Fish response to altered flows in riverine systems

Analysis of the influence of low head hydropower turbines and anthropogenic obstructions used for natural flood management on fish passage and fish behaviour


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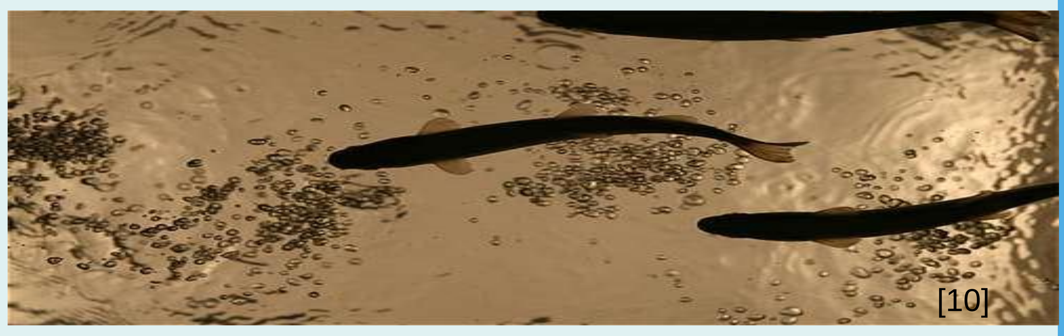
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Motivation

EU WFD states the ecological status of water courses including the ability of fish migration and passability of anthropogenic structures such as:

Fig. 1 European Water Frame Work Directive (EU WDF) taken from [1,2]

- **Free-stream turbines** (focus: 3 blade horizontal axis turbines)
- **Anthropogenic obstructions used for natural flood management (NFM)** (focus: leaky debris dams)


Fig. 2 Example of a leaky debris dam taken from [3]

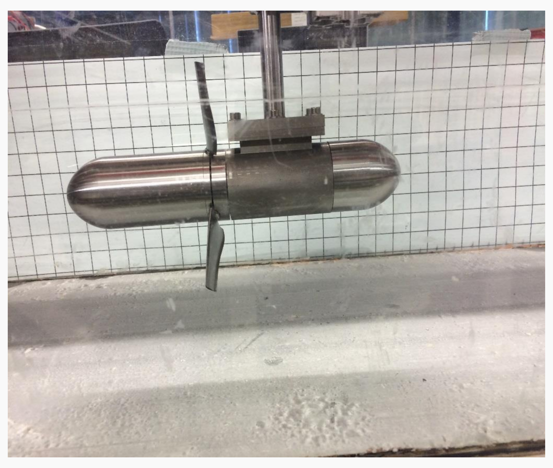
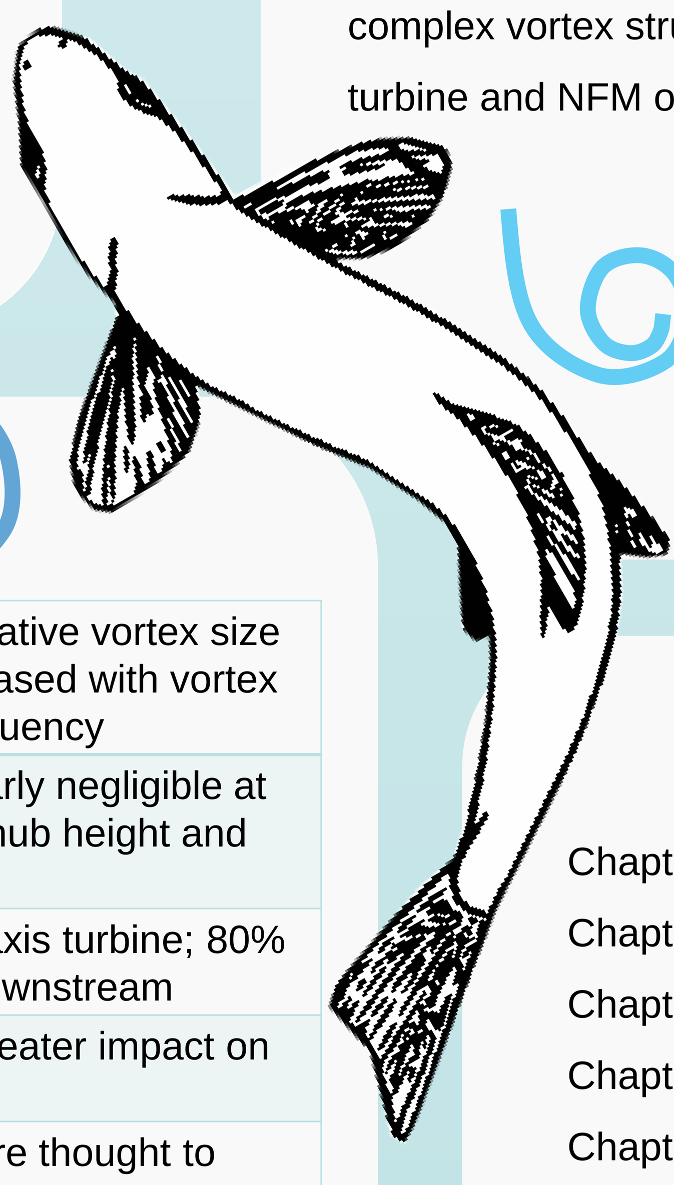


Fig. 3 horizontal axis free-stream turbine

Research Gap

1. Effect of turbines on fish behaviour remains **unknown, unexplored and poorly understood**
2. Most fish behaviour studies of turbines based on observational results
3. Conclusions drawn to potential and likely reasons for avoidance behaviour
4. Lack of peer-reviewed research on leaky dam flow dynamics
5. Small scale leaky dam structures and their impact on fish passage have not yet been studied in a controlled environment.



Literature Review

Link et al. (2017)	Correlation between fish Strouhal number with relative vortex size and shedding frequency; tail beat amplitude increased with vortex length scale, decreased with vortex shedding frequency
Chamorro et al. (2013)	High tangential velocities near wake core and nearly negligible at turbine tip radius; lager turbulence intensity near hub height and turbine tip (horizontal axis turbine study)
Neary et al. (2013)	Analysis of near and far field flow of a horizontal axis turbine; 80% of the flow recovery after approx. 10 diameters downstream
Tritico and Cotel (2010)	Horizontal axis vortices are expected to have a greater impact on stability than vertical axes
Lupandin (2005)	Vortices greater than 2/3 of the fish body length are thought to decrease swimming performance
Enders et al. (2003)	Swimming cost may increase with flow velocity standard deviation for a given mean flow velocity

Methodology

1. Fish Behaviour Experiments

1. **Free-stream turbine experiment**
2. **Leaky dam experiments**

in experimental flumes at HRC using camera system to track fish behaviour


Fig. 4 Fish swimming through turbine, taken from [4]

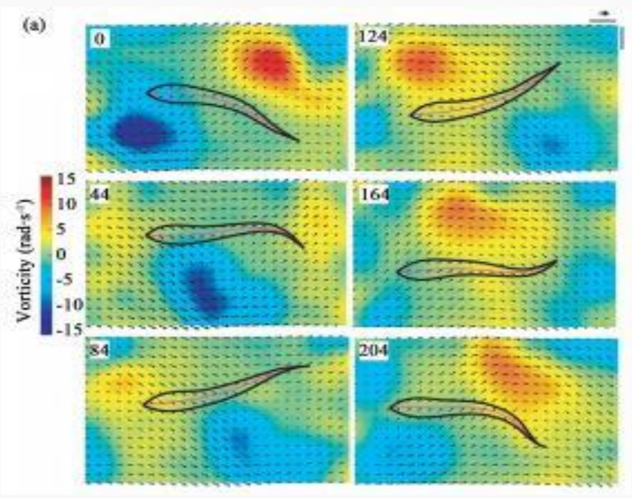


Fig. 5 Interaction of fish with vortices, taken from [5]

2. Hydraulic measurements

Velocity measurements using **Acoustic Doppler Velocimetry (ADV)** for different volume flow rates and turbine speeds

Analysis of turbulence metrics based on the IPOS Framework [11]:

Intensity	Turbulence intensity $\overline{u'u'}$ Turbulent kinetic energy $k = 0.5(\sigma_u^2 + \sigma_v^2 + \sigma_w^2)$ Reynolds shear stress $-\rho\overline{u'v'}, -\rho\overline{v'w'}, -\rho\overline{u'w'}$ Vorticity $\vec{\omega} = \nabla\vec{u}$
Periodicity	Predictability – dominant frequency of shedding Energy spectra
Orientation	Axis of vortex orientation Direction of dominant fluctuation
Scale	Turbulent and eddy length scale Eddy diameter Obstacle and Fish Reynolds number

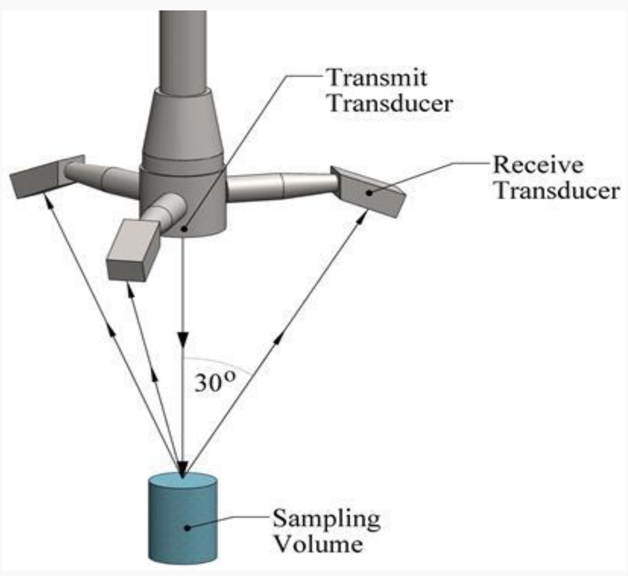


Fig. 6 ADV measurement principle, taken from [6]

3. LES Numerical Simulations

Large Eddy Simulations using **Hydro3D** to visualize the wake and its complex vortex structures in the near wake field of a horizontal axis turbine and NFM obstructions

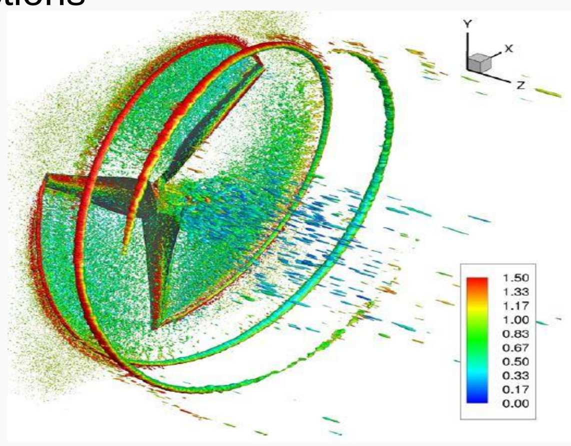


Fig. 7 Iso-surface of vertical structures past a turbine showing the non-dimensional velocity magnitude, taken from [7]

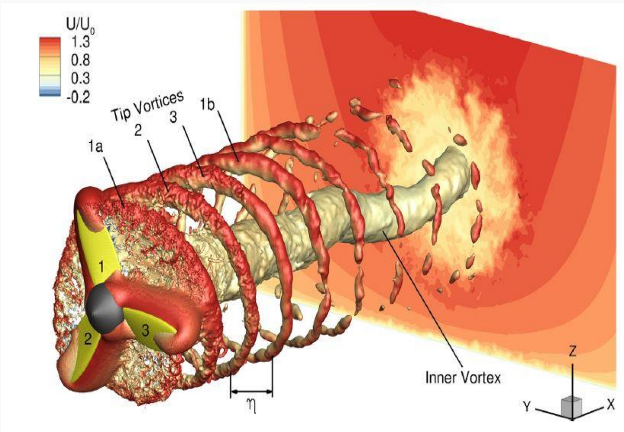


Fig. 8 Iso-surface of vertical structures past a turbine showing instantaneous non-dimensional stream-wise velocity, taken from [8]

Thesis Structure

Chapter 1 – Introduction

Chapter 2 – Review of Literature on NFM, Fish Behaviour in Turbulent Flows, Horizontal Axis Turbines

Chapter 3 – The Impact of Turbine Swirl on Fish Swimming Stability

Chapter 4 – Large Eddy Simulation of the Wake behind a Horizontal Axis Turbine

Chapter 5 – Near-field Flow Field around a Leaky Dam and the Impact of Fish Movement

Chapter 6 – Large Eddy Simulation of the Flow Field around a Leaky Dam

Chapter 7 – Conclusions (Summary of the pertinent results and how the results impact on the design of anthropogenic obstructions).

References

[1] https://www.google.co.uk/search?q=european+water+framework+directive+logo&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwiepLf9itDbAhVNEVAKHQ3wDvoQsAQIKw&biw=1745&bih=885#imgrc=YpXAqFZUfmiLAM: (access: 13/06/2018); [2] http://www.wiser.eu/background/water-framework-directive/ (access: 13/06/2018); [3] http://www.jbatrust.org/news/reducing-flood-risk-by-working-with-nature/ (access: 13/06/2018); [4] Hammar et al.; "Hydrokinetic Turbine Effects on Fish Swimming Behaviour", Plos One, Vol. 8:12, 2013; [5] Sayeed-Bin-Asad et al., "A review of Particle Image Velocimetry for Fish Migration", World Journal of Mechanics, Vol. 6, pp. 131-149, 2016; [6] Palmer, "Acoustic Doppler Velocimetry", 2002; [7] Kang et al., "Numerical simulation of 3D flow past a real-life marine hydrokinetic turbine", Advances in Water Resources, Vol. 39:1, pp. 33-43, 2012; [8] Ouro et al., "Hydrodynamic loadings on a horizontal axis tidal turbine prototype", Journal of Fluids and Structures, vol. 71:5, pp. 78-95, 2017; [9] http://www.divernet.com/photography/p316635-an-octopus-dances-and-a-french-diver-lands-the-big-prize.html (access: 13/06/2018); [10] http://www.sicb.org/divisions/DCB/singleresearcher.php3?resid=49 (access:13/06/2018); [11] (fish, adapted) https://www.researchgate.net/figure/Karman-vortex-gait-The-fish-is-swimming-directly-behind-a-bluff-body-which-is_fig3_264873332 (access: 13/06/2018); [11] Lacey et al., "The IPOS Framework: linking fish swimming performance in altered flows from laboratory experiments to rivers", River Research and Applications, Vol. 28, pp. 429-443, 2012

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