Lowering fish mortality at hydropower stations in Dutch rivers

Dead ends and new chances

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Since 1990: 3 HPS in Dutch rivers

Max flow 400-450 m³/s
Max head 3-4.6 m
Lower Rhine

Rhine

Meuse

= weir

= HPS

Rijkswaterstaat
Design HPS: 4 horizontal Kaplan bulb turbines
Direct fish mortality at HPS Linne in river Meuse

Silver eel: 13-24% (18%)

Smolts: 6-8%
Other species: <5%
Fish >30 cm: < 10 %
Eel mortality vs turbine flow HPS Linne

Mortality chance vs Turbine flow (m3/s)

- 1990 (av length=55.9 cm)
- 1999 (av length=62.8 cm)
- 2002 (av length=64.4 cm)
Direct fish mortality at HPS Maurik in river Rhine

Silver eel: 7-22% (turbineflow 100 and 50 m3/s)

Smolts: 4-10%
Policy on hydropower

- Late 90’s: several plans for new HPS’s in river Meuse
  → Risk: high cumulative mortality for migratory species (eel, salmonids)

- 2001: Maximum cumulative mortality rate of 10% in river Meuse was set for eel and salmon

- Existing cumulative mortality rate was already >10% in river Meuse

- 2002: Parliament demanded to take measures
  → Desk study on possible measures
  → NGO: idea for testing an innovative fish guidance system at HPS Linne (2009-2012)
Fish Guidance System Fish Flow Innovations

Flow bypasses = 5 m³/s (<2 % of HPS)
Passage through bypass:

- 0% silver eel
- 4% smolts
- <2% other species
Eel friendly turbine management

Since nov 2011 implemented at all 3 HPS’s

What is it?

- Turbine flow ranges from 30-120 m3/s and is regulated by turning the blades
- The higher the turbine flow, the more space between the blades, and the lower the mortality of silver eel
- When the river flow is divided over less turbines, turbine flow is higher and mortality of silver eel is lower
- For example: instead of 4 turbines of 50 m3/s, they use 2 turbines of 100 m3/s
Mortality silver eel & turbine flow at HPS Linne

3 years of research
av. Length 60-65 cm

$y = 676.41x^{-0.97}$

$R^2 = 0.85$
Mortality silver eel & turbine management

- Normal operation
- Max turbine flow

River flow (m3/s) vs. Mortality (%)

1° turbine
2° turbine
3° turbine
4° turbine

Sterfte (%)
Rivierdebiet (m3/s)
Eel friendly turbine management

• Eel mortality can be lowered by 1/3
• But: turbine flow can’t be max when head is high (techn. damage)
• So: eel mortality can be lowered by ¼ at max
• Average mortality from 18% → 14%
• This is not enough to reach the target of <5% at HPS

More measures are needed
Expert workshop fish protection at HPS’s (2013)

- Cooperation of Government, Energy companies & Dutch Angling Association
- Experts from Canada, USA, UK, Germany

3 types of measures:
- Behavioural systems
- Mechanical systems
- Fish friendly turbines
Results workshop fish protection HPS’s 2013

Behavioural systems (lights & acoustics):
• It is uncertain if this works efficient on these locations (deep, turbid water, lots of debris)
• It doesn’t work for all species
• Enormous system when built at the right angle (across the entire river, trash racks needed in front)

Mechanical systems:
• Largely proven, feasible and work for all species
• Questions about required scale and cleaning possibilities
• Enormous costs (10-30 million euro)
Results workshop Fish protection 2013 (2)

Fish friendly turbines: two options are suitable for exist. HPS’s

- Pentair Fairbanks Nijhuis FFI turbine (0% eel mortality in test with scale model)
- Improved Kaplan turbine (no test available)

Fish friendly turbines are most promising solution

We want a full scale experiment with a fish friendly turbine at HPS Linne
Which turbine is best for HPS Linne?

- Nijhuis FFI turbine (expensive) or
- Improved Kaplan turbine (much cheaper)

Study with models predicting fish mortality (2014)

Computational Fluid Dynamics model of HPS Linne shows that:
- Fish damage by ‘’shear’’ force is low
- Fish damage by ‘’low pressure’’ is present at high turbine flows for some species, but is not seen in field research

Thus:
- Mortality is mainly caused by mechanical damage (collision with the runner blades)
Estimate fish mortality with blade strike model

Blade strike model of Techn Univ. Eindhoven (van Esch) is based on:
- fish species
- fish length
- thickness of the leading edge of the runner blades
- angle of the runner blades and guide vanes
- turbine flow
- speed of runner
- number of runner blades
- position of fish entering the turbine (near the hub or tip)

→ fish mortality is calculated for different Head and Turbine flows (Hill charts)
Predicted mortality eel (65 cm) at HPS Linne
Validation with field research HPS Linne

Deviations < 5%
Best fit: eel passes near the tip of the blades (dark blue)
Predicted mortality eel (65 cm) at HPS Linne based on turbine flows during okt-dec over last 18 yrs

Existing Kaplan: 13%

Improved Kaplan: 7%
   (Minimum gap, thick leading edge)

Nijhuis-FFI: 2%
   (spiral vanes, thick leading edge, variable speed)
Which turbine is best?

- Improved Kaplan is the most cost effective measure
- Target = max 5% eel mortality at HPS
- This can only be achieved by Nijhuis FFI turbines
- AIM: experiment with Nijhuis FFI turbine at HPS Linne

Keep in mind:
- Average size of silver eels in the Meuse has increased from 60 cm in 1990 to 90 cm in 2015!
- Model predicts 19% mortality of eel 90 cm, instead of 13% for 65 cm eel, for existing turbine of HPS Linne.
Experiment with Nijhuis FFI turbine possible?

- Rel. high cost of Nijhuis turbine → Looking for subsidies to start experiment at HPS Linne
- Subsidy on sustainable energy was guaranteed on a yearly basis during 15 years of energy production
- But: financing in advance was not possible
- Energy company didn’t want to make long term investments
- Rijkswaterstaat/ministry isn’t allowed to finance the turbine

DEAD END?

- Rijkswaterstaat started a permitting process for the HPS’s to achieve max 5% mortality on silver eel and smolts at each HPS.
Stopping turbines during migration

Problem:
• Long migration period for silver eel (aug-jan) and smolts (march-may)
• Migration is concentrated in peaks and depends highly on river discharge (eel) and temperature (smolts)
• We need to predict migration peaks by an early warning system
Early warning system silver eel: MIGROMAT

- Tested at HPS’s Meuse in 2002
- Reduction of silver eel mortality max 69%
Migromat - considerations

- Bad results in river Shannon (Ireland) - because of lake conditions?
- Good results in river Weser and Main (publications?)
- Software has been improved → more accurate alarms
- Efficient enough for HPS Meuse and Rhine to reach the target of 5%?
- Eel mortality is much higher these days (av. length of 90 cm)
- Efficiency must be >75% to lower eel mortality from 19% to 5%
Stopping turbines during migration (2)

Early warning system for **smolts** hasn’t been developed yet.

Idea:
- Use the existing monitoring stations of smolts in Ourthe and Roer (tributaries of Meuse)
- Develop a migration model which predicts migration peaks, based on water temperature and maybe also discharge in the tributaries were smolt migration starts
Smolt migration in river Ourthe (Mery) in 2013
Trap & transport eel

- Started in Rhine and Meuse at 2 HPS’s in 2013-2015
- Fishermen catch eel with fykenets upstream the HPS and release them downstream the HPS
Trap & Transport eel (2)

Results **Meuse** at HPS Lith:
- autumn catch = 1,4 - 2,7 ton
- estimated silver eel migration (by Imares) = 80 ton → 1/30 less mortality
- HPS mortality (Imares) = 15% → 14,5%

Results **Rhine** at HPS Maurik:
- Autumn catch = 1,2 - 1,4 ton
- Estimated eel migration (Imares) = 9 ton → 1/6 less mortality
- HPS mortality (Imares) = 16% → 13,3%

-> LOW efficiency!!
Conclusions (1)

- Fish guidance system of FFI doesn’t work for large HPS’s (>400 m³/s) in Dutch rivers **DEAD END**

- Other fish guidance systems (behavioural an mechanical) are not effective enough or very expensive (10-30 million) and debris is likely to be a problem **DEAD END**

- Eel friendly turbine management is implemented but not enough to reach the target of <5% mortality for 1 HPS

- A full scale experiment with Nijhuis FFI turbine at HPS Linne is highly recommended as a sustainable solution for all species, but financing is a problem **CHANCE !!**
Conclusions (2)

- Stopping the turbines during peak migration is possible for silver eel by using the Migromat, but it has to be monitored very well to prove that efficiency is enough to reach target <5%.  **CHANCE for eel**

- Stopping the turbines during peak migration is **maybe** possible for smolts, but an early warning system has to be developed for the Meuse, together with Belgium  **CHANCE?? for smolts**

- Trapping and transport of silver eel show that it isn’t effective at HPS in Meuse and Rhine, and it is not sustainable  **DEAD END**
Thank you!