How European Standards are Advancing Fish-Friendly Pumping Stations

BART VAN ESCH

Prime Fluid Management, Webinar, 19 June 2025

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Bart van Esch

Professor, Lecturer, Researcher, and Senior Hydraulic Engineer

Eindhoven, North Brabant, Netherlands · Contact info

CEN - European Committee for Standardization

NEN – Dutch institute for Standardization

Experience

UHD / Associate professor
Eindhoven University of Technology
Sep 1997 - Present · 27 yrs 10 mos
Eindhoven, The Netherlands

Professor - National Pump Research Center, China
Jiangsu University
Oct 2017 - Present · 7 yrs 9 mos
Zhenjiang, Jiangsu Province, China

Part time professor at Jiangsu University, National Pump Research Center, China

Senior Hydraulic Engineer
Bosman Watermanagement BV
Oct 2000 - Present · 24 yrs 9 mos

Associate Editor - ASME Journal of Fluids Engineering
ASME (The American Society of Mechanical Engineers)
Jan 2012 - Jan 2018 · 6 yrs 1 mo

Committee Member CEN/TC 230/WG 24 "Fish monitoring"
CEN - European Committee for Standardization
Oct 2022 - Present · 2 yrs 9 mos

NEN 8775 author and committee member
NEN
May 2016 - Present · 9 yrs 2 mos

- Author of Dutch NEN standard 8775 about fish safety in pump and hydropower stations
- Member of NENcommittee 'Visveiligheid van pompen en turbines'

Consultant
Environment Agency
Jan 2020 - Present · 5 yrs 6 mos

The Netherlands

- delta region
- 50% below sea level
- polder integrity
  - sluices, weirs, embankments, canals
  - pumping stations (~ 5,000)

Need for fish protection

- pumping stations are hazards to fish
- European Parliament directive (2000/60/EC)
  - preservation of fish habitat
  - unobstructed migration of fish

Developments in the Netherlands

- monitoring of ~20 pumping stations since 2005
- establish relation fish damage versus pump type/size, flow rate, shaft speed, head, and fish type/size
- review of US studies on biological criteria for fish damage
- standards on fish damage assessment:
  - Dutch NEN 8775:2020
  - European EN 18110
- several new fish-friendly pumps and turbines

mortality

injury

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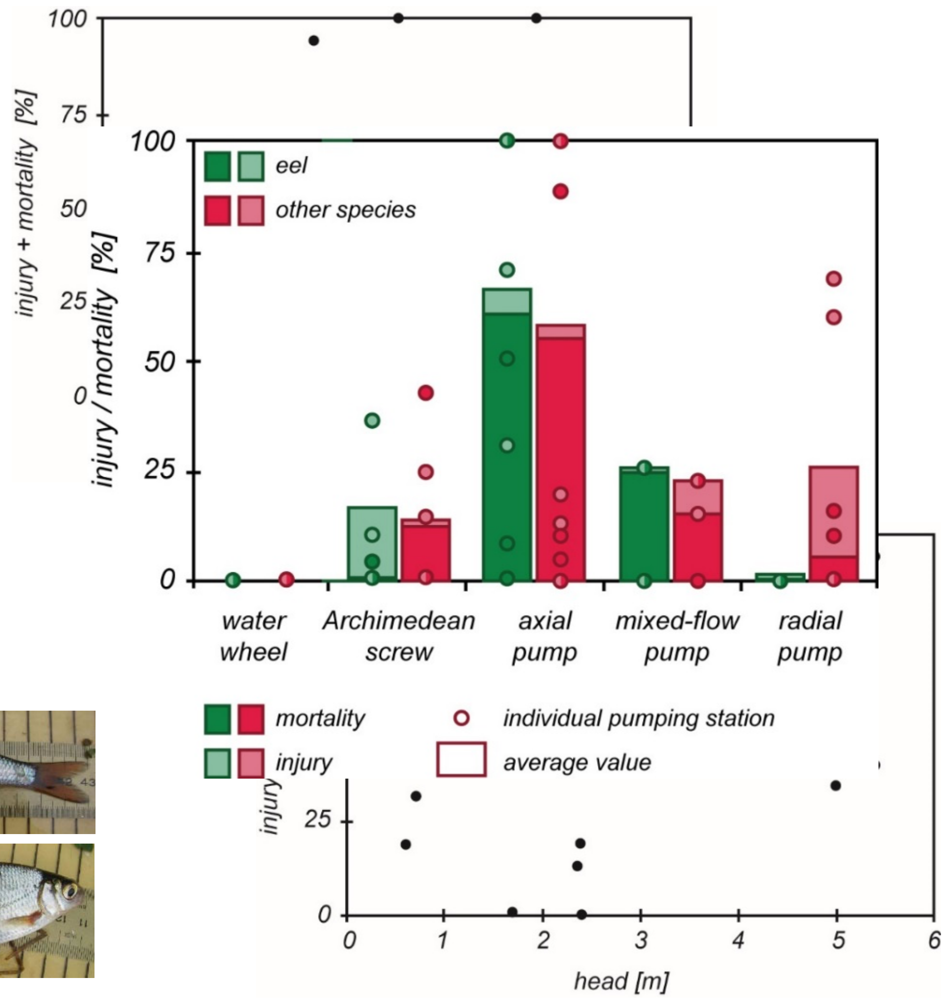



mortality

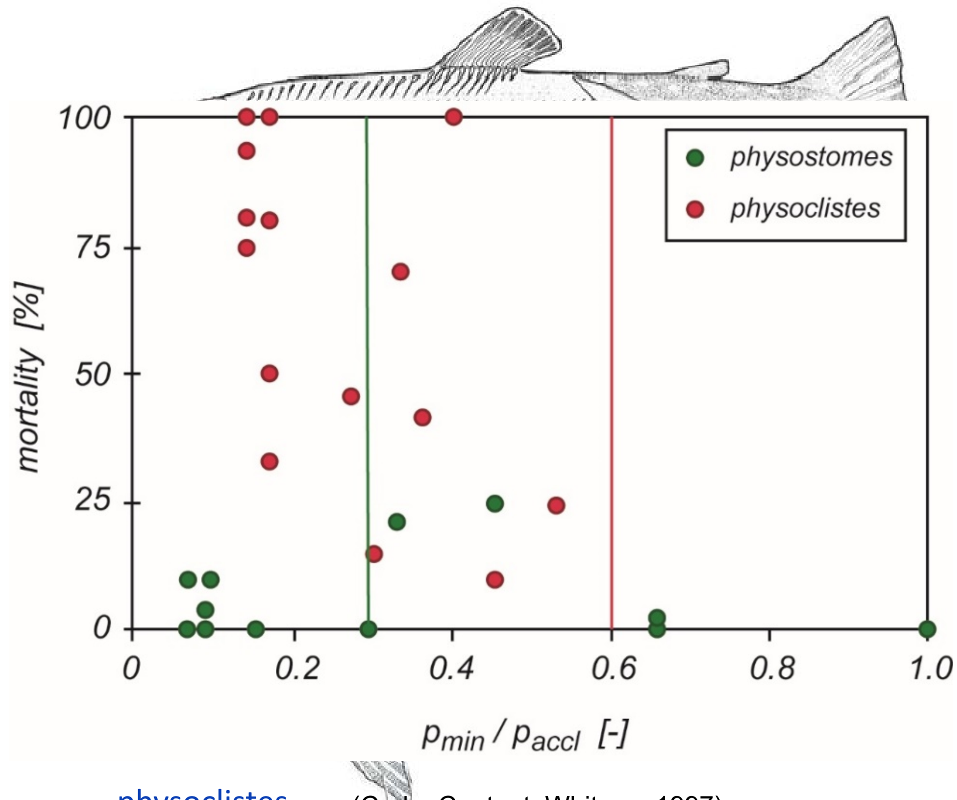

injury

Research program in USA

- Advanced Hydropower Turbine Systems program (AHTS) started in 1994
- strategy: study of biological criteria for injury and mortality
- research labs:
  - Pacific Northwest National Laboratory (PNNL)
  - Oak Ridge National Laboratory
  - Alden Research Laboratory
- primary injury mechanisms :
  - pressure changes
  - shear forces
  - mechanical: blade strike, grinding, entrapment

Pressure changes

- compression:
  no adverse effects
- decompression can lead to
  - rupture of swim bladder
  - haemorrhage
  - release of dissolved gas
- safe margin
  - physostomes can vent gases quickly
    $p > 0.3\ p_{accl}$
  - physiclists require minutes/hours to diffuse gas into the blood
    $p > 0.6\ p_{accl}$



physoclistes (Cada, Coutant, Whitney, 1997)
perch, bass, bluegill sunfish, crappie

Shear forces

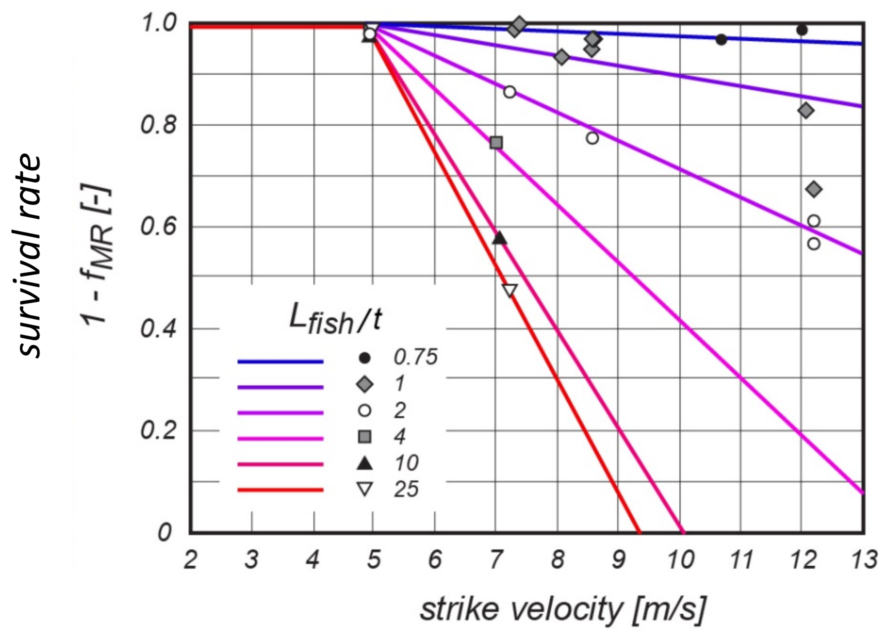
Test Fish	Test Orientation	Strain Rate (cm/s/cm [Δy=1.8 cm])		
		No Significant Injury	No Significant Major Injury	No Significant Deaths
Fall chinook (age-0)	Headfirst	517	852	1008
Fall chinook (age-1)	Headfirst	517	517	852
Spring chinook	Headfirst	517	688	1008
Rainbow trout	Headfirst	688	1008	1008
Steelhead	Headfirst	517	1008	1008
American shad	Headfirst	517	517	517
Fall chinook (age-1)	Tailfirst	688	1008	1008
Spring chinook	Tailfirst	688	1008	1008
Steelhead	Tailfirst	852	1008	1008
Rainbow trout	Headfirst w/ predators	517	NA	NA

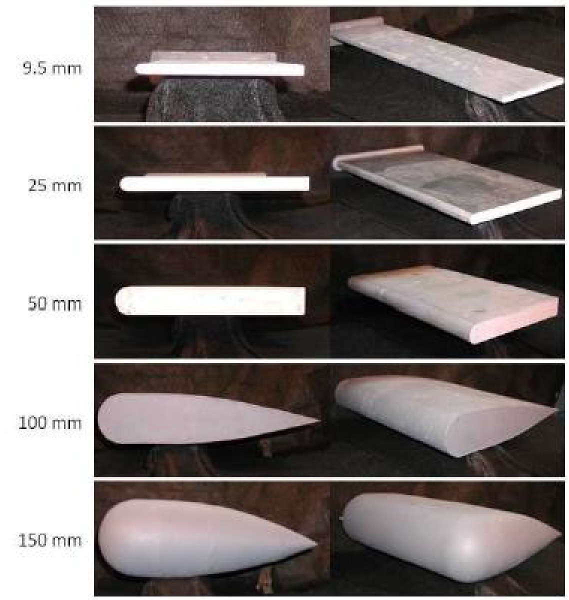
(Neitzel, Richmond, Cada et al., 2000)

Safe margin:

$$\frac{dv_i}{dx_j} < 500/sec$$

Blade strike





t= blade thickness

(Amaral, Hecker, Dixon, 2011)
(van Esch & Spierts, 2014)

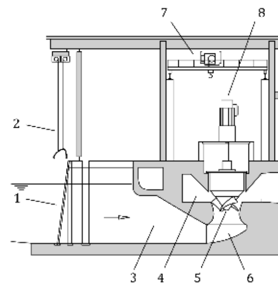
$$f_{MR} = \left[a \cdot \ln\left(\frac{L_{fish}}{t}\right) + b\right](v_1 - 4.8)$$

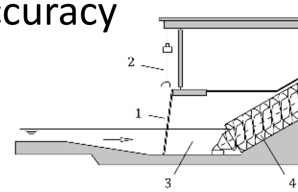
correlation for mutilation ratio f_{MR}

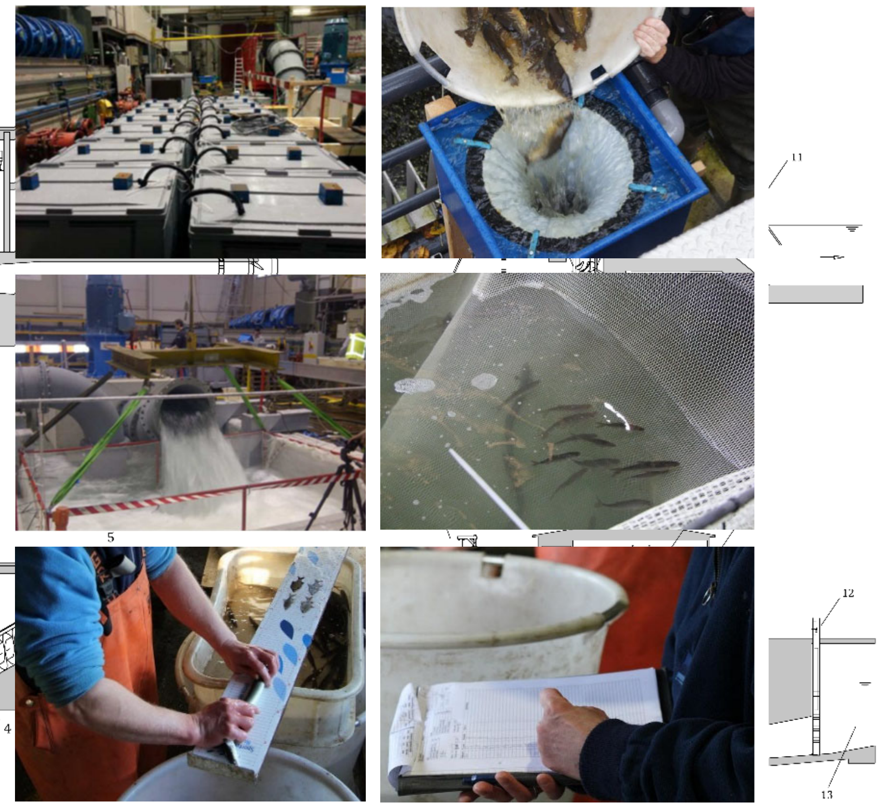
NEN 8775:2020 / EN 18110:2025 standards

Assessment of fish damage in pumps and turbines:

- Tests with live fish
  - choice and origin of fish
  - transportation and storage
  - requirements set-up
  - preparing and conducting experiments
  - assessment of damage, sedation
  - number of fish, statistics, and accuracy
- Fish mortality model
  - blade strike mortality
  - low to moderate head values







Blade strike mortality model

Model for a pump (simplified)

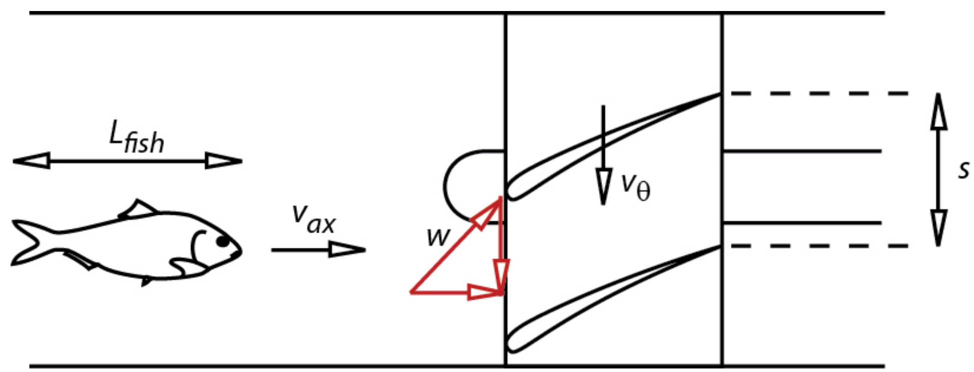
$$t_{fish} = \frac{L_{fish}}{v_{ax}} = \frac{L_{fish} A_1}{Q}$$

$$t_{blade} = \frac{s}{v_\theta} = \frac{2\pi r / n}{N 2\pi r / 60} = \frac{60}{nN}$$

$$P_{co} = \frac{t_{fish}}{t_{blade}} = \frac{L_{fish} A_1 nN}{60Q}$$

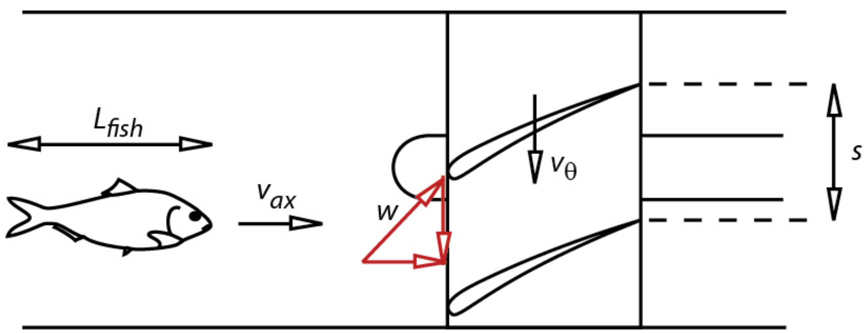
$$f_{MR} = \left[a \cdot ln\left(\frac{L_{fish}}{t}\right) + b\right](w - 4.8)$$

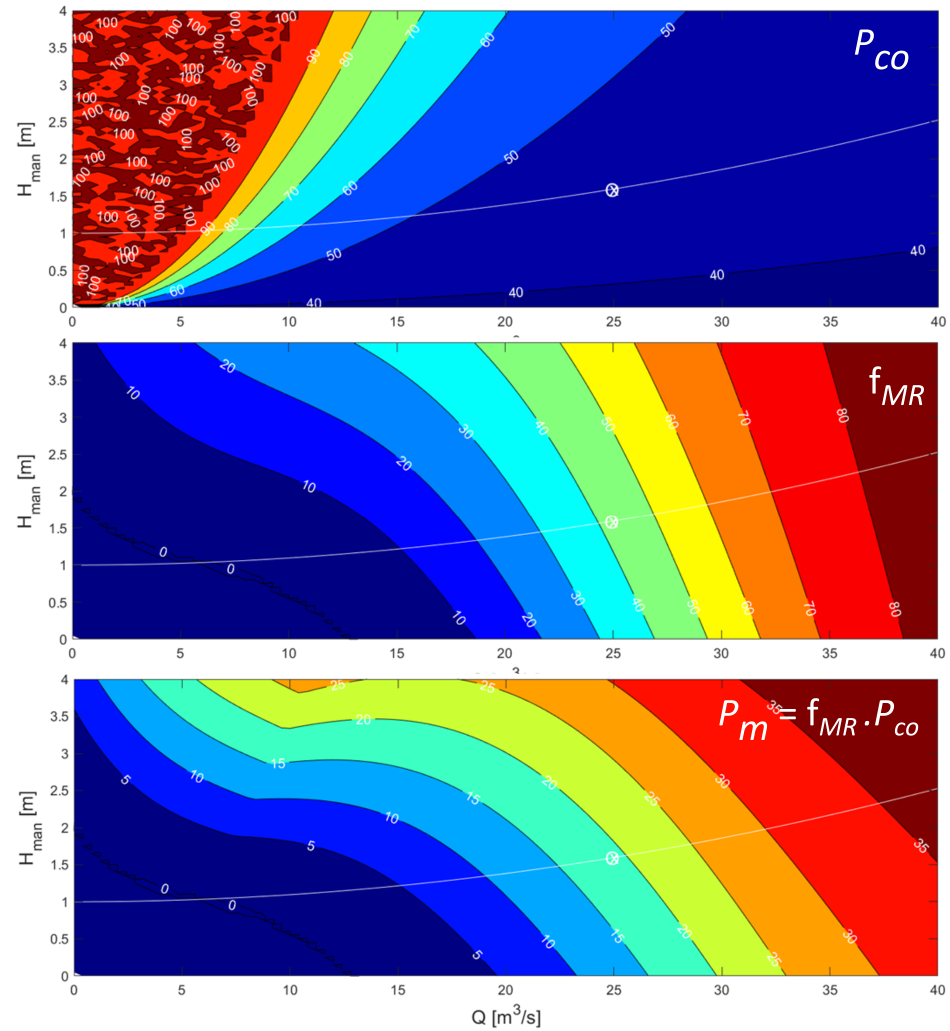
$$P_m = f_{MR} P_{co}$$



Blade strike mortality model

axial-flow pump (N_s = 4.5)
conventional design
D = 2.80 m
N_{blade} = 4
variable speed drive
Trout 25 cm





Blade strike mortality model

Model for a turbine (simplified)

$$w_\theta = \Omega r - \frac{v_r}{\tan\alpha}$$

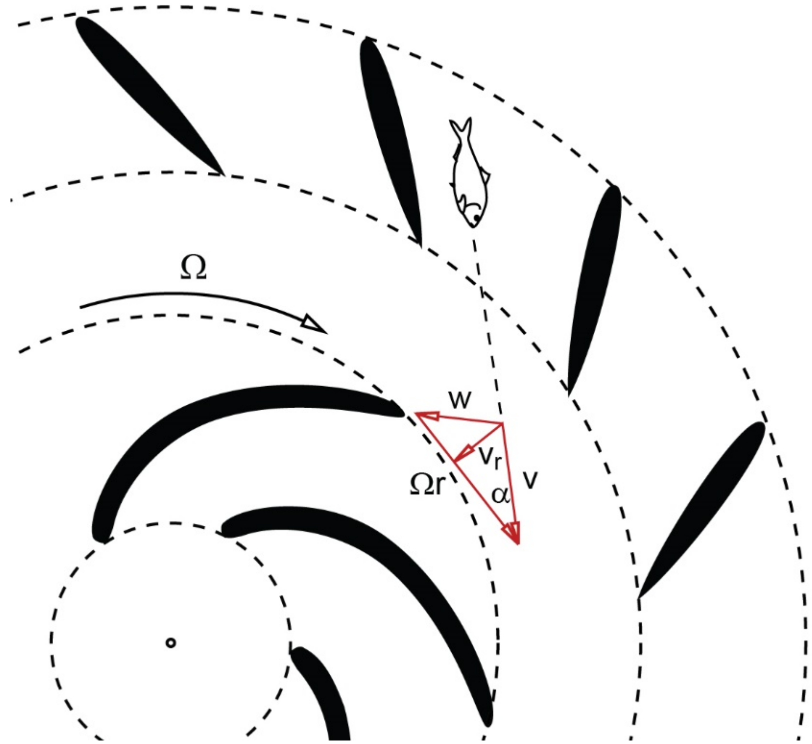
$$t_{fish} = \frac{L_{fish}\sin\alpha}{v_r} = \frac{L_{fish}\sin\alpha\, 2\pi r B}{Q}$$

$$t_{blade} = \frac{s}{w_\theta} = \frac{2\pi r/n}{w_\theta}$$

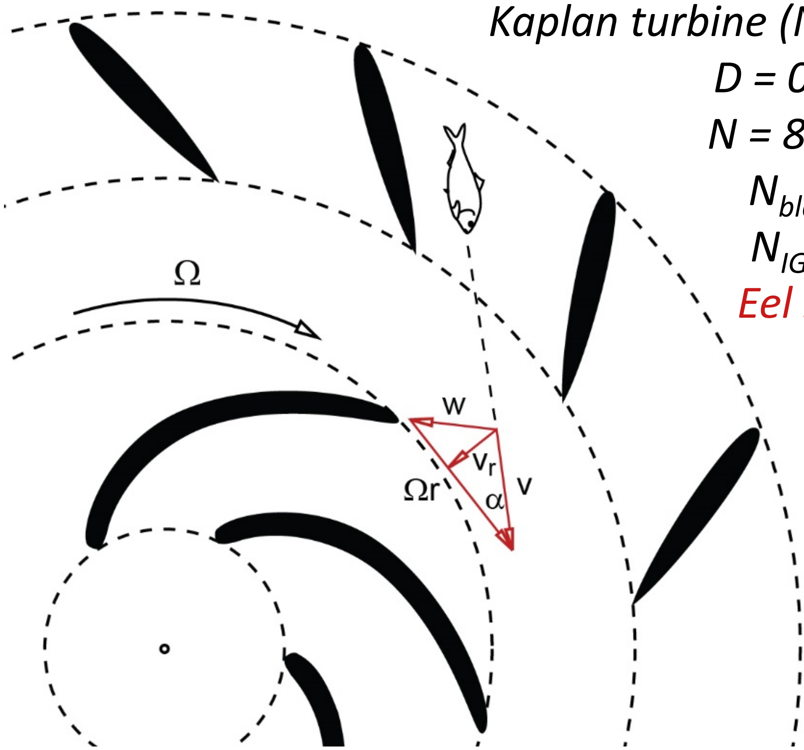
$$P_{co} = \frac{t_{fish}}{t_{blade}}$$

$$f_{MR} = \left[a \cdot \ln\left(\frac{L_{fish}}{t}\right) + b\right](w - 4.8)$$

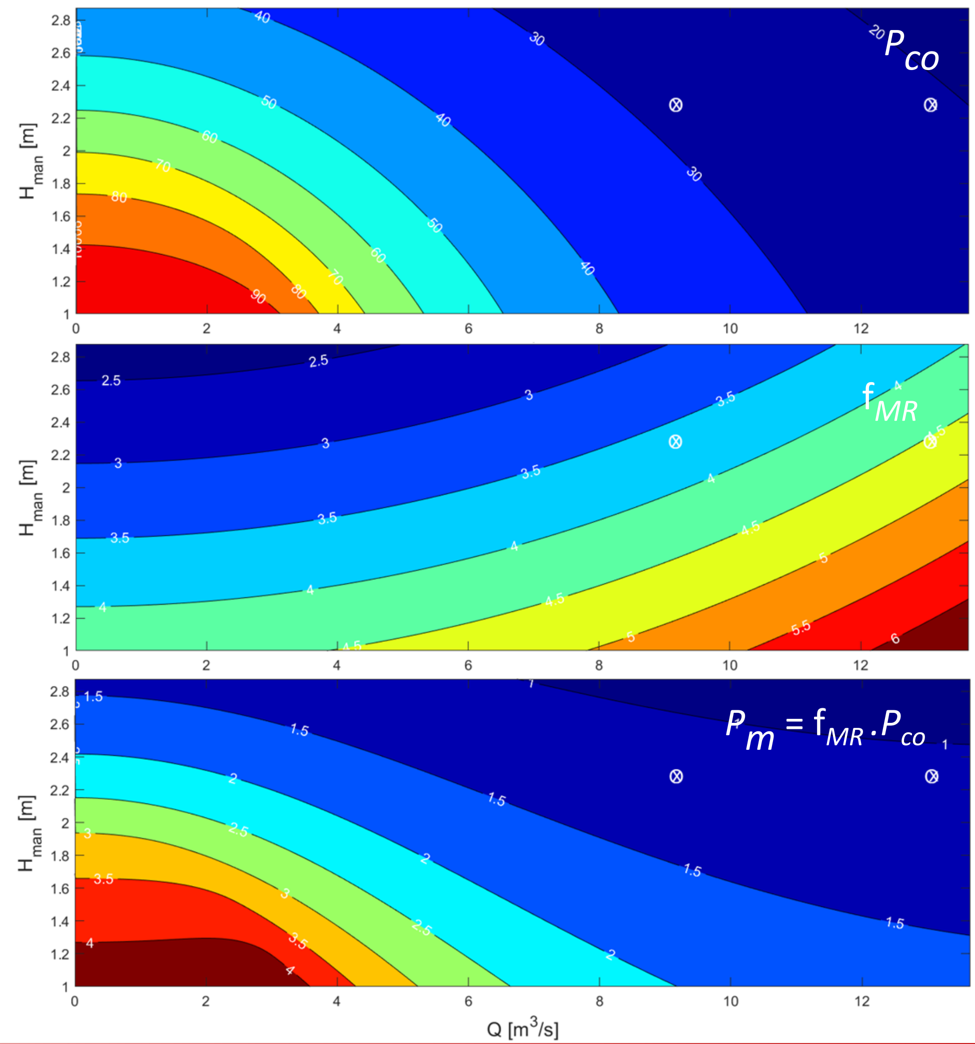
$$P_m = f_{MR} P_{th}$$



Blade strike mortality model



Kaplan turbine (N_s = 4)
D = 0.65 m
N = 88 rpm
N_{blade} = 4
N_{IGV} = 14
Eel 20 cm



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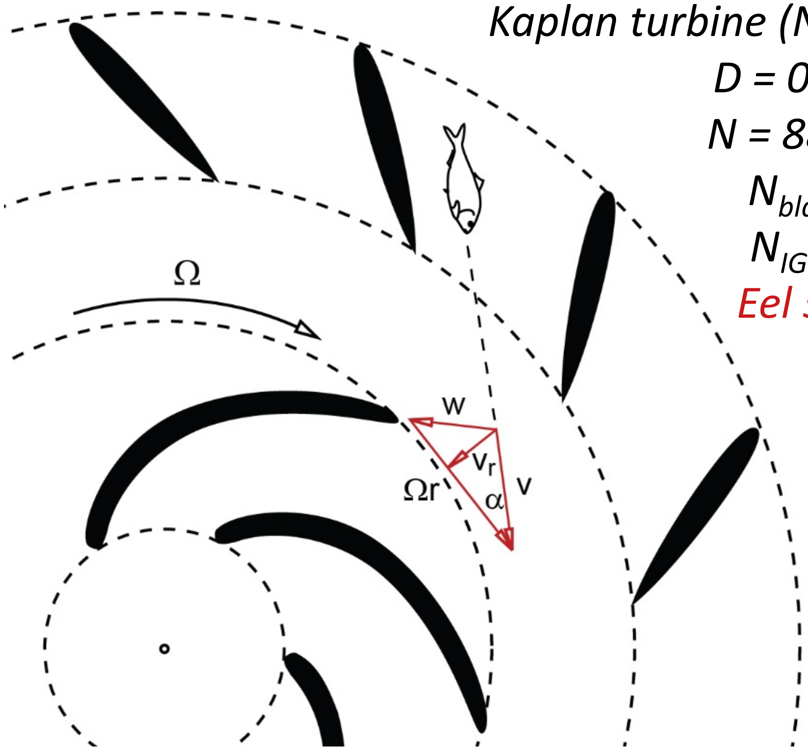


Kaplan turbine ($N_s = 4$)

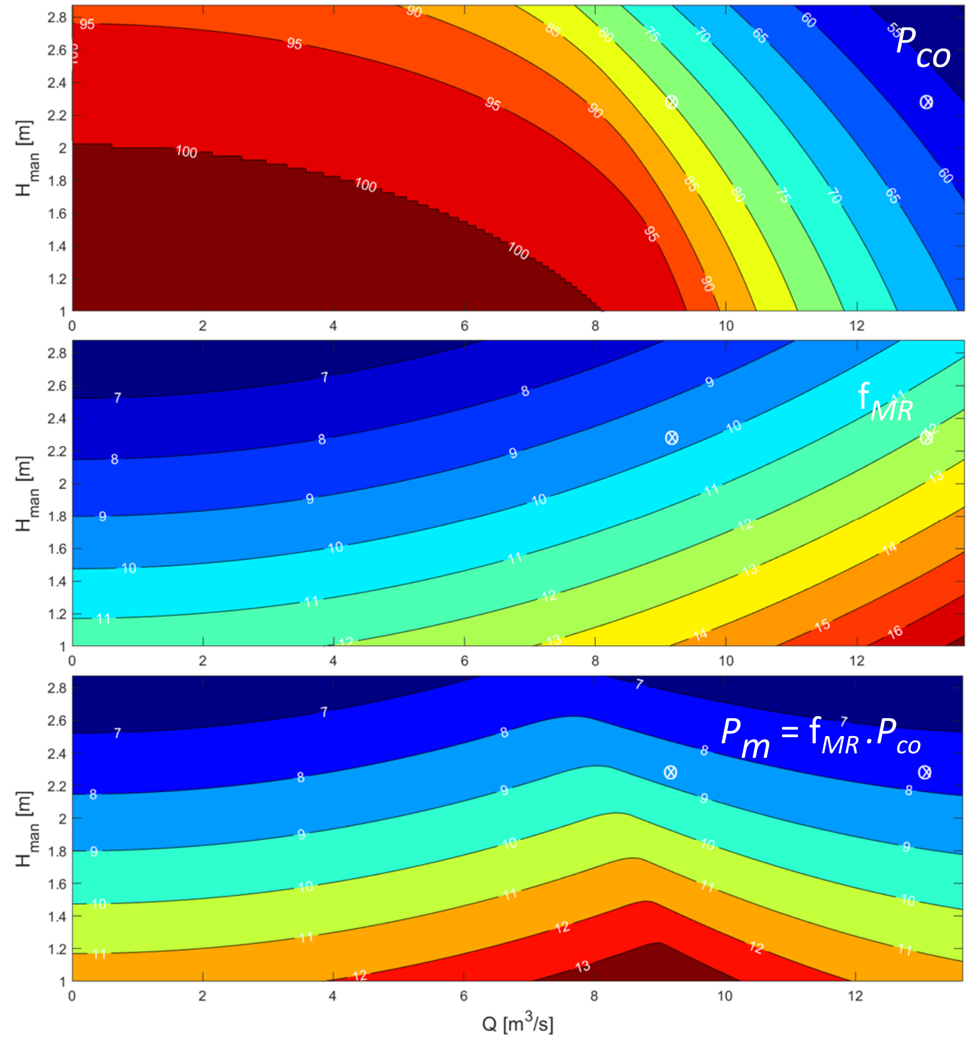
$D = 0.65$ m

$N = 88$ rpm

$N_{blade} = 4$

$N_{IGV} = 14$

Eel 50 cm



Model validation

Flowserve

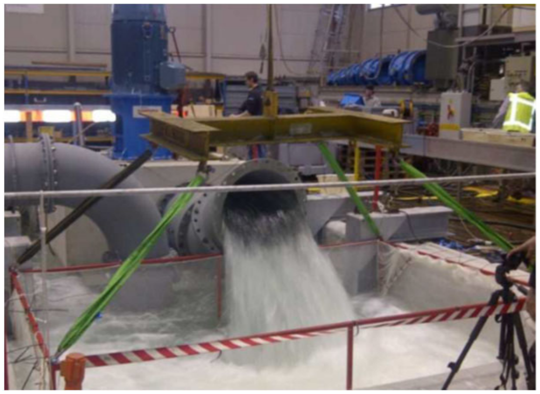
axial-flow, two-bladed pump

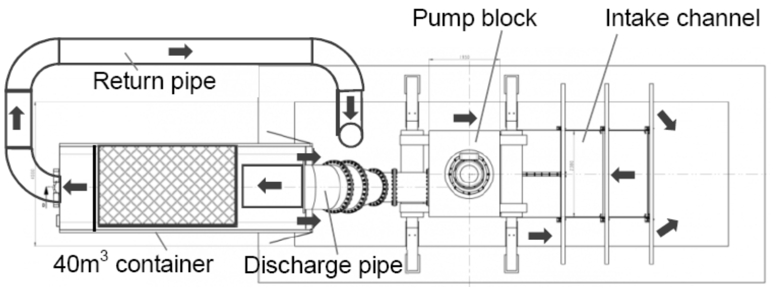
slanted leading edge

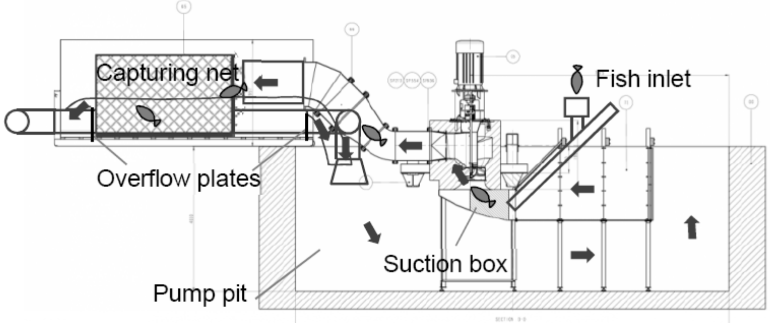
D_i = 56 cm

Speed: 200-380 rpm

Head: 1.4 – 4.0 m







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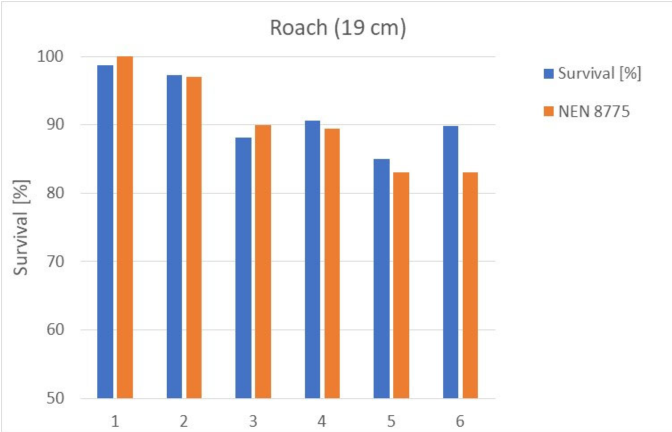
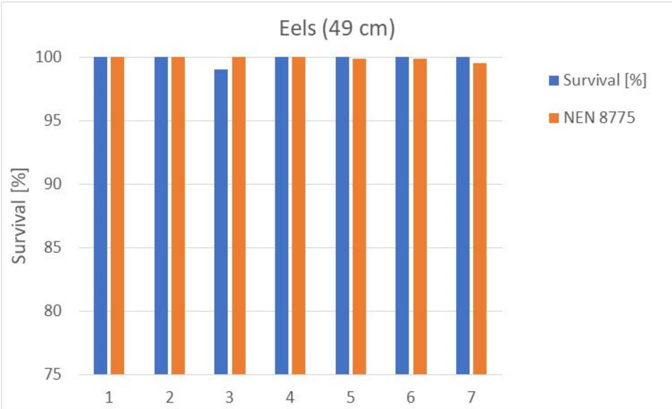
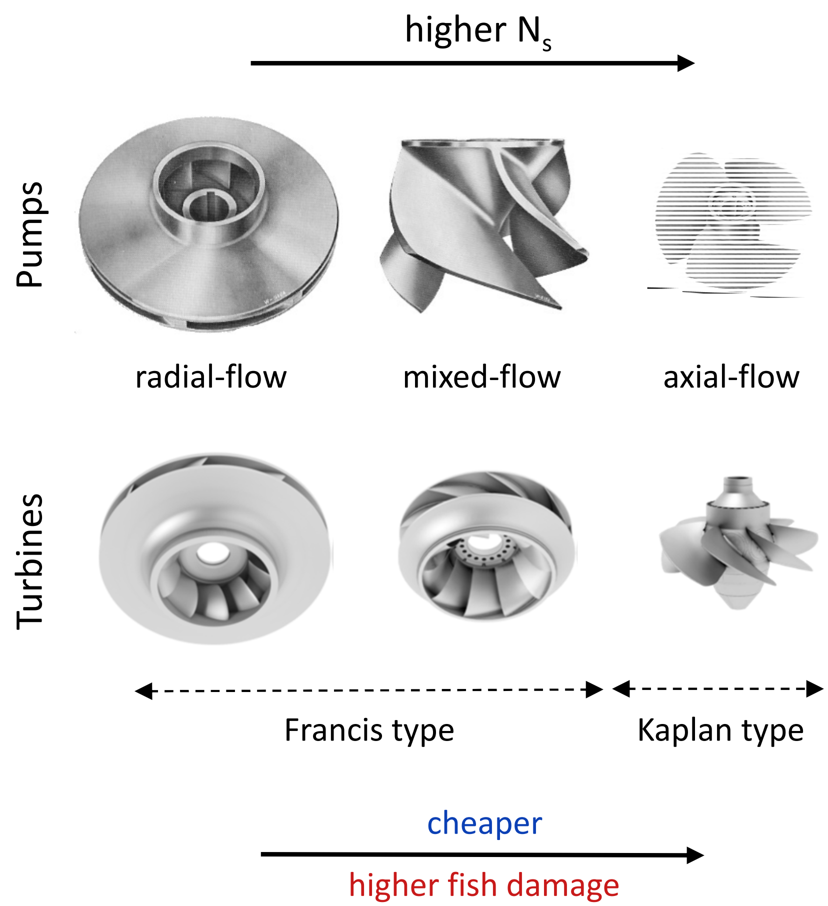




Blade strike damage vs. specific speed

Pump and turbine selection:

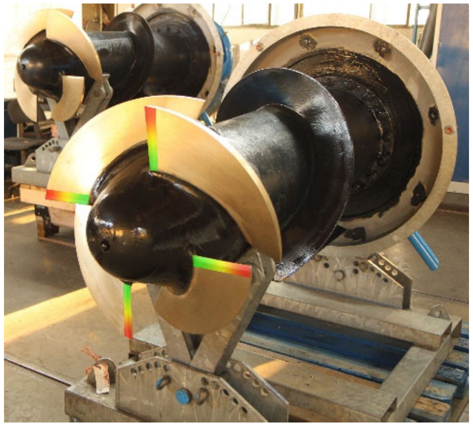
- range of specific speed values N_s
  - low N_s : radial-flow type
  - medium N_s : mixed-flow/Francis type
  - high N_s : axial-flow/Kaplan type
- for same duty head and flow rate:
  larger N_s ⟶ smaller size and higher speed
- for same duty and fish length:
  larger N_s ⟶ higher strike probability
  & higher mutilation ratio



Recent developments

Pump and turbine selection/design

- lower specific speed pump:
  - more fish friendly
  - larger size & lower speed, more expensive
- fewer blades
- leading edges with high slant angle
- thicker leading edges



conventional pump

fish-friendly pump

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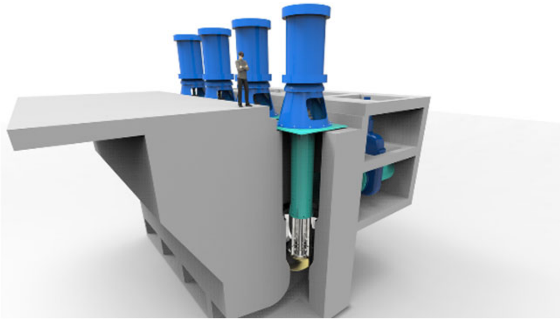
New pump designs

Pentair-Nijhuis

Bedford pumps



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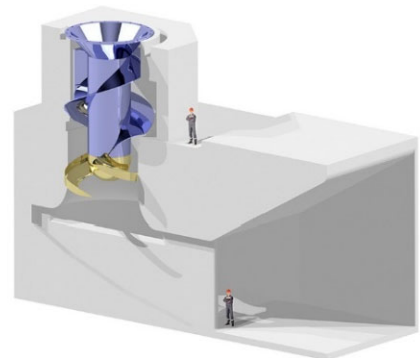
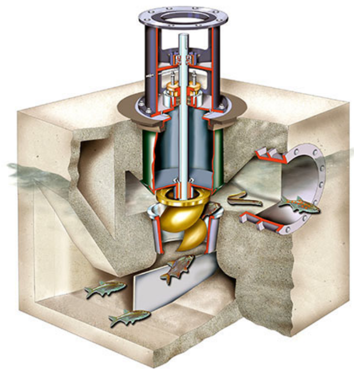
Flowserve



Bosman Watermanagement



Recent developments

New turbine designs

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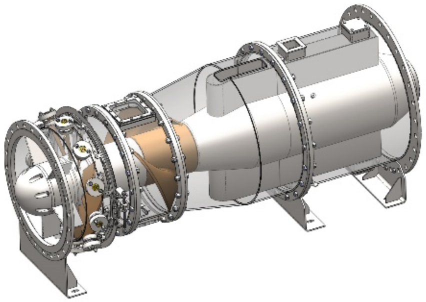
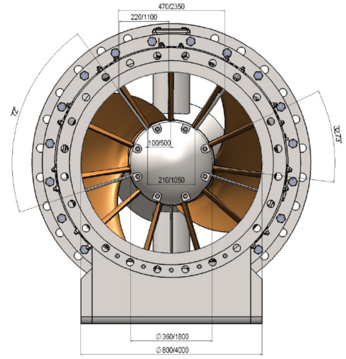
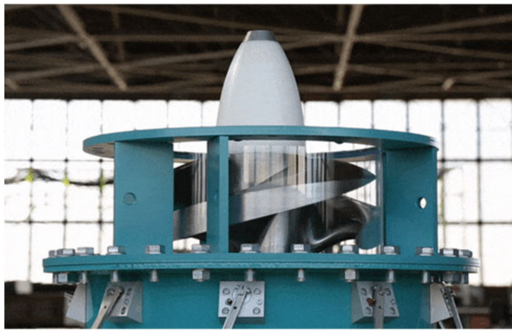
Pentair-Nijhuis





Natel Energy



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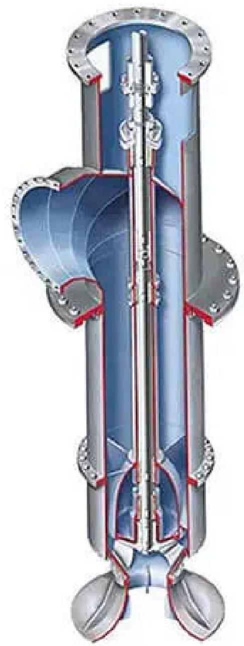
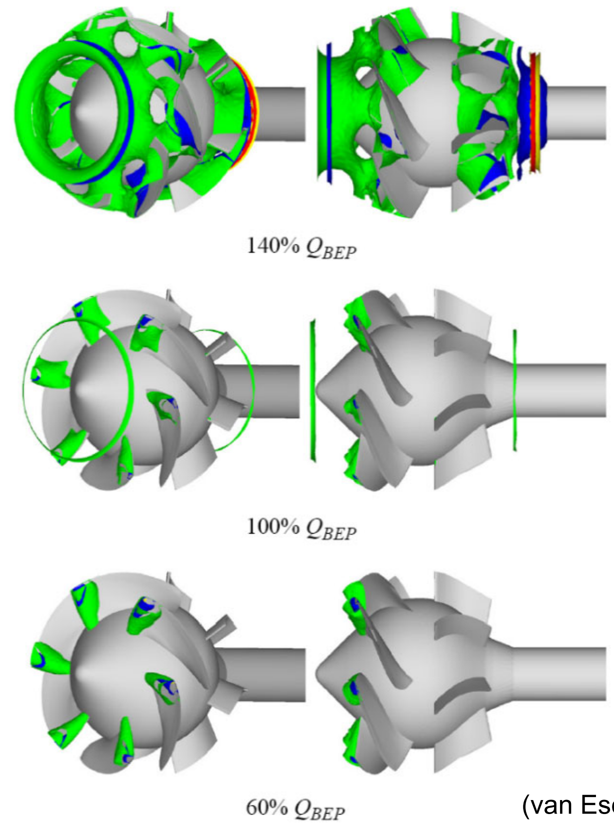
Fish damage in low head pumps



Decompression



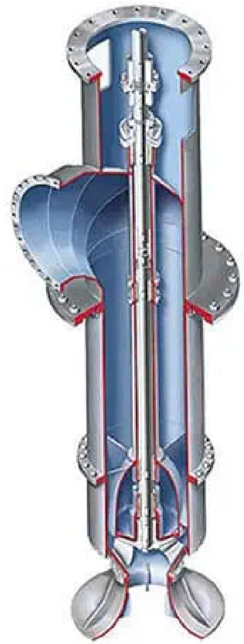
(van Esch, 2012)

Pumping stations:

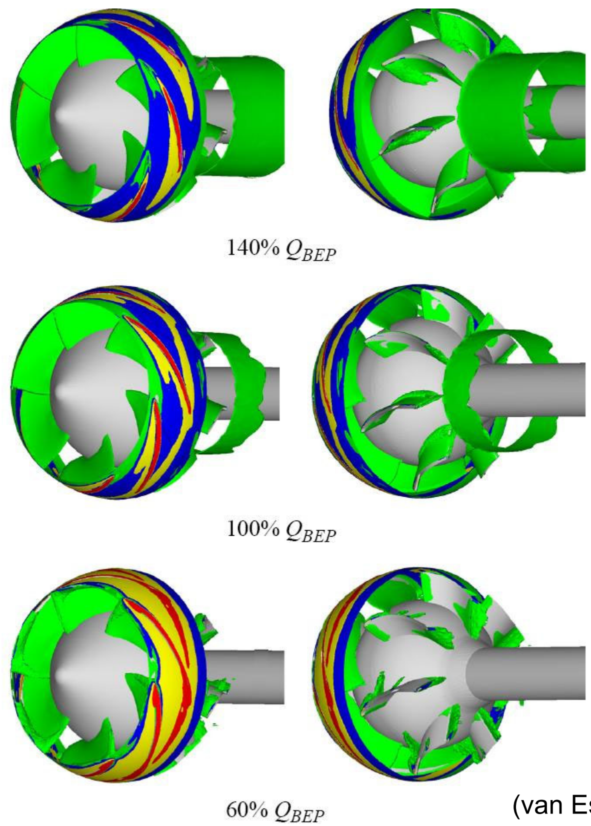
- mixed-flow: ND_1 = 200-300 [rpm.m]
- axial : ND_1 = 250-350 [rpm.m]

$$\frac{p}{p_{atm}} = \quad 1-0.1\left(\frac{ND_1}{200}\right)^2 \; ; \; 1-0.2\left(\frac{ND_1}{200}\right)^2 \; ; \; 1-0.4\left(\frac{ND_1}{200}\right)^2 \; ; \; 1-0.6\left(\frac{ND_1}{200}\right)^2$$

Fish damage in low head pumps



Velocity shear



(van Esch, 2012)

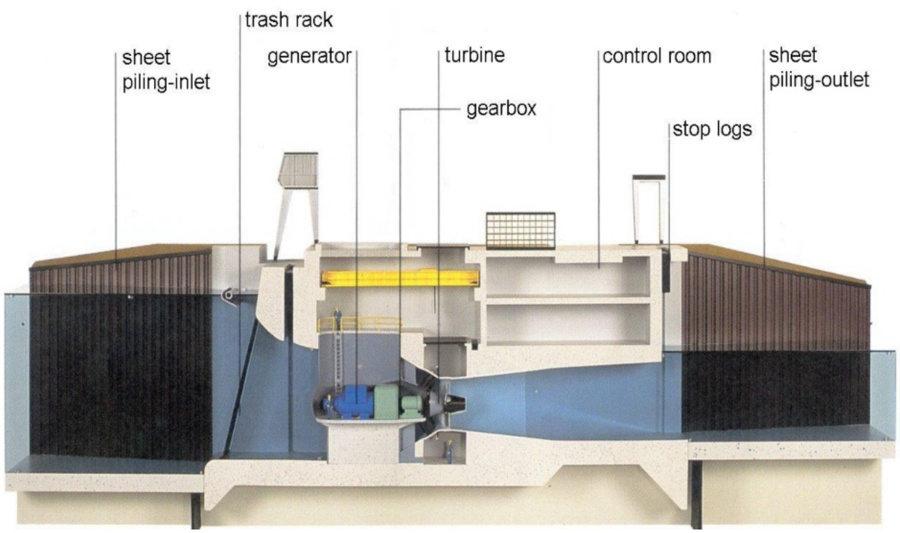
Pumping stations:

- mixed-flow: N = 100-200 [rpm]
- axial : N = 200-700 [rpm]

$$|\underline{\omega}| = 500\left(\frac{N}{700}\right)\ ;\ 1000\left(\frac{N}{700}\right)\ ;\ 2000\left(\frac{N}{700}\right)\ ;\ 4000\left(\frac{N}{700}\right)\ ;\ 8000\left(\frac{N}{700}\right)\ [s^{-1}]$$

TU/e

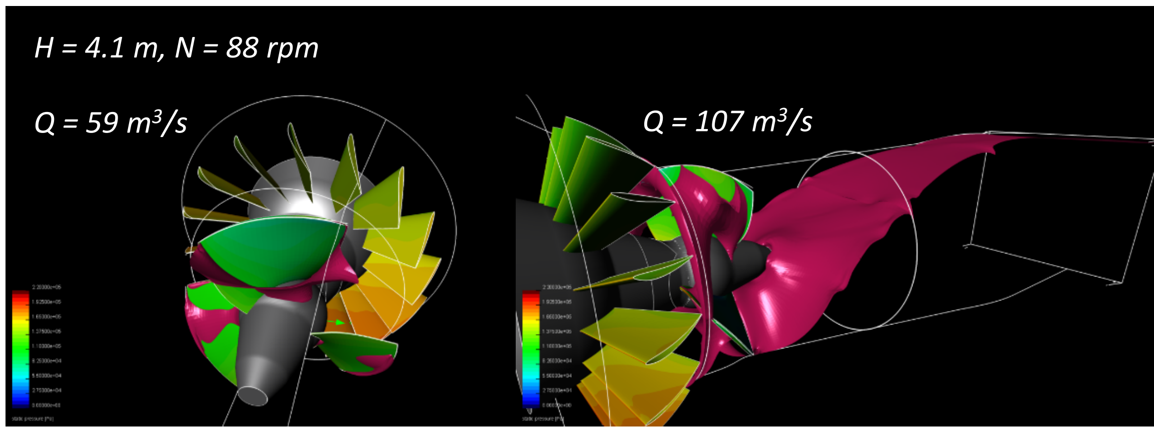
Fish damage in low head turbines



D_{runner} = 4 m
N_{blade} = 3
N = 88 rpm

Decompression

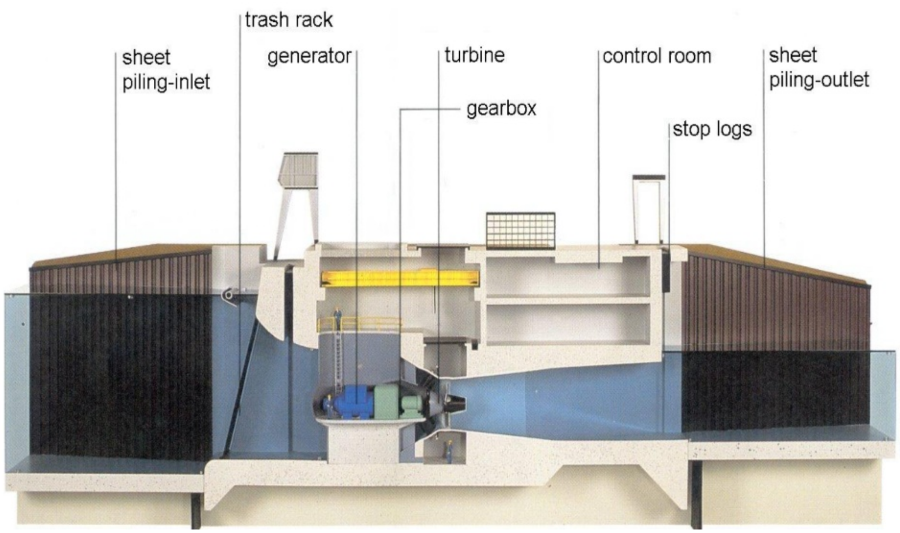
level		depth	acclimation pressure		criteria for barotrauma	
		[m]	[m]	[kPa]	physoclists < 60%	physostomes < 30%
water surface	20.85 m+NAP	0	10	100	60	30
mid-level	12.6 m+NAP	8.25	18.25	182.5	109.5	54.75
bottom	8.18 m+NAP	12.67	22.67	226.7	136.02	68.01



Iso-pressure surfaces of 110 kPa

(van Berkel, van Esch, Vriese, 2014)

Fish damage in low head turbines



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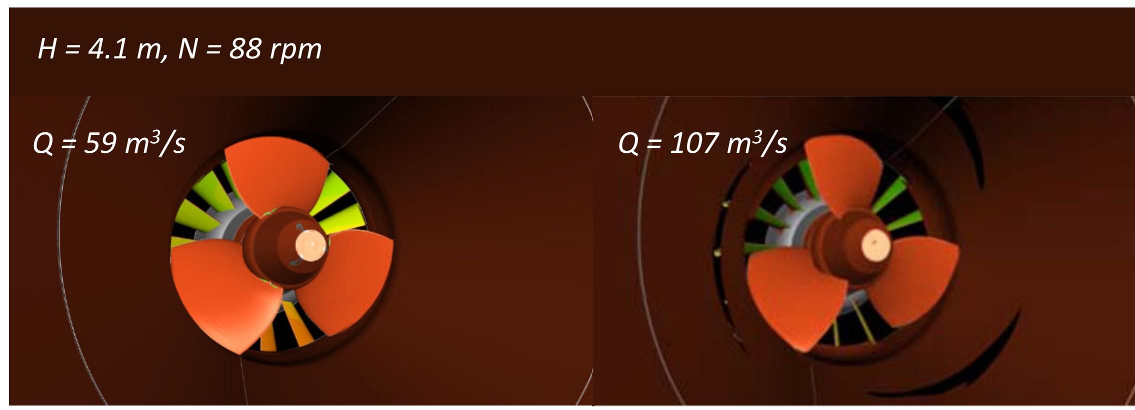
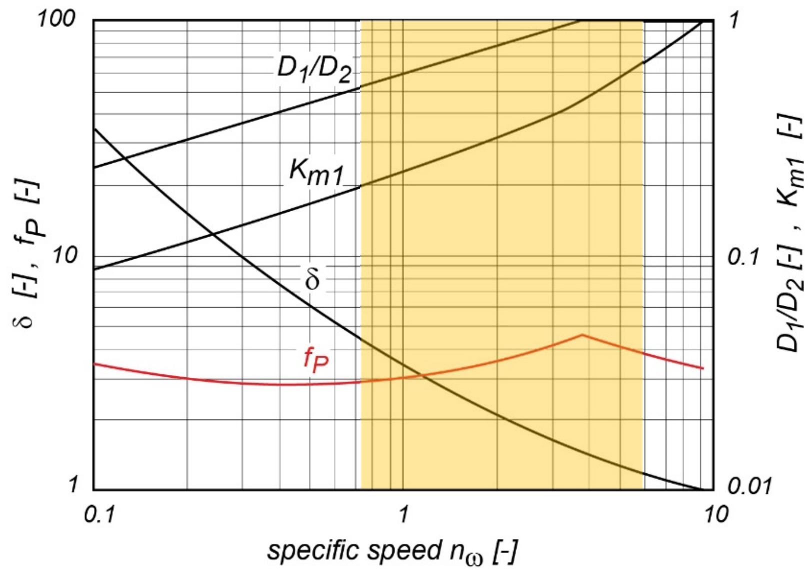


Iso-vorticity 500 s^{-1} (orange)

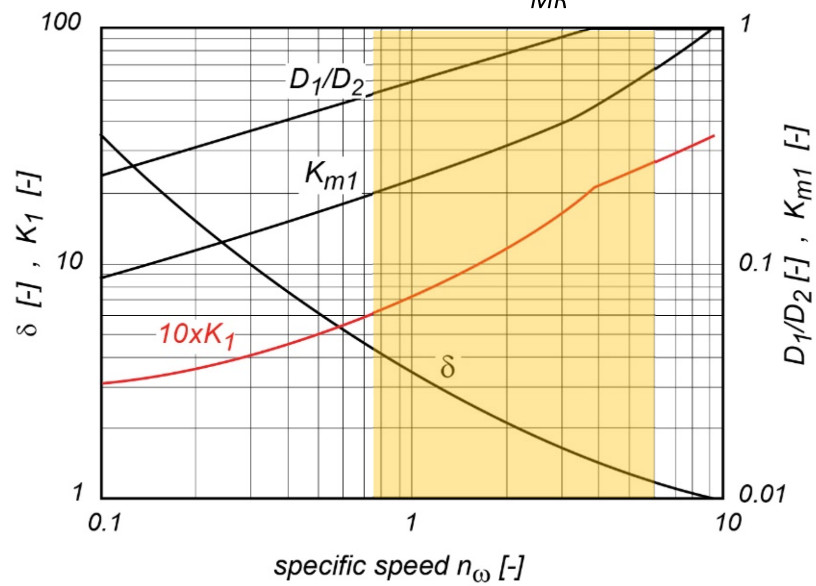
(van Berkel, van Esch, Vriese, 2014)

Blade strike damage vs. specific speed

Strike probability P_{th}



Mutilation rate f_{MR}



$$K_{m1} = \frac{v_1}{\sqrt{2gH}}$$

$$P_{co} = \frac{t_{fish}}{t_{blade}} = \frac{L_{fish} \cdot nN}{60\, K_{m1} \sqrt{2gH}} = f_P \frac{L_{fish} n}{\pi D_1} \quad ; \quad f_P = \frac{1}{2\sqrt{2}} \frac{D_1}{D_2} \frac{n_\omega \delta}{K_{m1}}$$

$$V_{s,1} = \sqrt{V_{m,1}^2 + V_{t,1}^2} = K_1 \sqrt{2gH}$$

$$K_1 = \sqrt{K_{m,1}^2 + K_{t,1}^2} \quad ; \quad K_{t,1} = \frac{1}{2\sqrt{2}} \frac{D_1}{D_2} n_\omega \delta$$

(van Esch, 2012)