ETH zürich

Fish Protection and Downstream Migration at Low-Head Hydropower Plants

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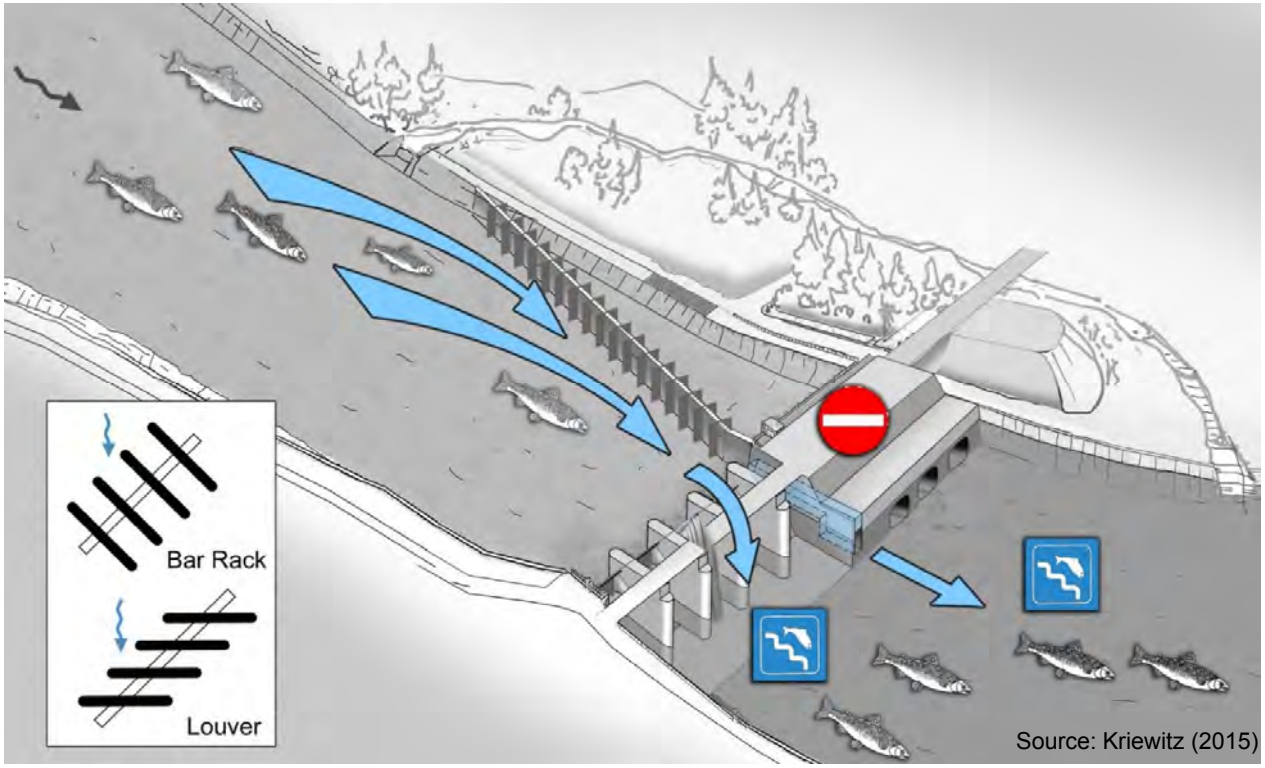
Laboratory of Hydraulics, Hydrology and Glaciology

Fish migration corridors and motivation for downstream passage



→ fish injuries and mortality without downstream passage facilities

→ Swiss Water Protection Act (until 2030) and European Water Framework Directive demand fish migration continuum (up- and downstream)

State of knowledge of fish guidance structures (FGS)

Physical barriers

Clear bar spacing s_b = 10÷30 mm

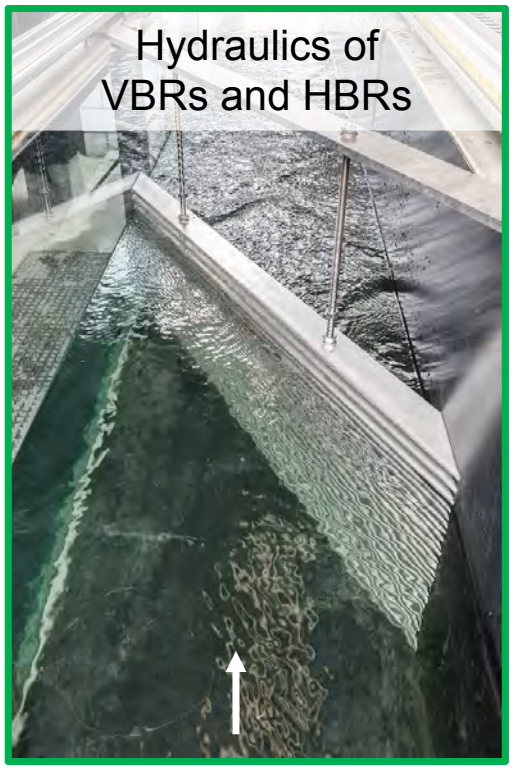
- e.g. Horizontal bar racks (HBRs)
- Installed at small to medium sized HPPs (currently Q_d ≤ 120 m³/s)

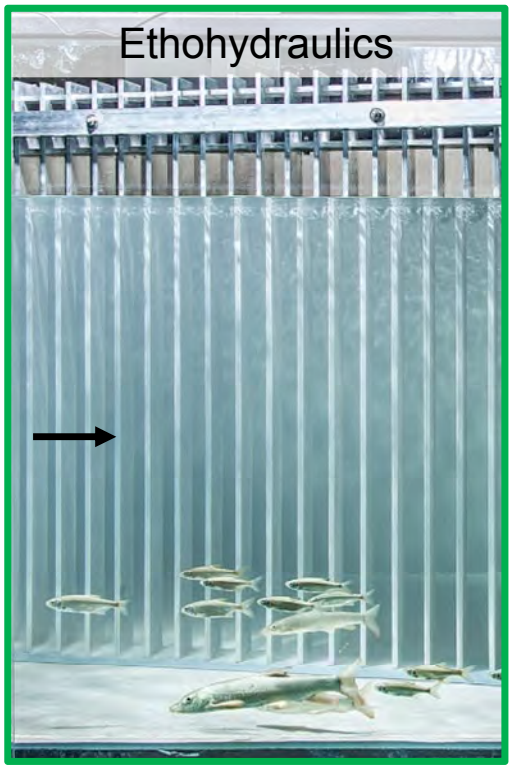
Mechanical behavioral barriers

Clear bar spacing s_b ≥ 25 mm

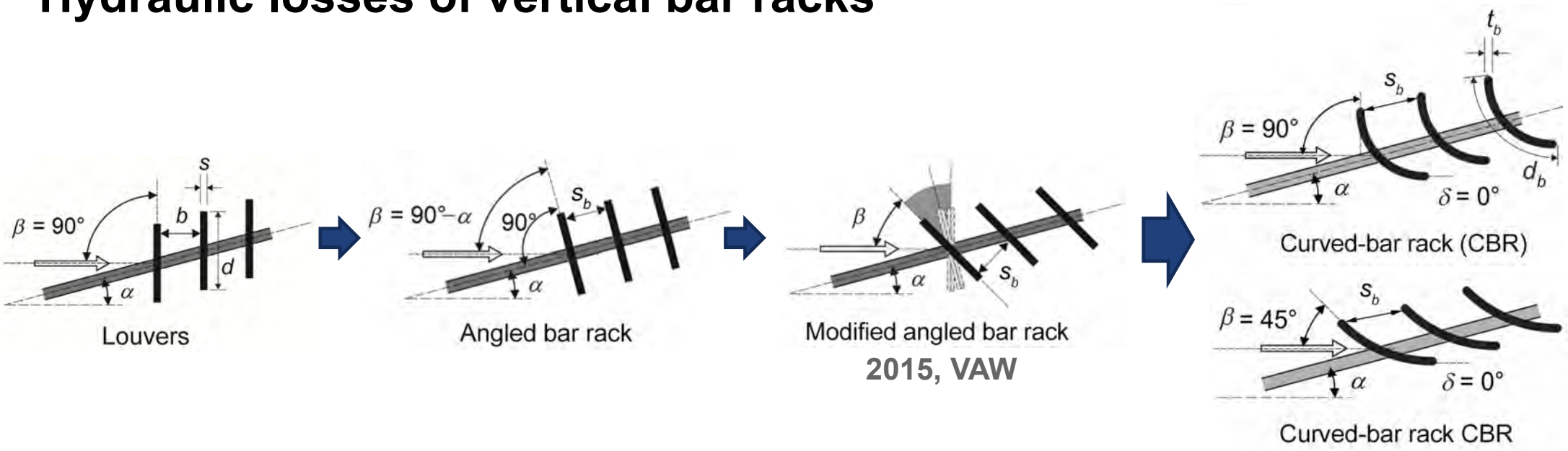
- Vertical racks (VBR, e.g. louver, bar rack)
- Also suitable for larger HPPs

Overview laboratory investigation





Hydraulic losses of vertical bar racks

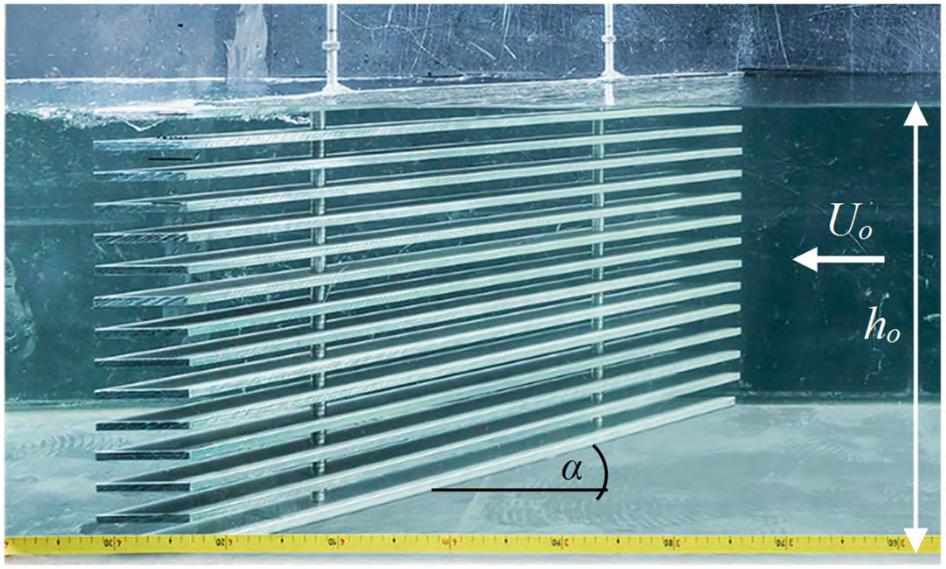


Reduction of loss coefficient

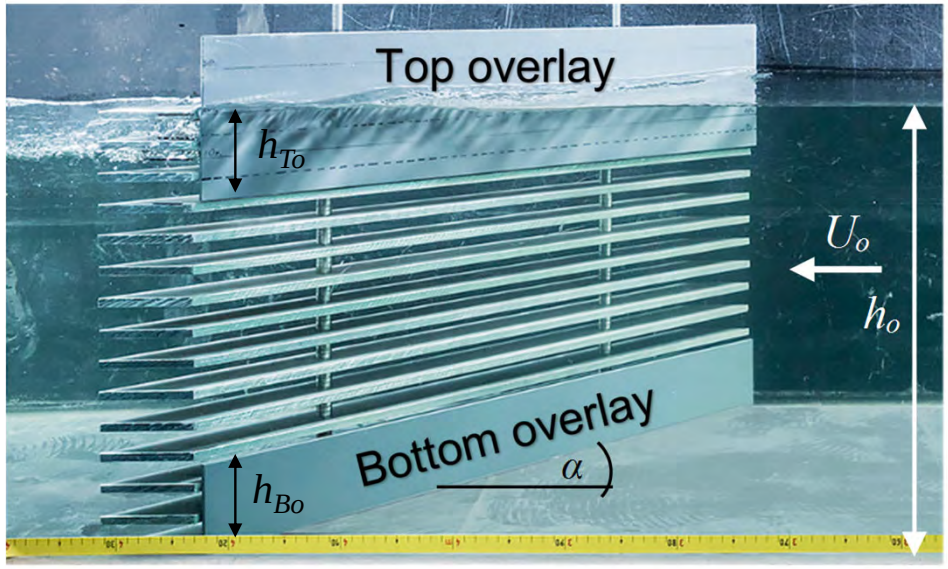
Example: approach flow angle α = 30°, clear bar spacing s_b = 50 mm:

ξ_R = 14 → ~ξ_R/5 = 2.6 → ~ξ_R/20 = 0.6

Effect of bottom and top overlay (HBR)

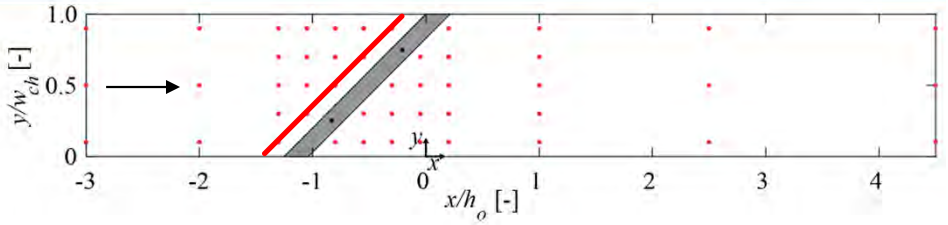


- Rectangular bars
- α = 45°
- s_b = 20 mm
- $h_{Bo} = h_{To} = 0$

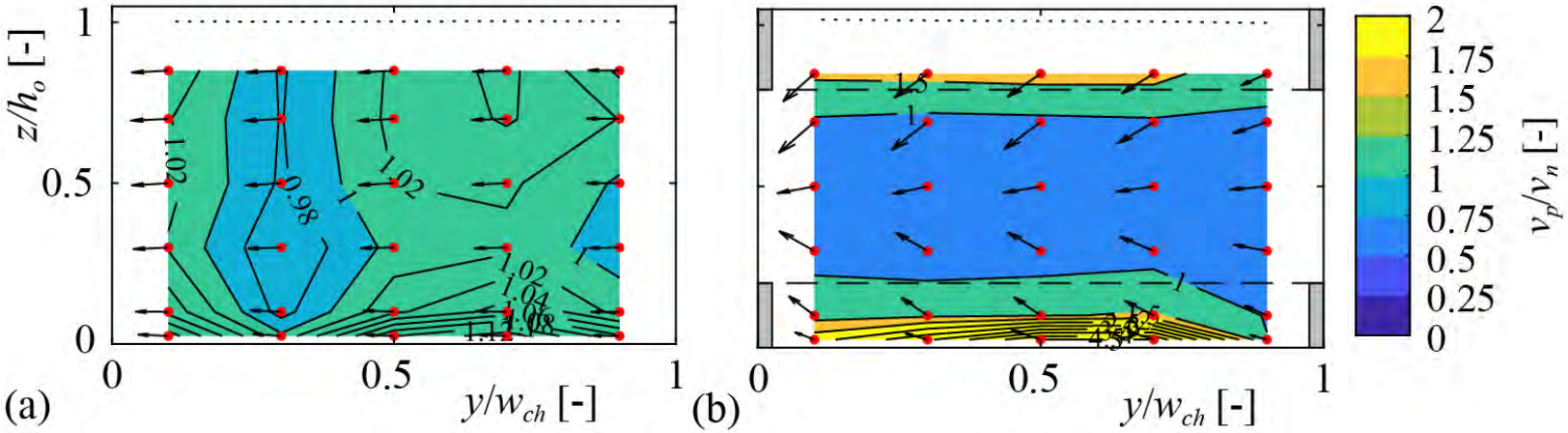


- Rectangular bars
- α = 45°
- s_b = 20 mm
- $h_{Bo} = h_{To} = 0.2\ h_o$

Effect of bottom and top overlay



$h_{Bo} = h_{To} = 0$ $\quad$ $h_{Bo} = h_{To} = 0.2\ h_o$



Criterion fish guidance capacity

$$v_p / v_n \overset{!}{>} 1$$

according to
Courret and Larinier (2008)

+ Potential increase of fish guidance efficiency (bottom and surface oriented)
+ Potential improvement of guidance efficiency of floating debris and sediments
− Increase of hydraulic losses (in this case 5.5 times)
− Asymmetric turbine approach flow

Ethohydraulic

- Investigate fish behavior and quantify fish-biological guidance efficiency
  - Selected rack configuration
  - 3 different bypass configurations

→ 3D fish tracking

Rack: Vertical

α [°]: 30

Bypass: Open channel

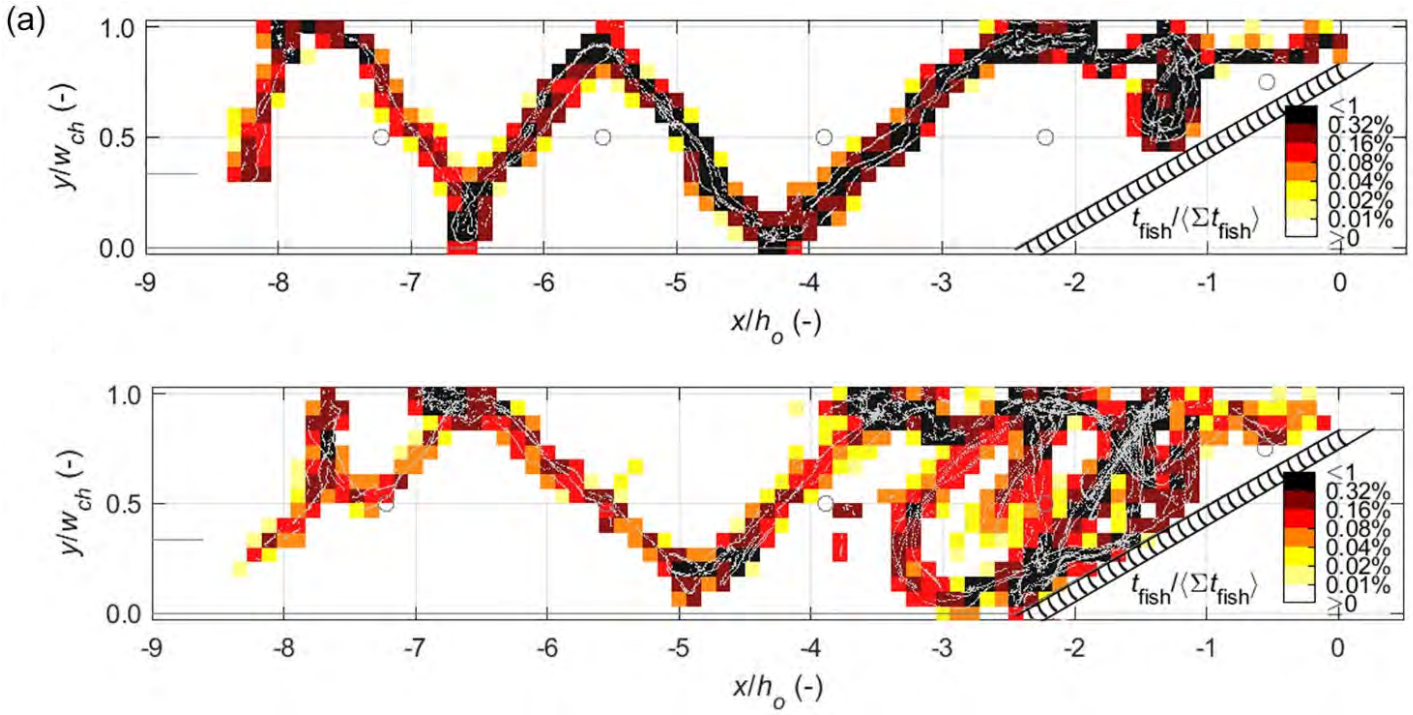
Species: Barbel

U_o [m/s]: 0.5

U_{by} [m/s]: 0.7

Rack:	Horizontal
α [°]:	30
Bypass:	Open channel
Species:	Eel
U_o [m/s]:	0.5
U_{by} [m/s]:	0.6

Data analysis ethohydraulic: Examples of heat maps



3 spirlins
CBR
U_o = 0.5 m/s
$U_{by,in}/U_o$ = 1.2

3 spirlins
CBR
U_o = 0.5 m/s
$U_{by,in}/U_o$ = 1.4

→ Faster bypass acceptance for smaller flow accelerations

Summary and Outlook

- Safe fish downstream migration challenging at low-head hydropower plants
- Downstream migration facilities required by Swiss law until 2030
- Technical solutions exist
  - Horizontal bar racks (state-of-the-art for small- to medium HPPs)
  - Curved bar racks (state-of-research; pilot & demonstration project in preparation)
- Laboratory experiments valuable to develop design guidelines, e.g.
  - Configurations with small hydraulic losses
  - Configurations with symmetric turbine admission
  - Flow accelerations towards the bypass for high fish guidance efficiencies
- Low-voltage electrification of guidance rack to enhance fish protection

Thank you

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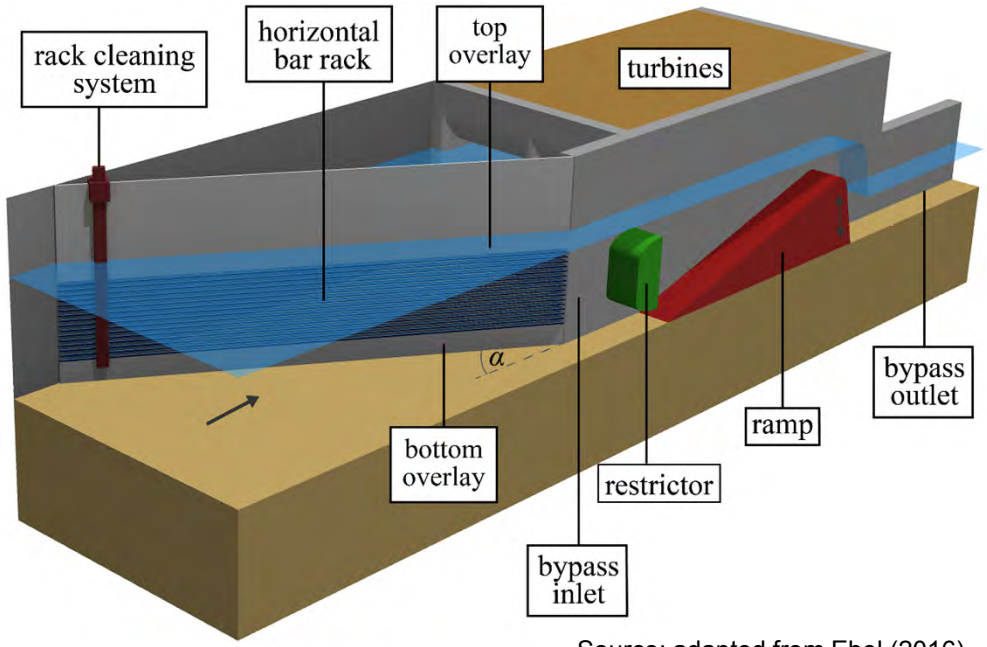
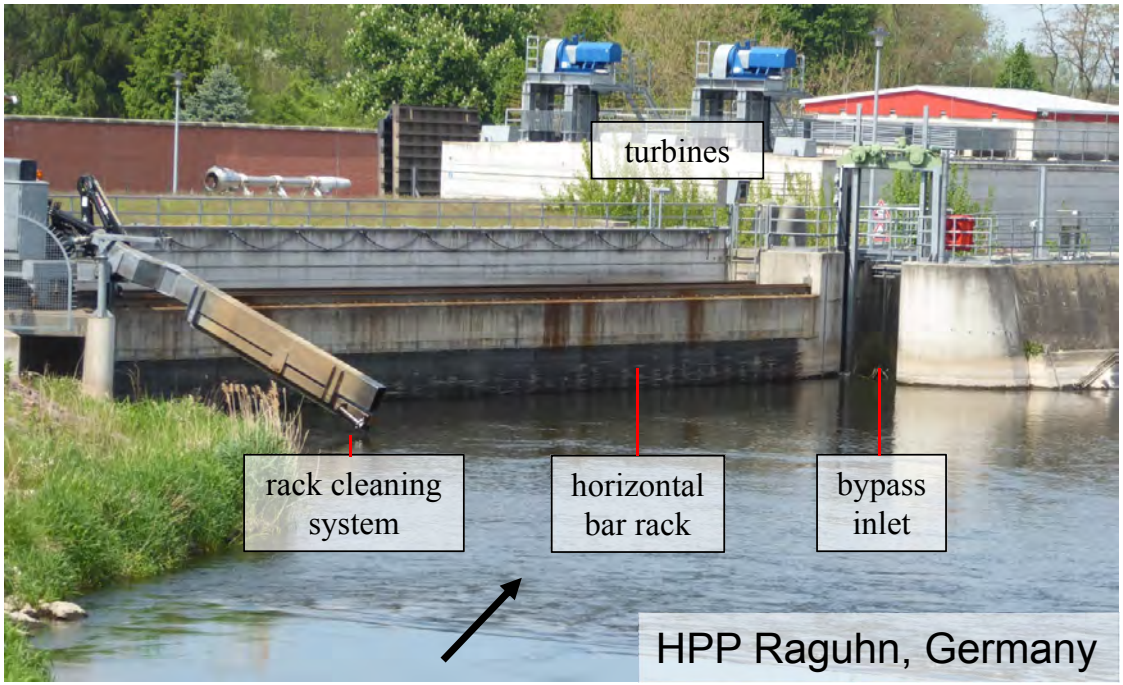
Principle of horizontal bar rack bypass systems (HBR-BSs)



Source: adapted from Ebel (2016)



Zusammenfassung Horizontal- und Vertikalrechen

Horizontalrechen

- An vielen Kraftwerken eingesetzt (D-A-CH)
- Hydraulik bisher kaum untersucht

→ geringe hydraulische Verluste
→ geringer Einfluss auf Strömung

- Verlegung durch Laub & Geschwemmsel?
- Leitwände für Fische, Schwimmstoffe und Sedimente

Modified Curved-Bar Racks

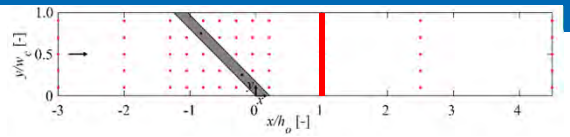
- Aus Laborstudien:

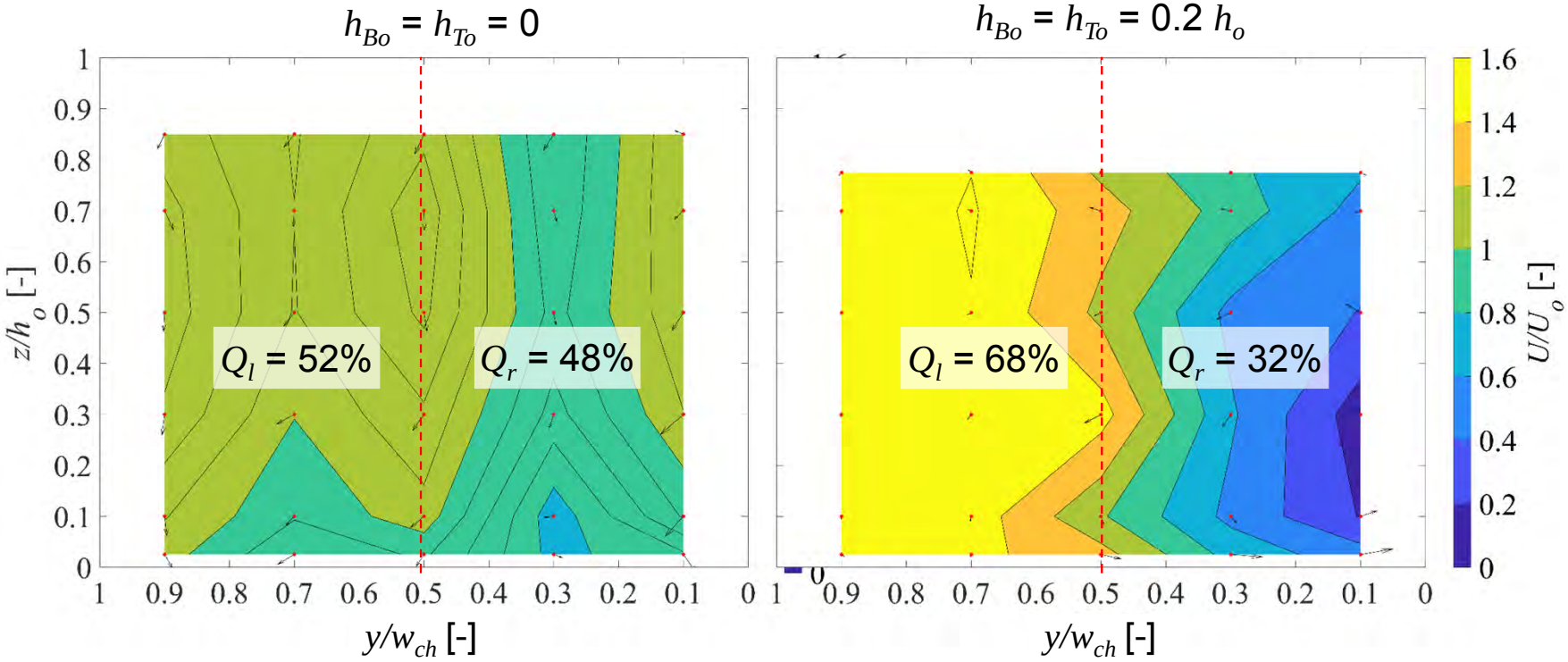
  → reduzierte hydraulische Verluste
  → symmetrische Turbinenbeaufschlagung

- Grosses Potenzial für Einsatz an grösseren KW mit hohem Sediment- und Schwemmholzaufkommen

- Pilotanlage um weitere Erfahrungen zu sammeln

Effect of bottom and top overlay





Criterion for turbines

$$\Delta Q = |Q_l - Q_r| \overset{!}{<} 5\%$$

according to Godde (1994)

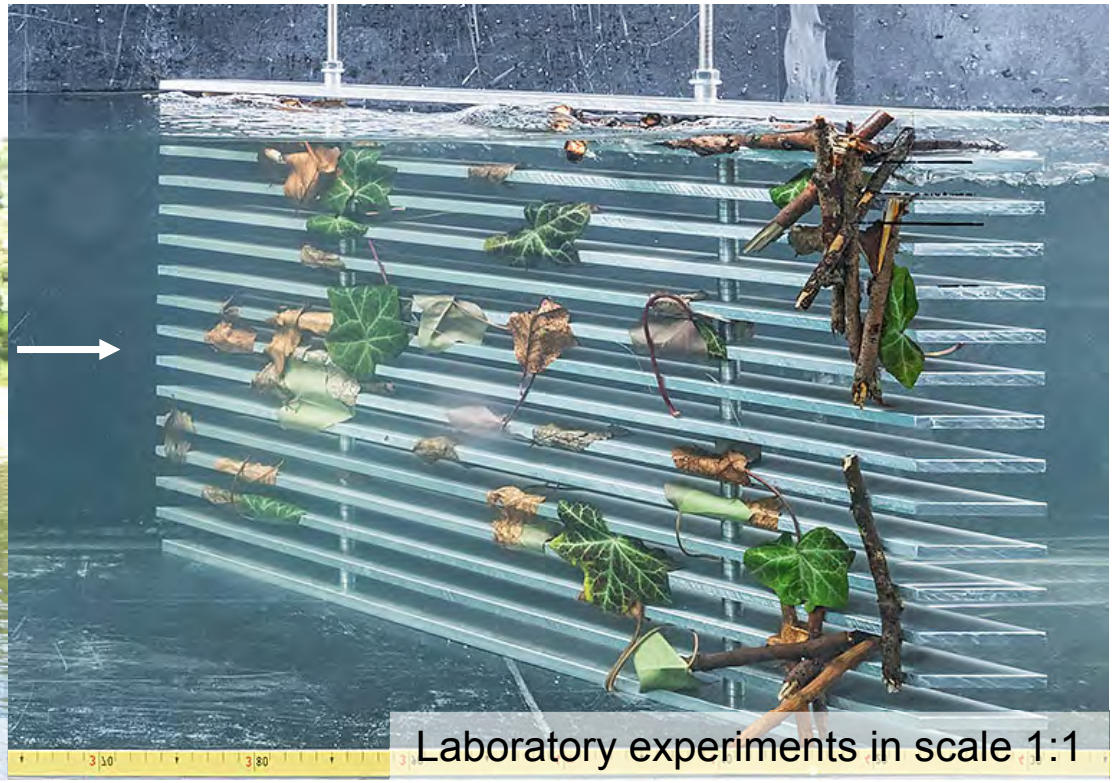
− Asymmetric turbine approach flow

Betriebliche Aspekte: Transport von Laub

Sihl, am 15.10.2018

Operational aspects and limitations

HPP Schiffmühle, Switzerland



Laboratory experiments in scale 1:1

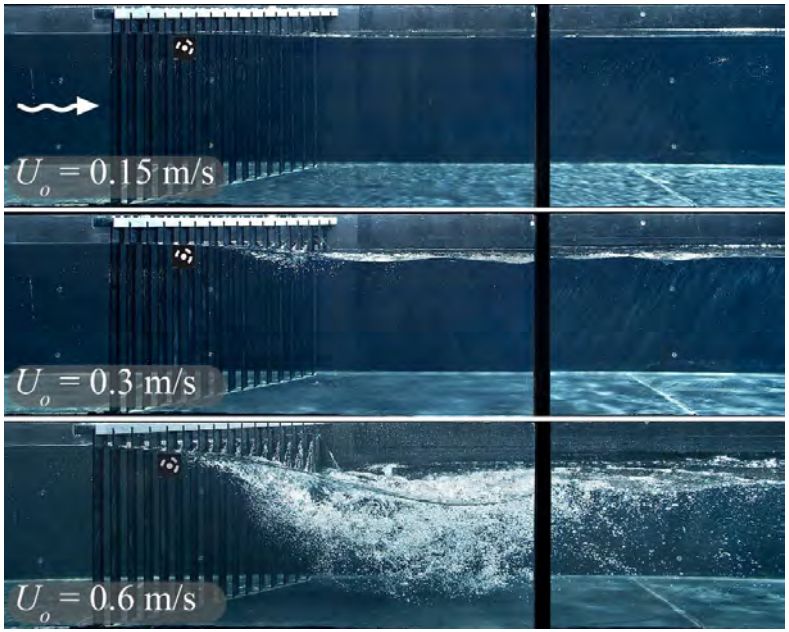
Energieverluste

Rechenwinkel: 45°

Stabwinkel: 90°

Stababstand: 5 cm

Stabform: rechteckig

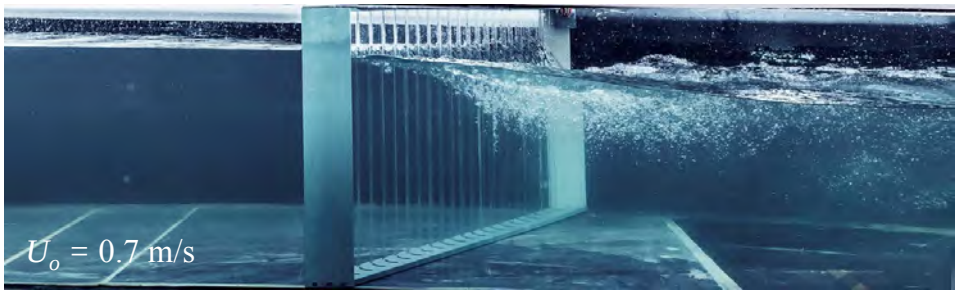


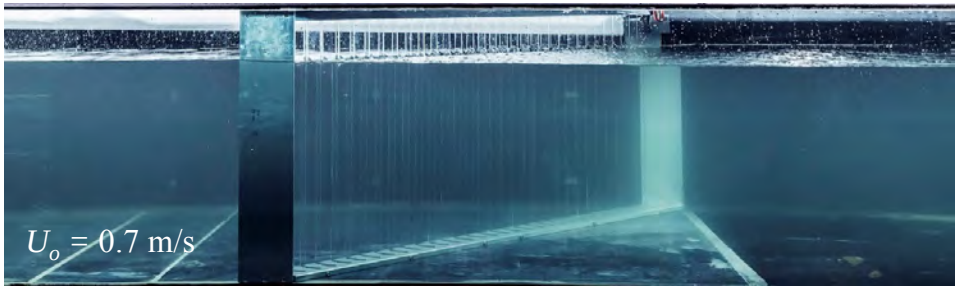
Rechenwinkel: 45° vs. 30°

Stabwinkel: 90° vs. 45°

Stababstand: 5 cm

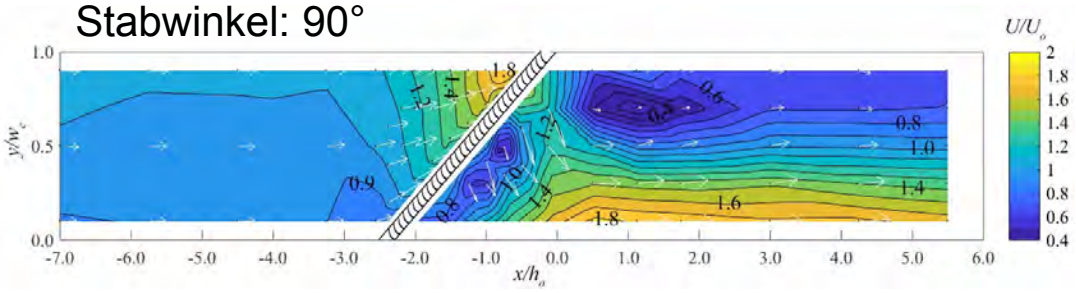
Stabform: gebogen





Geschwindigkeitsfeld am «Modified Curved-Bar Rack»

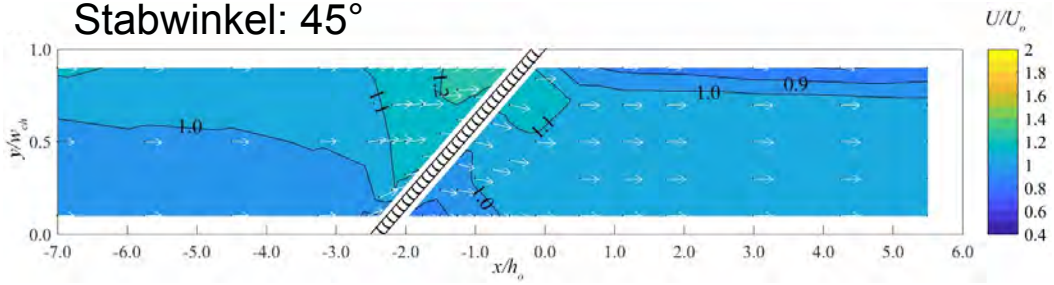
Stabwinkel: 90°



→ Ungünstige Strömungsverhältnisse:

- Starke Geschwindigkeitsgradienten
- Grosse Energieverluste
- Asymmetrische Turbinenanströmung

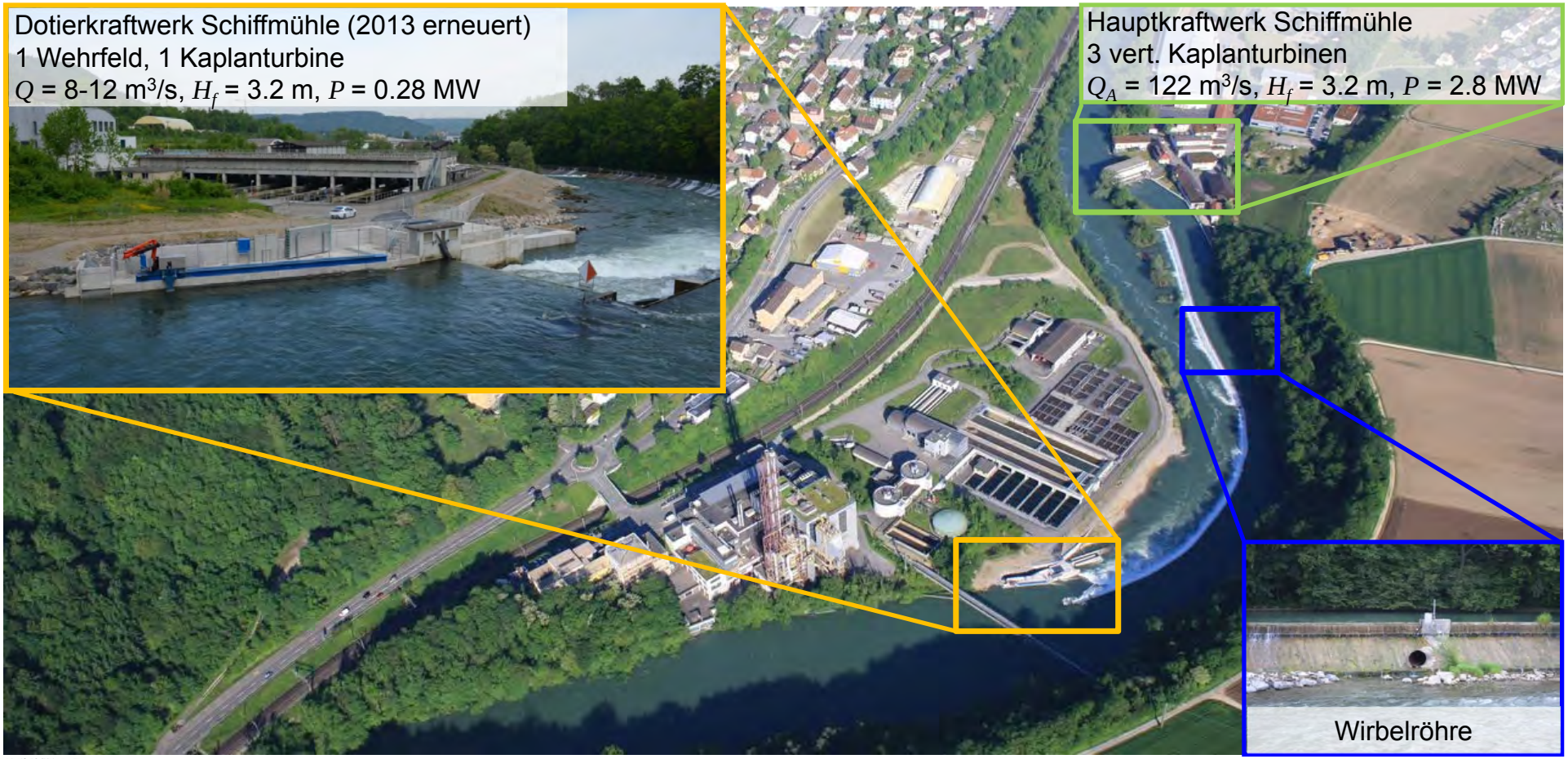
Stabwinkel: 45°



→ Optimale Konfiguration:

- Milde Geschwindigkeitsgradienten fördern die Fischleiteffizienz
- Kleine Energieverluste
- Symmetrische Turbinenanströmung

FIThydro – Fallstudie Schiffmühle



FIThydro – Fallstudie Bannwil

Hydraulic investigation (ADCP)

3D numerical simulation

Fish monitoring
(Didsonsonar und Radiotelemetrie)

Ethohydraulik

<u>Ethologie</u>
Wissenschaft des
Verhaltens von Tieren

<u>Hydraulik</u>
Lehre vom Strömungsverhalten
von Flüssigkeiten

Schneider

Bachforelle

Barbe

Äsche

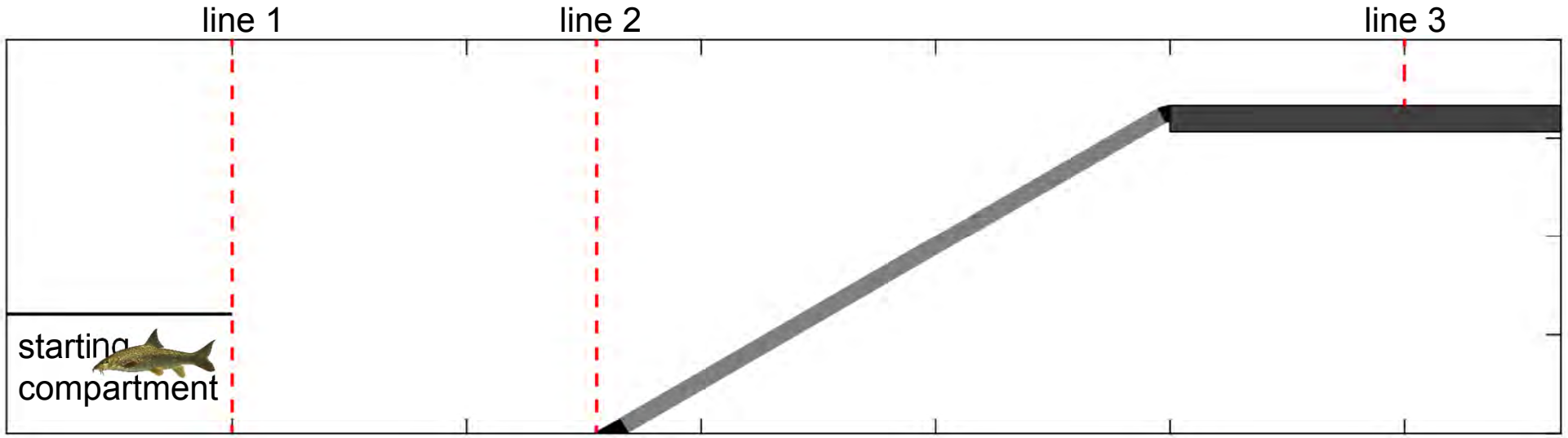
Aal

Atlantischer Lachs (Smolt)

Nase

Pictures from roggo.ch

Fish behavior



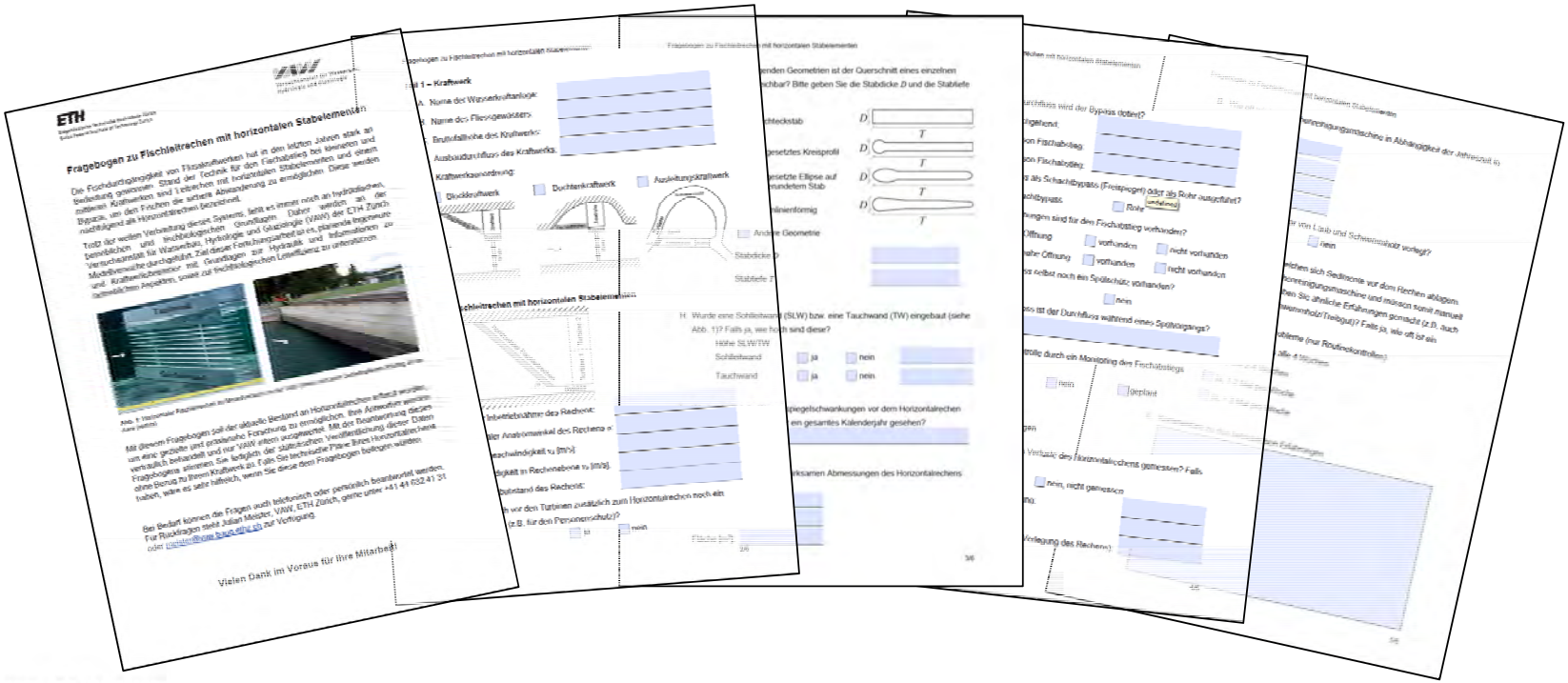
1. Not crossing line 1 } Not willing to descend
2. Not crossing line 2 } → excluded from analysis
3. Bypass passage (crossing line 3)
4. Rack passage
5. Refusal (crossing line 2, but after 30 min neither bypass nor rack passage)

The behavior observed first counts

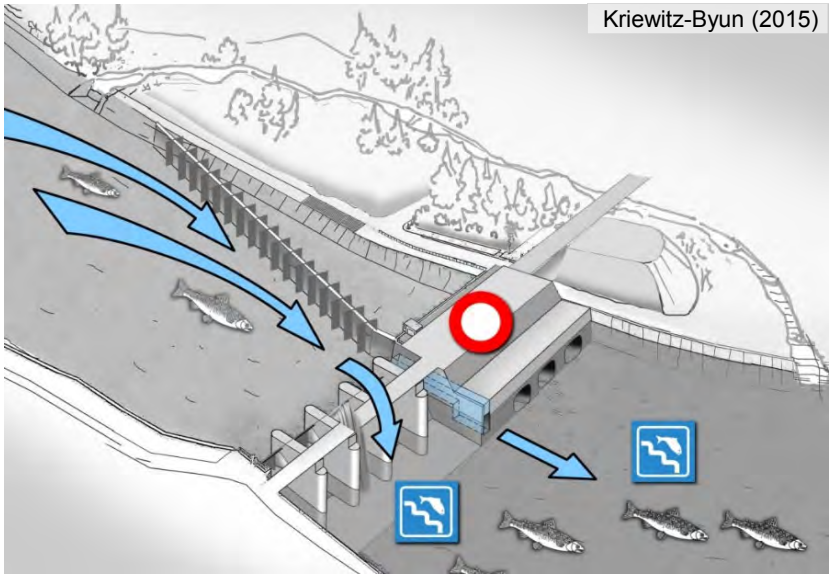
Example: rack passage

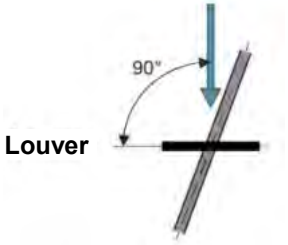
State of knowledge

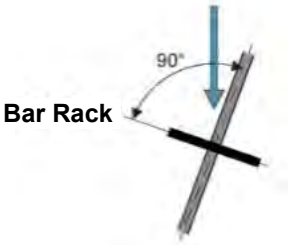
- 70 HPPs (hydropower plants) with horizontal bar rack bypass systems in Germany, Switzerland, and Austria
- Questionnaire sent to 50 operators (25 responses)

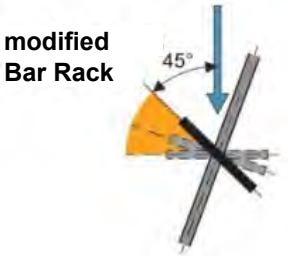


Stand der Technik von Vertikalrechen: Mechanische Verhaltensbarrieren









- \+ Hohe Fischleiteffizienz im Labor (73…100%)
- − Asymmetrische Turbinenbeaufschlagung
- − Hohe hydraulische Verluste ($\xi \approx 2.5…17$)
- − Bypass Design und Betrieb nicht optimal