COLLEGE OF ENGINEERING
UNIVERSITY *of* WASHINGTON

Numerical Modeling of Marine Hydrokinetic (MHK) Turbines and their Environmental Effects

Teymour Javaherchi
Alberto Aliseda

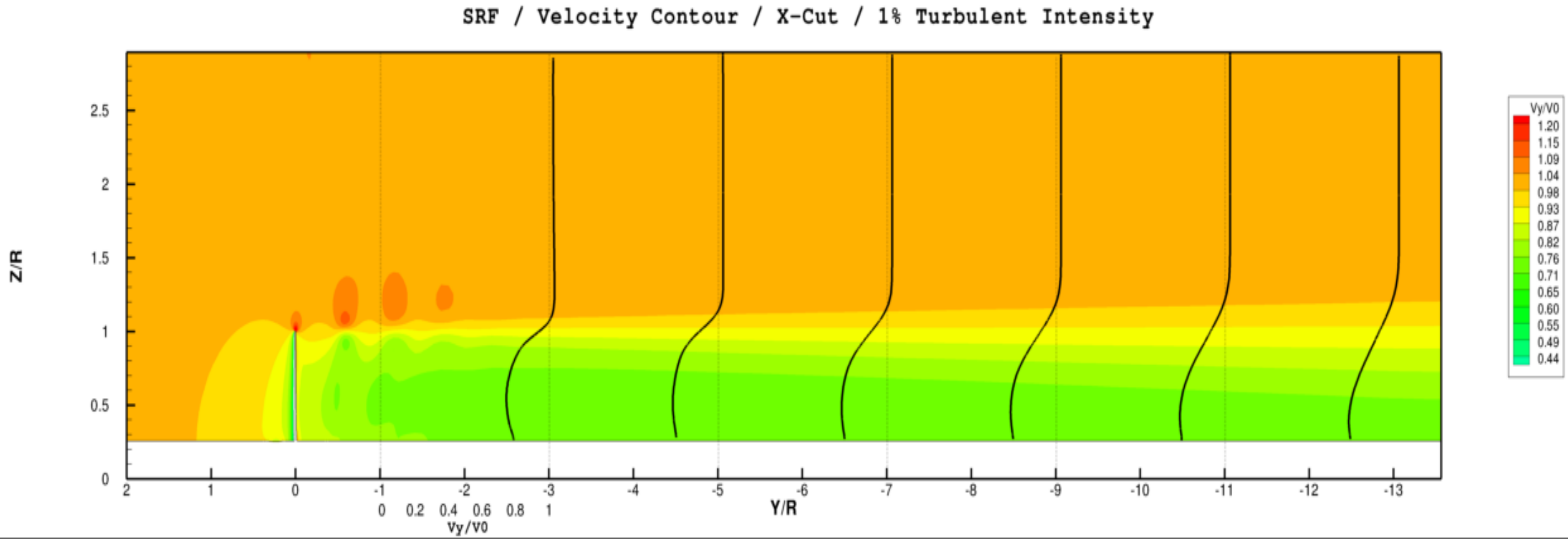
Background

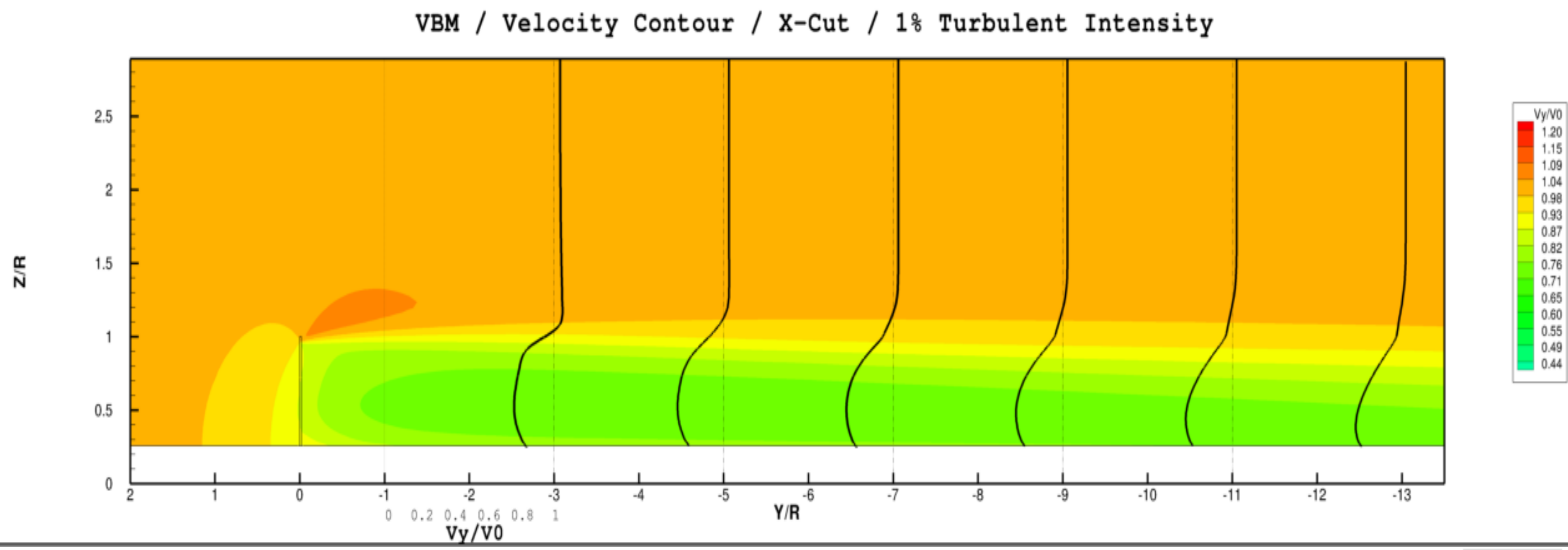
- A numerical methodology for simulating flow field around and in the wake of a horizontal axis MHK turbine was developed and validated.

- Two of the numerical models in this methodology are:
  - Single Reference Frame (SRF)
  - Virtual Blade Model (VBM)

- These models have different level of fidelity and adequacy in capturing detail physics of the flow field.

- The simulated and validated flow field is used toward studying the potential environmental effects of the MHK turbines.

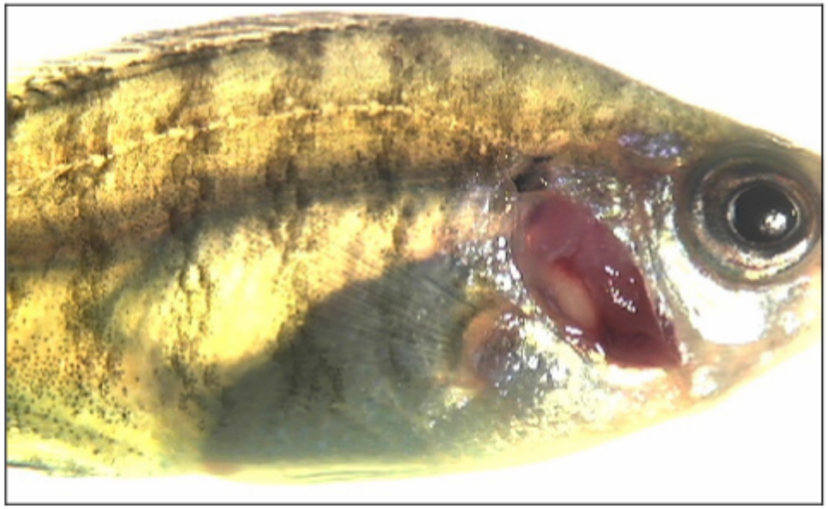

SRF / Velocity Contour / X-Cut / 1% Turbulent Intensity
Z/R
Y/R
Vy/V0
0 0.2 0.4 0.6 0.8 1
Vy/V0
1.20
1.15
1.09
1.04
0.98
0.93
0.87
0.82
0.76
0.71
0.65
0.60
0.55
0.49
0.44

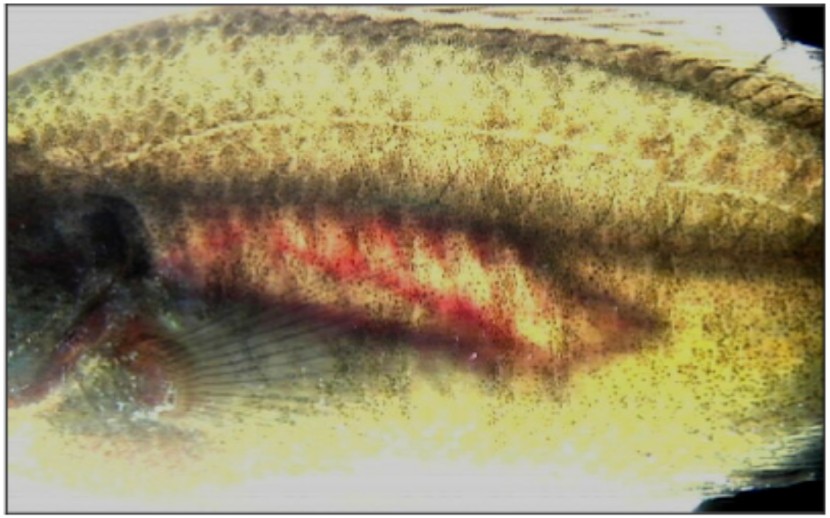

VBM / Velocity Contour / X-Cut / 1% Turbulent Intensity
Z/R
Y/R
Vy/V0
0 0.2 0.4 0.6 0.8 1
Vy/V0
1.20
1.15
1.09
1.04
0.98
0.93
0.87
0.82
0.76
0.71
0.65
0.60
0.55
0.49
0.44

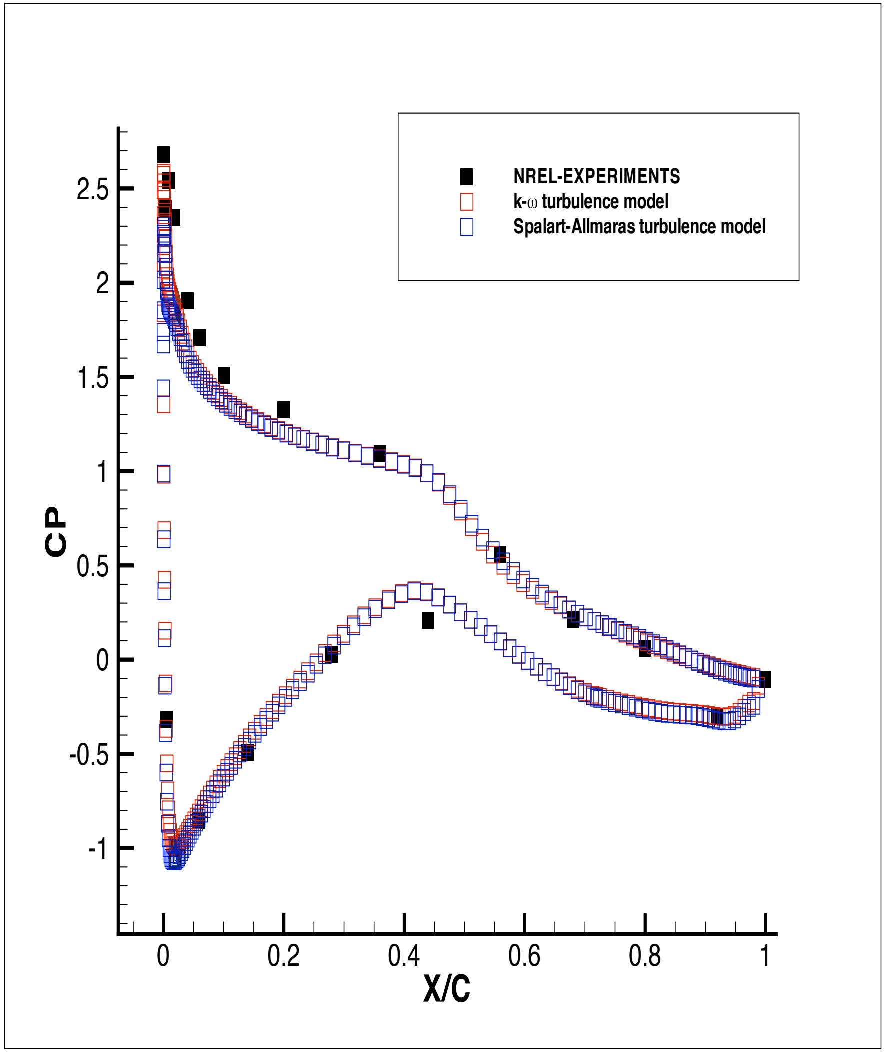
Potential Environmental Effects

- Study of the sudden pressure fluctuation impact on small marine species swimming through turbine blades.
- Study the sedimentation process of suspended particles in a tidal channel as they interacting with the turbulent wake of the turbine.

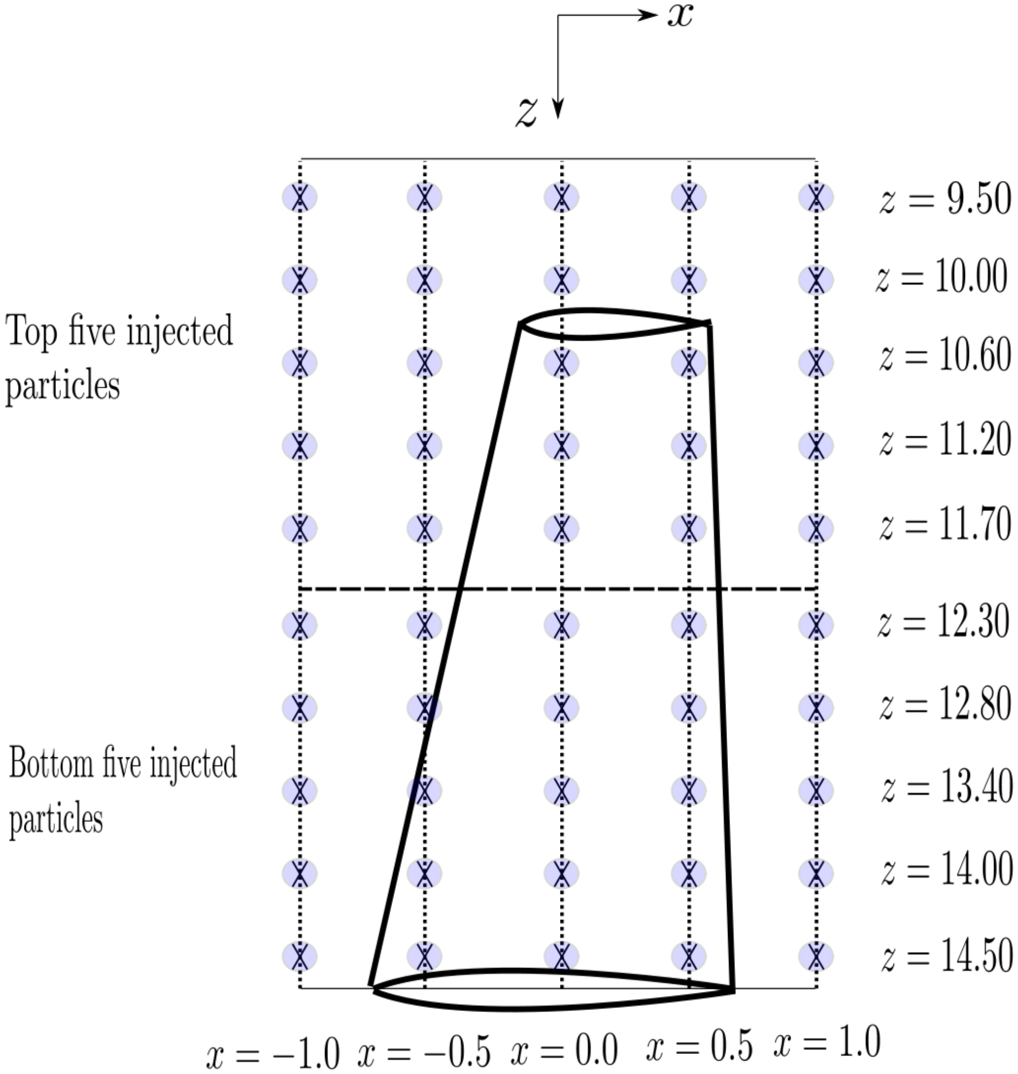
Sudden Pressure Fluctuation Effect





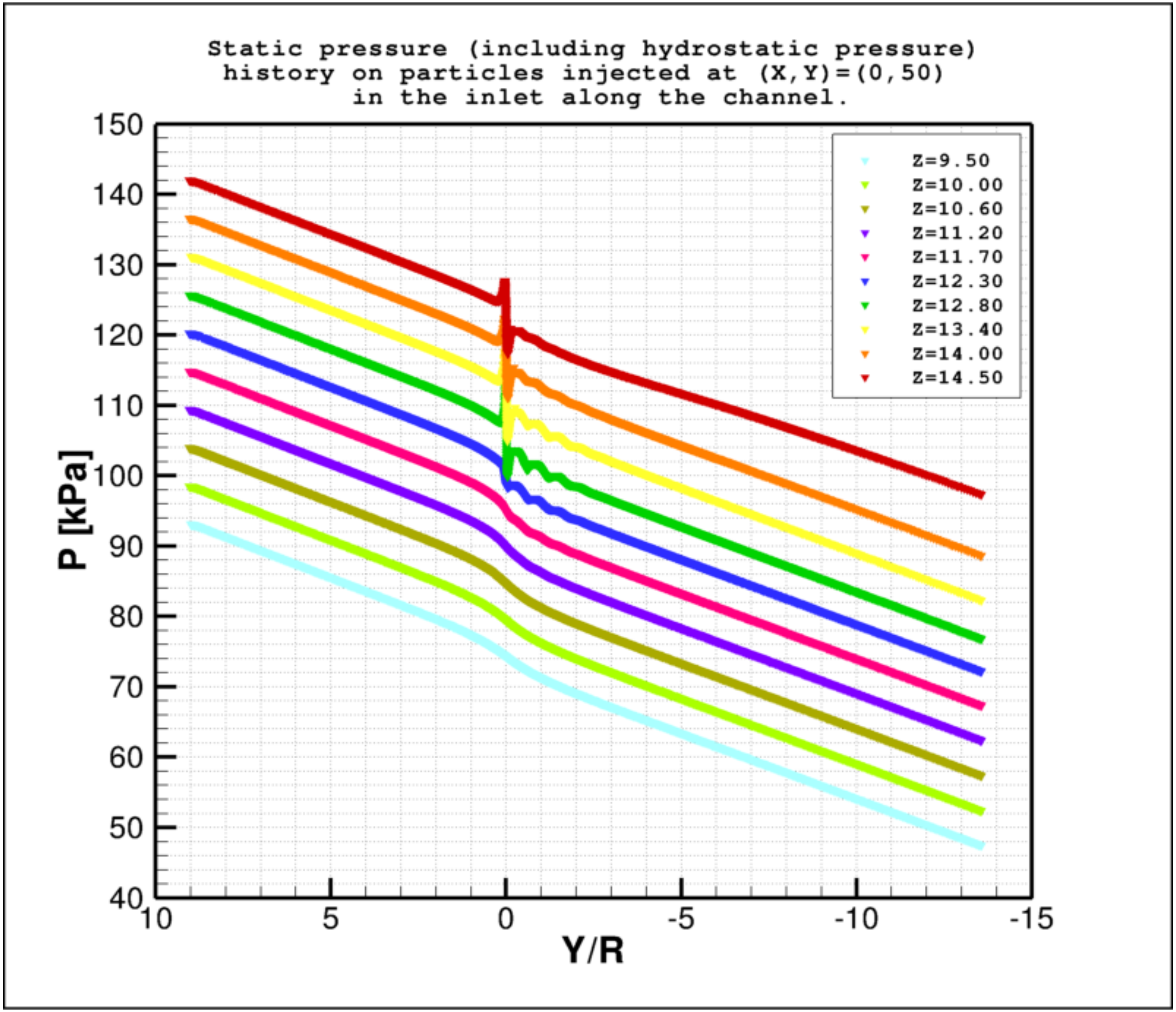


Injection Grid and Assumptions

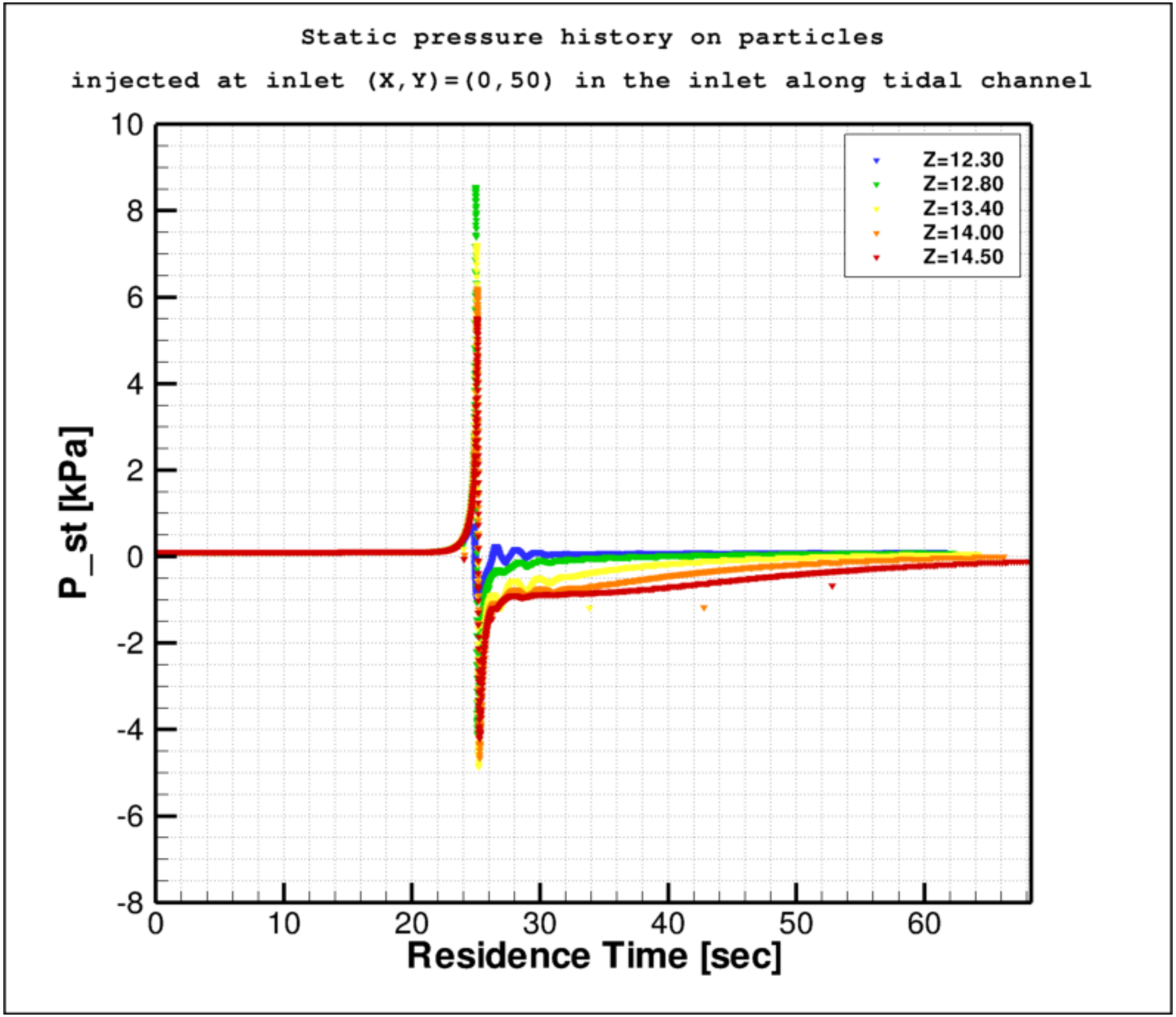


Numerical model	Single Reference Frame (SRF)
Injection plane	At the Inlet
Particle Distribution	5 x 10 [evenly located particles on each rake]
Diameter	5 [mm]
Density ratio w.r.t water	0.95

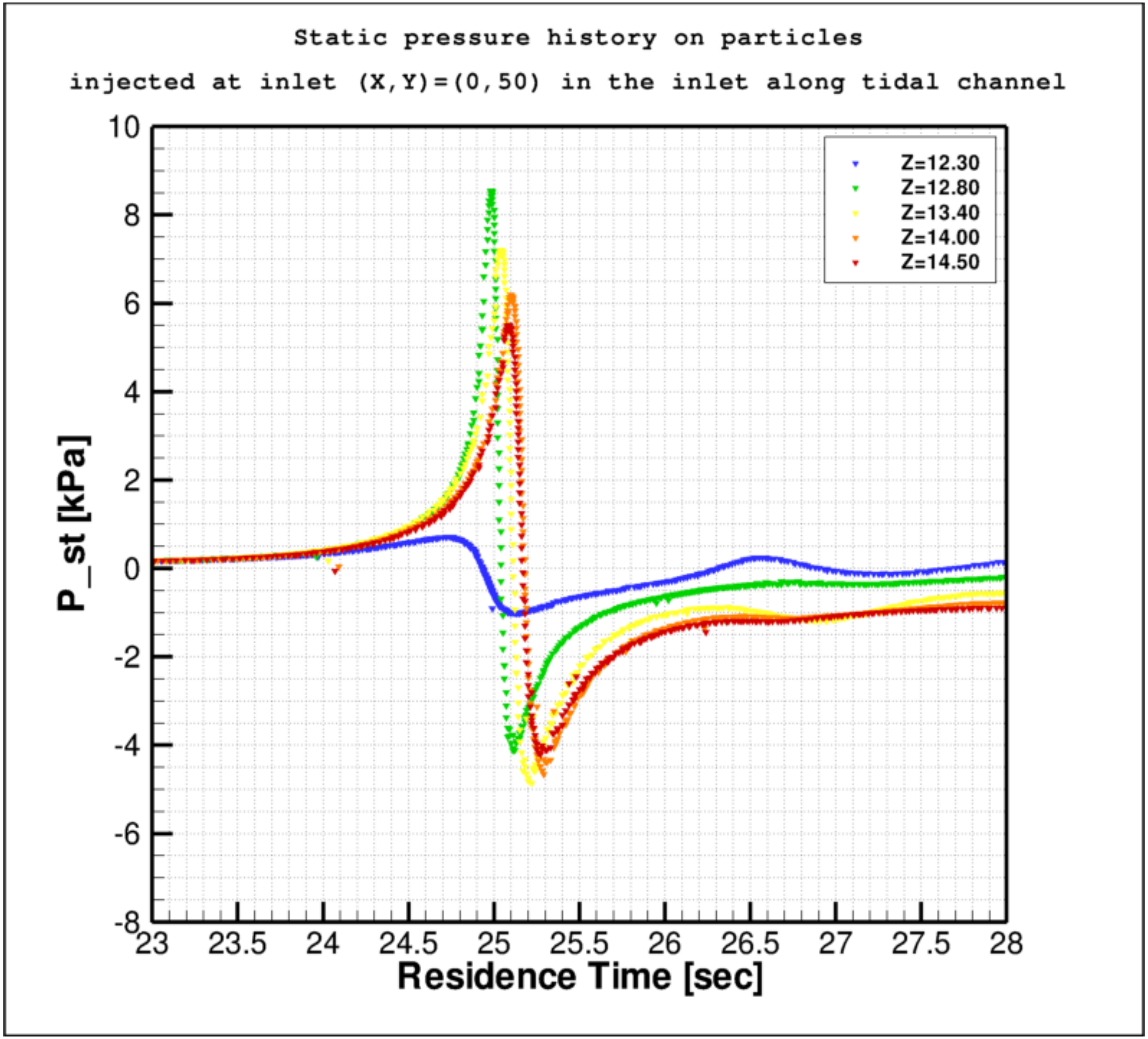
Results


Static pressure (including hydrostatic pressure) history on particles injected at (X,Y)=(0,50) in the inlet along the channel.
Z=9.50
Z=10.00
Z=10.60
Z=11.20
Z=11.70
Z=12.30
Z=12.80
Z=13.40
Z=14.00
Z=14.50
P [kPa]
150
140
130
120
110
100
90
80
70
60
50
40
10
5
0
-5
-10
-15
Y/R

Results


Static pressure history on particles
injected at inlet (X,Y)=(0,50) in the inlet along tidal channel
Z=12.30
Z=12.80
Z=13.40
Z=14.00
Z=14.50
P_st [kPa]
Residence Time [sec]
10
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
60

Results


Static pressure history on particles
injected at inlet (X,Y)=(0,50) in the inlet along tidal channel
Z=12.30
Z=12.80
Z=13.40
Z=14.00
Z=14.50
P_st [kPa]
Residence Time [sec]
10
8
6
4
2
0
-2
-4
-6
-8
23
23.5
24
24.5
25
25.5
26
26.5
27
27.5
28

Modeling Results vs. Experimental Data from PNNL

$Z_{initial}$	$\Delta t[sec]$	$\Delta P[kPa]$	$\frac{\Delta P}{\Delta t}[\frac{kPa}{sec}]$
12.80	0.13	12.95	99.62
13.40	0.18	12.36	68.67
14.00	0.20	11.18	55.90
14.50	0.18	10.02	55.67

Test #	$\Delta t[sec]$	$\Delta P[kPa]$	$\frac{\Delta P}{\Delta t}[\frac{kPa}{sec}]$
1	0.40	131.70	329.25
2	0.40	111.40	278.50

Potential Environmental Effects

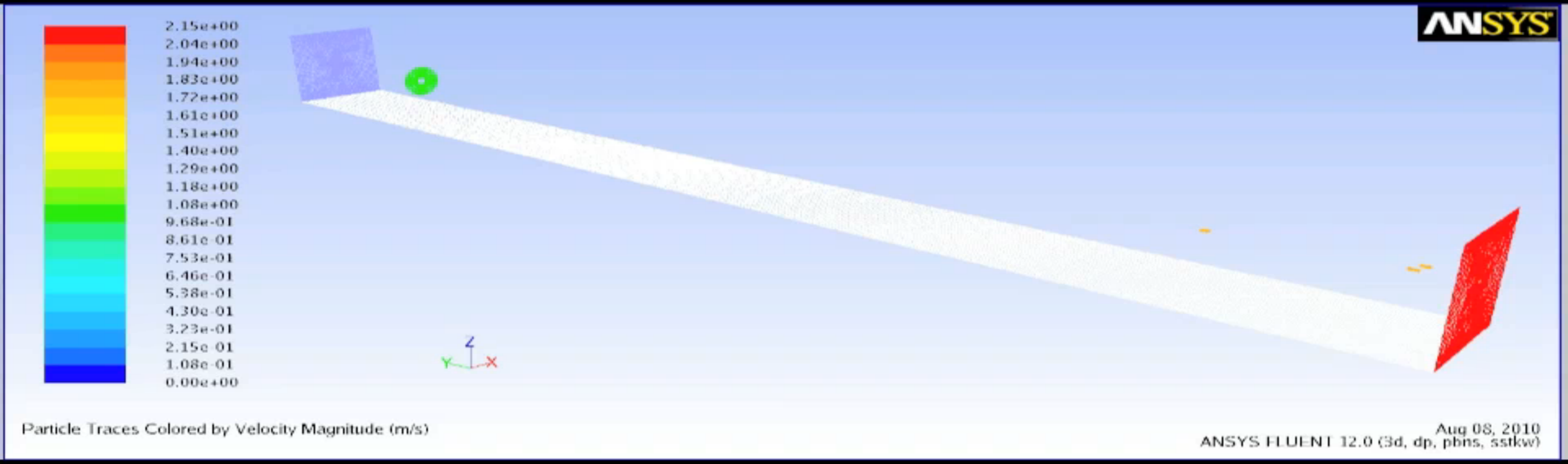
- Study of the sudden pressure fluctuation impact on small marine species swimming through turbine blades.

- Study the sedimentation process of suspended particles in a tidal channel as they interacting with the turbulent wake of the turbine.

Study the Sedimentation process of Suspended Particles in the Turbulent Wake of the device

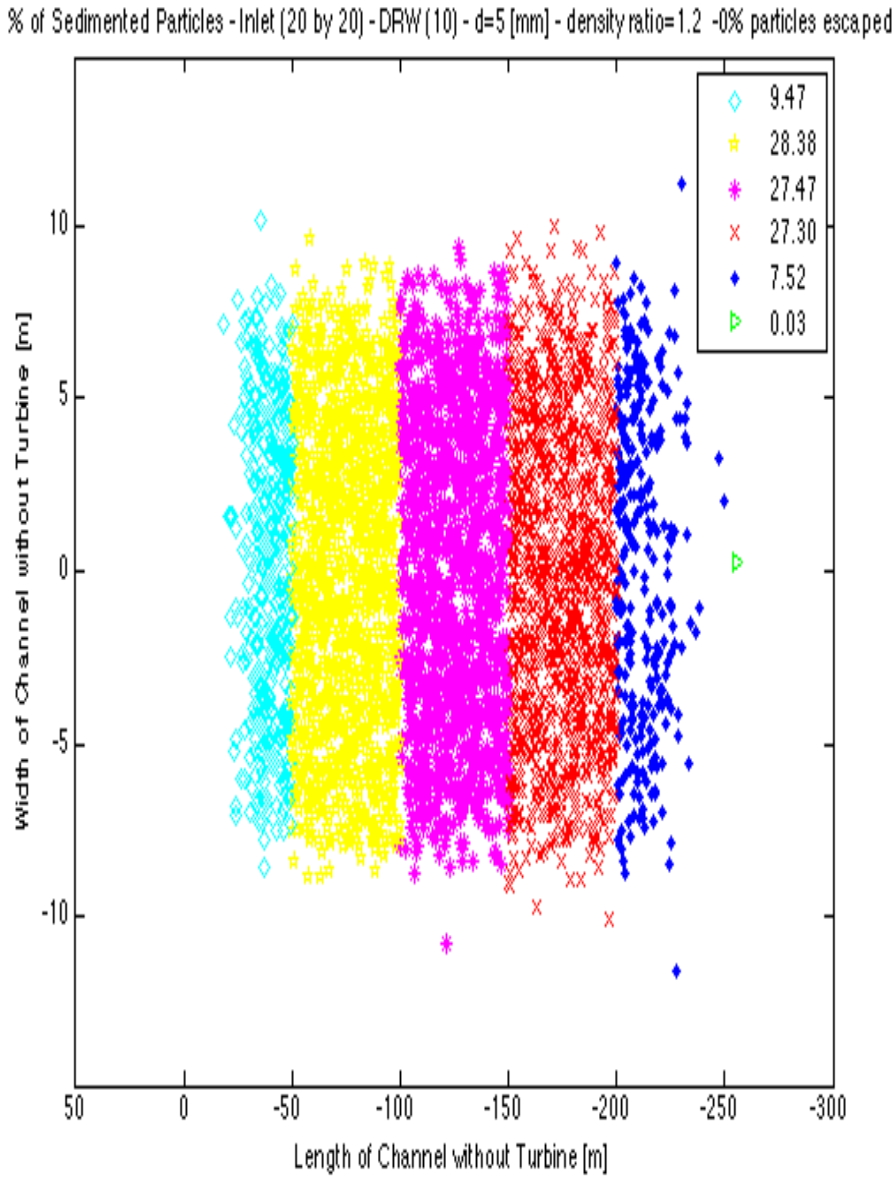
Assumptions

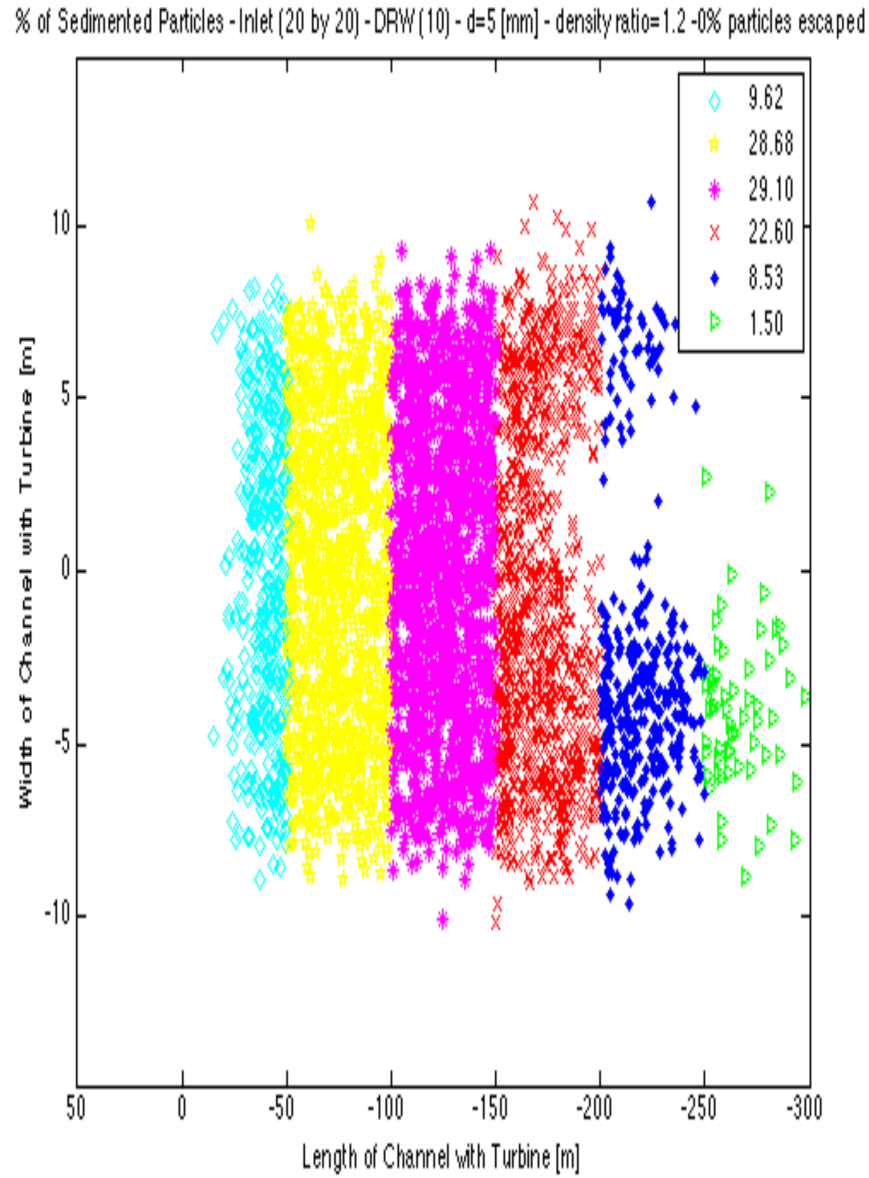
- Virtual Blade Model (VBM)
- Spherical Particles
- Particle size: 1 [cm], 5 [mm], 1 [mm], 100 [micron]
- Particle density: 1200 [kg.m-3]
- Injected from a 20 by 20 grid at the inlet
- Discrete Random Walk (DRW) model
- 10 realizations for each particles



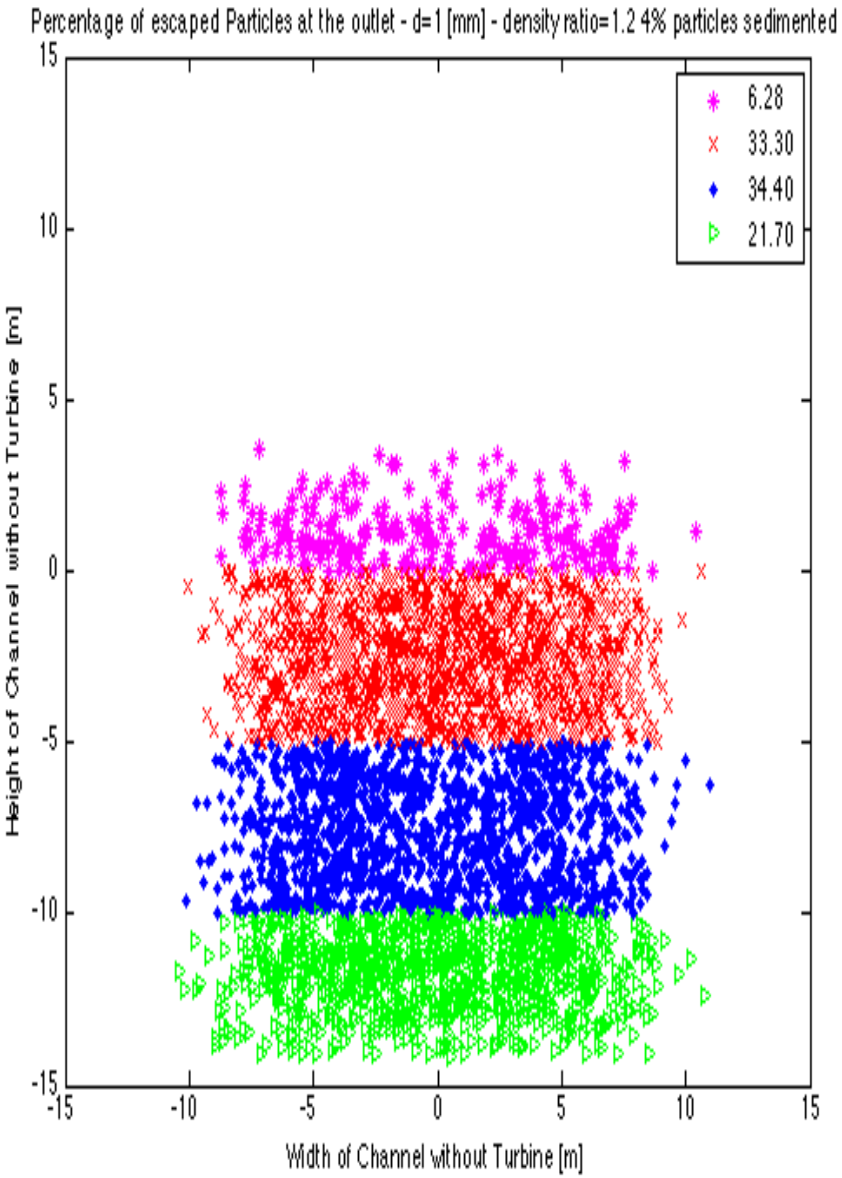
COLLEGE OF ENGINEERING
UNIVERSITY *of* WASHINGTON

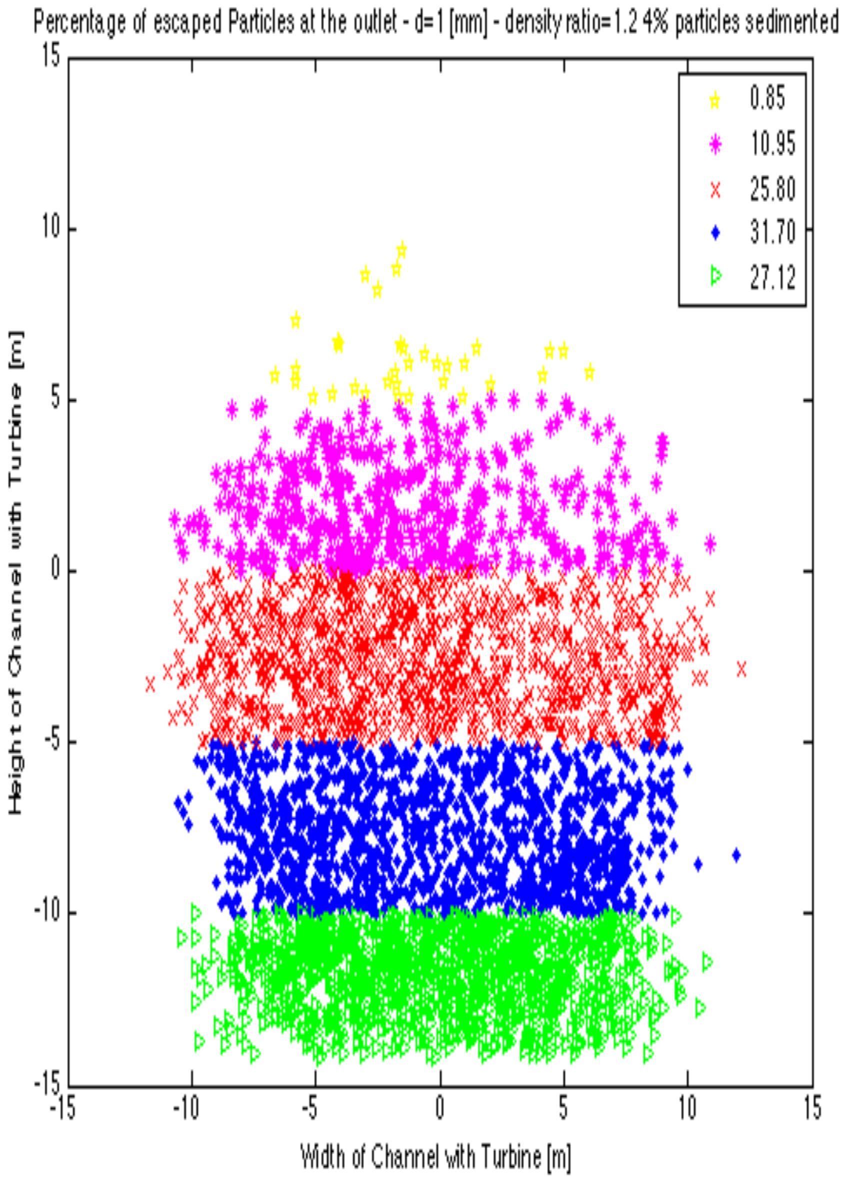
Sedimentation of 5[mm] particles on the bottom of the channel





Percentage of 1[mm] Particles at the Outlet of the Channel.





Modification of the Turbulent Intensity Value at the Inlet of the Channel

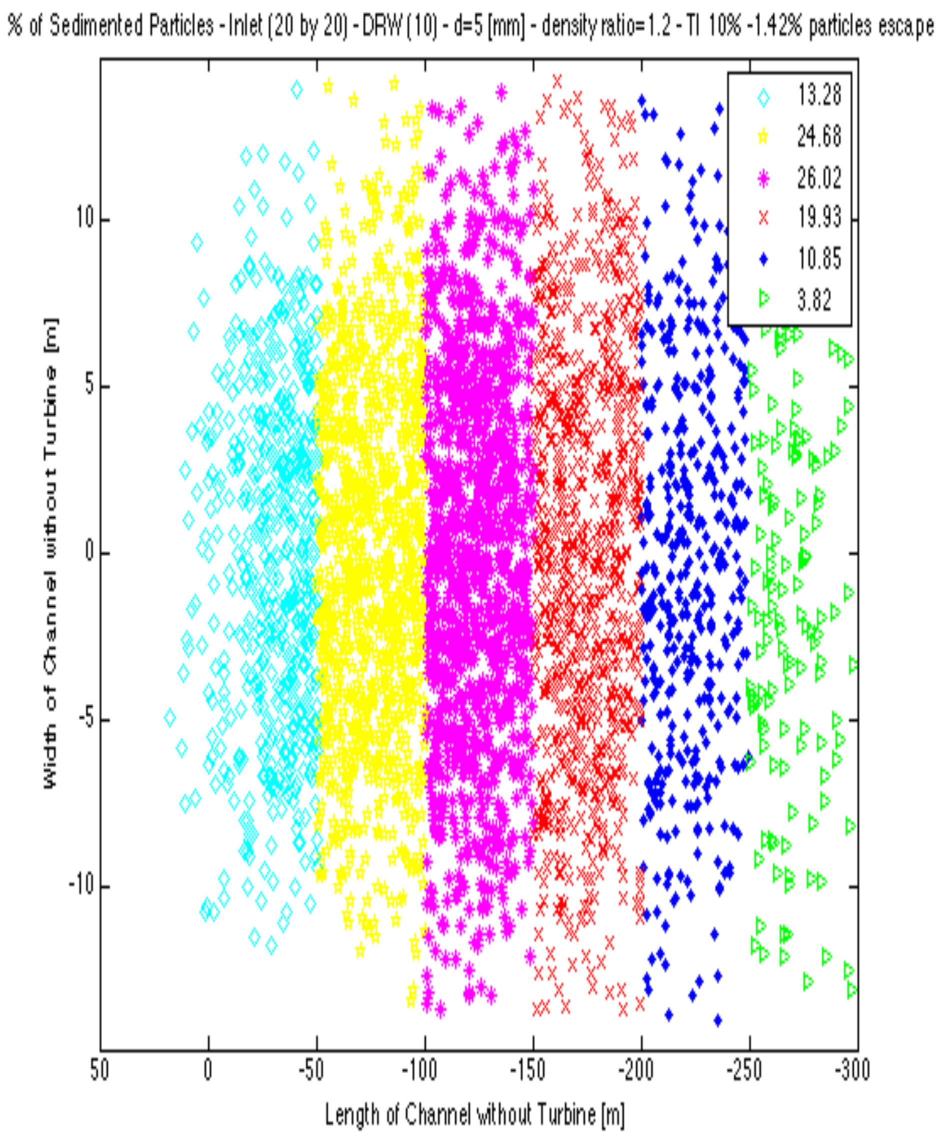
Turbulence intensity is defined as the ratio of Root-Mean-Square (RMS) of turbulent velocity fluctuations to the mean velocity of the flow:

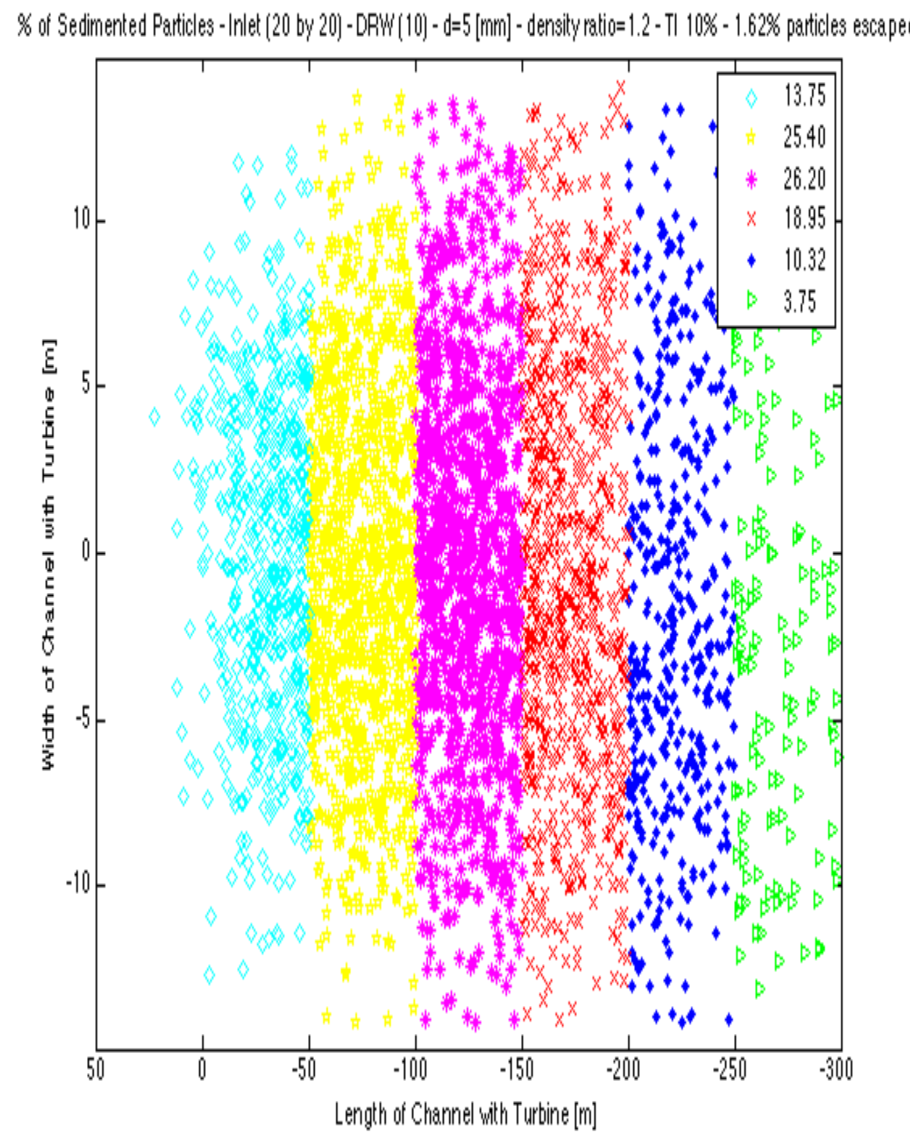
$$I = \frac{\sqrt{< u'^2 >}}{< u >}$$

In order to have more realistic boundary conditions, the value of turbulent intensity at the inlet of the channel was increased from 1% to 10%.
[J. Thomson and B. Polagye 2010]

COLLEGE OF ENGINEERING
UNIVERSITY *of* WASHINGTON

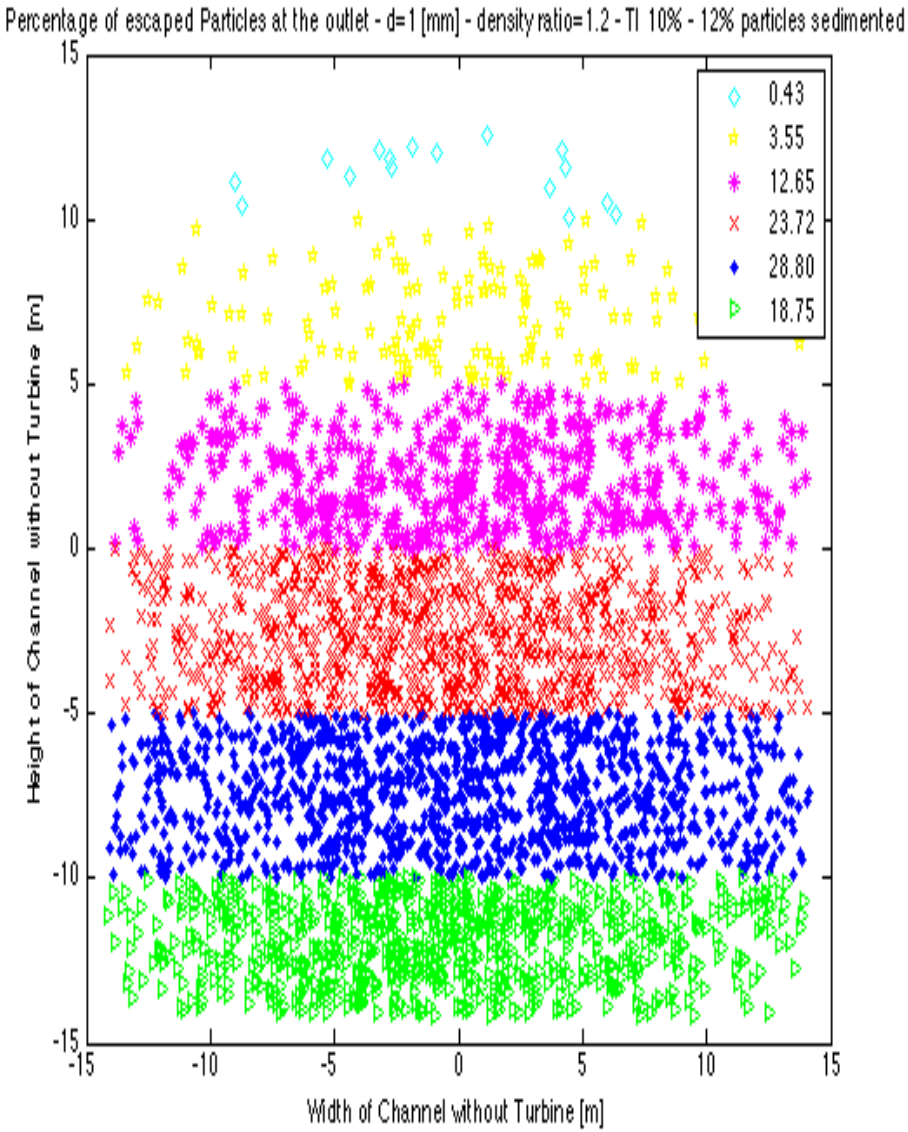
Sedimentation of 5[mm] particles on the bottom of the channel (TI=10%)

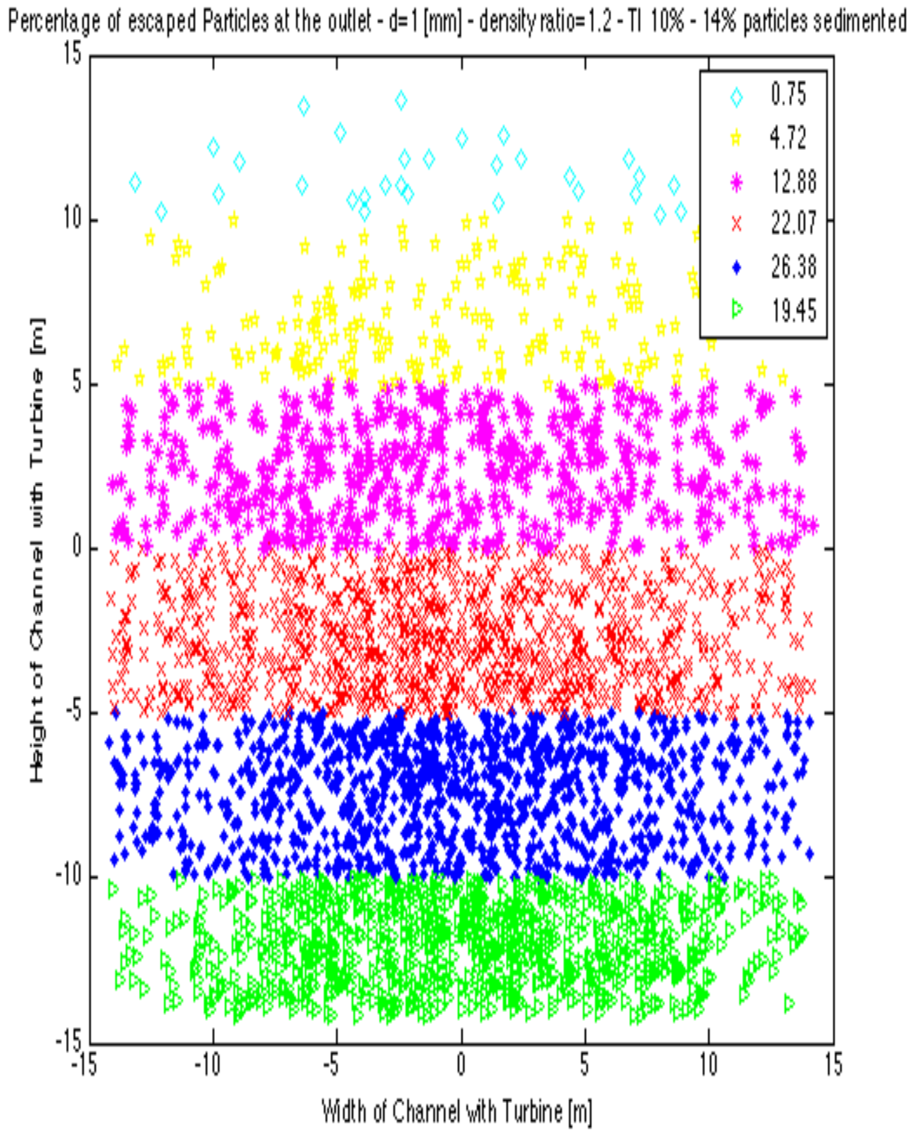




COLLEGE OF ENGINEERING
UNIVERSITY *of* WASHINGTON

Percentage of 1[mm] Particles at the Outlet of the Channel (TI=10%)





Summary

- A methodology was developed to study the pressure history on slightly buoyant particles, representing juvenile fish, going through the turbine blades.

- The strongest pressure fluctuations were observed for particles that flow through the tip of the blade, on the suction side.

- Sedimentation process of large particles were dominated by gravity and turbulent fluctuations in the wake did not effect them significantly.

- Sedimentation process of intermediate size particles was enhanced on bands close to the turbine due to the momentum deficit in the turbulent wake.

- Small particles were pushed up and pulled down significantly due to the turbulent fluctuations generated by rotating blades of the MHK turbine.

- Higher value of turbulent intensity at the inlet (10%) results in more homogeneous and less concentrated sedimentation on the seabed.

Questions or Comments?