ETH zürich

Laboratory of Hydraulics, Hydrology and Glaciology

Advanced Bypass System for Downstream Migration of European Key Umbrella Fish Species

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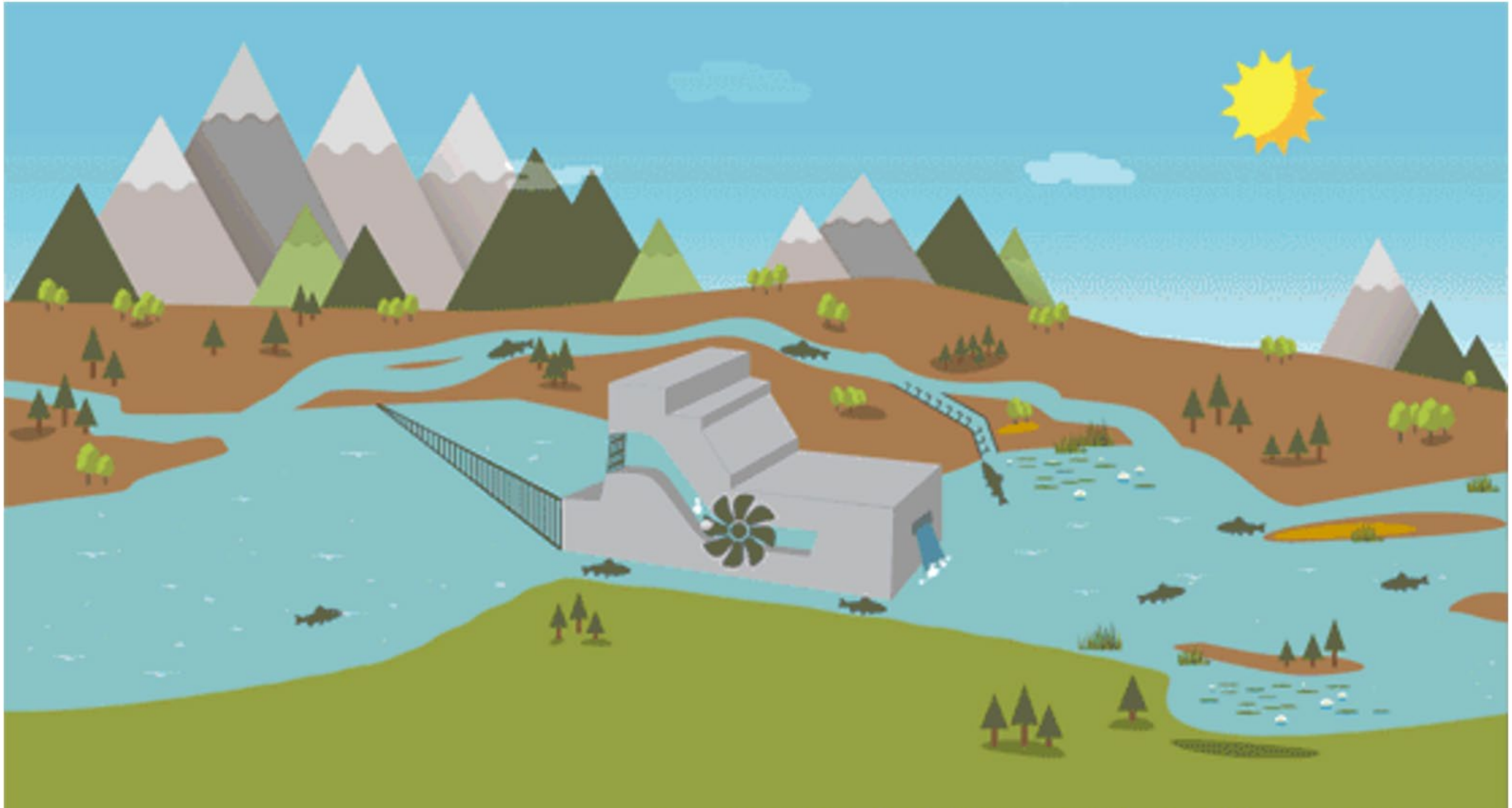
The 2nd International Conference on
Sustainability in Hydropower 2023
–Ecological mitigation, best practises and governance

(Photo: VAW)

Reestablishing river connectivity in Switzerland



Source: https://www.bafu.admin.ch/bafu/de/home/themen/biodiversitaet/dossiers/fischwanderung.html

Reestablishing river connectivity in Switzerland

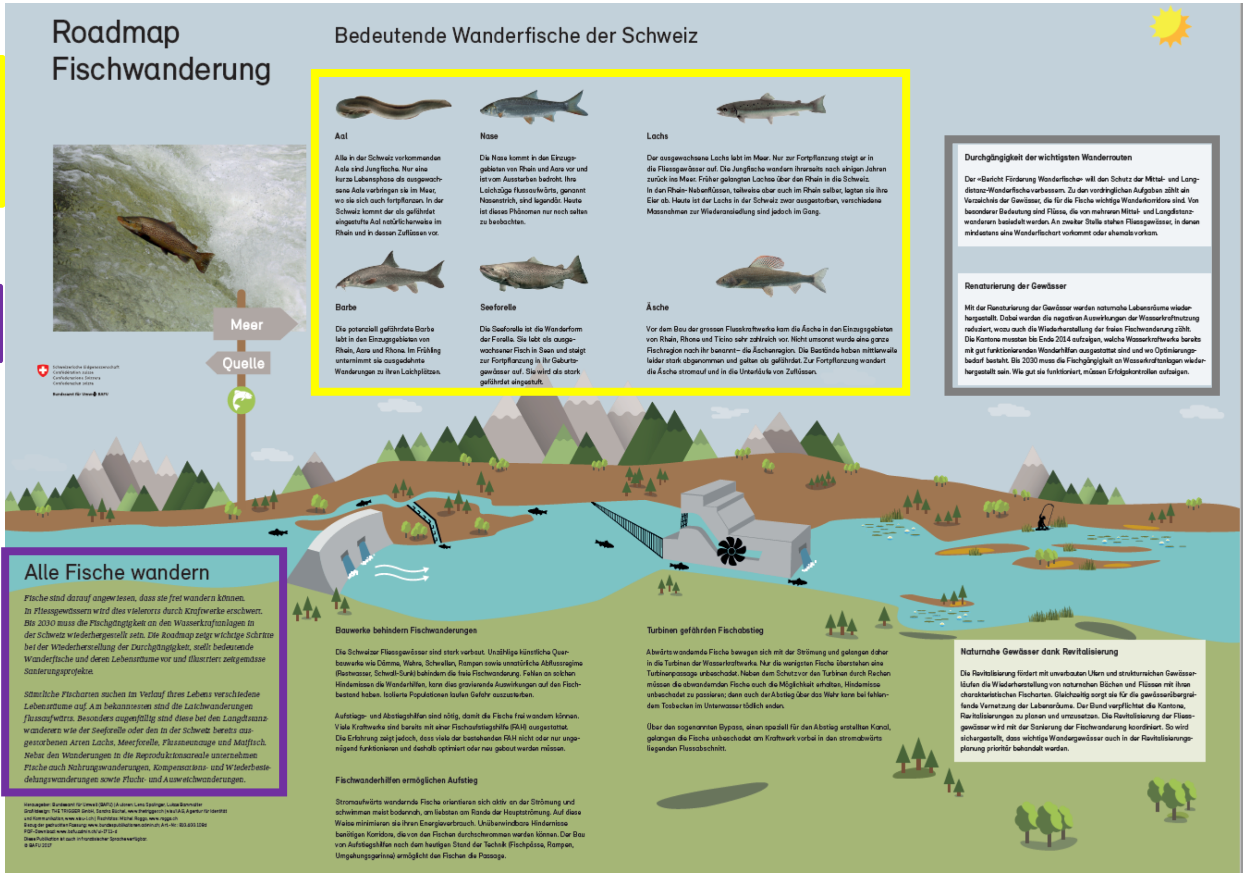
Restore river connectivity for fish movements

- Target migratory species – Eels; nase; Brown trout; Barbus; Lake Brown trout; Grayling

- All fish move – need to go up and downstream

- Set of priorities
  - ➢ Prioritize systems with two or more medium to long distance migrants
  - ➢ Then go to rivers with at least one migratory species present
- 2014 – Cantons to define which hydropower dams to install fish passages
- 2030 – All have to show efficiency

Target-setting and monitoring?



Source: BAFU Roadmap Fischwanderung

https://www.bafu.admin.ch/dam/bafu/de/dokumente/biodiversitaet/ud-umwelt-diverses/roadmap-fischwanderung.pdf.download.pdf/BAFU_Roadmap_DE_Fischwanderung.pdf

Current state of research in the field

Design of bypass systems

Various bypass designs have been studied
(e.g., Haro *et al*., 1998; Meister, 2020; Beck, 2020)

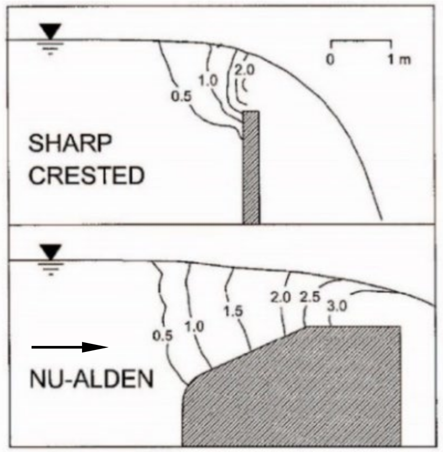
A few bypass design guidelines including hydraulic and geometric threshold values are available, e.g.,

- Q_{by}/Q_d = 2−10% (USBR, 2006; Ebel, 2018)
- $U_{by,in}$ = 0.3−1.5 m/s (Lehmann *et al*., 2016)
- $U_{by,in}/U_o$ = 1.0−2.0 (Ducharme, 1972; Ebel, 2018)

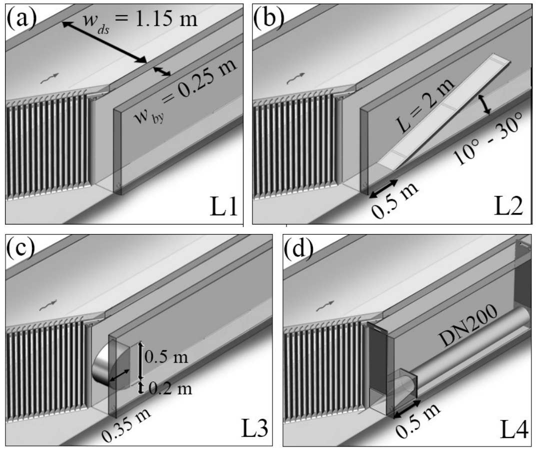
Recommendations partly differ among each other and are often limited to certain fish species

Q_d (m³/s)	design discharge of HPP
Q_{by} (m³/s)	bypass discharge
U_o (m/s)	average approach flow velocity
$U_{by,in}$ (m/s)	average flow velocity at bypass openings

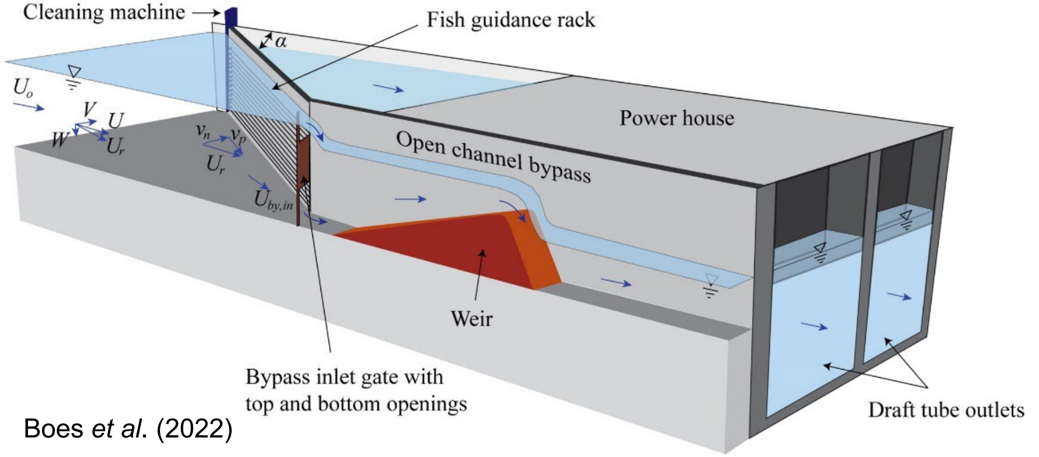
Average velocity contours (m/s)



Adapted from Haro *et al*. (1998)



Beck (2020)

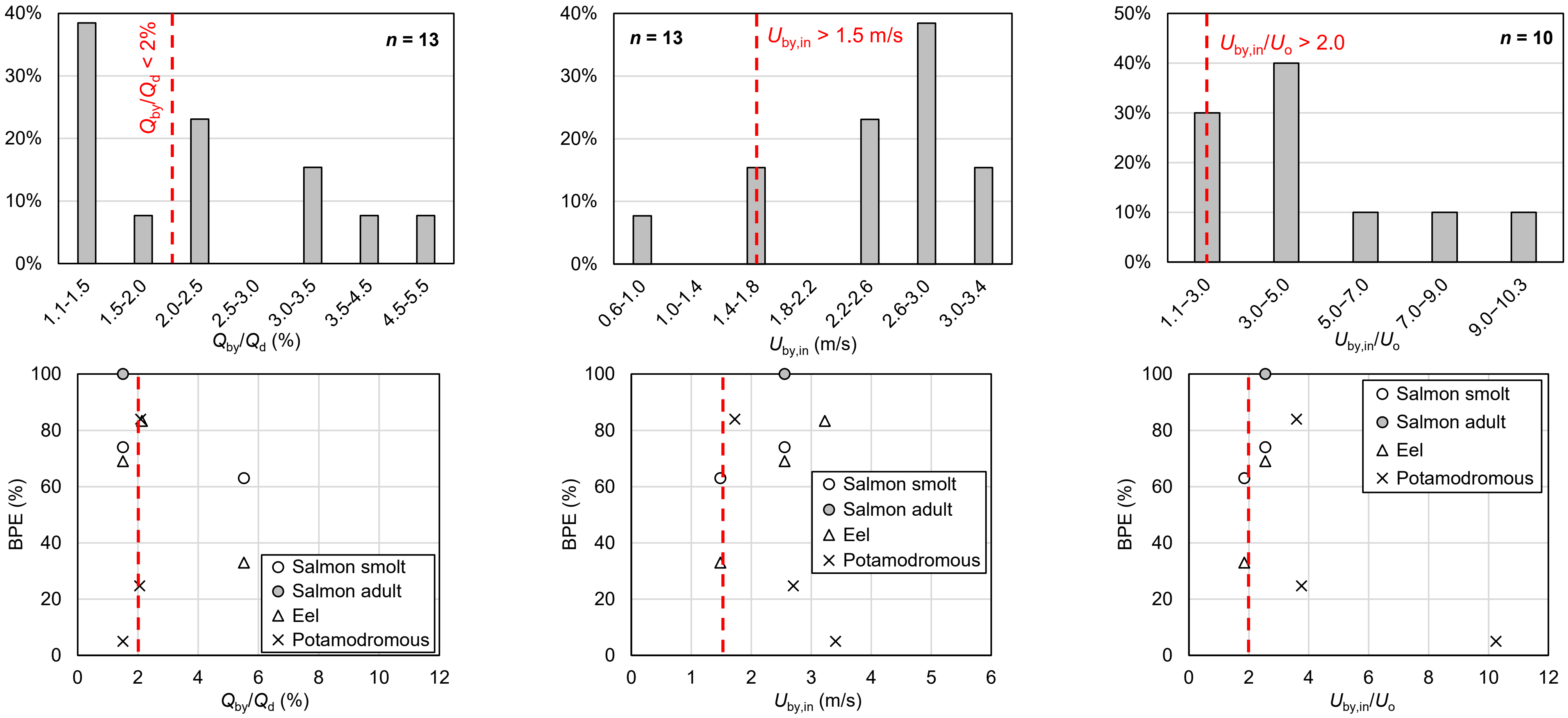


Boes *et al*. (2022)

Current state of research in the field

Review of international case studies

Bypass passage efficiency (BPE) of horizontal bar racks with open channel bypass equipped with inlet gate with bottom and/or top openings

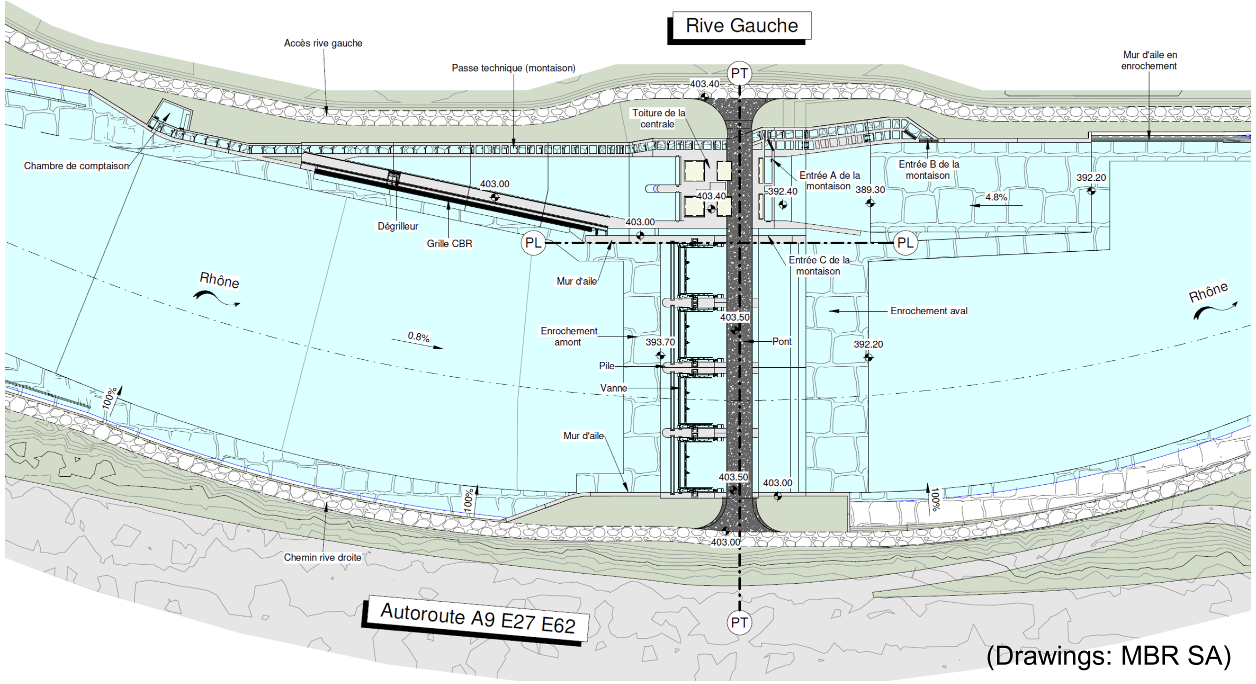


Ethohydraulic tests of a state-of-the-art bypass design
Overview

Investigation of fish swimming behavior and passage at bypass inlet gate with bottom and top opening

Pilot project HPP Massongex-Bex-Rhone as reference case


(Visualization: MBR SA)



(Drawings: MBR SA)

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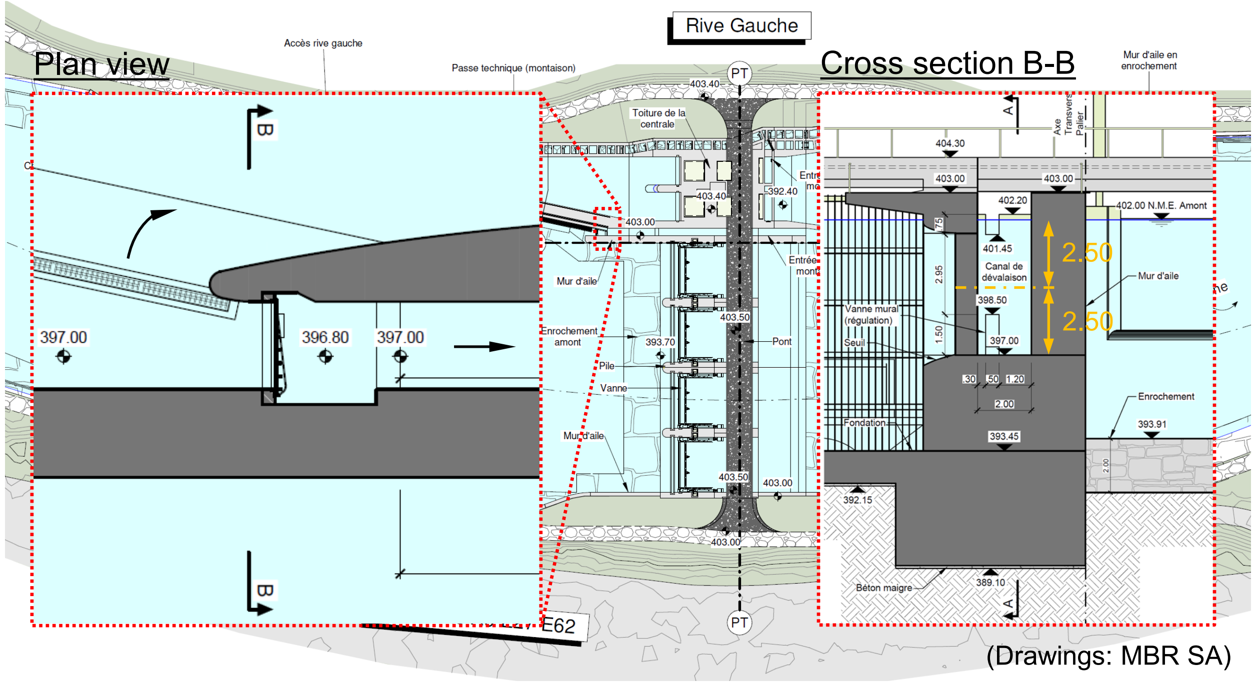
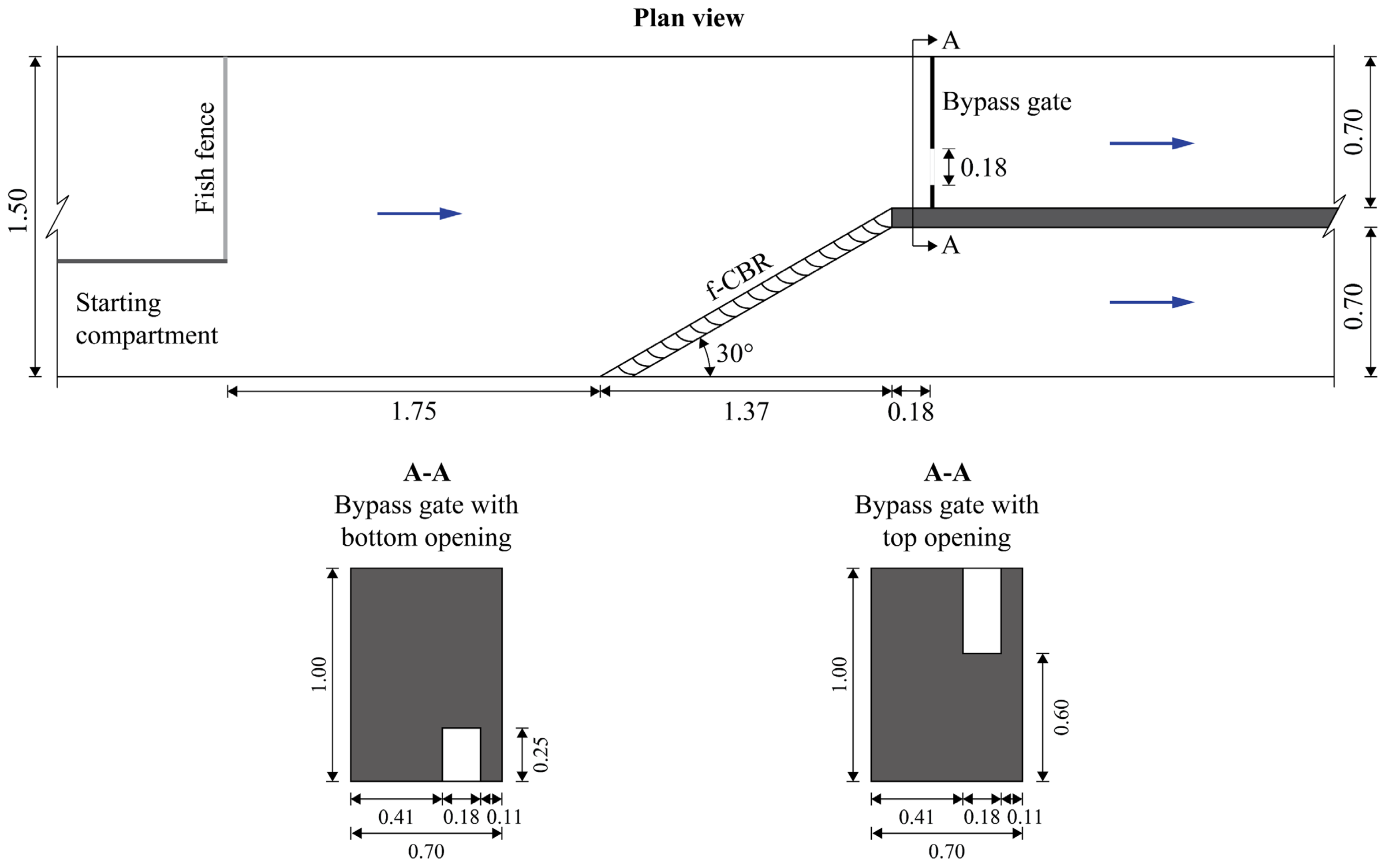


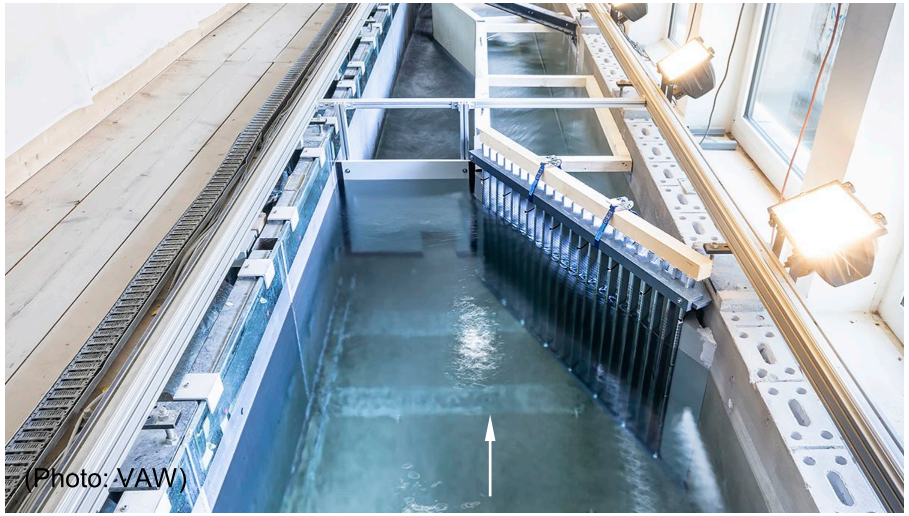
(Drawings: MBR SA)

Ethohydraulic tests of a state-of-the-art bypass design

Physical model



(Photo: VAW)



(Photo: VAW)

Ethohydraulic tests of a state-of-the-art bypass design
Methodology

Flow field measurements with acoustic Doppler velocimetry (ADV) and propeller flowmeter

Position of bypass inlet opening	Discharge	Water depth		Flow velocity		
	Approach flow Q_o [l/s]	Approach flow h_o [m]	Bypass h_{by} [m]	Approach flow U_o [m/s]	Bypass inlet $U_{by,in}$ [m/s]	Ratio $U_{by,in,max}/U_o$ [-]
top	400	0.90	0.50	0.30	0.8-1.7	5.7
	540	0.90	0.50	0.40	0.8-1.7	4.3
	670	0.90	0.50	0.50	0.8-1.7	3.4
bottom	400	0.90	0.50	0.30	1.9-2.0	6.8
	540	0.90	0.50	0.40	1.9-2.0	5.0
	670	0.90	0.50	0.50	1.9-2.0	4.0

4 weeks of ethohydraulic tests with

- Brown trout (*Salmo trutta*)
- Common barbel (*Barbus barbus*)

Test procedure

- 8 replicates for each fish species and configuration
- Groups of 3 fish for each test
- Acclimatization in starting compartment for 15 min
- Test duration max. 45 min
- Visual observation and video recordings

Brown trout (*Salmo trutta*)

Length: 176 + 24 mm (Range: 114 mm to 229 mm)

Common barbel (*Barbus barbus*)

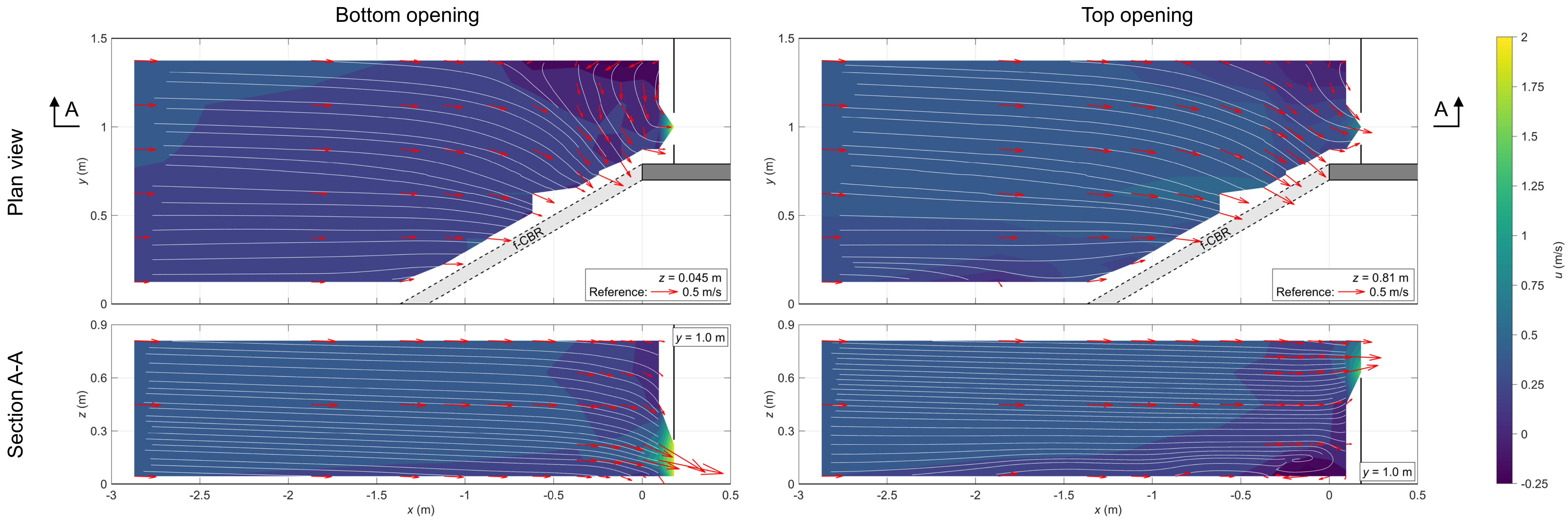
Length: 158 + 47 mm (Range: 96 mm to 269 mm)

(Photos: M. Roggo)

Ethohydraulic tests of a state-of-the-art bypass design

Mean streamwise flow velocity for U_o = 0.4 m/s

Results from ADV measurements.



Ethohydraulic tests of a state-of-the-art bypass design

Video recordings of (attempted) bypass passage

Ethohydraulic tests of a state-of-the-art bypass design

Proportions of bypass passage and refusal

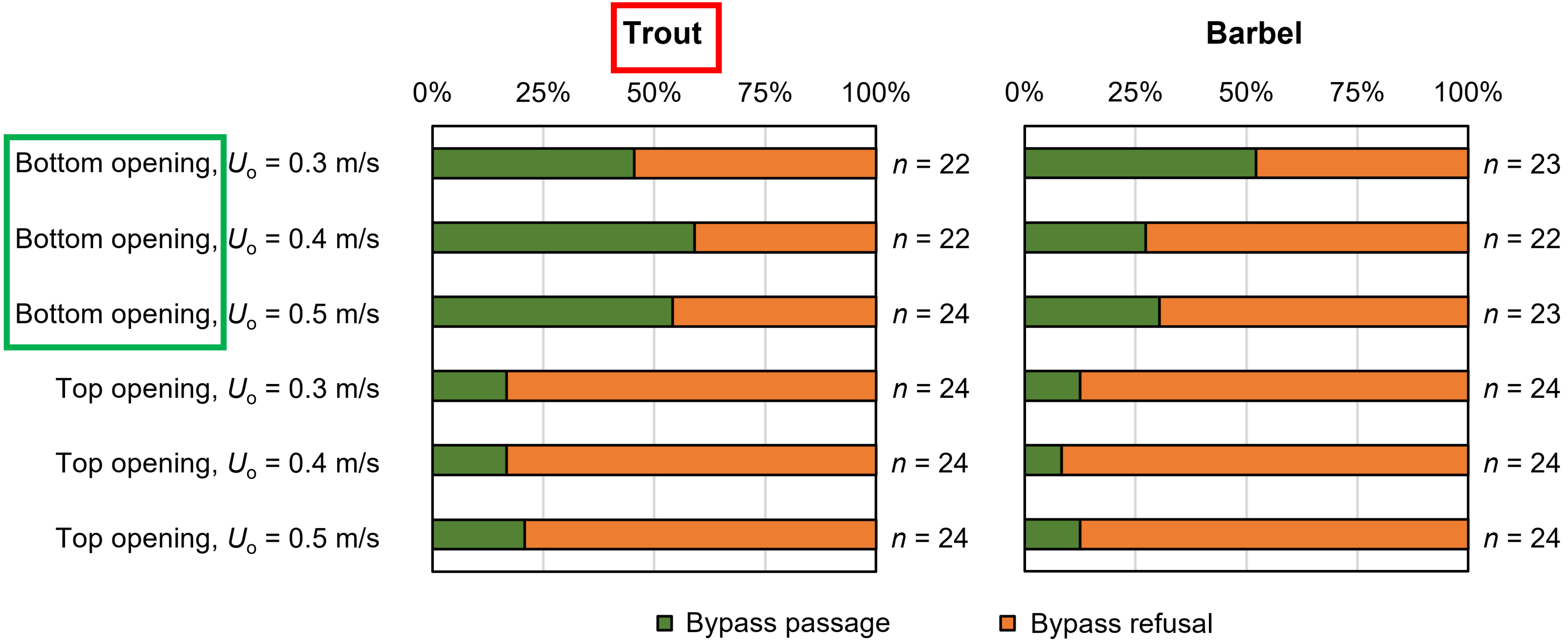
Bypass passage efficiency: $$\text{BPE} = \frac{N_{by}}{N_{by} + N_{ref}}$$

N_{by} number of successfully bypassed fish

N_{ref} number of fish, which refused bypass opening

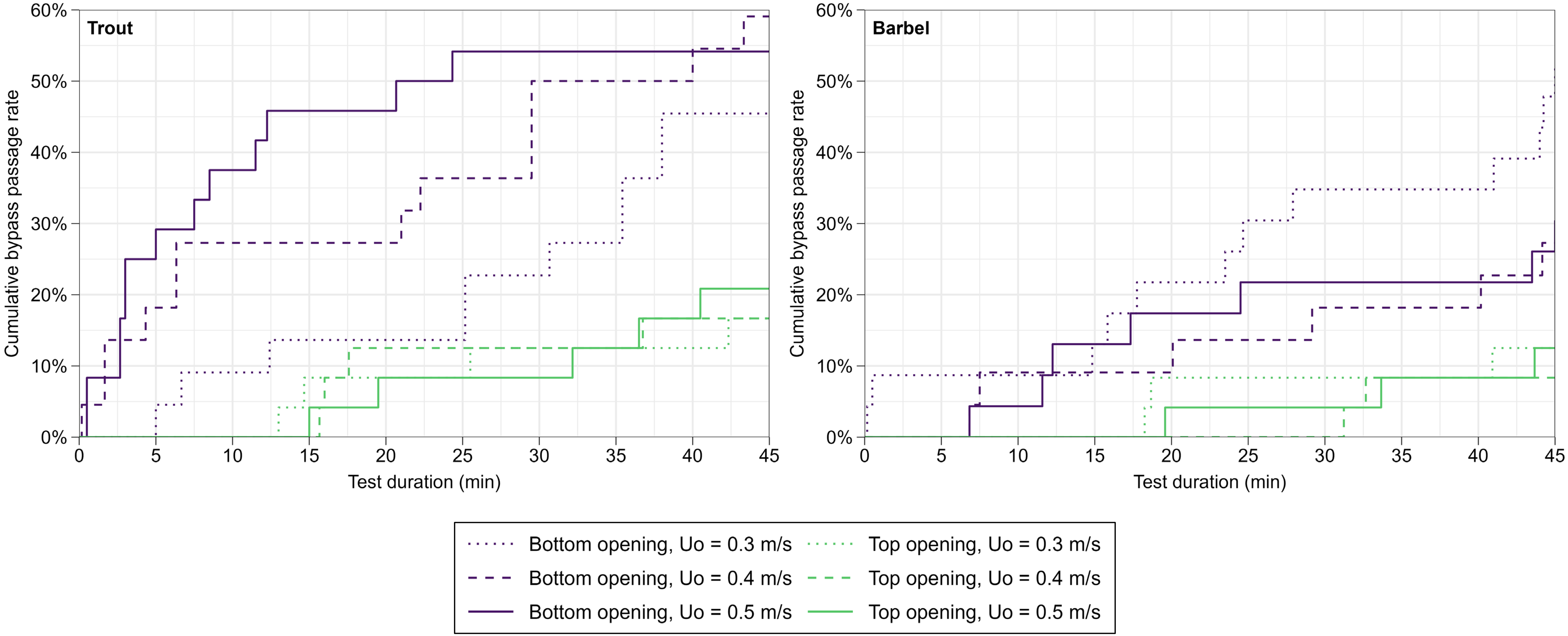
Two-sided χ^2–tests (incl. Cramér's V) and one-sided Fisher's exact tests for significance level $\alpha = 5\%$

Multivariate regression using generalized linear mixed models (GLMM) including random effect r.



Ethohydraulic tests of a state-of-the-art bypass design

Time-to-event analysis



Ethohydraulic tests of a state-of-the-art bypass design
Conclusions and outlook

Flow velocity increases sharply at top and bottom openings of bypass inlet gate

Trout and barbel often showed avoidance behavior to high velocity gradients

Preferred hydraulic conditions are species specific for bypass gate with bottom opening

Overall, trout showed higher and faster bypass passage compared to barbel

Results highlight importance of bypass inlet design to enhance fish guidance efficiency

Data analysis: quantification of fish behavior by video imaging analysis.

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Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Energie BFE
Office fédéral de l'énergie OFEN

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Thank you!

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