Field and numerical assessment of turning pool hydraulics in a vertical slot fishway, relative to fish passage

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Presentation Overview

- Introduction of fishways
  - Turning pools – function, application, need for research, benefits
- Project description
- Hydraulics Results
  - Context of fish passage
- Next steps

Fishways

- Function
  - Fishways function as a means of passage around hydraulic barriers for fish migrating both upstream and downstream.
- Types
  - Traditional engineered structures
    - Vertical slot
    - Denil
    - Pool and weir (orifice)
  - Natural simulating environments

Vertical slot design

- Function over a range of discharges and river water levels
- Allow fish to ascend at any depth in the water column
- Commonly large
- Single slot and turning pools

Turning pools

- Fishway built to pass over tall structures
- Structurally
  - Connect single slot pools at either ends of adjacent ladders
  - Fold-back or staircase pattern
- Primary functions
  - Turn the flow
  - Provide resting space for fish
- Benefits
  - Create a more compact fishway design
  - Fishway entrance closer to hydraulic barrier

Examples

Bonneville Dam fishway
Columbia River, Washington

Vianney-Legendre fishway
Richelieu River, Quebec

Fold-back pattern

Vianney-Legendre fishway
Richelieu River, Quebec

Torrumbarry fishway
Murray River, Australia

Cause for research

- Hydraulics
  - Very little existing research
    - A single study of a Denil prototype
  - No studies on vertical slot fishways
    - Detailed hydraulic information not available
  - No design guidelines for turning pools
    - Contrary to single slot pools
  - Common in relatively large fishways
- Biology
  - Potential problems with fish passage
    - Companion study on 88 adult lake sturgeons *Acipenser fulvescens*
      - 20/56 passage failures occurred in the turning pools
      - fish spent disproportionately longer time in turning pools than single slot pools
    - Other species have had difficulty negotiating turning pools
      - bony herring *Nematalosa erebi*, silver perch *Bidyanus bidyanus*, and golden perch *Macquaria ambigua*
  - Fishway entrances as close as possible to the hydraulic barrier

Research overview

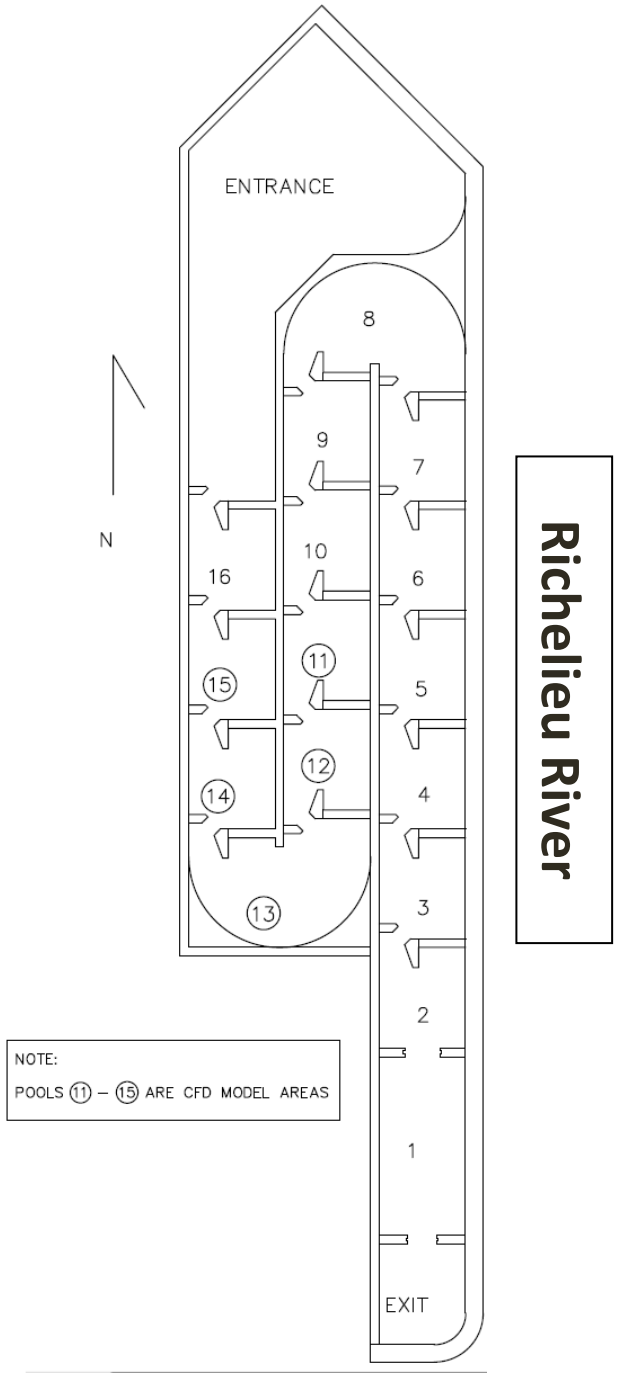
- Field and computational fluid dynamics (CFD) study of turning pool hydaulics
  - Vianney-Legendre vertical slot fishway
- Field
  - Velocity measurements in 2 turning pools
- CFD
  - Simulations for 7 design geometries
  - Assess hydraulics in terms of suitability to fish passage

Study Site

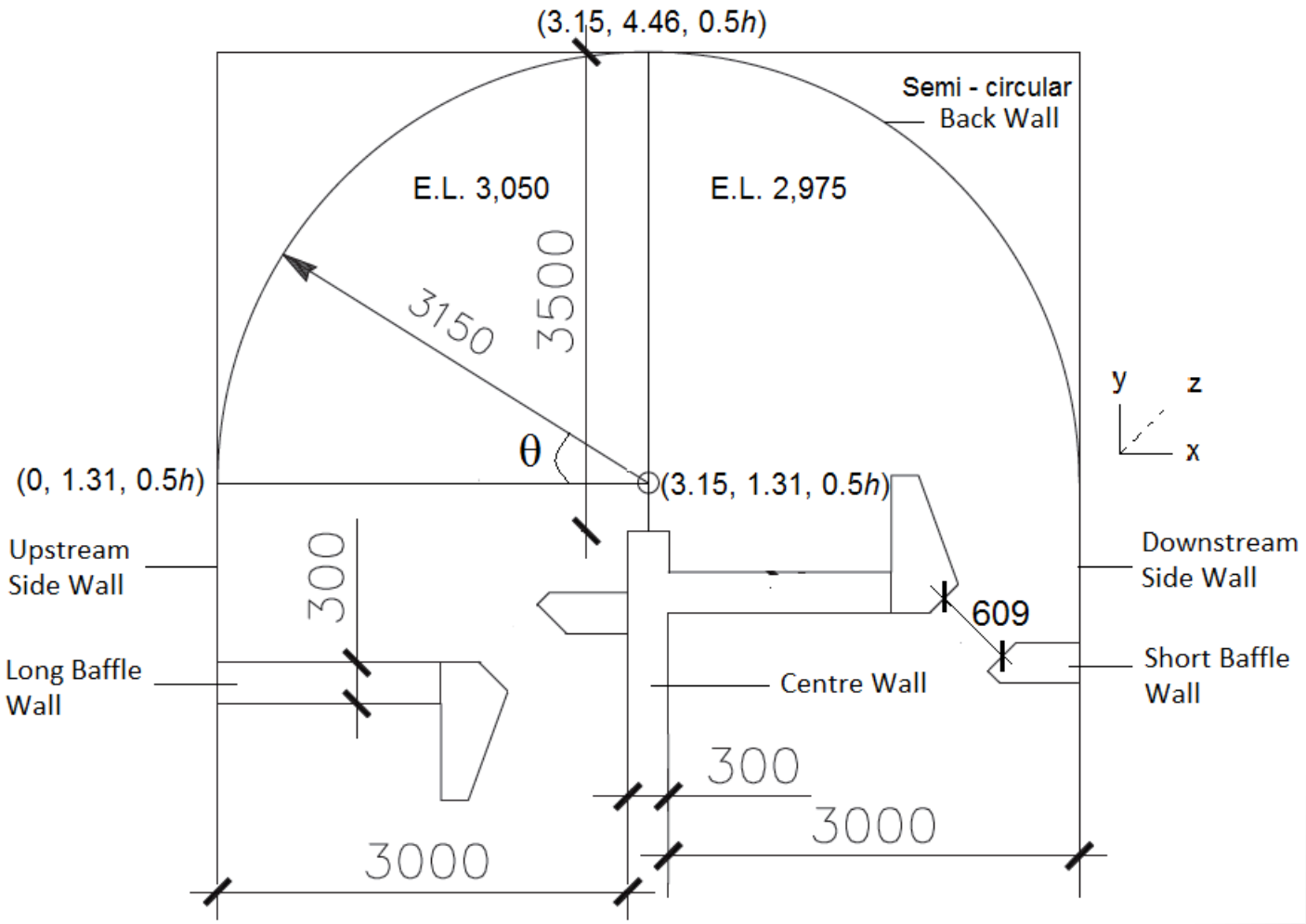

Saint-Cuthbert
Baie-du-Febvre
Berthierville
Pierreville
Chertsey
Rawdon
Saint-Charles-Borromée
Joliette
Saint-Thomas
Saint-Paul
Crabtree
Sainte-Julienne
Saint-Calixte
Saint-Jacques
Lanoraie
Saint-Esprit
Saint-Roch-de-l'Achigan
Saint-Lin-Laurentides
Lavaltrie
Saint-Roch-de-Richelieu
Contrecœur
Sainte-Sophie
L'Assomption
La Plaine
Saint-Denis-sur-Richelieu
Verchères
Sainte-Anne-des-Plaines
Mascouche
Repentigny
Charlemagne
Terrebonne
Varennes
Saint-Marc-sur-Richelieu
La Présentation
Mirabel
Blainville
Lorraine
Rivière-des-Prairies-Pointe-aux-Trembles
Saint-Amable
Saint-Liboire
Acton Vale
Sainte-Thérèse
Montréal-Est
Saint-Hyacinthe
Boisbriand
Laval
Anjou
St Leonard
Boucherville
Saint-Eustache
Saint-Martin
Mercier-Hochelaga-Maisonneuve
Beloeil
Saint-Dominique
Roxton Falls
McMasterville
Sainte-Marthe-sur-le-Lac
Ahuntsic-Cartierville
Longueuil
Saint-Basile-le-Grand
Saint-Jean-Baptiste
Mt Royal
Montreal
Pointe-Calumet
Saint-Laurent
Saint-Hubert
Saint-Pie
Westmount
Roxton Pond
Pointe-Claire
Parc-nature de l'Anse-à-l'Orme
Dorval
Le Sud-Ouest
Brossard
Saint-Mathias-sur-Richelieu
Beaconsfield
L'Île-Dorval
LaSalle
Chambly
Marieville
Rougemont
Saint-Paul-d'Abbotsford
Baie-d'Urfé
Kahnawake
La Prairie
Carignan
Saint-Césaire
Granby
Parc national de la Yamaska
10 km
5 mi
Google Maps

Site fishway layout

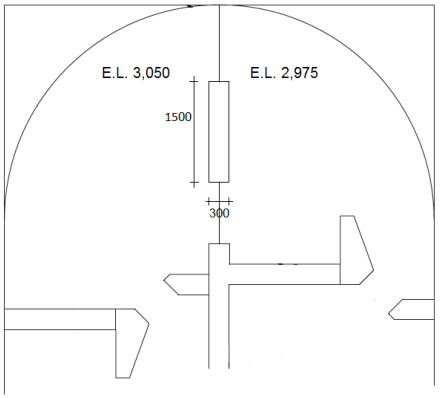
- Field measurements
  - Pools 8 and 13
- CFD model study
  - Pools 11 - 15



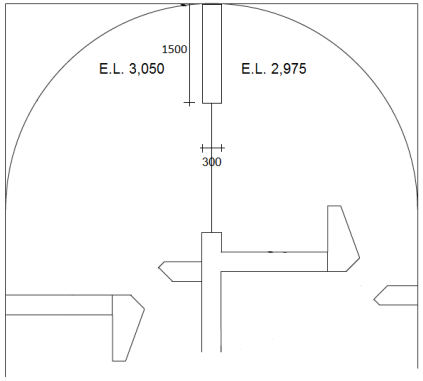
Pool 13 (Design 1) layout



CFD design 2-7



Design 2



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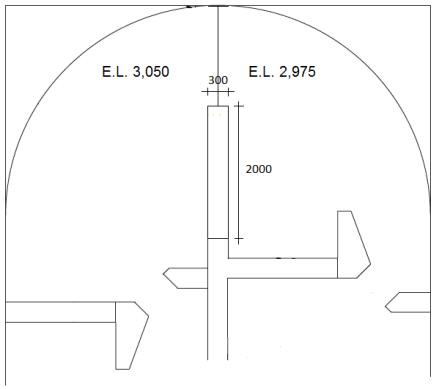

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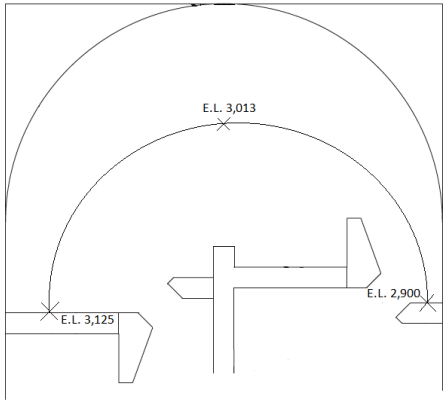

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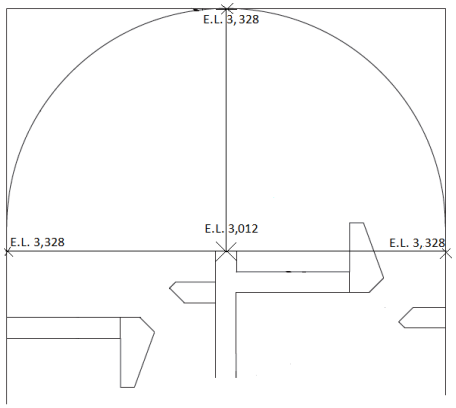

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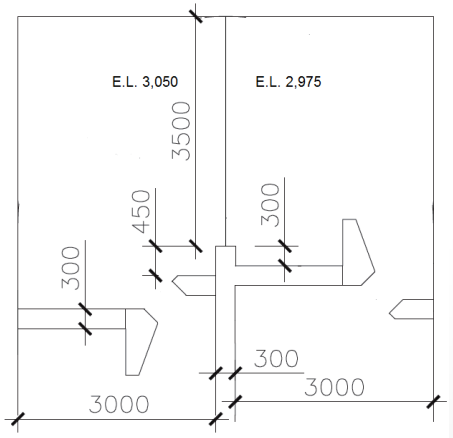
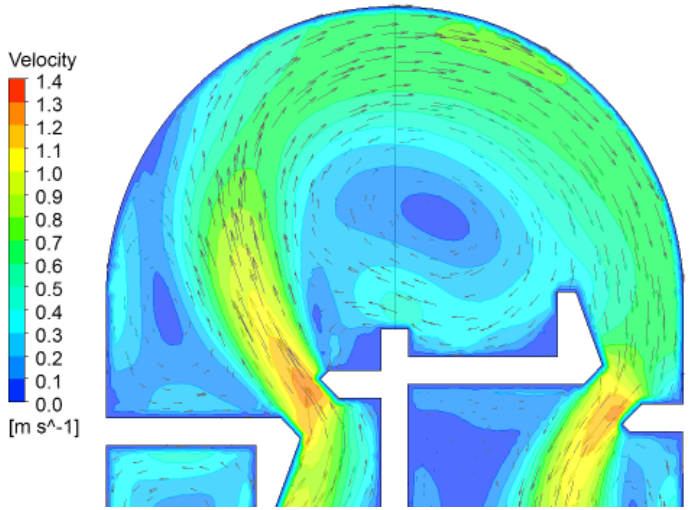


Design 7

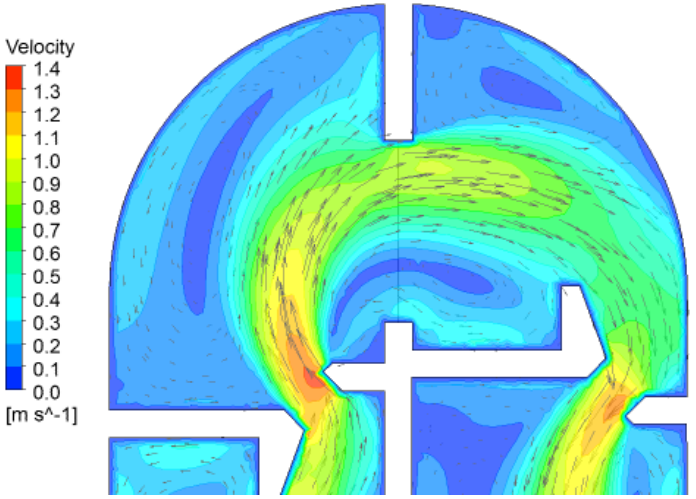
Assessment Criteria

- Velocity
  - Time-averaged velocity magnitude, *V*
    - $V = \sqrt{\bar{u}^2 + \bar{v}^2 + \bar{w}^2}$
      - where $\bar{u}$, $\bar{v}$, and $\bar{w}$ represent the longitudinal (*x*), transverse (*y*), and vertical (*z*) components of time-averaged velocity, respectively
  - Maximum theoretical velocity, V_{theor}
    - $V_{theor} = \sqrt{2g\Delta h}$
      - where Δh represents the water level difference between adjacent pools
- Turbulence
  - Turbulent kinetic energy, *K*
    - $K = \frac{1}{2}\left(u'^2_{rms} + v'^2_{rms} + w'^2_{rms}\right)$
      - where *u'*, *v'* and *w'* are the stream-wise, cross-stream and vertical fluctuating velocities, respectively
      - *K* levels are categorized as 'low', for $K \leq 0.05$ m^2/s^2; and 'high' for $K > 0.05$ m^2/s^2
- Vorticity in the horizontal (*x, y*) plane, ω_Z
  - $\omega_z = \frac{1}{2}\left(\frac{\partial \bar{u}}{\partial y} - \frac{\partial \bar{v}}{\partial x}\right)$
    - where $\frac{\partial \bar{u}}{\partial y}$ and $\frac{\partial \bar{v}}{\partial x}$ are components of angular velocity in along the x-axis and y-axis, respectively
- Vortex Dimensions
  - Length and width
- Average volumetric energy dissipation, $\bar{\varepsilon}$
  - $\bar{\varepsilon} = \frac{\rho g Q \Delta h}{B_T L_T y_0}$
    - where *Q* represents the volumetric flow rate, Δh represents the difference in water levels between adjacent pools, and y_0 represents the depth of flow

Velocity results



Design 1



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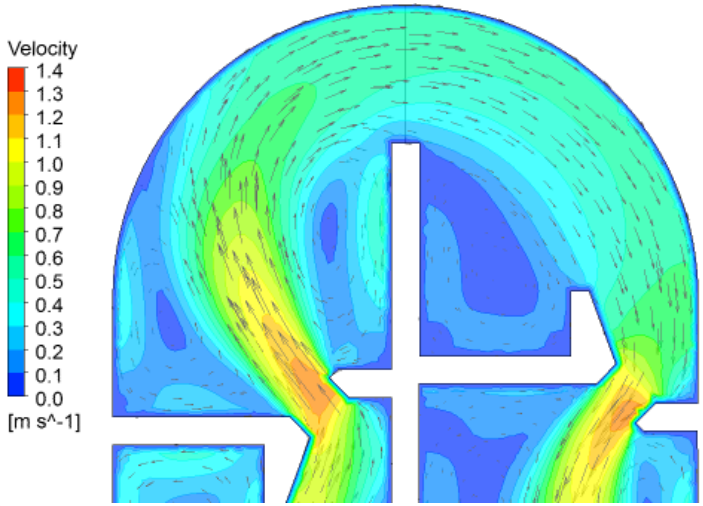
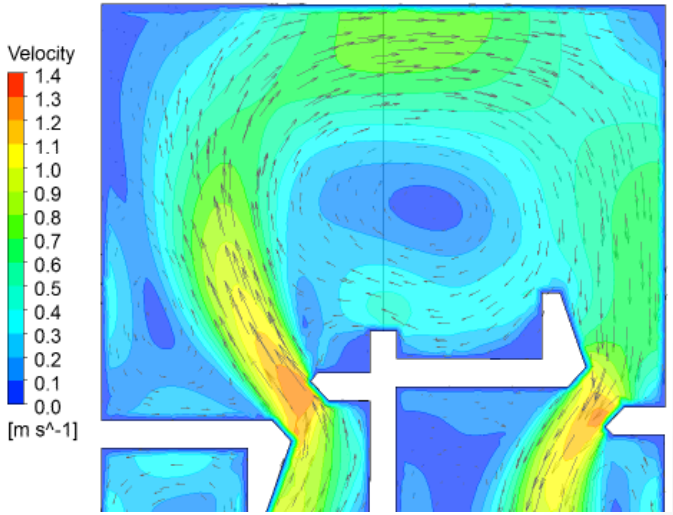


Design 4



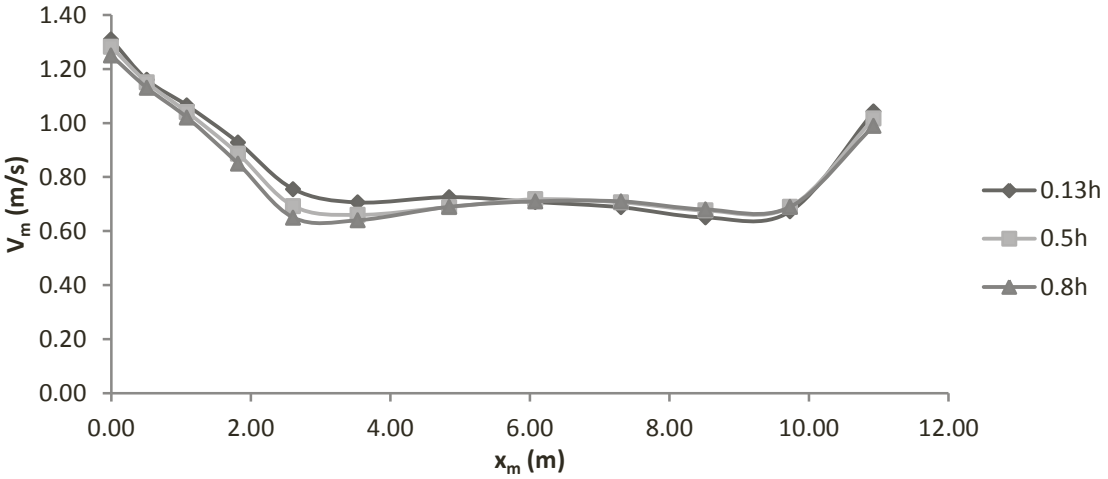
Design 7

Vortex dimensions

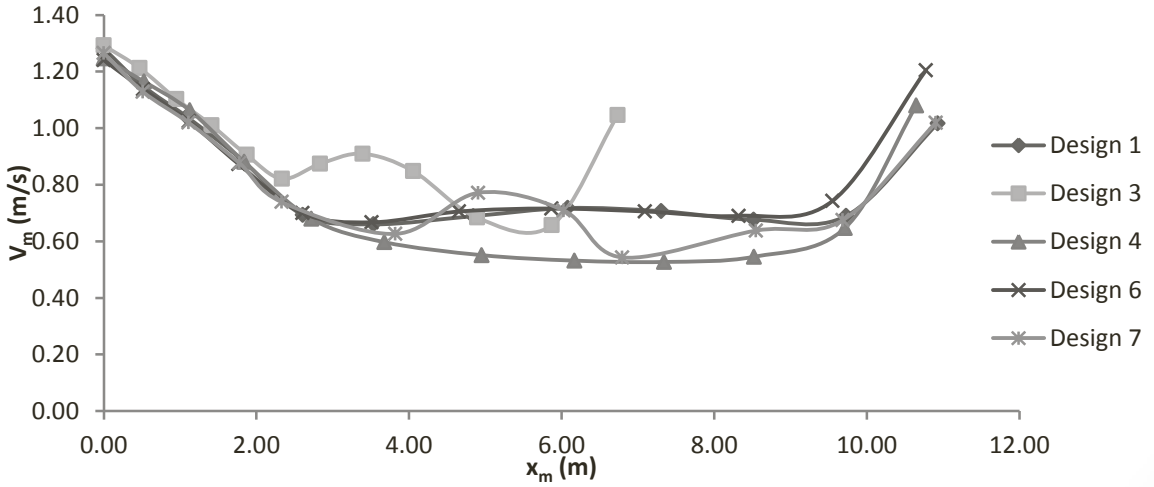
Design	L_V (m)	B_V (m)
	x - dir.	y - dir.
Pools 8 and 13	3.0	2.5
1	3.0	2.1
3 (centre)	1.9	1.2
3 (upstream)	1.3	4.5
3 (downstream)	1.8	1.3
4 (upstream)	0.9	2.0
4 (downstream)	1.4	2
6	3.0	2.1
7	3.2	2.5

Variation of maximum velocity, V_m

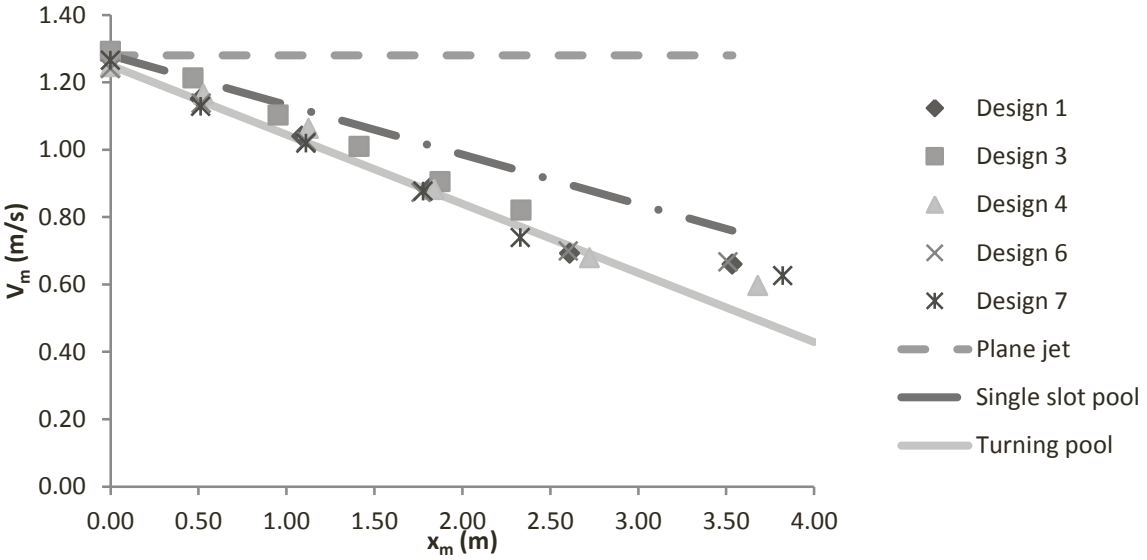
Design 1



$z = 0.5h$

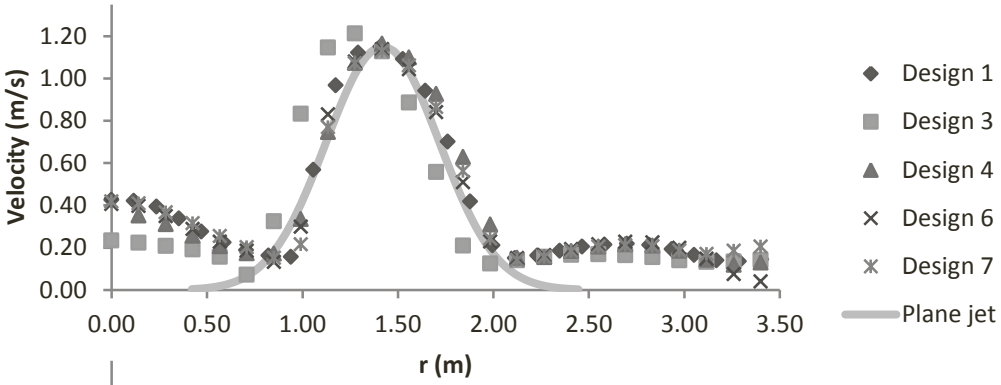


Jet velocity decay

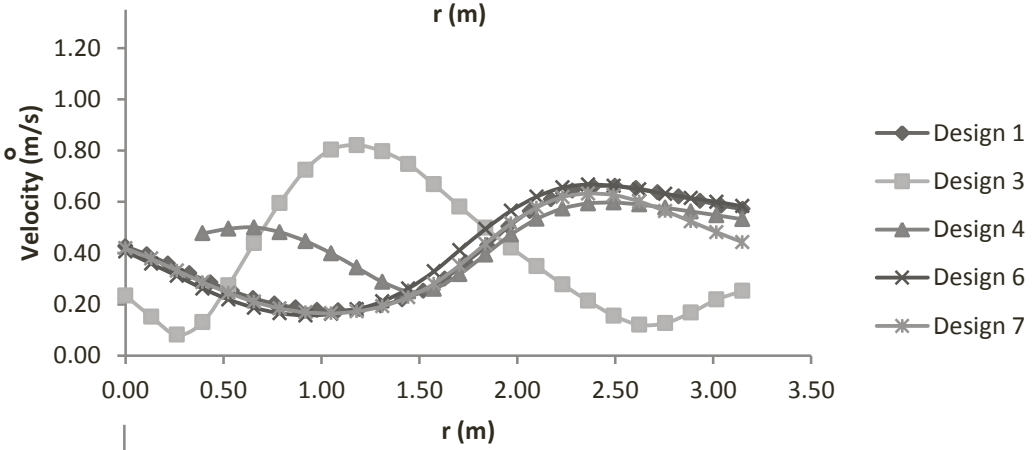


Velocity profiles

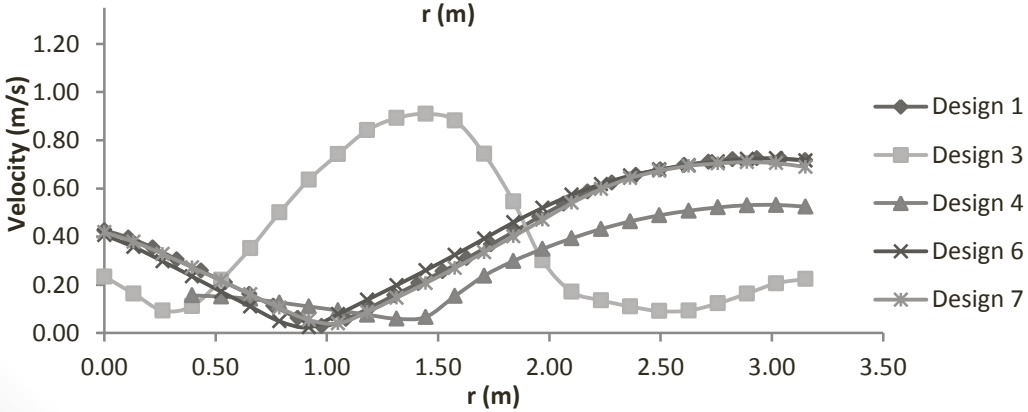
θ = -27°
z = 0.5*h*

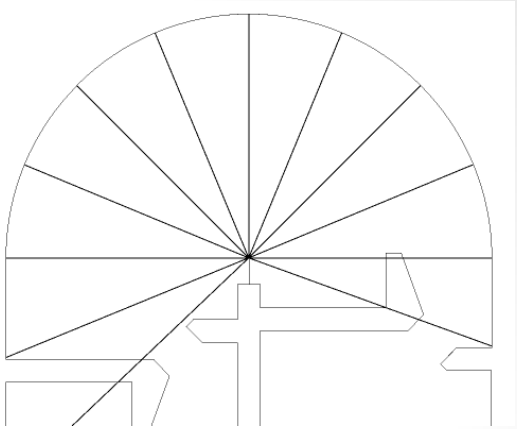


θ = 67.5 °
z = 0.5*h*

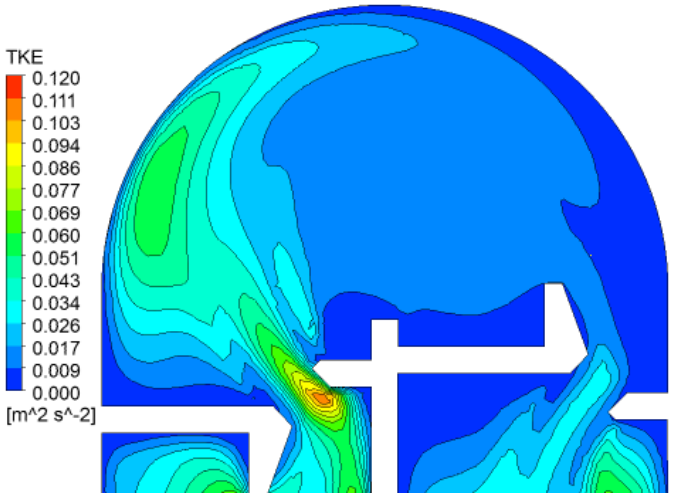


θ = 112.5°
z = 0.5*h*

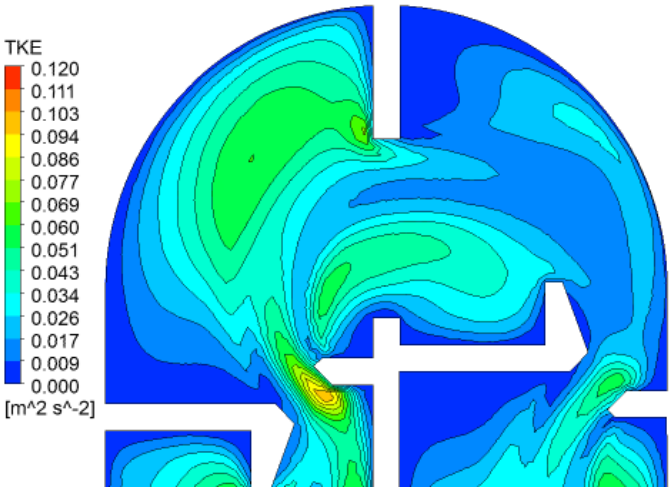




Turbulent kinetic energy



Design 1



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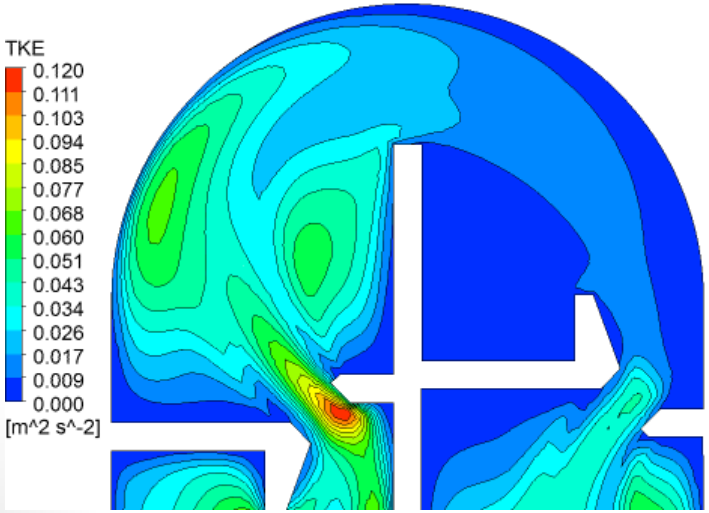

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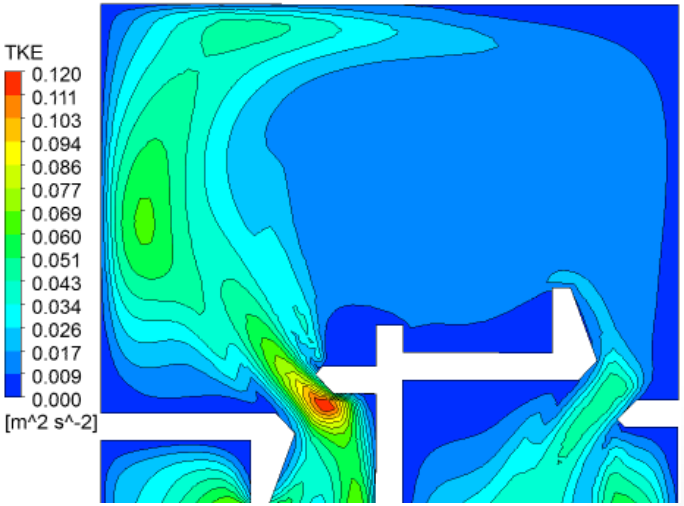
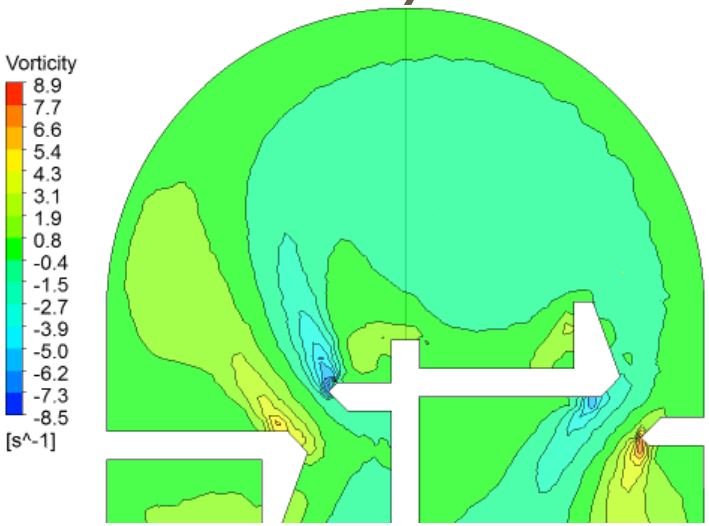
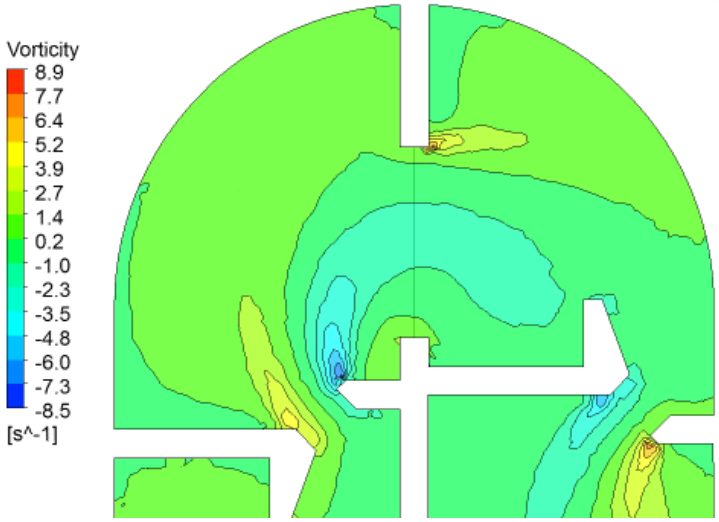


Design 7

Vorticity



Design 1



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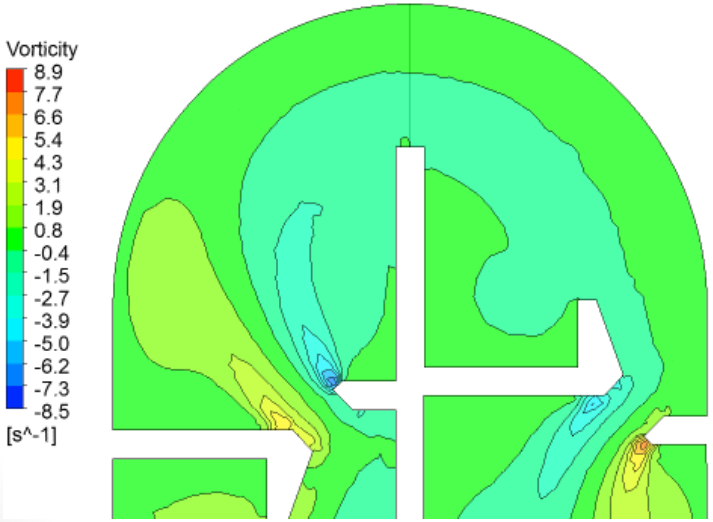

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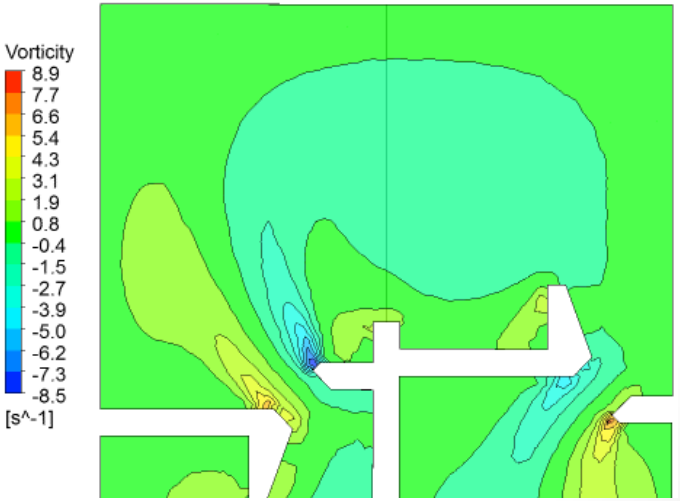

Design 7

Next Steps

- Testing of recommended designs
  - Fish passage efficiency and behaviour
  - Hydraulics
- Fish behaviour
  - Thresholds for species
    - Turbulence parameters – TKE, vorticity
    - Vortex dimensions
- Alter and improve design hydraulics

Thank you / Questions

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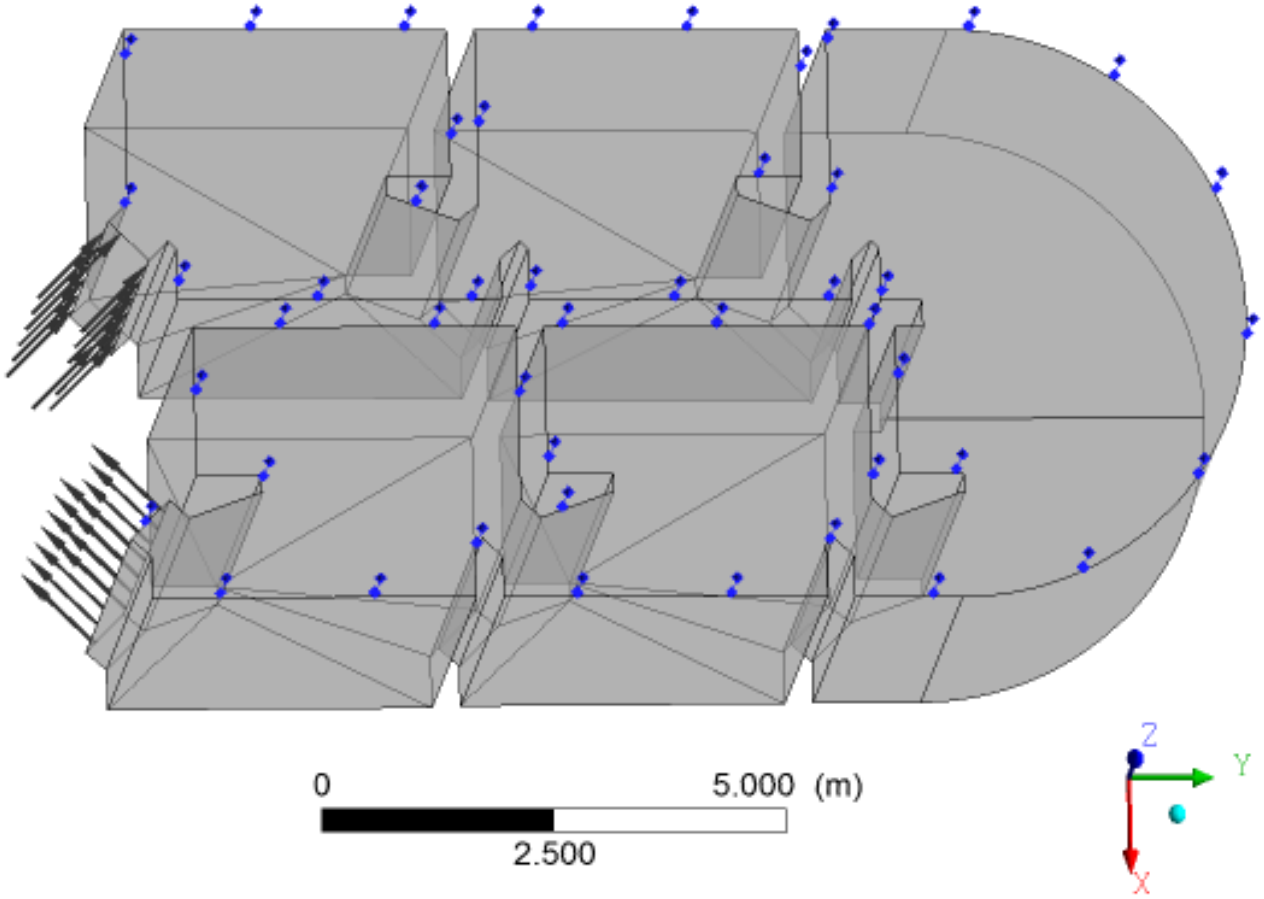
CFD model geometry



Design 1 velocity streamlines