Dec 13th, 8:45 AM - 10:15 AM

A "Fluid" perspective on fish passage design and performanc

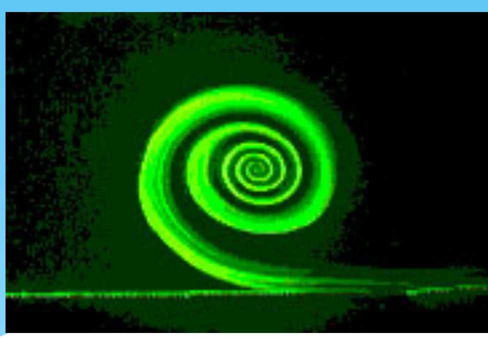
Aline Cotel
University of Michigan, Ann Arbor, MICHIGAN, United States

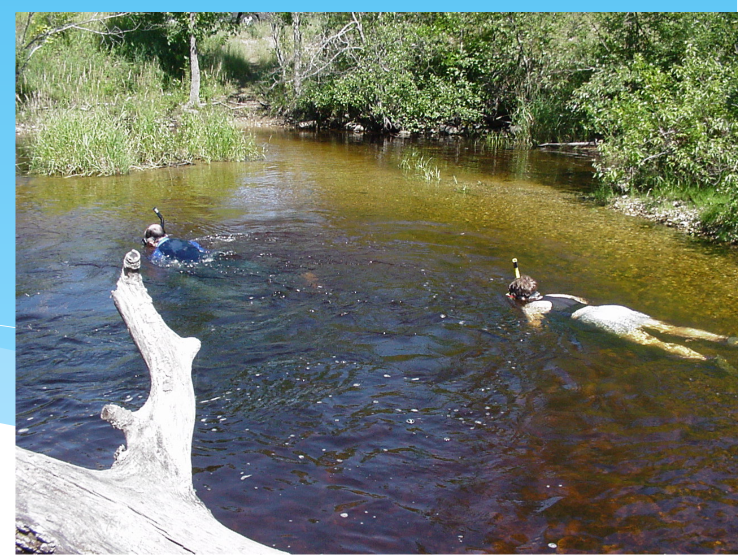
A "Fluid" perspective on fish passage design and performance

Aline J Cotel

Civil and Environmental Engineering

University of Michigan






I'VE A FEELING
WE'RE NOT IN
KANSAS
ANYMORE
Fish

Motivation

Wide range of species

+

Wide range of design and therefore specific hydrodynamic conditions

+

Range of success metrics

Need to define metrics that can be applied to different types of design and fish species – HARMONIZATION !

Fishes in aquatic systems experience turbulence

How do fishes respond to typical features of environmental flows?

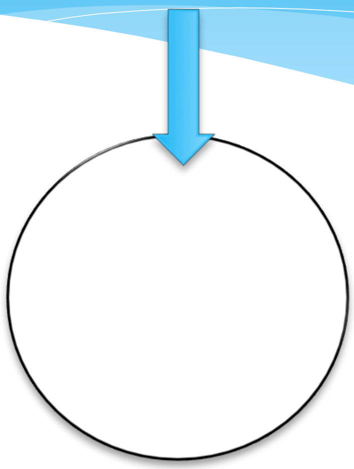
Turbulence arises from flow interacting with structures –
bottom topography, banks, protruding structures.

-> Wide range of results.

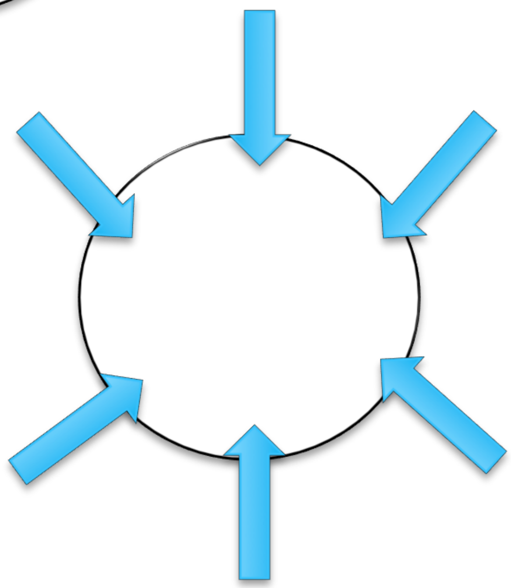
Bur first a few words on turbulence…

What is the most effective design for creating turbulence and mixing 2 fluids?

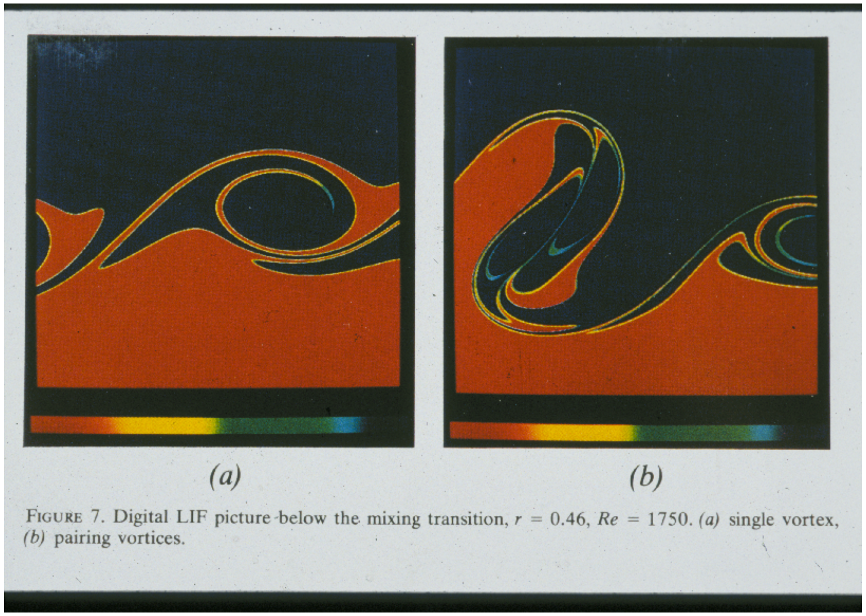
- Option 1:

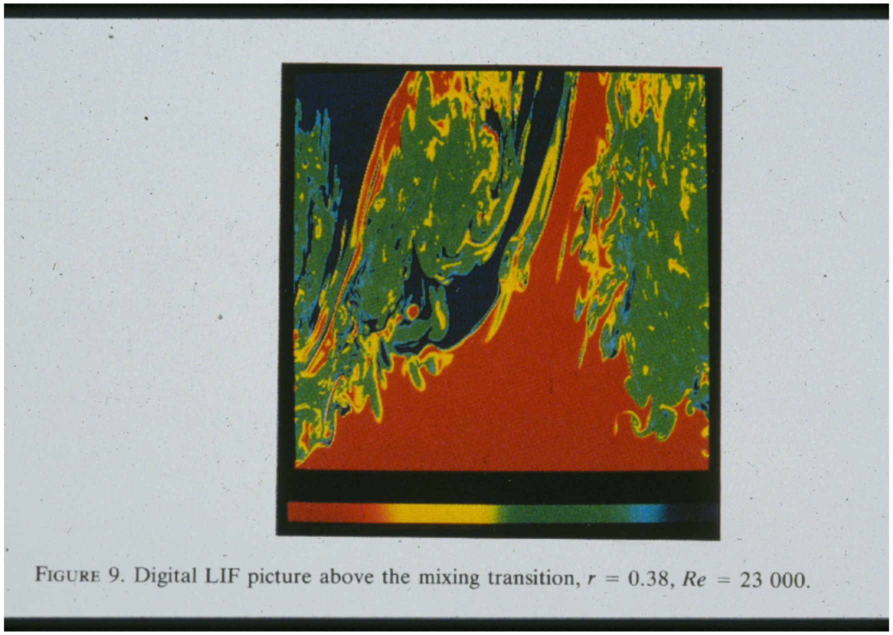


- Option 2:



Example of shear layers



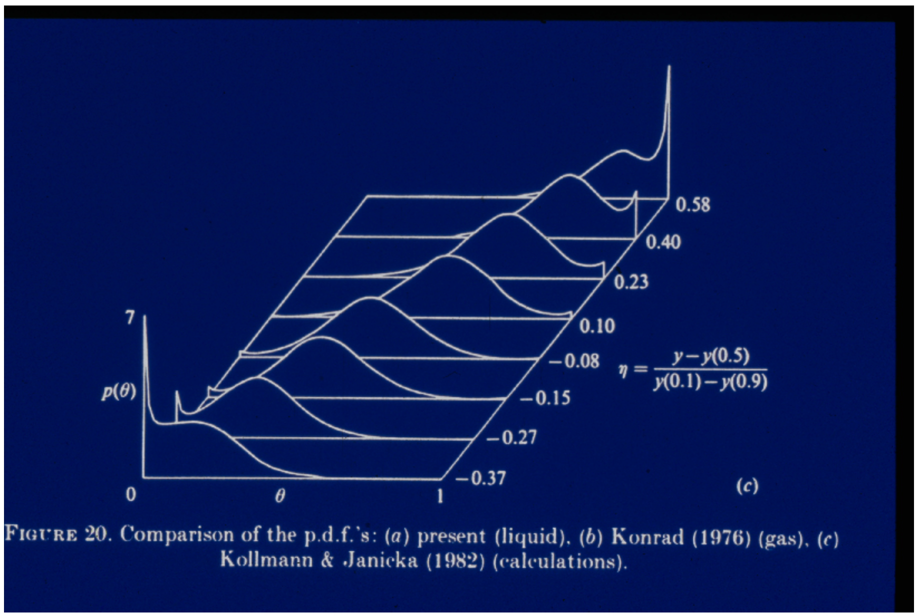


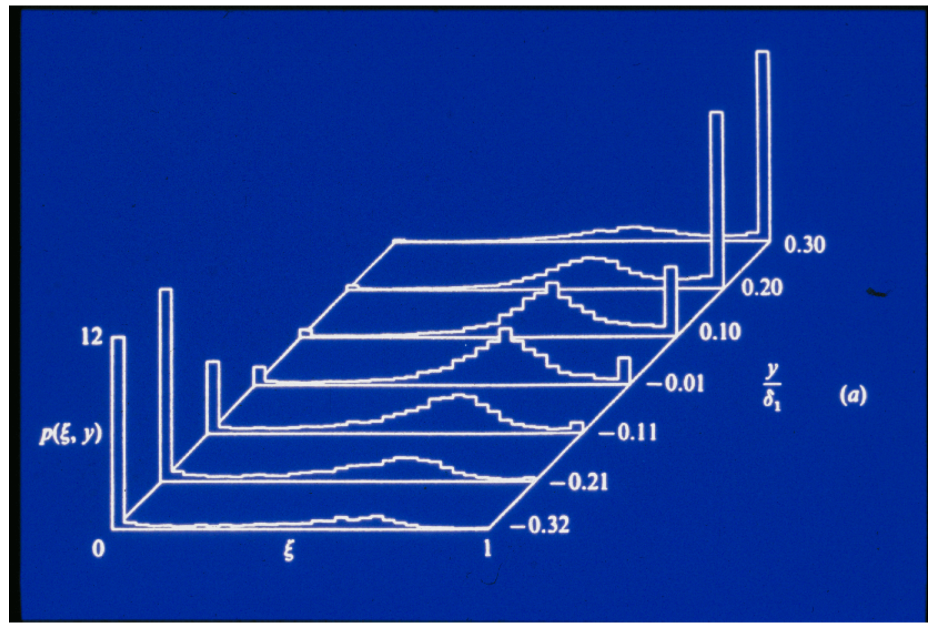
Low Re

High Re

Koochesfahini, 1989

Probability Density Function





Gradient diffusion

From data

Corrsin's Criterion (1974)

"A necessary condition for a self-consistent gradient-diffusion model is that **turbulent motions have a scale that is small** compared with that over which the concentration of the diffusion quantity changes significantly…"

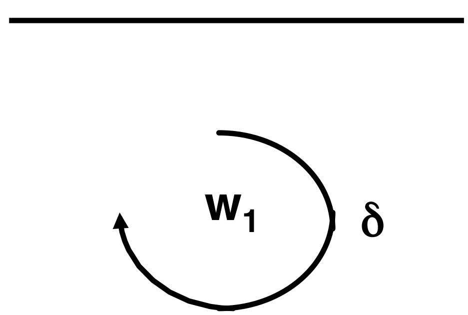
"And nearly all traditional turbulent transport problems VIOLATE this requirement…"

Implication for turbulence modeling – when using turbulent diffusivity or eddy viscosity for example. Need very good calibration data…

Turbulence

- Two approaches: statistical versus physical
- Depends on measurements techniques:
  - point (turbulent velocity fluctuations, TI, TKE, Reynolds stresses)
  - planar or volumetric (eddy size, vorticity, circulation)
- Impacts how we do modeling
- One important parameter: Reynolds number. Defines flow regime as well as range of turbulent length scales. Similitude studies.

$$\mathrm{Re} = \frac{w_1 \delta}{\nu}$$



Negative effects of eddy-dominated flow on fishes

Fish avoid high levels of turbulence in laboratory trials.

Fish swimming performance is reduced by higher turbulence intensity (e.g. Pavlov et al. 1982, 1983, 2000).

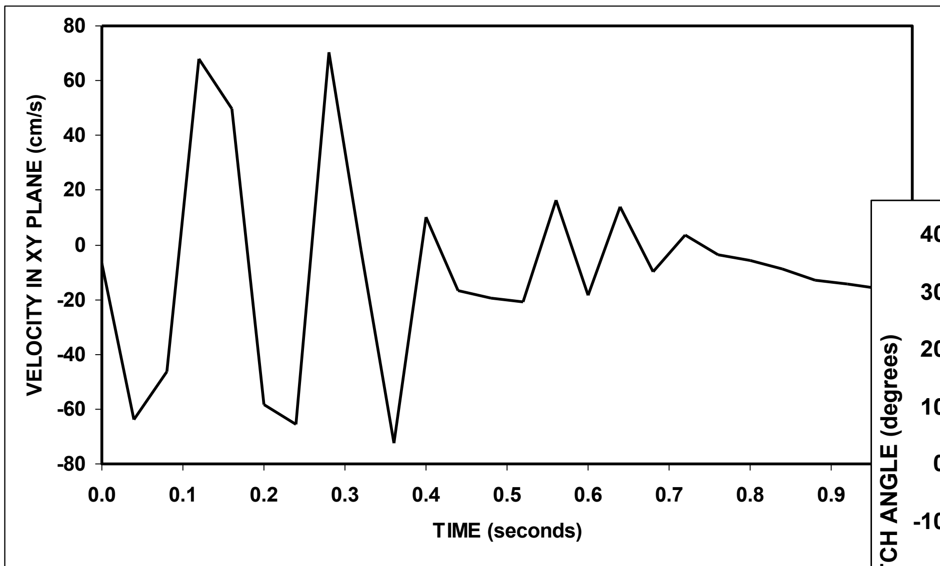
Stronger swimmers are found in more energetic flows.

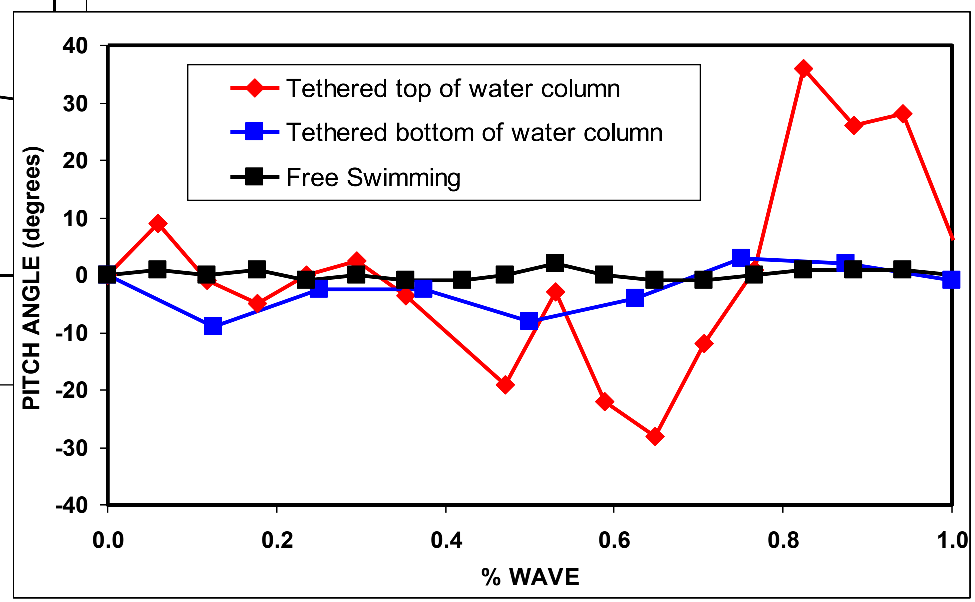
More turbulent flows increase oxygen consumption (Enders et al. 2003)

A Common Feature

Turbulence can challenge control of body posture and swimming trajectories.

Spottail shiner - waves created by boat on sandy beach.

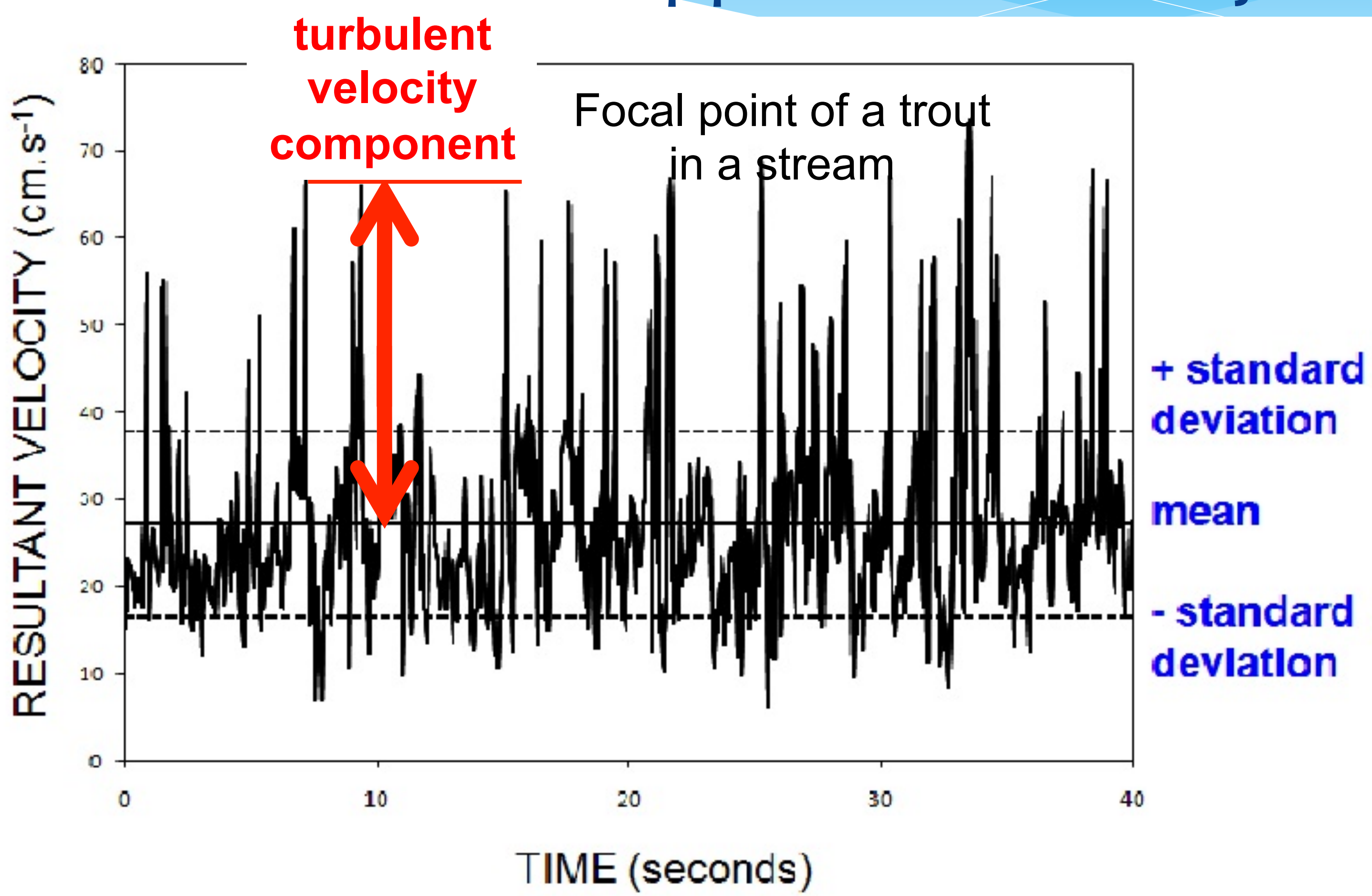




Cotel, A. J. and Webb, P. W. 2004.

MEASURING TURBULENCE

with Acoustic Doppler Velocimetry

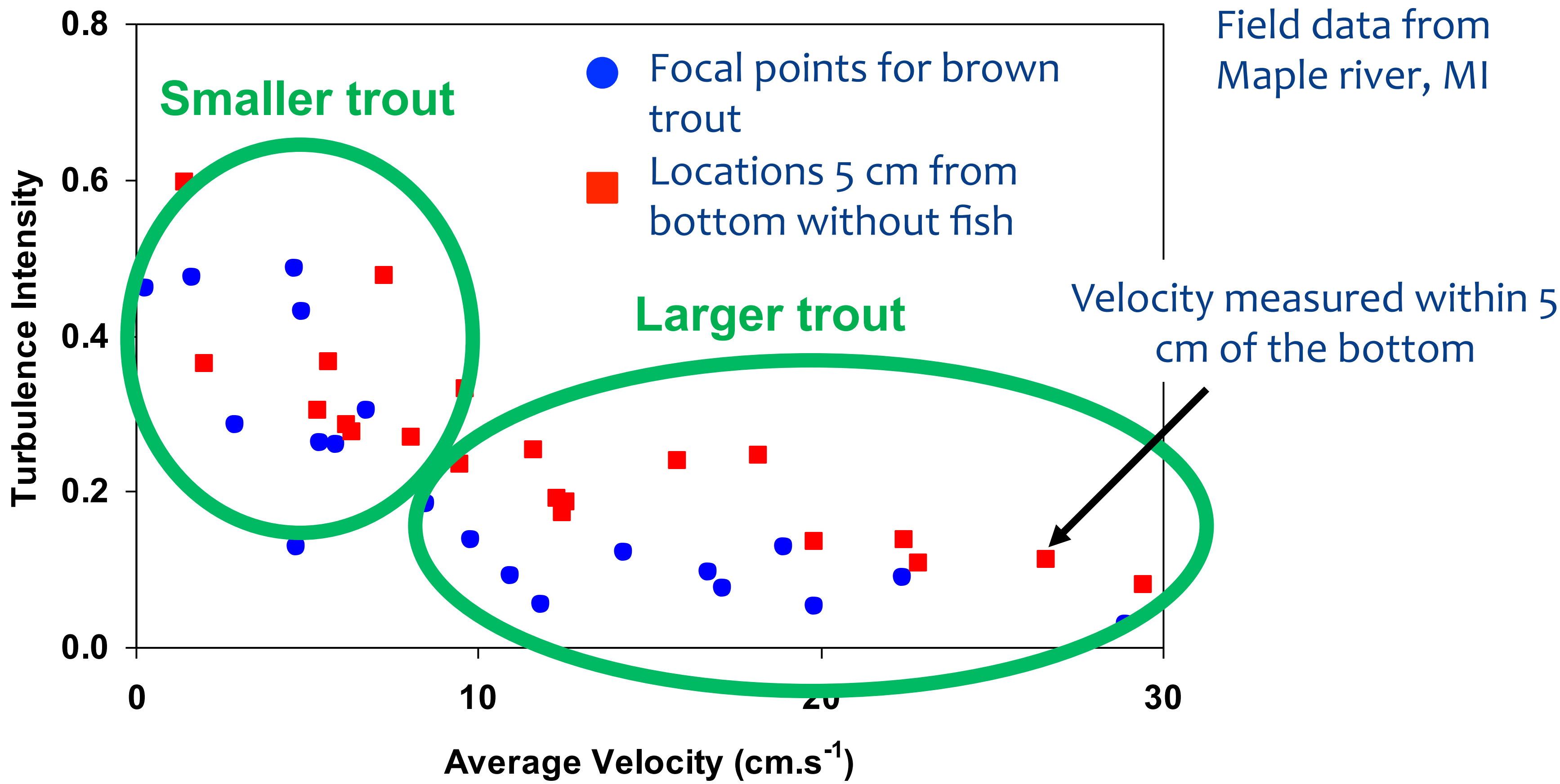


Turbulent Intensity = TI = standard deviation / mean velocity

Turbulent Kinetic Energy = TKE = 0.5 (standard deviation)^2

Fishes choose regions of lower turbulence intensity

Field data from Maple river, MI



Turbulence Intensity = $\frac{\text{standard deviation of current velocity}}{\text{mean current velocity}}$

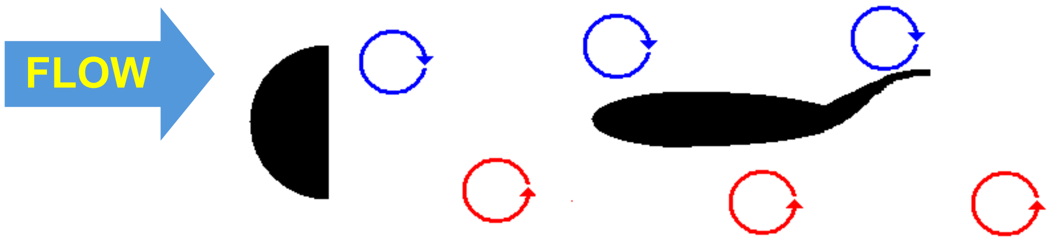
Cotel, A. J., Webb, P. W. and Tritico, H. 2006. Do trout choose habitats with reduced turbulence? Trans. Amer. Fish. Soc. 135;610-619

Uncertain/positive effects of eddy-dominated flow on fishes

Unsteady flow created by wavy walls or jets.

Swimming performance unaffected by intensity of turbulence.

Swimming performance improved in unsteady flow.



Nikora V I, Aberlee J, Biggs B J F, Jowett I G, and Sykes J R E. 2003. *Effects of fish size, time to fatigue, and turbulence on swimming performance: a case study of <u>Galaxias maculatus</u>*. J. Fish Biol 63:1365-1382.

Perry, R., Farley M., Hansen G., Morse J,, and Rondorf D. 2005. *Turbulence Investigation and Reproduction for Assisting Downstream Migrating Juvenile Salmonids, Part II of II; Effects of Induced Turbulence on Behavior of Juvenile Salmon*. BPA Report DOE/BP-00007427-1. http://www.efw.bpa.gov/publications/D00007427-1.pdf

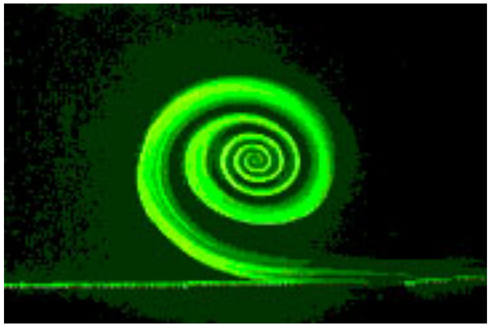
Liao, J., Beal, D. N., Lauder, G. V. and M. S. Trianyafyllou. 2003b. *The **Kármán gait**: Novel body kinematics of rainbow trout swimming in a vortex street.* Journal of Experimental Biology 206: 1059-1073.

Some negative effects of turbulence, some positive…

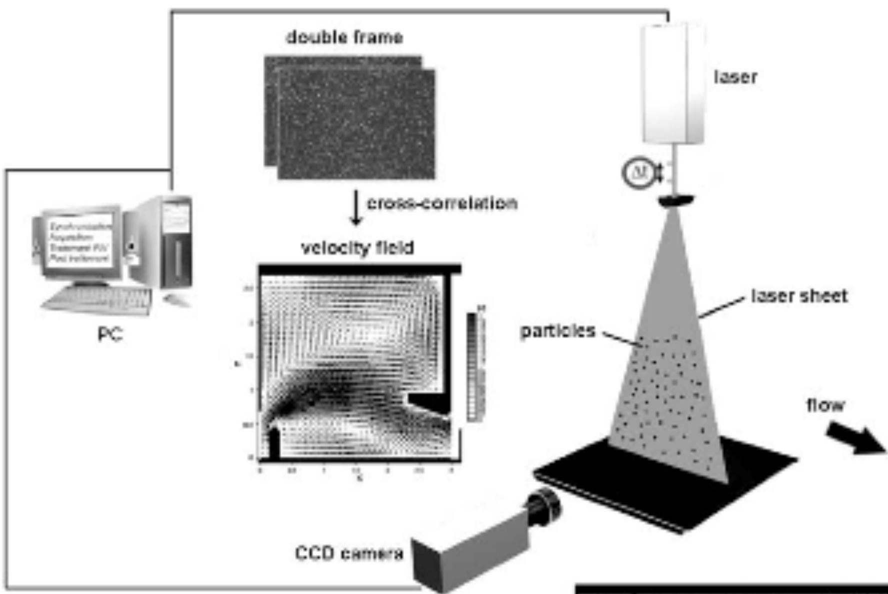
WHY???

Could it be the way we define turbulence?

Need for harmonization?



Vertical slot fishways - PIV measurements



Instantaneous measurement of velocity, vorticity, TKE.

Allows for calculations of average parameters as well as localized quantities, on a fish scale for example.

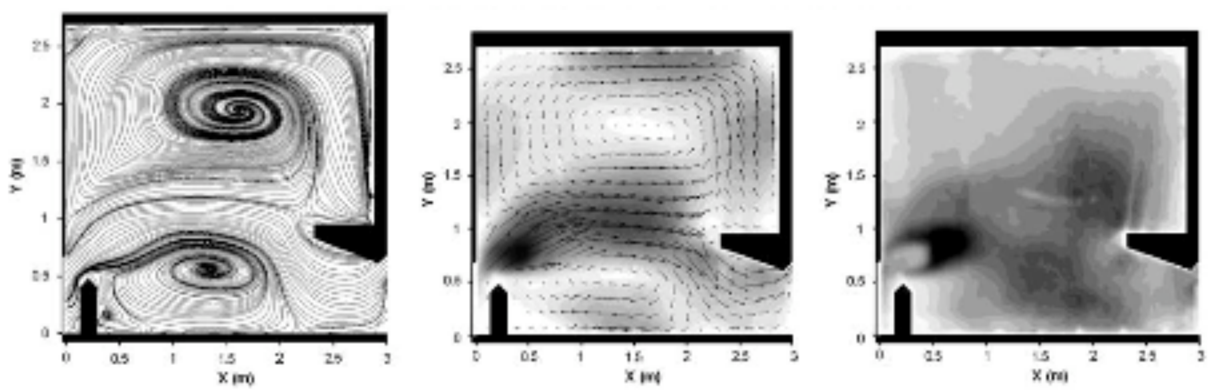
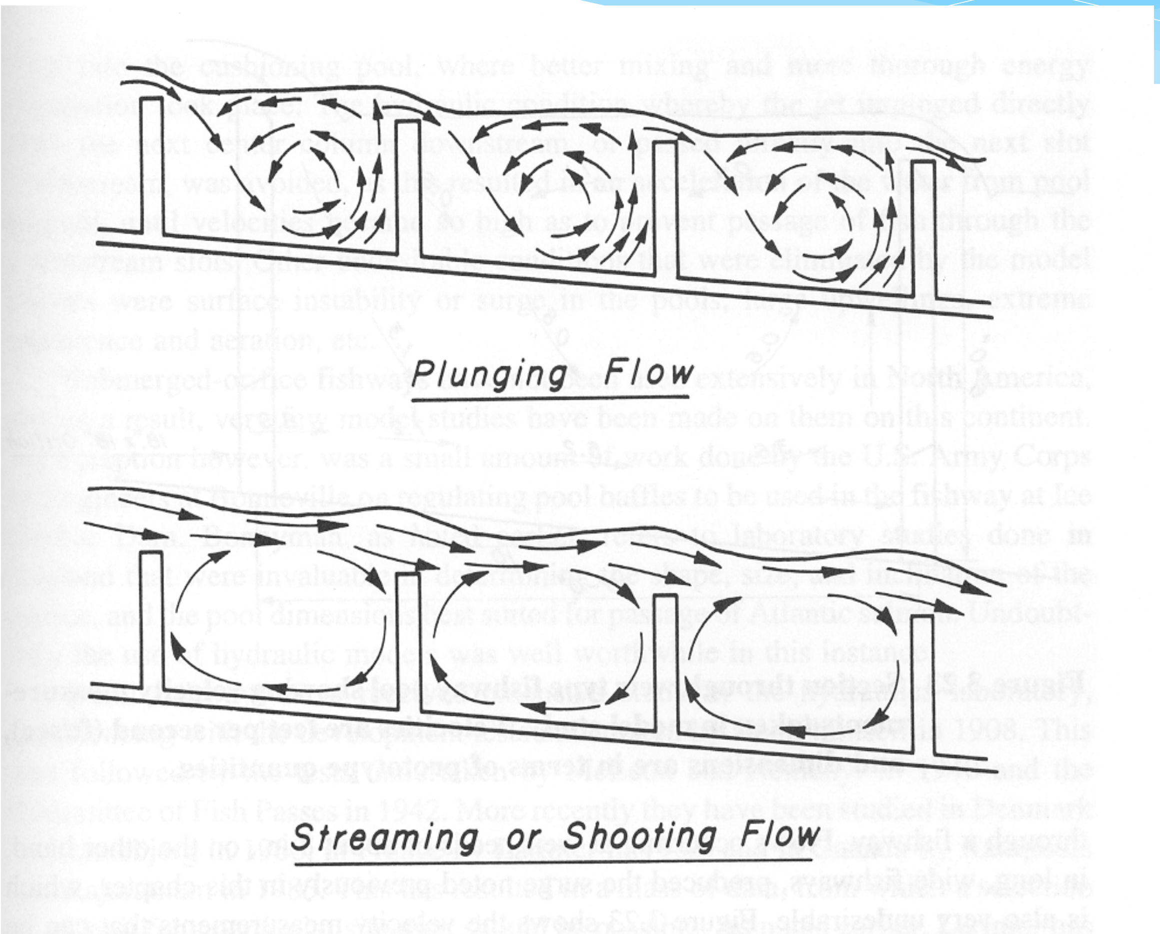


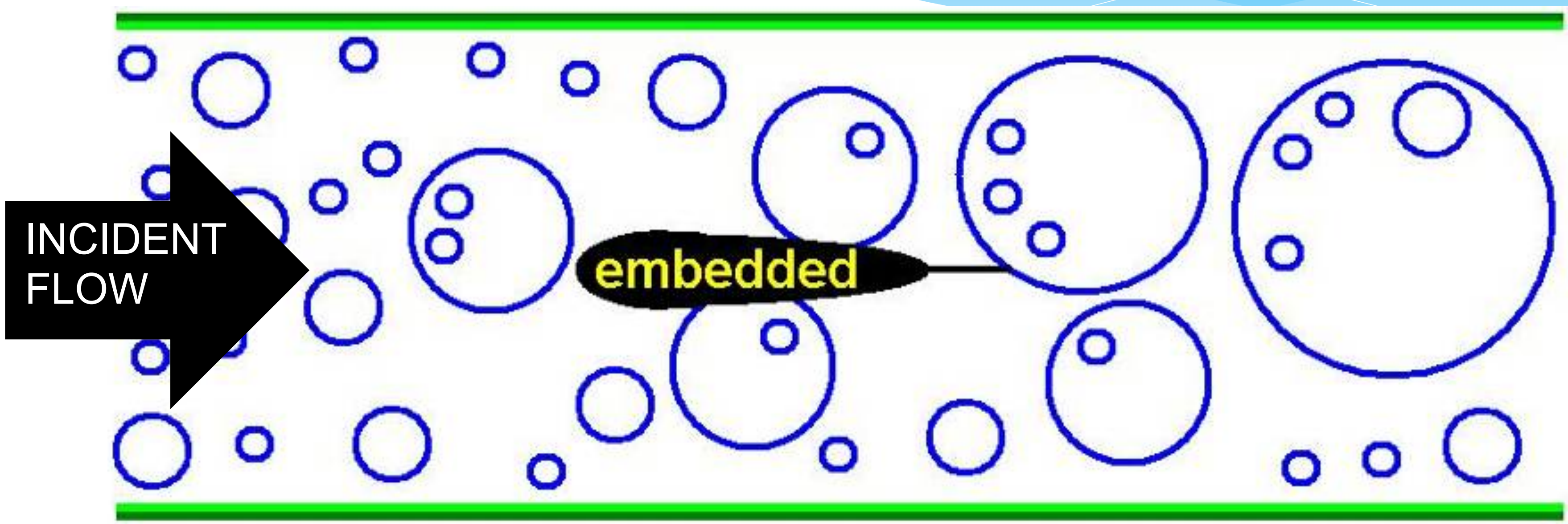
Fig. 5 Streamlines, velocity and turbulent energy in a vertical slot fishway: $I = 10\%$, $B = 2.7$ m, $Q = 736$ L/s at $Z = 0.08$ m

Tarrade et al. (2008)

Pool-weir fishways



Turbulent Flow is comprised of eddies in which a fish is embedded

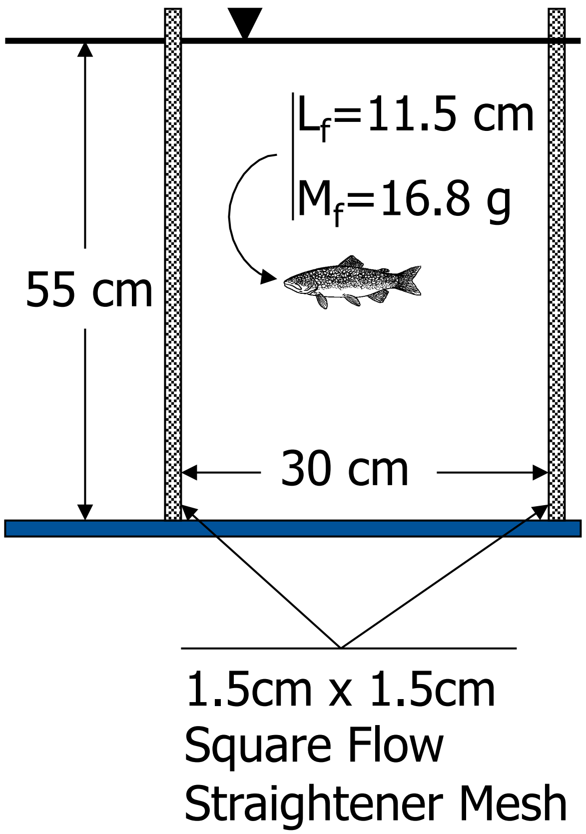


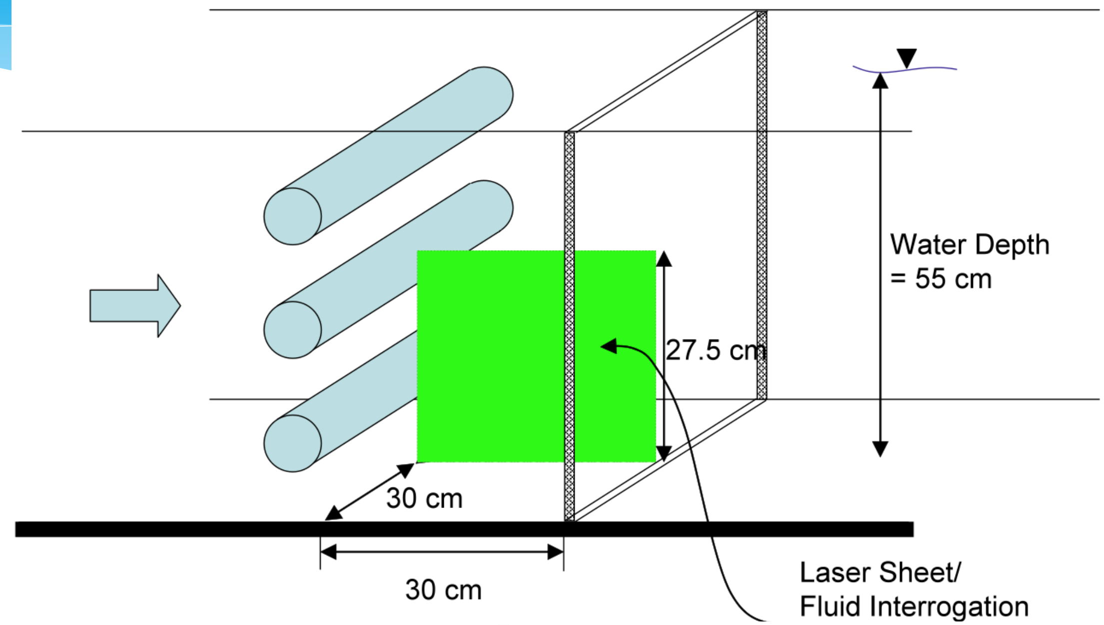
Incident Flow and Embedded Body interactions linked by:

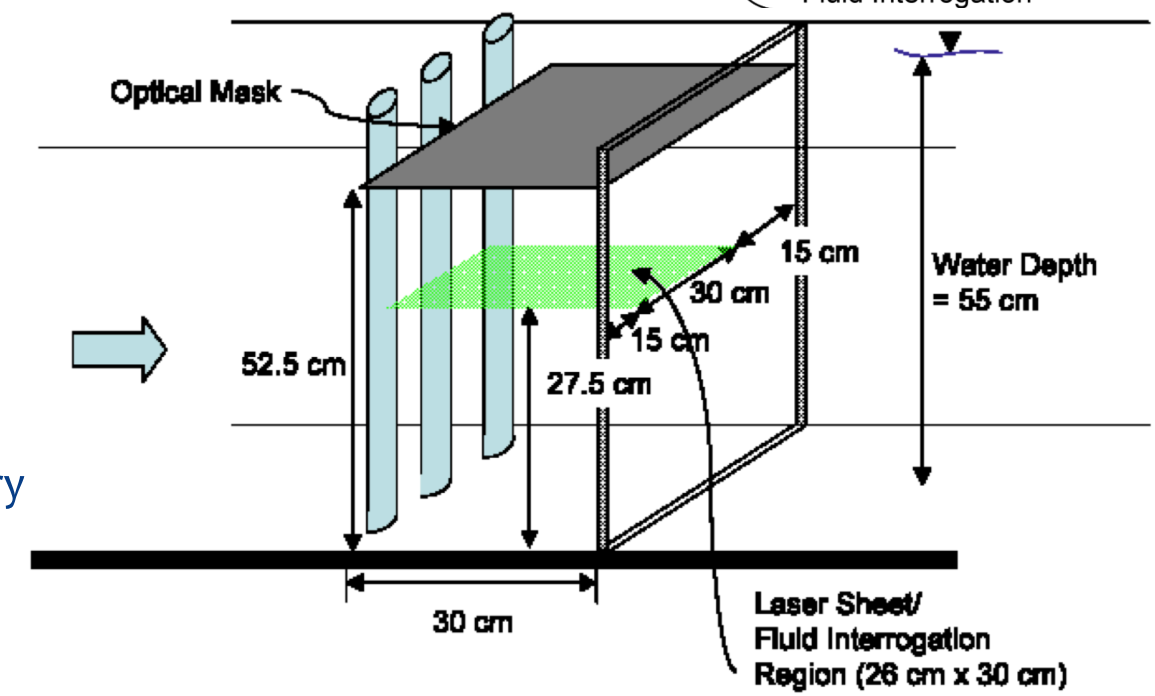
Relative Spatial Scale - Eddy size relative to the size of the embedded body (from larvae to adults).

Relative Time Scale – Eddy frequency and periodicity relative to response latency of embedded body.

Flume experiments



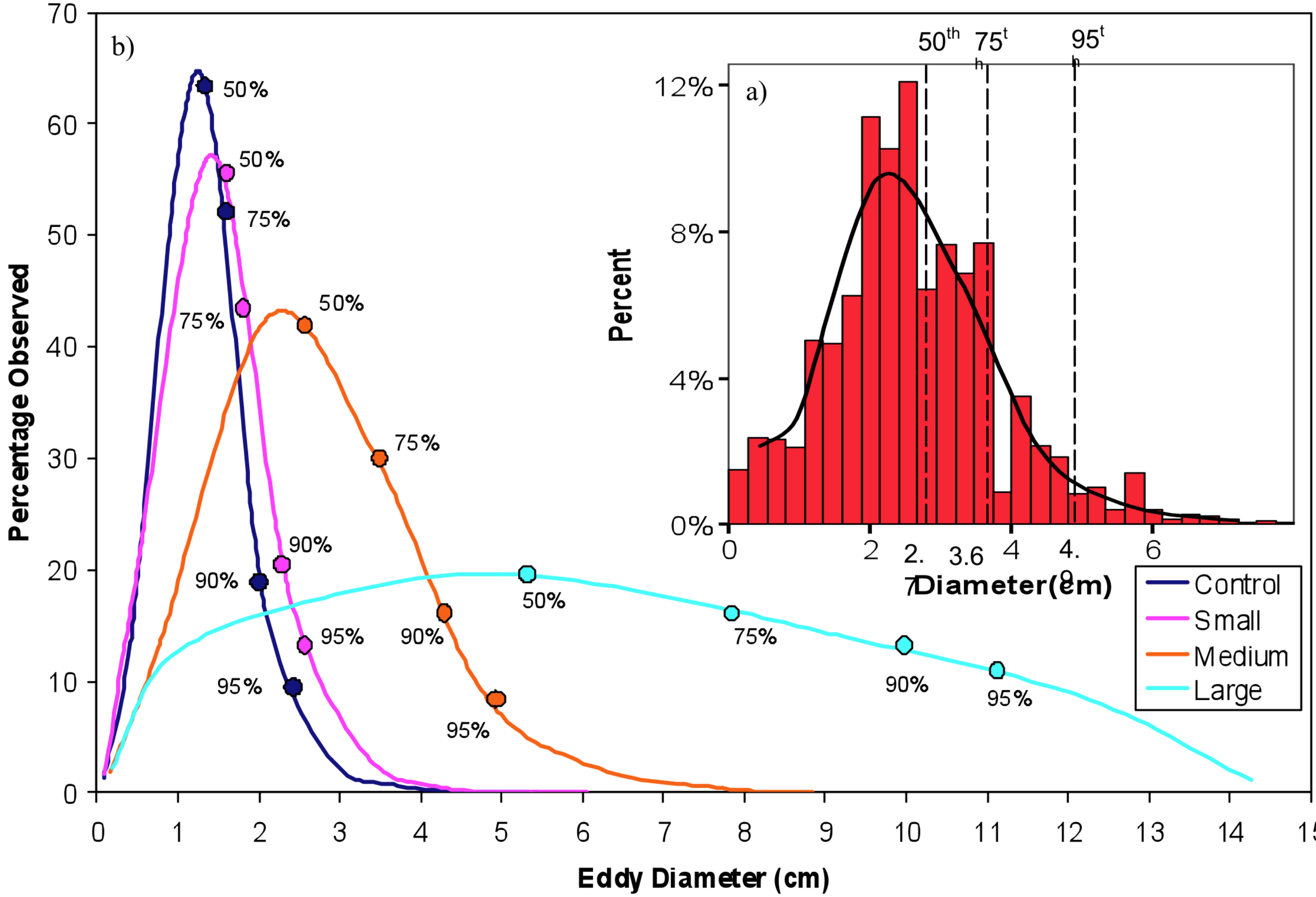




Cylinder diameters: 0.4, 1.6 and 8.9cm

Technique: Particle Image Velocimetry

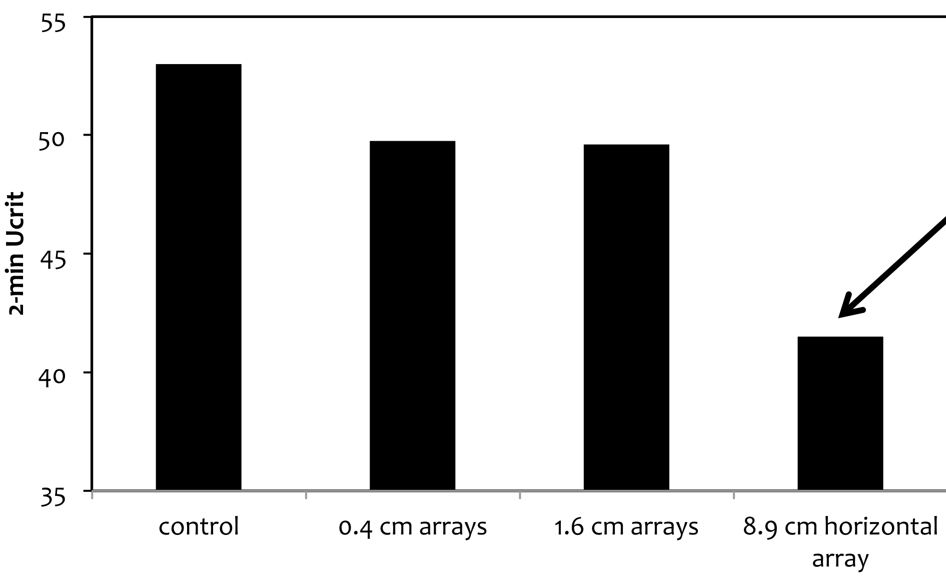
Results – eddy sizes

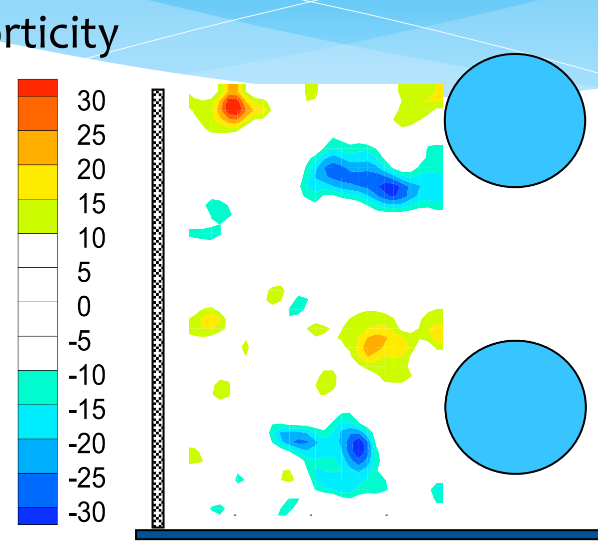


Eddies identified using Drucker and Lauder (1999) from PIV data

Results – fish performance

Increasing velocity test with creek chub, 11.5 cm total length





Horizontal Cylinders

Occurrence of eddies up to 8.4 cm in diameter shed by the large cylinders significantly reduced U_{crit}

Tritico and Cotel(2010)

Relevant parameters

Flow Parameters	Definition	Value
Length scale	Eddy diameter identified from PIV data	1 – 8 cm
Circulation	$\Gamma = \omega_e A_e$	5 – 640 cm^2/sec
Momentum flux/thrust	$T = \rho V_e^2 L_e^2$	25 to 409,600 cm^4/sec^2

The range is for the different sets of experiments performed, from the small to the large cylinders configurations, with the highest water tunnel velocity (56cm/s).

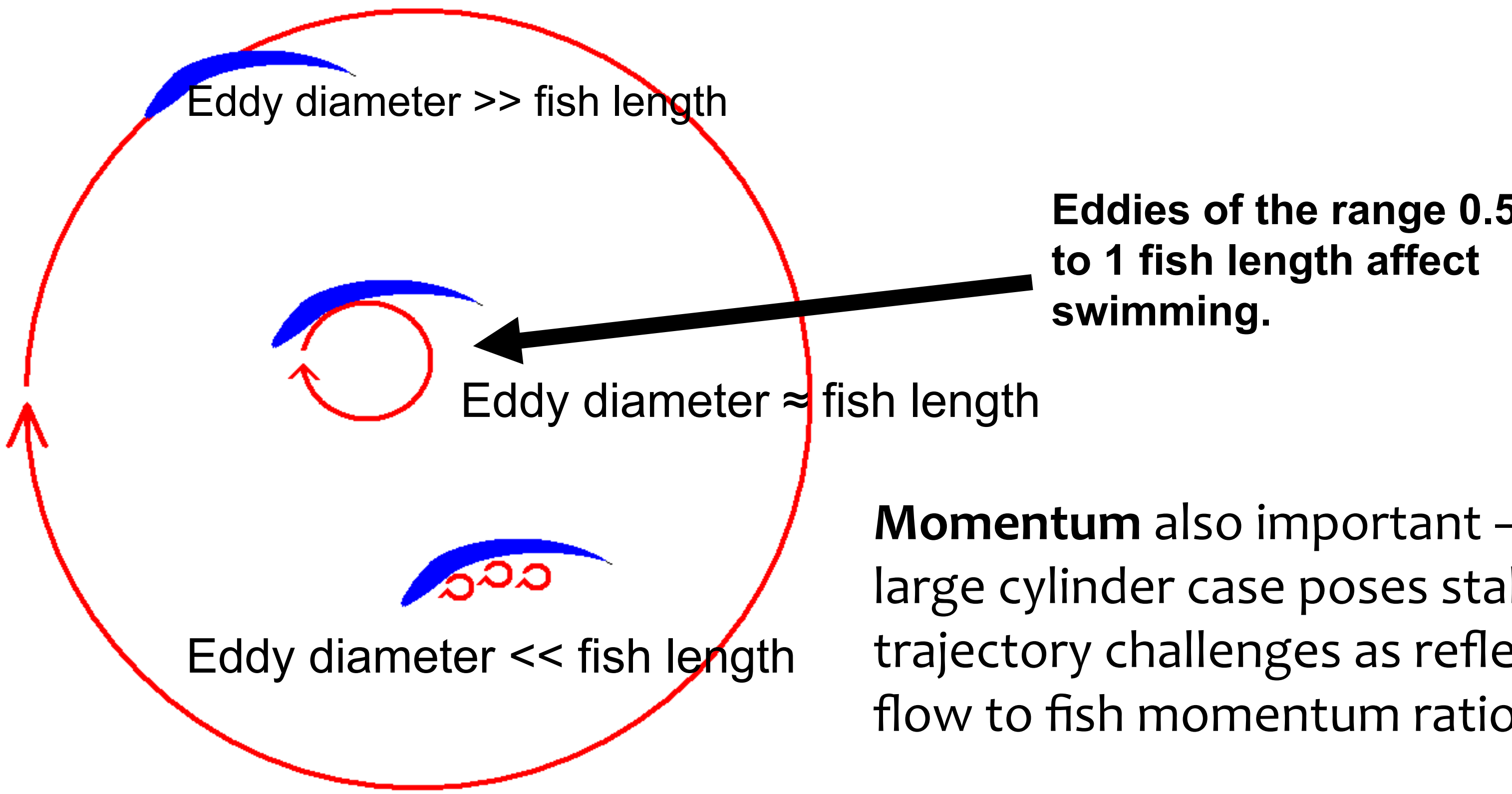
Fish Parameters	Definition	Value
Length scale	Body length	11.5 cm
Circulation	$\Gamma = \omega_f A_f = V_f L_f$	483 cm^2/sec
Momentum flux/thrust	$T = \rho V_f^2 L_f^2$	233,289 cm^4/sec^2

Based on fish lowest critical swimming speed (42 cm/sec).

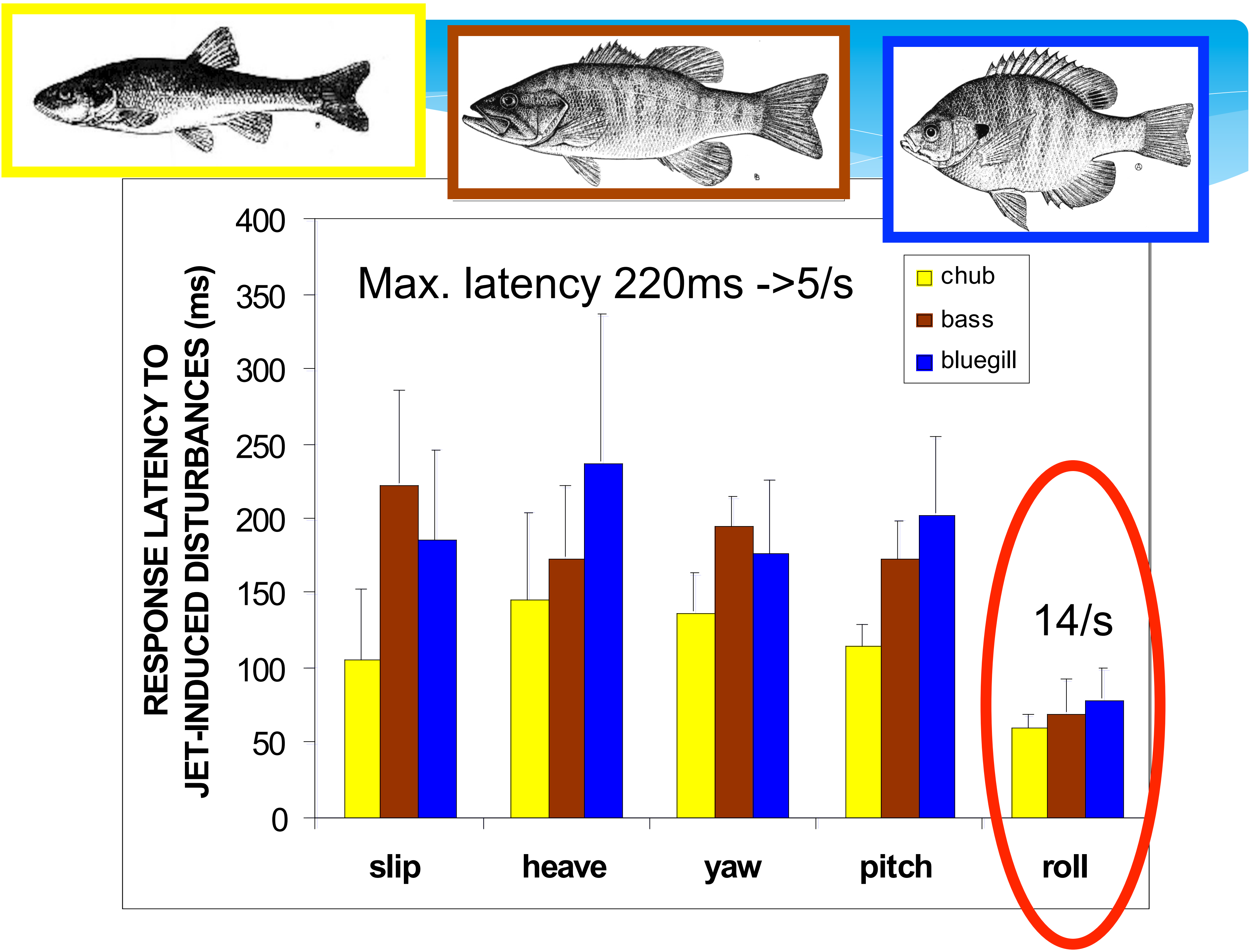
Cotel and Webb (2015)

Comparison – Flow to Fish

Scenario	Ratio of lengthscale	Circulation ratio	Momentum ratio
Small cylinders	0.09	0.01	0.0001
Medium cylinders	0.25	0.09	0.0087
Large cylinders	0.69	1.32	1.76



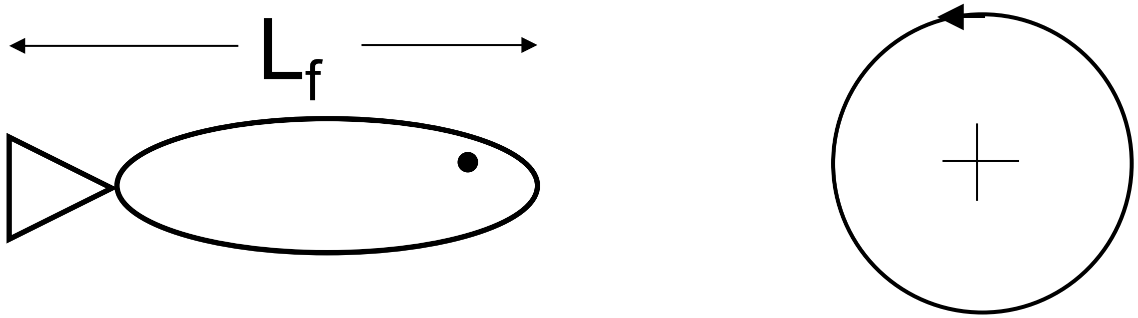
Momentum also important – only the large cylinder case poses stability and trajectory challenges as reflected in the flow to fish momentum ratio.


Max. latency 220ms ->5/s
chub
bass
bluegill
RESPONSE LATENCY TO JET-INDUCED DISTURBANCES (ms)
400
350
300
250
200
150
100
50
0
14/s
slip
heave
yaw
pitch
roll

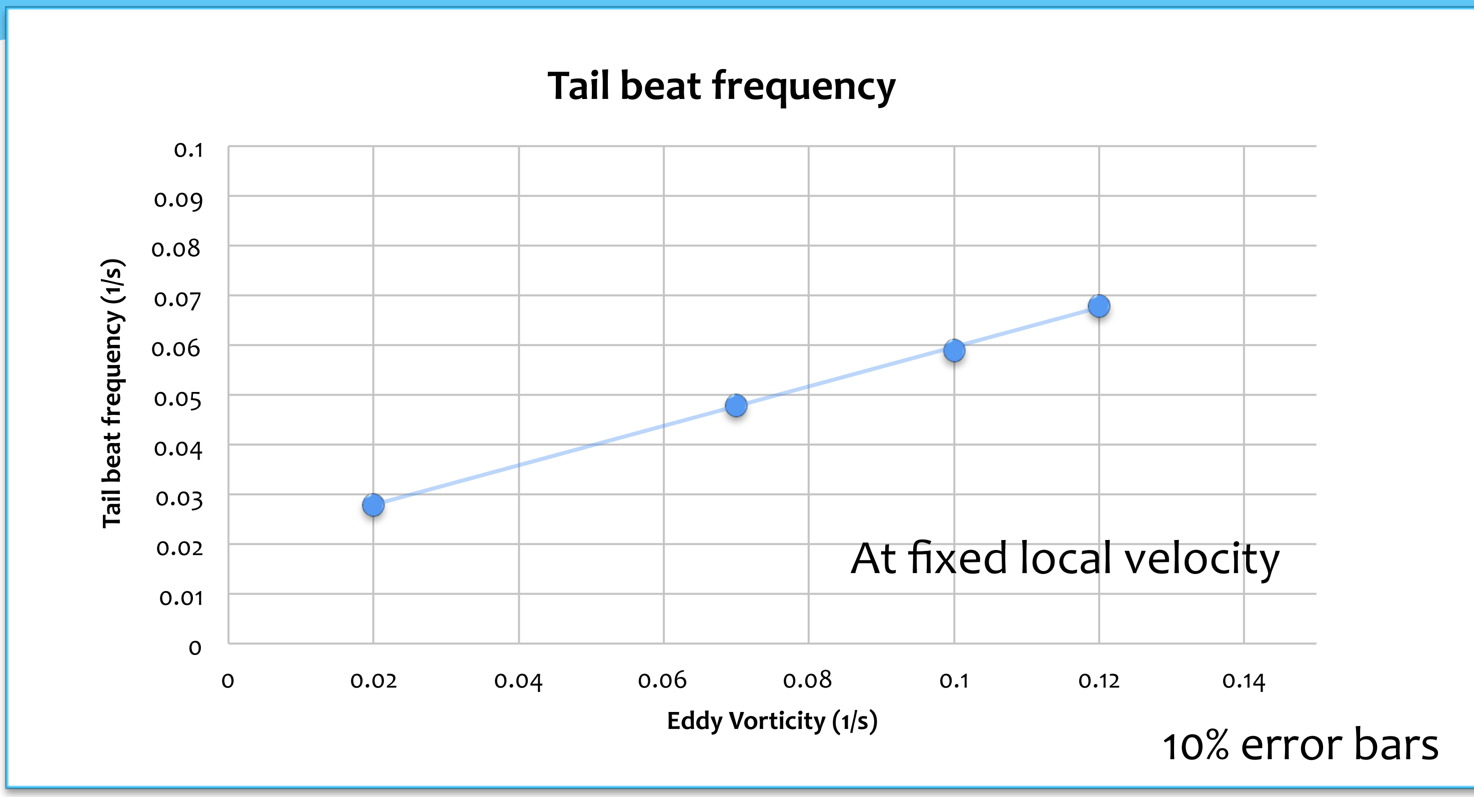
More on time scale!

- How long fish are interacting with turbulent eddies will impact their performance thru fishways.

- Persistence parameter (Cotel, 1995) defines the stationarity of vortices with respect to a surface, i.e. ratio of eddy rotational to translational velocity.



- It would represent here how long fish are experiencing significant interaction with eddies.



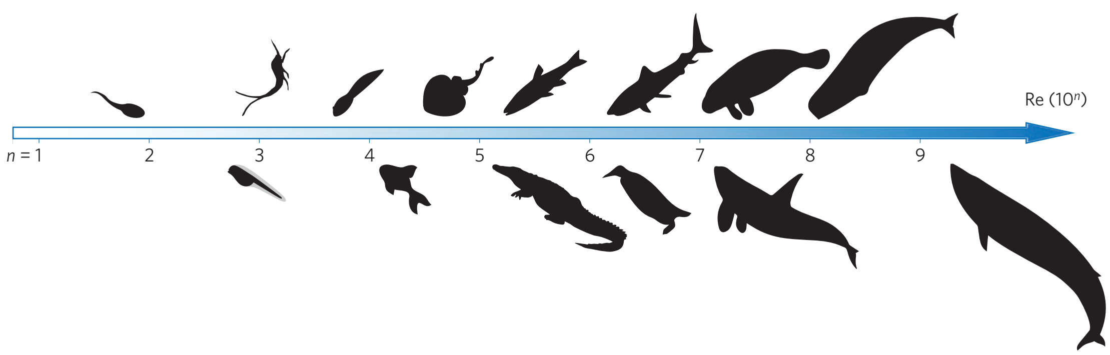
STRONG correlation between tail beat frequency and eddy vorticity

Tritico (2008)

Aquatic locomotion - Moving away from Strouhal number

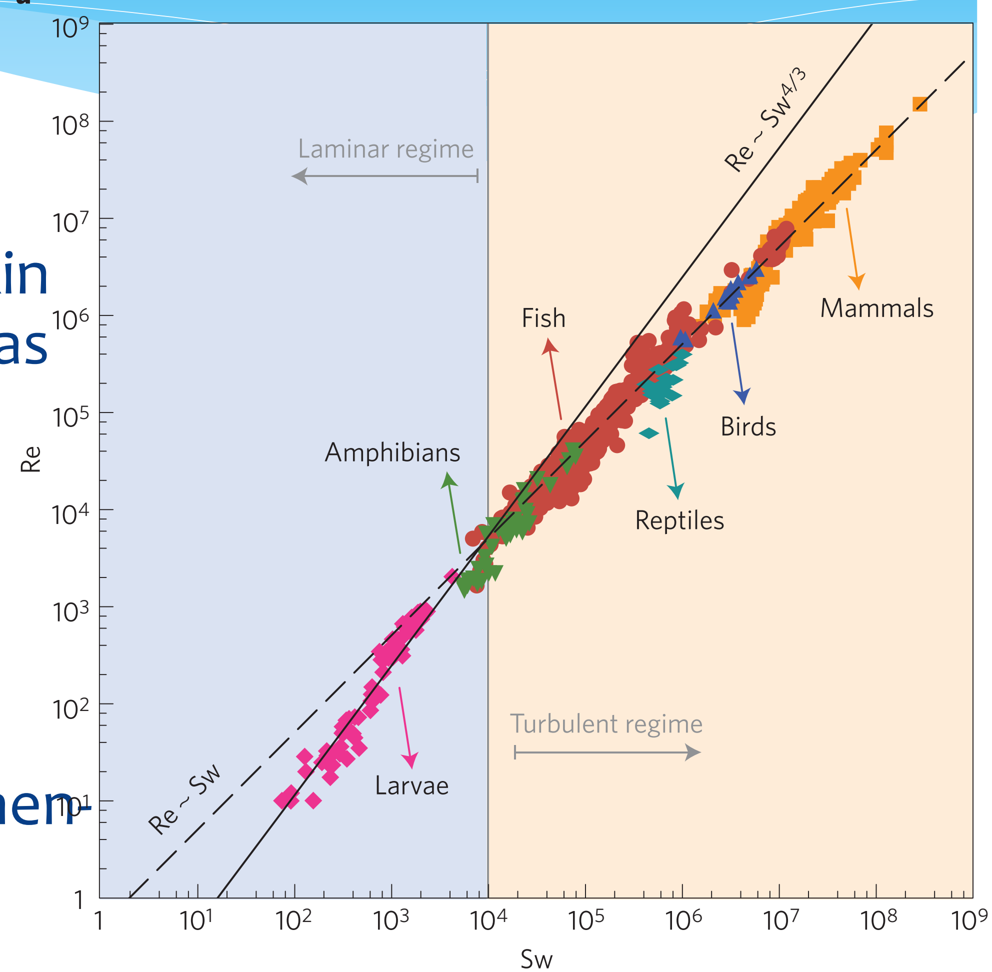
- St = fA/u where f is the tail beat frequency, A the tail beat amplitude and u the local velocity. It mixes input and output variables!

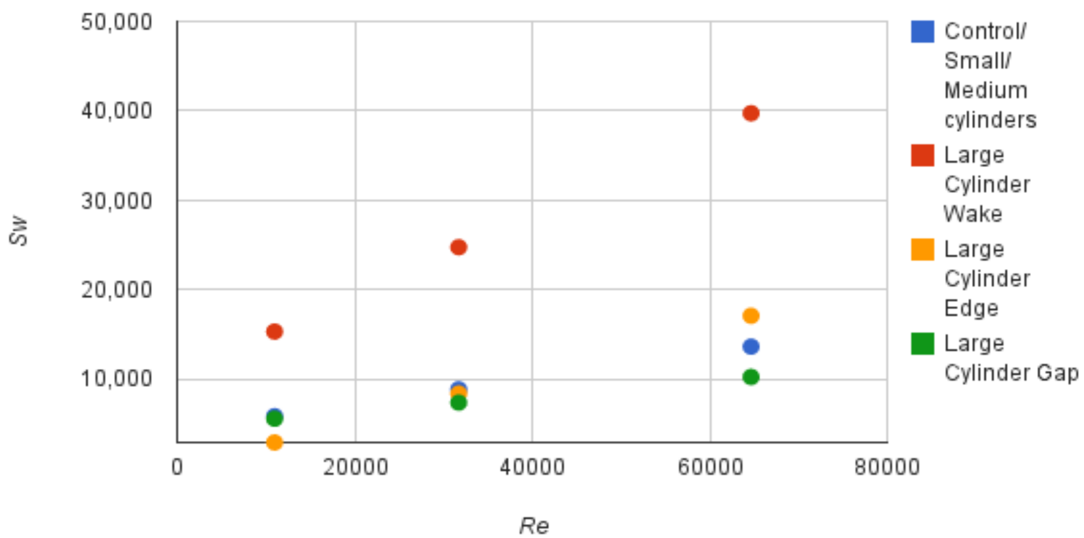
- Gazzola et al. (2014): Unifying principle for locomotion -> Swimming Number.
- Valid over 8 orders of magnitude of Re.

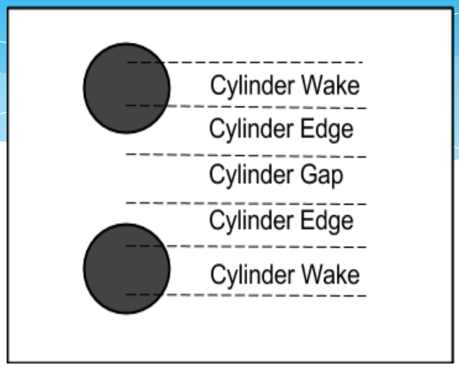


Swimming number

- $Sw = fAL/\nu$
- Laminar (Balance between skin friction and thrust) - Re goes as $Sw^{4/3}$
- Turbulent (Balance between pressure drag and thrust): Re goes as Sw.
- Locomotion described by dimensionless parameters only!





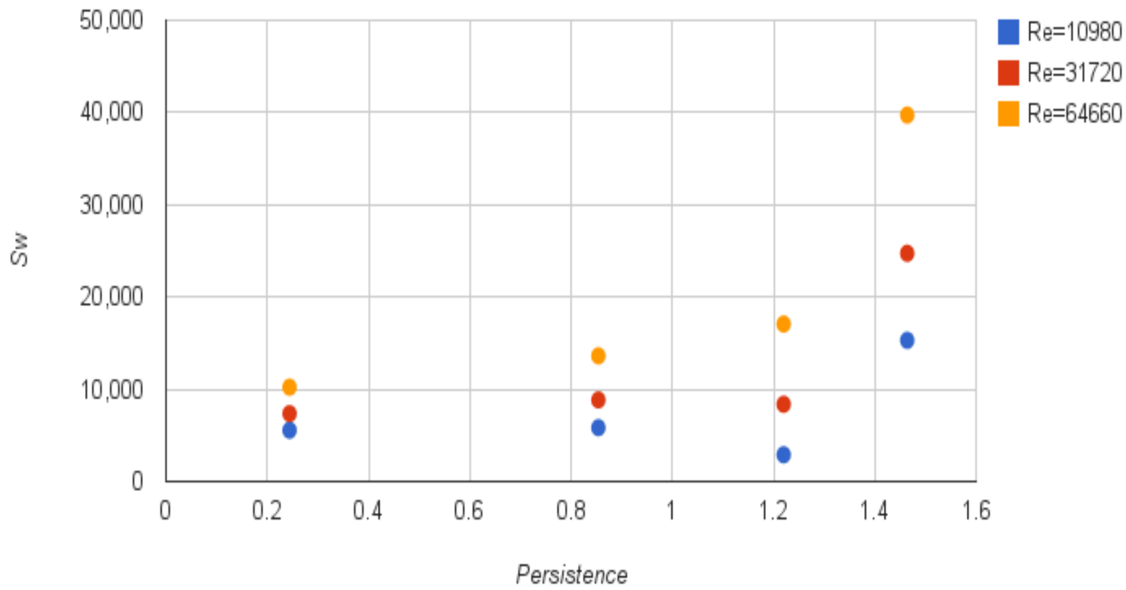


- As expected, in the turbulent regime for aquatic locomotion, Sw is linearly proportional to Re.

- Higher Sw -> higher drag.

- Could we use Sw as a dimensionless parameter to quantify energy expenditure during fish passage?

Cotel and Webb (2015)

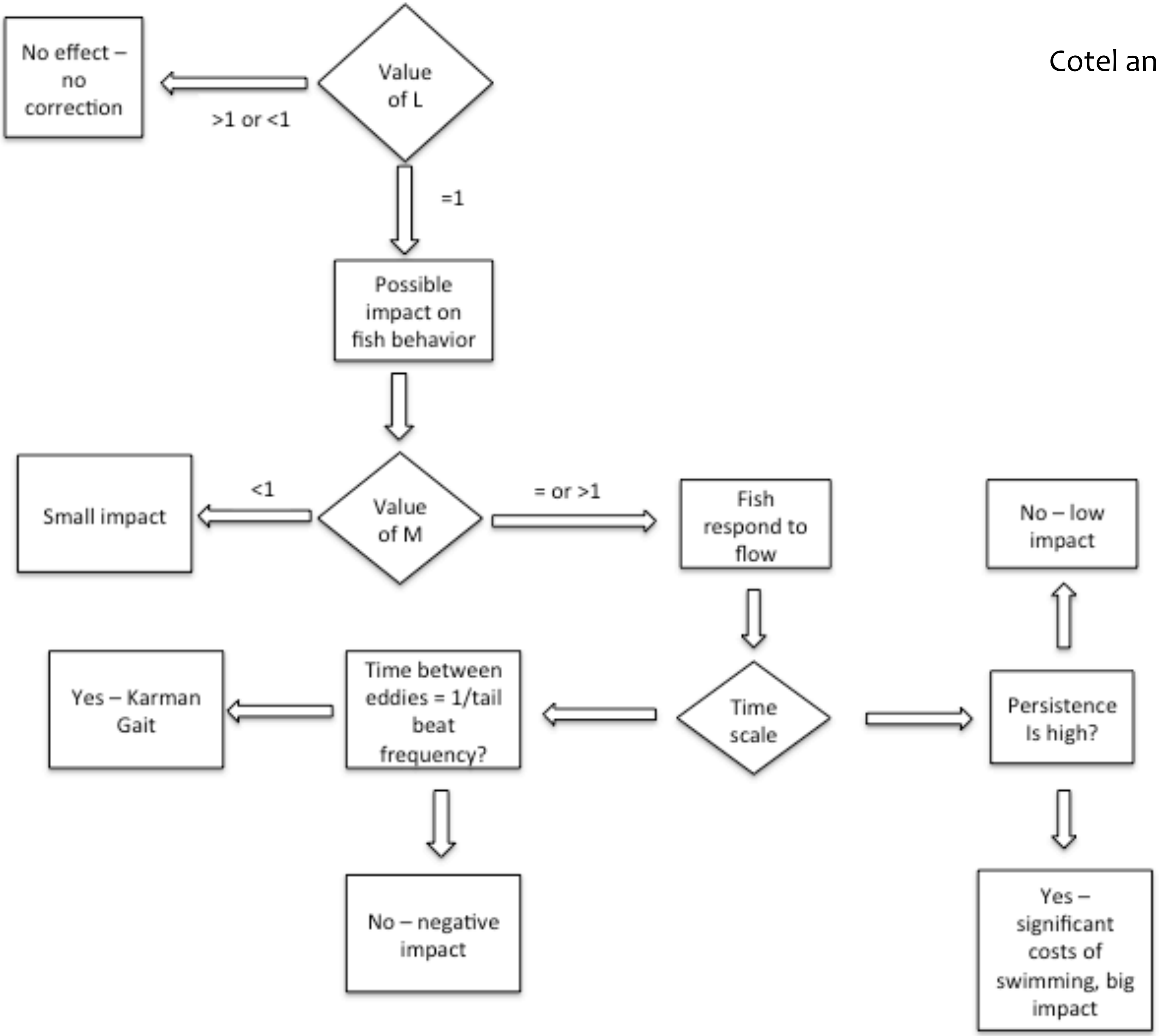


Sw as a function of Persistence for different Re for creek chub swimming downstream of cylinder arrays

Small difference until we get into the Large Cylinder regime, which is the regime that causes most challenges for fish.

A high persistence number, i.e. longer interaction with eddies, has a strong effect on fish responses.

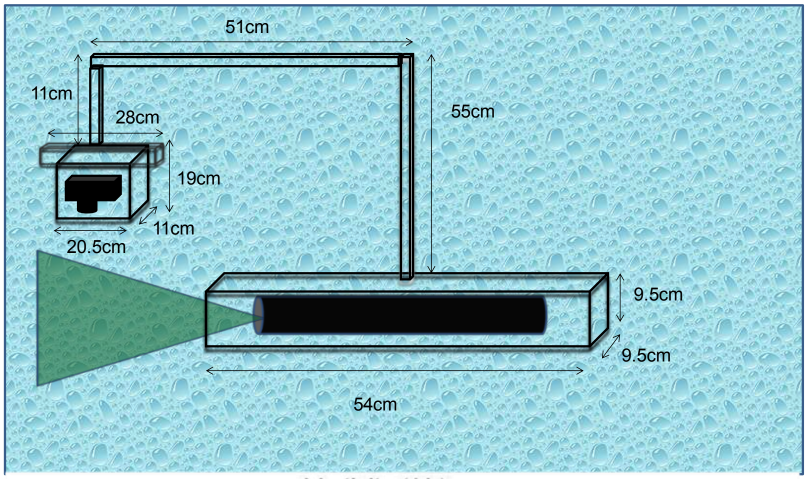
Cotel and Webb (2015)

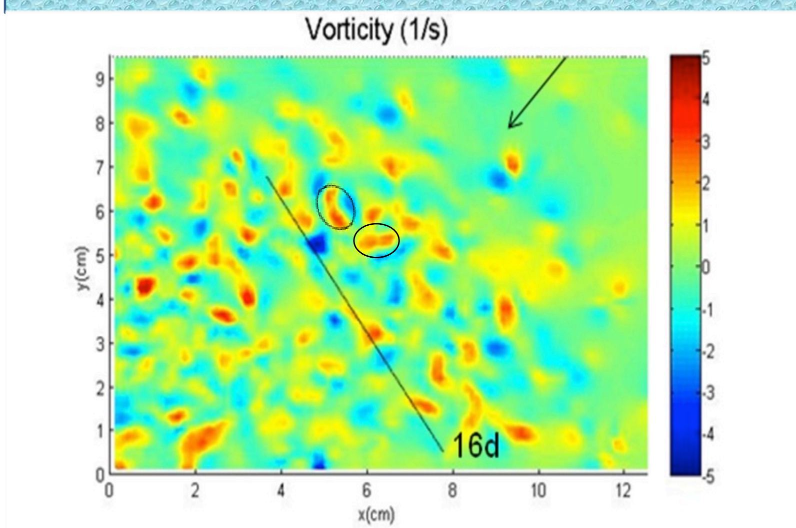


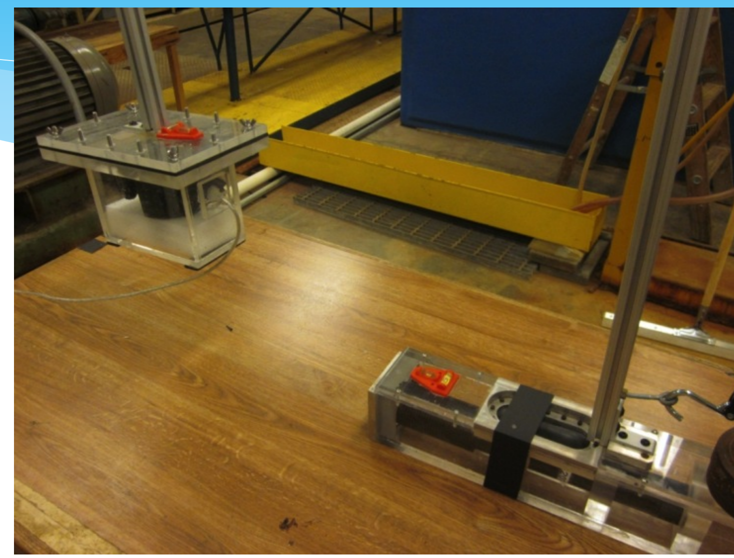
Cotel and Webb (2015)

Field measurement techniques

- Underwater PIV

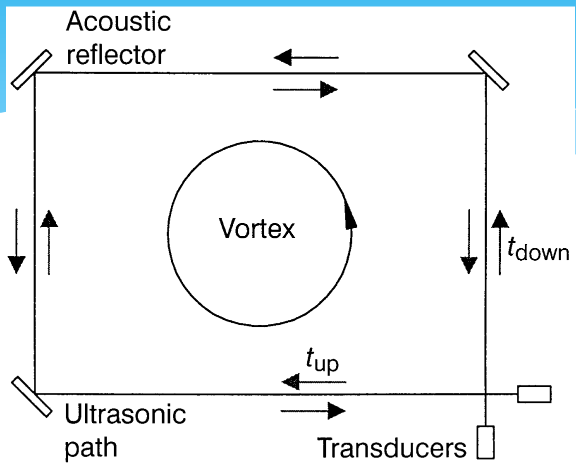






Clarke, Tritico and Cotel (2007)

Direct measure of circulation by ultrasound



- Measures transit time of ultrasonic pulses traveling in the direction of vortex rotation and against it.
- Tested in air and water
- No need to calibrate for speed of sound
- Could be installed in fishways as monitoring devices and used as a sensor for adaptive management strategies.

Johari and Durgin (1998)

FishPass Conceptual Design

LEGEND

- Lawn
- Meadow
- Riprap & Live Stakes
- Stormwater Seeding
- Gravel Boat Launch

PLAN KEY

- (A) New Pedestrian Connection to Cass Street
- (B) Rehabilitated Boardwalk & Accessible Kayak Launch
- (C) Labyrinth Weir
- (D) Kayak Portage Rail
- (E) Pedestrian Bridge
- (F) FishPass Research Building/ Public Restrooms
- (G) Interpretive Overlook 1
- (H) Bypass Channel w/ Boulder Armoring & Native Vegetation
- (I) Fish Sorting Channel
- (J) Interpretive Overlook 2
- (K) Service Drive/Pedestrian Walk on City Easement
- (L) Research Access Way & Security Fence
- (M) Fishing Pier
- (N) Outdoor Classroom
- (O) Pervious Pavers
- (P) Rain Garden To Manage Building/Parking Runoff
- (Q) Rehabilitated Boardwalk
- (R) New Boardwalk
- (S) Tailwater Entrance Pad
- (T) Amphitheater
- (U) TurfStone Vehicular Access

Summary

- Turbulence is measured in several ways that can lead to contradictory biological impacts.
- Need new unifying reference frame to evaluate fish responses to turbulent flows -> A **physical** framework to link flow conditions to fish responses is proposed.
- Based on dimensionless parameters to allow applications for a wide range of length and time scales.
- Future steps require the acquisition of more field data using different instruments as there is a need to move away from point measurements.

Questions?