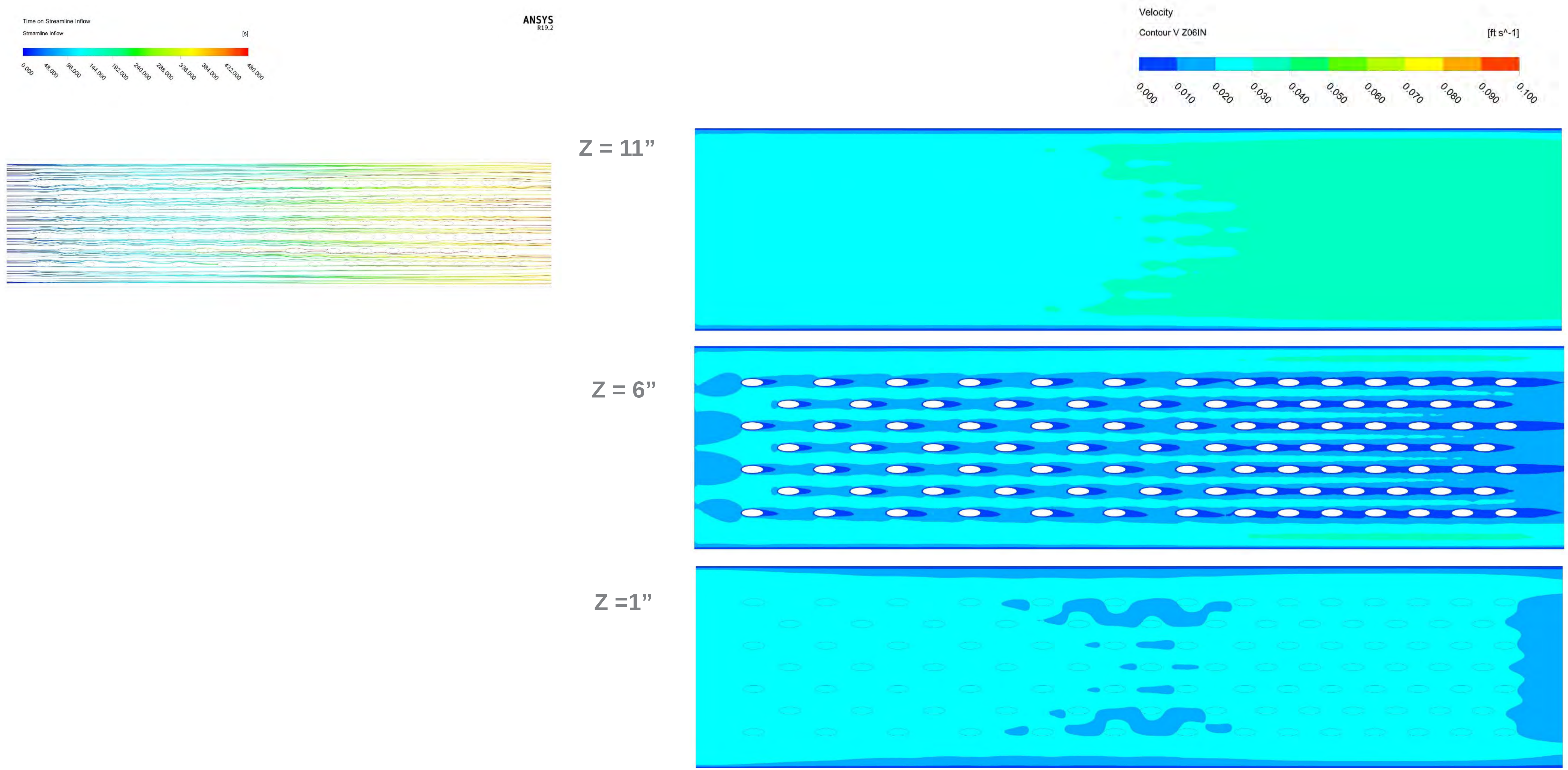


Figure 3-4: CFD Model Results for Spatial Arrangement #2b: Back-loaded Distribution, Streamlined

4 Constructed Mesocosm Layout

Two mesocosm systems were constructed in parallel; each consisting of a 1000L head tank, a 10'x 2'x 1' (L x W x D) experimental tank with a smaller, "catch" tank underneath (**Figure 4-1**).

One experimental tank was used as a control without ribbed mussels while the other experimental tank contained live ribbed mussels **(Figure 4-2)**. Tanks were rotated each experimental day.

Seawater was pumped from the head tank into the experimental tank at 17gpm and would exit via a drain into the catch tank where it was pumped back into the head tank.

A multichannel peristaltic pump continuously dripped bacteria laden seawater into each head tank at 10ml/min from a 15L container with bacteria that sat on a stir plate to keep the bacteria in suspension.

Figure 4-1 Experimental tank set-up with the header tanks shown in the foreground

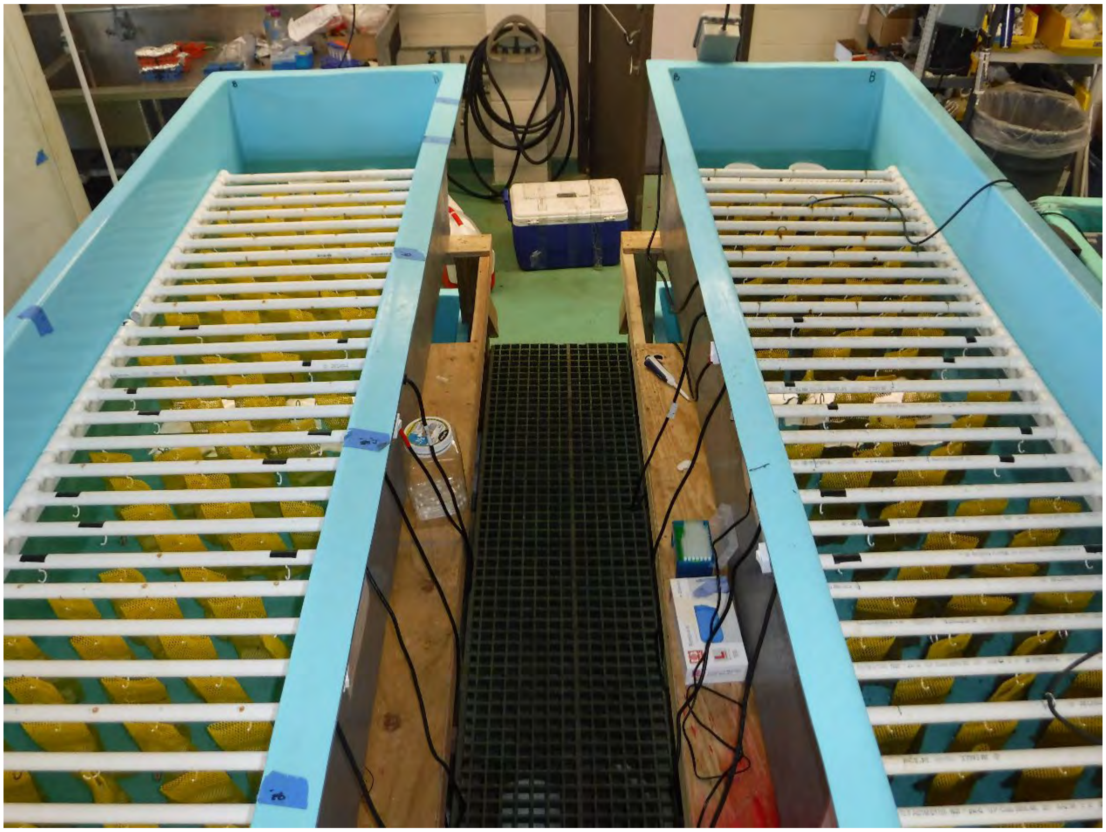


Figure 4-2: Ribbed Mussels suspended in mesh bags arranged in a 4:3:4:3 configuration

5 Literature Cited

Chanson, Hubert. (1999). The Hydraulics of Open Channel Flow. Arnold, 338 Euston Road, London NW1 3BH, UK. Chapter 14

National Oceanic and Atmospheric Administration. Jamaica Bay and Rockaway Inlet NOAA Booklet Chart 12350. https://www.nauticalcharts.noaa.gov/charts/noaa-raster-charts.html#booklet-charts (Accessed June 1, 2021)

Appendix A: Typical Year Velocity Profiles for Bergen Basin Model Segments

Model Segment: 1

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	**3/10/2008**	1.68	-0.22	-0.14	0.03	-0.44	-0.21	-0.12	0.21	0.08	0.12
7/22/2008	**7/25/2008**	0.44	-0.43	-0.01	0.12	-0.38	-0.10	-0.04	0.09	0.09	0.12
9/5/2008	**9/8/2008**	0.85	-0.28	-0.11	0.09	-0.35	-0.15	-0.08	0.07	0.09	0.10
11/30/2008	**12/3/2008**	0.78	-0.02	-0.10	0.07	-0.48	-0.11	-0.07	0.08	0.09	0.11
Average (4 sample storms)			**-0.24**	**-0.09**	**0.08**	**-0.41**	**-0.14**	**-0.08**	**0.11**	**0.09**	**0.11**
Average (all typical year storms)			**-0.18**	**0.02**	**0.01**	**-0.33**	**-0.10**	**-0.05**	**0.10**	**0.09**	**0.11**

Model Segment: 2

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	**3/10/2008**	1.68	-0.36	0.00	0.02	-0.46	-0.13	-0.06	0.15	0.13	0.07
7/22/2008	**7/25/2008**	0.44	-0.48	0.08	0.03	-0.41	-0.09	-0.06	0.13	0.11	0.06
9/5/2008	**9/8/2008**	0.85	-0.34	0.02	0.04	-0.33	-0.07	-0.05	0.05	0.09	0.05
11/30/2008	**12/3/2008**	0.78	-0.09	-0.01	0.00	-0.43	-0.08	-0.05	0.07	0.09	0.05
Average (4 sample storms)			**-0.32**	**0.02**	**0.02**	**-0.41**	**-0.09**	**-0.06**	**0.10**	**0.10**	**0.06**
Average (all typical year storms)			**-0.19**	**0.07**	**0.01**	**-0.30**	**-0.07**	**-0.05**	**0.09**	**0.11**	**0.05**

Model Segment: 3

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	3/10/2008	1.68	-0.38	-0.01	0.01	-0.49	-0.17	-0.06	0.11	0.10	0.06
7/22/2008	7/25/2008	0.44	-0.50	0.07	0.02	-0.45	-0.03	-0.06	0.17	0.09	0.05
9/5/2008	9/8/2008	0.85	-0.42	0.06	0.03	-0.35	-0.03	-0.04	0.07	0.09	0.04
11/30/2008	12/3/2008	0.78	-0.07	0.02	0.01	-0.39	-0.05	-0.05	0.09	0.08	0.04
Average (4 sample storms)			**-0.34**	**0.04**	**0.02**	**-0.42**	**-0.07**	**-0.05**	**0.11**	**0.09**	**0.05**
Average (all typical year storms)			**-0.21**	**0.06**	**0.01**	**-0.32**	**-0.05**	**-0.05**	**0.11**	**0.08**	**0.05**

Model Segment: 4

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	3/10/2008	1.68	-0.42	0.04	0.03	-0.49	-0.12	-0.06	0.14	0.11	0.07
7/22/2008	7/25/2008	0.44	-0.51	0.07	0.02	-0.51	-0.02	-0.04	0.16	0.08	0.05
9/5/2008	9/8/2008	0.85	-0.50	0.04	0.02	-0.42	-0.03	-0.03	0.10	0.08	0.04
11/30/2008	12/3/2008	0.78	-0.05	0.02	0.00	-0.41	-0.05	-0.04	0.12	0.09	0.04
Average (4 sample storms)			**-0.37**	**0.04**	**0.02**	**-0.46**	**-0.05**	**-0.04**	**0.13**	**0.09**	**0.05**
Average (all typical year storms)			**-0.23**	**0.06**	**0.02**	**-0.36**	**-0.05**	**-0.04**	**0.14**	**0.08**	**0.05**

Model Segment: 5

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	3/10/2008	1.68	-0.42	0.06	0.02	-0.54	-0.11	-0.06	0.13	0.12	0.07
7/22/2008	7/25/2008	0.44	-0.49	0.07	0.02	-0.49	-0.04	-0.06	0.23	0.09	0.06
9/5/2008	9/8/2008	0.85	-0.51	0.05	0.02	-0.39	-0.03	-0.06	0.10	0.09	0.05
11/30/2008	12/3/2008	0.78	-0.05	0.02	0.00	-0.42	-0.06	-0.06	0.11	0.10	0.05
Average (4 sample storms)			**-0.37**	**0.05**	**0.02**	**-0.46**	**-0.06**	**-0.06**	**0.14**	**0.10**	**0.06**
Average (all typical year storms)			**-0.23**	**0.06**	**0.02**	**-0.38**	**-0.06**	**-0.05**	**0.15**	**0.09**	**0.06**

Model Segment: 6

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	3/10/2008	1.68	-0.43	0.08	0.00	-0.46	-0.07	-0.07	0.13	0.13	0.08
7/22/2008	7/25/2008	0.44	-0.43	0.07	0.01	-0.47	-0.04	-0.07	0.21	0.10	0.06
9/5/2008	9/8/2008	0.85	-0.51	0.04	0.02	-0.38	-0.06	-0.07	0.12	0.09	0.06
11/30/2008	12/3/2008	0.78	-0.07	0.02	0.00	-0.39	-0.07	-0.07	0.13	0.11	0.05
Average (4 sample storms)			**-0.36**	**0.05**	**-0.01**	**-0.42**	**-0.06**	**-0.07**	**0.15**	**0.11**	**0.06**
Average (all typical year storms)			**-0.23**	**0.06**	**0.00**	**-0.38**	**-0.06**	**-0.07**	**0.19**	**0.10**	**0.06**

Model Segment: 7

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	3/10/2008	1.68	-0.43	0.07	0.01	-0.50	-0.06	-0.06	0.17	0.11	0.06
7/22/2008	7/25/2008	0.44	-0.40	0.07	0.00	-0.44	-0.07	-0.06	0.28	0.10	0.06
9/5/2008	9/8/2008	0.85	-0.52	0.03	0.02	-0.44	-0.06	-0.07	0.18	0.08	0.04
11/30/2008	12/3/2008	0.78	-0.07	0.03	-0.01	-0.40	-0.07	-0.06	0.16	0.11	0.05
Average (4 sample storms)			**-0.36**	**0.05**	**0.01**	**-0.45**	**-0.06**	**-0.06**	**0.20**	**0.10**	**0.05**
Average (all typical year storms)			**-0.24**	**0.06**	**0.00**	**-0.40**	**-0.06**	**-0.06**	**0.22**	**0.10**	**0.06**

Model Segment: 8

Sample Storms from Hydrodynamic Model Profiles			Average Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	3/10/2008	1.68	-0.44	0.06	0.01	-0.50	-0.08	-0.06	0.21	0.10	0.06
7/22/2008	7/25/2008	0.44	-0.37	0.06	0.01	-0.44	-0.06	-0.05	0.26	0.10	0.06
9/5/2008	9/8/2008	0.85	-0.52	0.03	0.01	-0.45	-0.07	-0.05	0.24	0.07	0.04
11/30/2008	12/3/2008	0.78	-0.06	0.02	0.00	-0.42	-0.08	-0.04	0.19	0.10	0.04
Average (4 sample storms)			**-0.35**	**0.04**	**0.01**	**-0.45**	**-0.07**	**-0.05**	**0.22**	**0.09**	**0.05**
Average (all typical year storms)			**-0.24**	**0.05**	**0.02**	**-0.42**	**-0.07**	**-0.05**	**0.24**	**0.10**	**0.06**

Model Segment: 1-4 Average

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	3/10/2008	1.68	-0.35	-0.03	0.02	-0.47	-0.16	-0.07	0.15	0.10	0.08
7/22/2008	7/25/2008	0.44	-0.48	0.05	0.05	-0.44	-0.06	-0.05	0.14	0.09	0.07
9/5/2008	9/8/2008	0.85	-0.38	0.00	0.05	-0.36	-0.07	-0.05	0.07	0.09	0.06
11/30/2008	12/3/2008	0.78	-0.06	-0.02	0.02	-0.42	-0.07	-0.06	0.09	0.09	0.06
Average (4 sample storms)			-0.32	0.00	0.03	-0.42	0.09	-0.06	0.11	0.09	0.07
Average (all typical year storms)			-0.20	0.05	0.01	-0.33	-0.07	-0.05	0.11	0.09	0.07

Model Segment: 2-5 Average

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	3/10/2008	1.68	-0.40	0.02	0.02	-0.49	-0.13	-0.06	0.13	0.11	0.07
7/22/2008	7/25/2008	0.44	-0.50	0.07	0.02	-0.47	-0.04	-0.06	0.17	0.09	0.06
9/5/2008	9/8/2008	0.85	-0.44	0.04	0.03	-0.37	-0.04	-0.05	0.08	0.09	0.04
11/30/2008	12/3/2008	0.78	-0.07	0.02	0.00	-0.41	-0.06	-0.05	0.10	0.09	0.05
Average (4 sample storms)			**-0.35**	**0.04**	**0.02**	**-0.44**	**-0.07**	**-0.05**	**0.12**	**0.10**	**0.05**
Average (all typical year storms)			**-0.22**	**0.06**	**0.01**	**-0.34**	**-0.06**	**-0.05**	**0.13**	**0.09**	**0.05**

Model Segment: 5-8 Average

Sample Storms from Hydrodynamic Model Profiles			Average Net Velocity (ft/s)			Average Outflow (ft/s)			Average Inflow (ft/s)		
Start Date	End Date	Total Precip. (in)	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer	Surface Layer	Middle Layer	Bottom Layer
3/7/2008	3/10/2008	1.68	-0.43	0.07	0.01	-0.50	-0.08	-0.07	0.16	0.11	0.07
7/22/2008	7/25/2008	0.44	-0.42	0.07	0.01	-0.46	-0.05	-0.06	0.24	0.10	0.06
9/5/2008	9/8/2008	0.85	-0.52	0.04	0.02	-0.41	-0.06	-0.06	0.16	0.08	0.05
11/30/2008	12/3/2008	0.78	-0.06	0.02	0.00	-0.41	-0.07	-0.06	0.15	0.10	0.05
Average (4 sample storms)			**-0.36**	**0.05**	**0.01**	**-0.45**	**-0.06**	**-0.06**	**0.18**	**0.10**	**0.06**
Average (all typical year storms)			**-0.24**	**0.06**	**0.01**	**-0.40**	**-0.06**	**-0.06**	**0.20**	**0.10**	**0.06**

Appendix B: CFD Model Results of Mesocosm Spatial Arrangements