



# Measures to facilitate safe *downstream fish migration* at large Central-European rivers

Carl Robert Kriewitz

# Measures to facilitate safe ***downstream fish migration*** at large Central-European rivers

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Research Partners (eawag):

Dr. Armin Peter, Tamara Boes,  
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Supported by:

Association of Aare-Rhine Power  
Plants (VAR)

*swisselectric research*

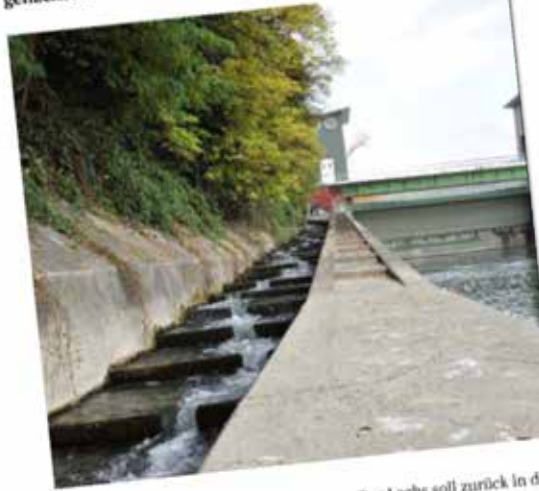
Federal Office for the Environment  
(FOEN)

Swiss Federal Office of Energy (SFOE)



Basler Zeitung WISSEN

**Basel wird für den Lachs zur tödlich**  
Von Nadine A. Brügger. Aktualisiert am 07.11.2013 19 Kommentare  
**Auf der ganzen Länge des Rheins wurden für viel Geld Fische**  
**allerdings nur in eine Richtung. Auf dem Rückweg werden die**  
**gehäckselt.**



Artikel zum Thema  
 Treppchen und Taxi für den Lachs  
 Der Lachs kehrt zurück  
 Rheintal ist für den Lachs bereit  
 Teilen und kommentieren

schlechter Witz: Einmal im Oberrhein, kann der Wanderfisch nicht mehr  
 Turbinen zerhackt.  
 Treppen und Lifte funktionieren nämlich nur in eine Richtung. Schwim  
 Richtung Atlantik, folgt er dem stärksten Strom und landet in den Turbi

Basler Zeitung / Donnerstag 7. Novem



Der Lachs soll wieder den Rhein hinaufschwimmen können – der Rückweg wird allerdings tödlich. AP  
**«Lachse werden gehäckselt»**

**BERN.** Der atlantische Lachs ist in der Schweiz seit den 1950er-Jahren ausgestorben, weil Flusskraftwerke ihm den Weg versperren. Bis 2020 sollen die Fische wieder angesiedelt werden: Das Lachsprogramm der Internationalen Kommission zum Schutz des Rheins sieht vor, den Weg vom Meer rhein-

aufwärts für den Lachs passierbar zu machen. Dafür werden Fischtrepfen, Lifte und Umgehungsgewässer gebaut.  
 Doch im Programm hat sich laut der «Basler Zeitung» ein fataler Fehler eingeschlichen: Für den sicheren Rückweg ins Meer wird nicht gesorgt. Die Lachse krepieren in den Turbi-

nen der Kraftwerke. «In der häufig installierten Pelton-Turbine werden die Fische gehäckselt wie im Mixer», sagt Chris Löhner, Inhaber von Flyfishing unlimited. Lösungen lägen bisher keine auf dem Tisch, denn Umrüstungen oder Schutz-Rechen würden für die Kraftwerke hohe Kosten bedeuten. vwo

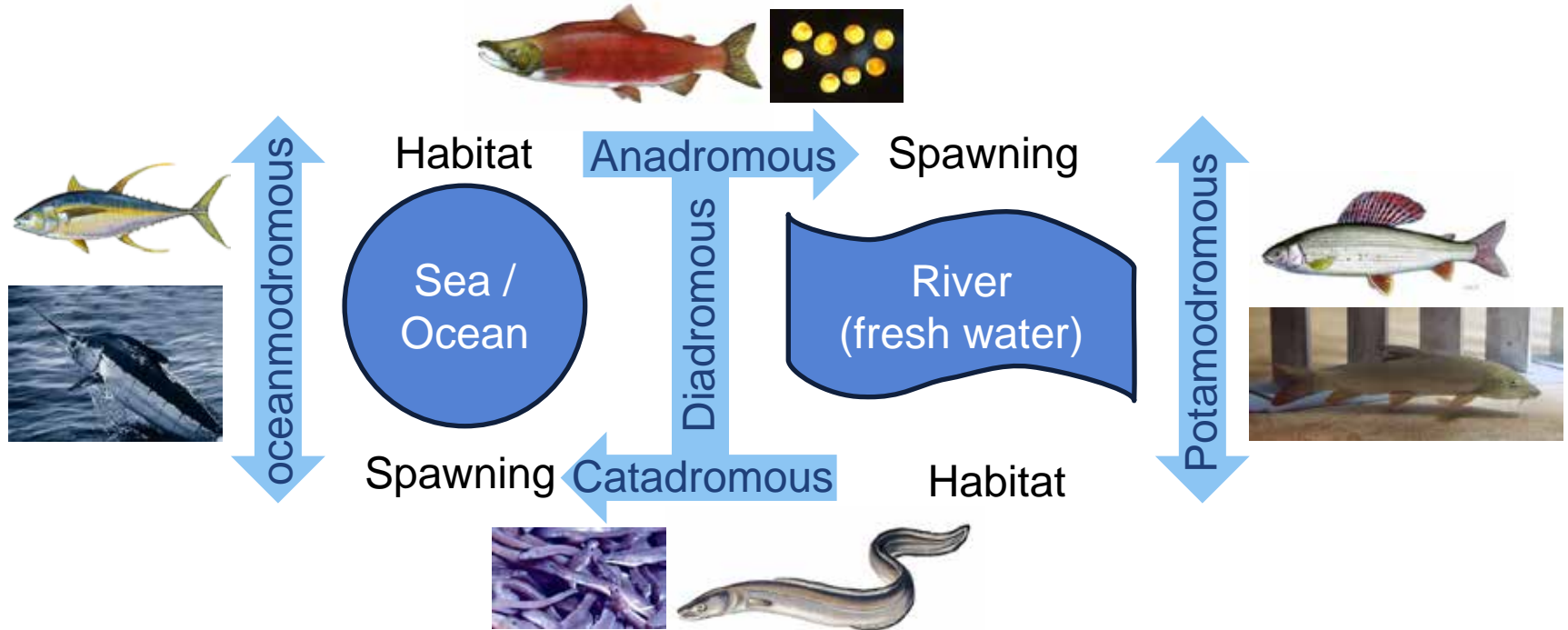
20minuten.ch / Freitag, 8. November 2013

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Fish Migration for Dummies (Engineers)

§ Downstream migration ≠ upstream migration

§ Which fish go where?



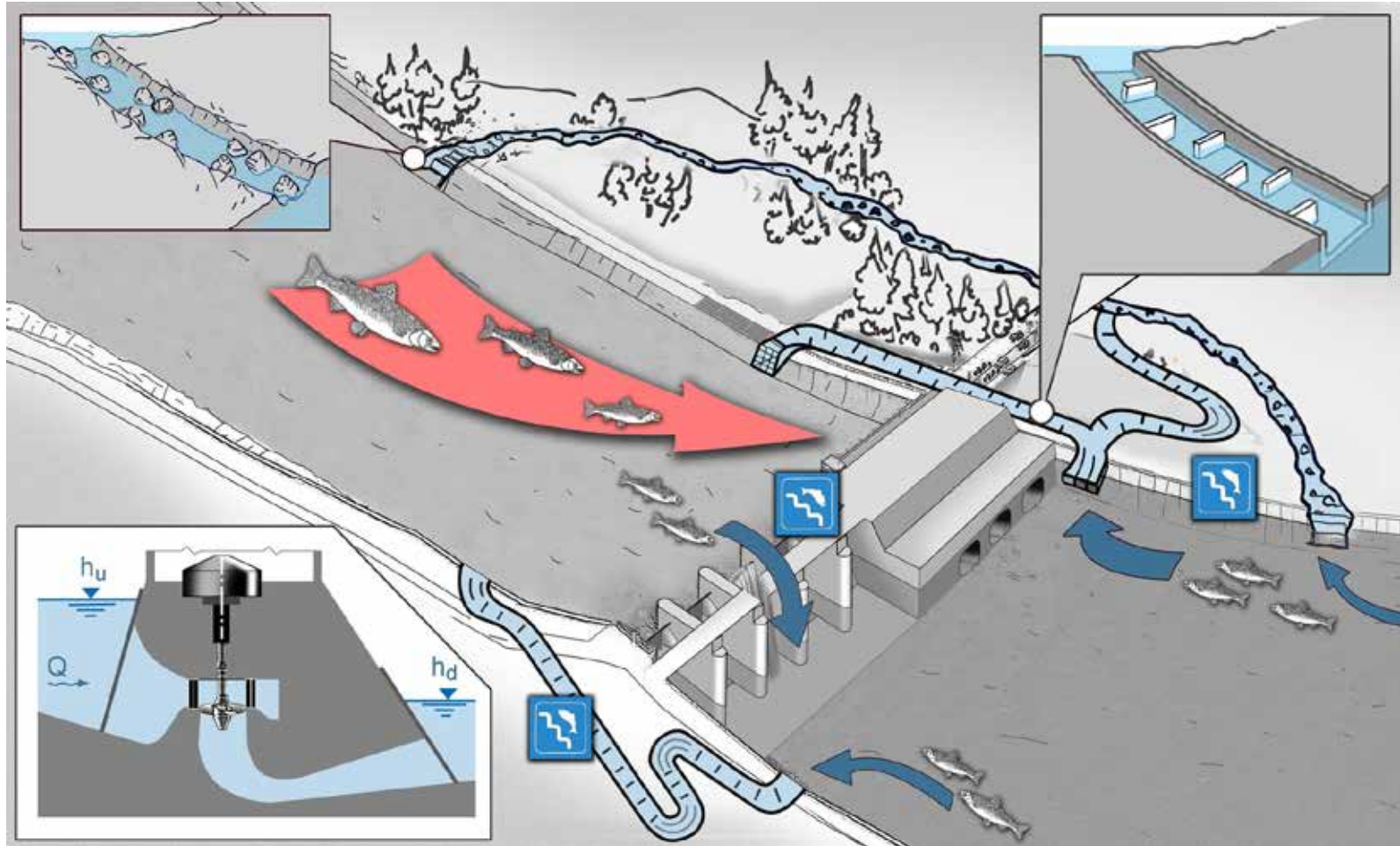
## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Fish Migration for Dummies (Engineers)

- § Why do fish migrate?
  - Spawning
  - Feeding
  - Habitat change
  
- § How do barrages influence fish migration in fresh water?
  - Migration delay in artificial reservoirs and at barrages
  - Potential injury during turbine passage (blade strike, pressure difference)
  - Potential injury during and after weir passage (TDG)
  - Predation
  
- § What can we do?
  - Prevent fish from entering potentially dangerous areas
  - &
  - Provide alternate routes to bypass obstacles

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## 101 of run-of-river HPPs



Introduction

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Situation in Switzerland

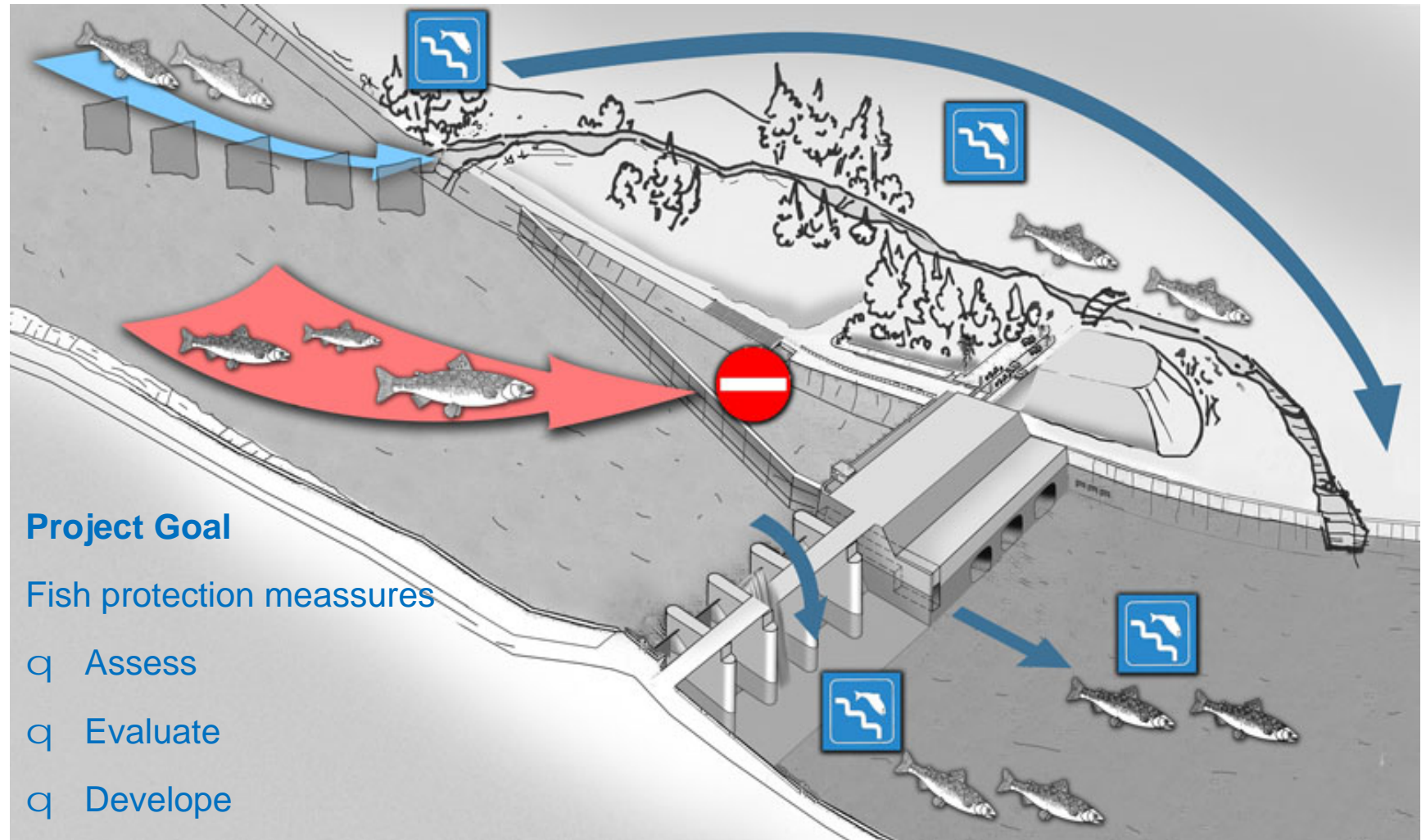
Importance of hydropower in Switzerland:

- § 56% of electricity production – 36000 GWh
- § 47% run-of-river HPPs, 49% storage HPPs, 4% pumped storage HPPs
- § Federal government promotes hydropower: until 2030 +2000 GWh

Revised Water Protection Act of 2011:

- § Plan of action until 2030
- § Revitalisation
- § Extension of riverine zones
- § Rehabilitation & Reduction of negative effects of hydro power plants
  - Hydropeaking
  - Sediment transport
  - **Fish migration** ∅ **But no solutions for HPPs > 90 m<sup>3</sup>/s**

## Measures to facilitate safe downstream fish migration at large Central-European Rivers



### Project Goal

#### Fish protection measures

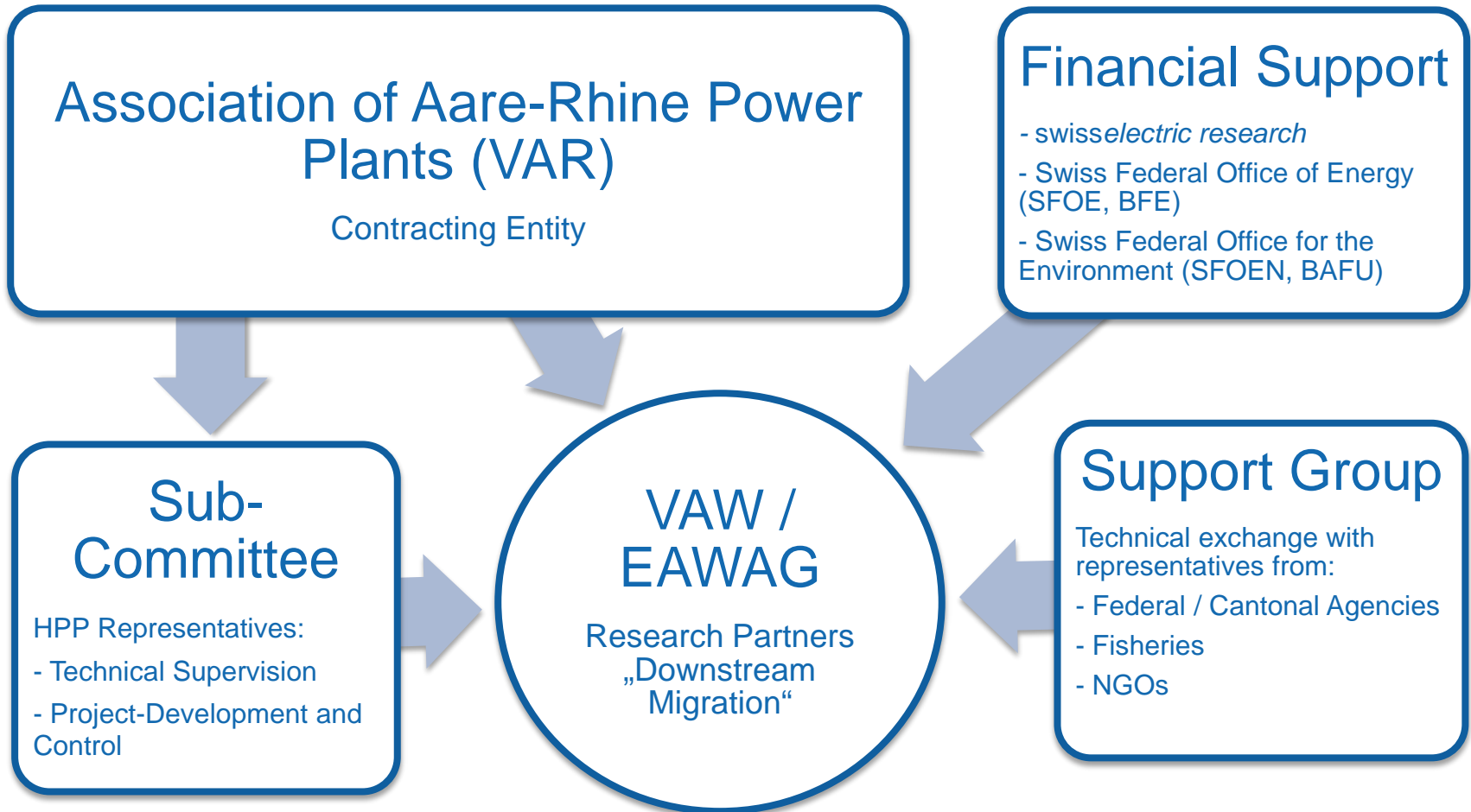
- q Assess
- q Evaluate
- q Develop



# Measures to facilitate safe downstream fish migration at large Central-European Rivers

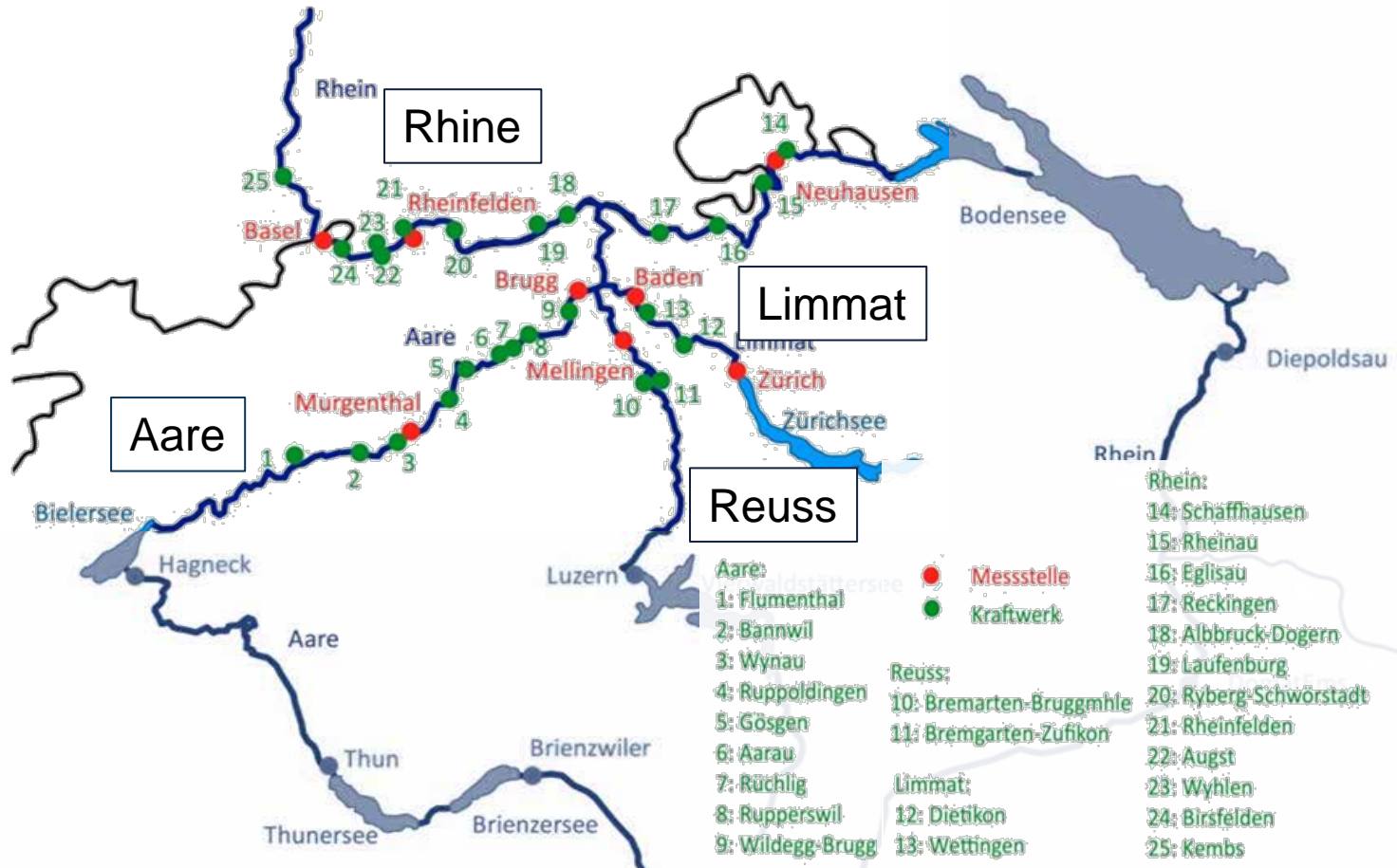
## Multi-disciplinary Project Structure

Project Overview



# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## VAR Hydro Projects - 28 Run-of-River Power Plants



## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### VAR Hydro Projects – Technical Data



Type: - Standard 64%  
- Bypass 32%  
- Bay 4%

Discharge: -  $Q_{\text{DesignAverage}} \approx 600 \text{ m}^3/\text{s}$   
-  $Q_{\text{YearlyAverage}} \approx 450 \text{ m}^3/\text{s}$   
-  $Q_{\text{Min/Max}} = 144 / 1500 \text{ m}^3/\text{s}$

Head: -  $H_{\text{Average}} = 8.8 \text{ m}$   
-  $H_{\text{Min/Max}} = 5 / 22 \text{ m}$

Turbines: - Mostly Kaplan/Bulb/Straflo  
- Several Francis

Fish protection:  
- Upstream migration facilities on all HPPs  
- *No downstream protection facilities*  
- *No operational changes during peak migration*

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Research Milestones

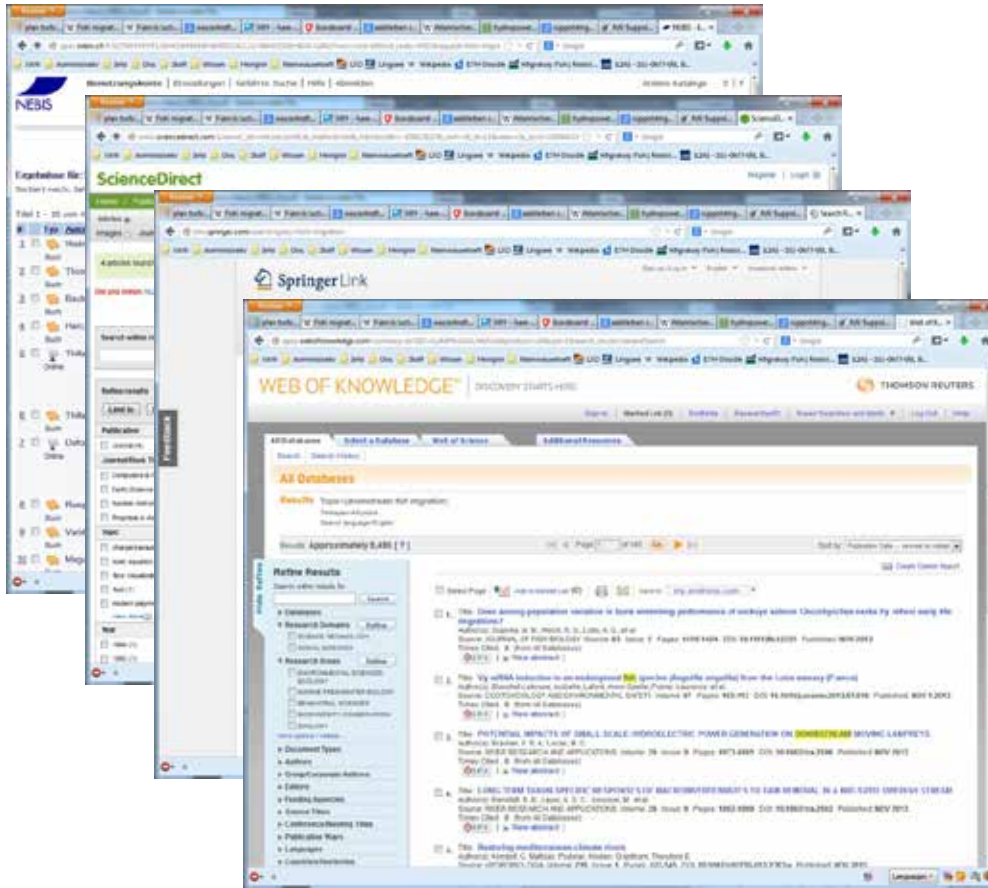
*Structural fish protection technologies for larger European rivers*

*5 research steps*

- I. Assessment of fish migration behaviour at Aare, Rhine, Reuss and Limmat Ü
- II. Identification of innovative, structural fish protection means Ü
- III. Physical model tests and adaptation of fish protection technologies with regard to larger European rivers Ü
- IV. Ethohydraulic experiments with European target species (Barbel, Spirlin, Greyling)
- V. Formulation of a guideline for downstream fish protection technologies

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

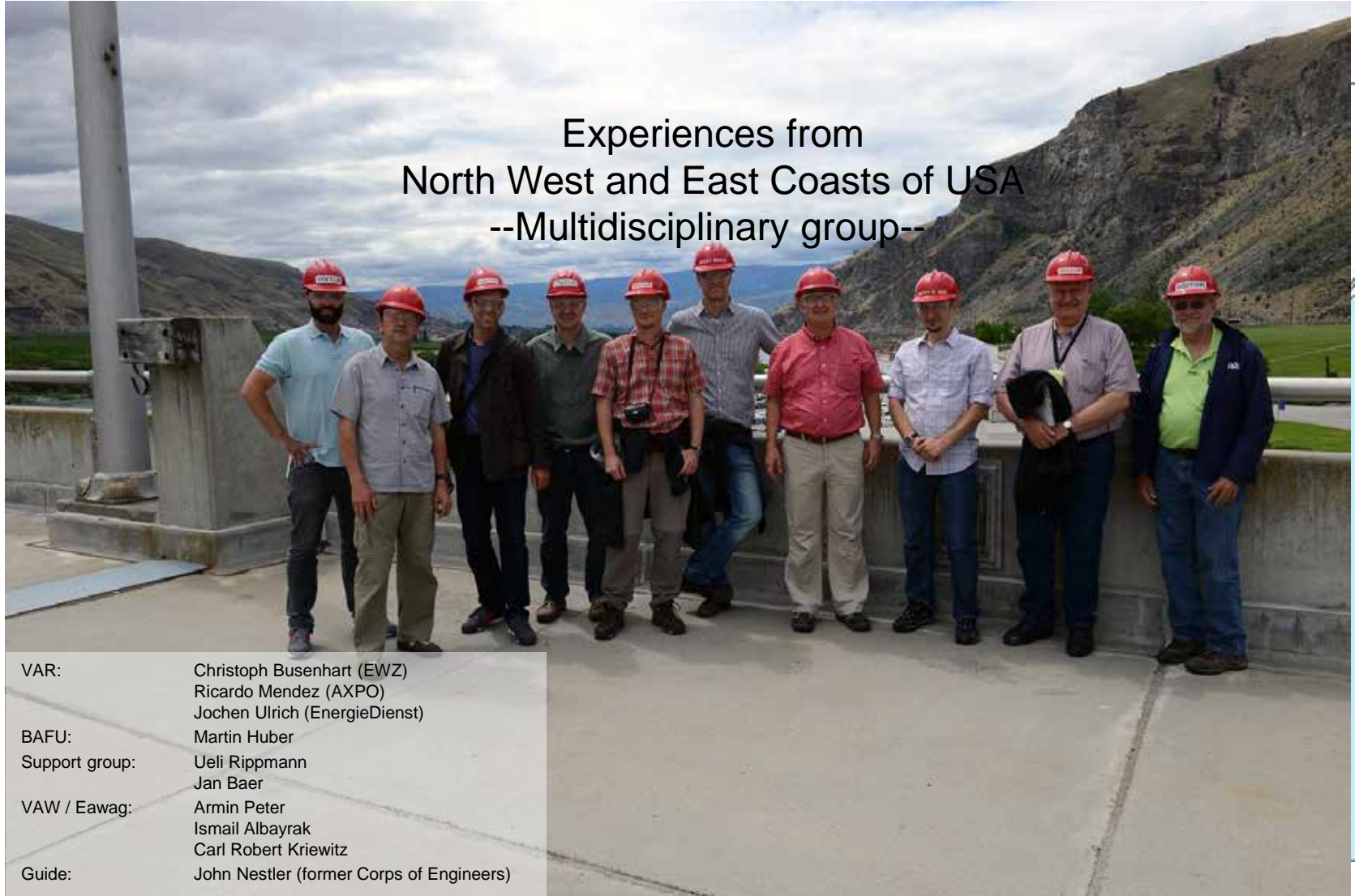
## Literature Review on Fish Protection Technologies



- § Over 400 papers, reports and publications reviewed
- § Conferences and workshops visited
- § Dialog with HPP operators in Switzerland
- § Fish management course to learn basics of fish biology
- § Applied research project – Physical model investigation on downstream fish migration at a new HPP

## Measures to facilitate safe downstream fish migration at large Central-European Rivers



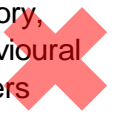



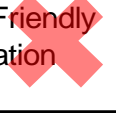
Experiences from  
North West and East Coasts of USA  
--Multidisciplinary group--



- |                |   |
|----------------|---|
| VAR:           | Christoph Busenhart (EWZ)<br>Ricardo Mendez (AXPO)<br>Jochen Ulrich (EnergieDienst) |
| BAFU:          | Martin Huber  |
| Support group: | Ueli Rippmann<br>Jan Baer   |
| VAW / Eawag:   | Armin Peter<br>Ismail Albayrak<br>Carl Robert Kriewitz                              |
| Guide:         | John Nestler (former Corps of Engineers)  |

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Literature Review and Knowledge Transfer – Results & Requirements

	Concept	Type	Measure
Knowledge Base	Fish Protection Technologies at HPP	Physical Barriers 	Fine Screens
			Submerged Bar Screens
			Rotary Screens
			Eicher-Screen
			Wedge-Wire-Screen
		Mechanical, Behavioural Barriers 	Skimming Walls
			Louvers
		Sensory, Behavioural Barriers 	Bar-Racks
			Plate Screens
			Trash Racks
Collection Systems 	Light (Strobe or Mercury)		
	Low Frequency Sound		
	Popper		
	Electricity		
Fish Friendly Turbines 	Air- / Water Curtains		
	Surface Collection Pipes		
Conveyance	Fish Friendly Turbines 	Traveling Screens	
		Fish Pumps	
		Trap and Truck	
	Fish Friendly Operation 	Alden Turbine	
		Voith - Minimum Gap Runner	
	Alstom - Fish Friendly Kaplan-Turbine		
	Early Warning Systems		
	Weir Overflow		
	No Partial Load Operation		

- § Physical barriers pose huge operational issues
- § Promising but a lot of knowledge gaps
- § Unreliable and too little field experience
- § Proven but limited species variety
- § High costs, only viable with HPP rehabilitation, no research expertise
- § Limited efficiency and species variability

Knowledge Base

Fish Protection Technologies at HPP

Screening / Shielding and Guidance

Conveyance

Bypass

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Literature Review and Knowledge Transfer – Preliminary Reports

Knowledge Base

Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der Eidgenössischen Technischen Hochschule Zürich

**Massnahmen zur Gewährleistung eines schonenden Fischabstiegs an grösseren, mitteleuropäischen Flusskraftwerken**

Zwischenbericht zum Literatur- und Massnahmenstudium

**Auftraggeber:** **Verband Aare-Rheinwerke**  
Gruppe des Schweizerischen Wasserversorgungsverbands

**Mit Unterstützung von:** **swiss<sup>electric</sup> research**  
Bundesamt für Energie

VAW 0843 Zürich, November 2012

Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie

**eawag**  
aquatic research 000

Das Wasserforschungsinstitut des ETH Bereichs  
Forschungszentrum für Ökologie,  
Evolution und Bioökonomie  
Abteilung Fischökologie + Evolution

**Massnahmen zur Gewährleistung eines schonenden Fischabstiegs an grösseren, mitteleuropäischen Flusskraftwerken**

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Bundesamt für Energie  
Kostantonibaum, Dezember 2012

Download at: <http://www.swv.ch/Portrait/Verbandsgruppen/Aare-Rheinwerke>



## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Literature Review and Knowledge Transfer – Results & Requirements

*State of the art fish protection technologies not directly applicable at large Swiss hydro projects*

- § No or limited transferability of technologies used on small European or large US-HPPs
- § Knowledge of behavioural biology of local fish species insufficient

**But:**

- § Mechanical behavioural guidance structures promising
  - ↳ - 1. Define target species
  - 2. Define research foci

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

In Switzerland, currently 63 native fish species exist

← Fish species in Hochrhein, Aare and Limmat

Fische	Hochrhein	Aare	Limmat
Forellen	mittel	häufig	mittel
Regenbogenforelle	mittel	mittel	mittel
Bachsaibling	mittel	mittel	mittel
Äsche	mittel	mittel	mittel
Felchen	mittel	mittel	mittel
Rotaugen	mittel	mittel	mittel
Hasel	mittel	mittel	Einzelfund
Alet/Döbel	mittel	mittel	mittel
Strömer	mittel	mittel	mittel
Elritze	mittel	mittel	mittel
Rotfeder	mittel	mittel	mittel
Schleie	mittel	mittel	mittel
Nase	mittel	mittel	mittel
Gründling	mittel	mittel	mittel
Barbe	mittel	mittel	mittel
Laube/Ukelei	mittel	mittel	Einzelfund
Schneider	mittel	mittel	mittel
Blicke	mittel	mittel	mittel
Brachsmen	mittel	mittel	mittel
Karpfen	mittel	mittel	Einzelfund
Bachschmerle	mittel	mittel	mittel
Wels	mittel	mittel	mittel
Aal	mittel	mittel	mittel
Hecht	mittel	mittel	mittel
Flussbarsch/Egli	mittel	mittel	mittel
Zander	mittel	mittel	Einzelfund
Kaulbarsch	mittel	mittel	Einzelfund
Sonnenbarsch	mittel	mittel	mittel
Moderlieschen	mittel	mittel	mittel
Groppe	mittel	mittel	mittel
Stichling	mittel	mittel	mittel
Trüsche	mittel	mittel	mittel

Knowledge Base

Advisory board  
pre-selected:

- § Barbel
- § Spiralin
- § Nase
- § Trout
- § Grayling
- § Eel

Final selection

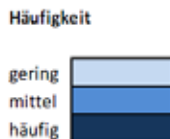
§ Barbel



§ Spiralin



§ Grayling



# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Angled Louver- and Bar

Concept	Type	Measure
---------	------	---------

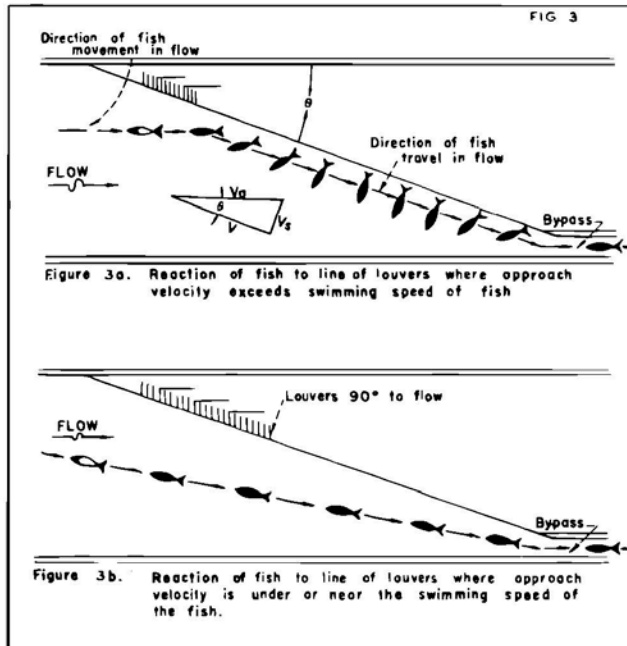
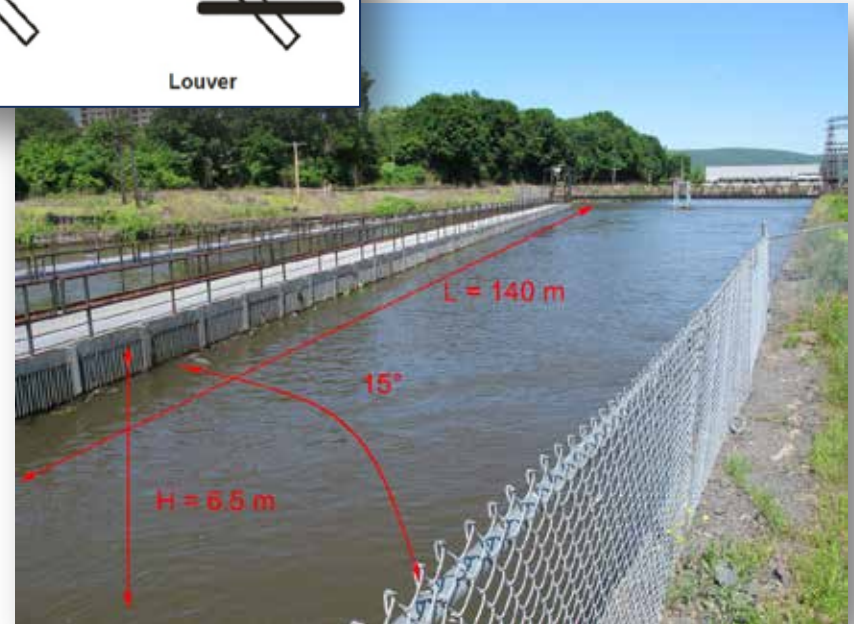
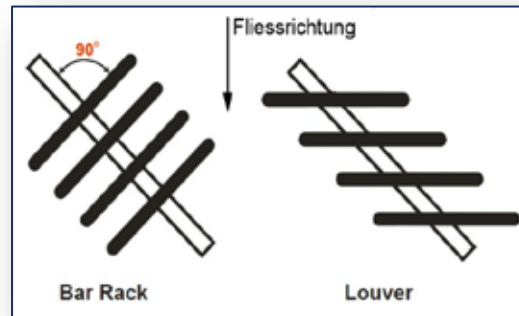


FIGURE 3.—Reaction of fish to line of louvers.

Bates and Visionhaler, 1957



Holyoke Canal – Louver installation

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

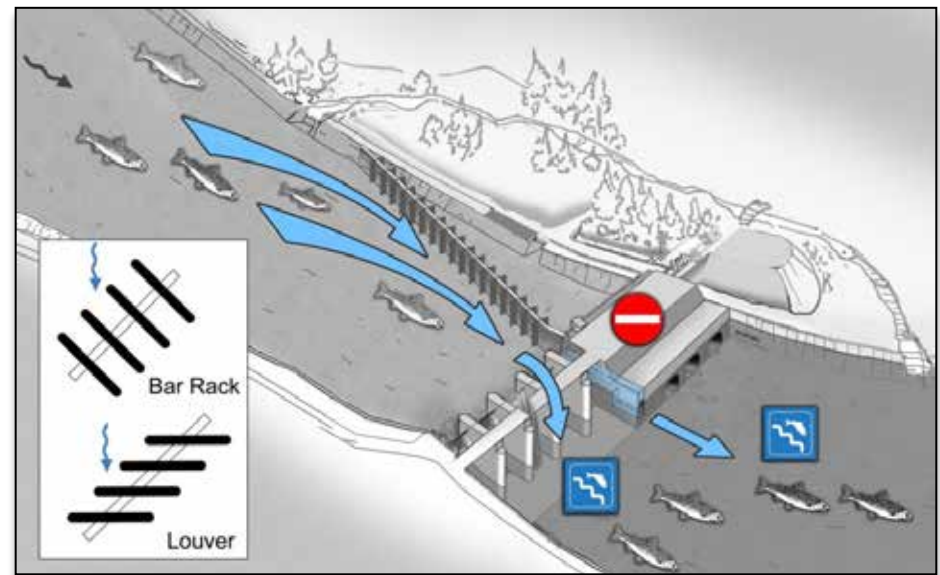
### Summery - Literature Review and Knowledge Transfer

#### **Target fish species:**

Barbel, Spirlin, Grayling

#### **Fish protection technology:**

Louver and angled bar rack-systems



# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Physical Model Investigations

Detailed model tests



Large scale model tests



Ethohydraulic model tests

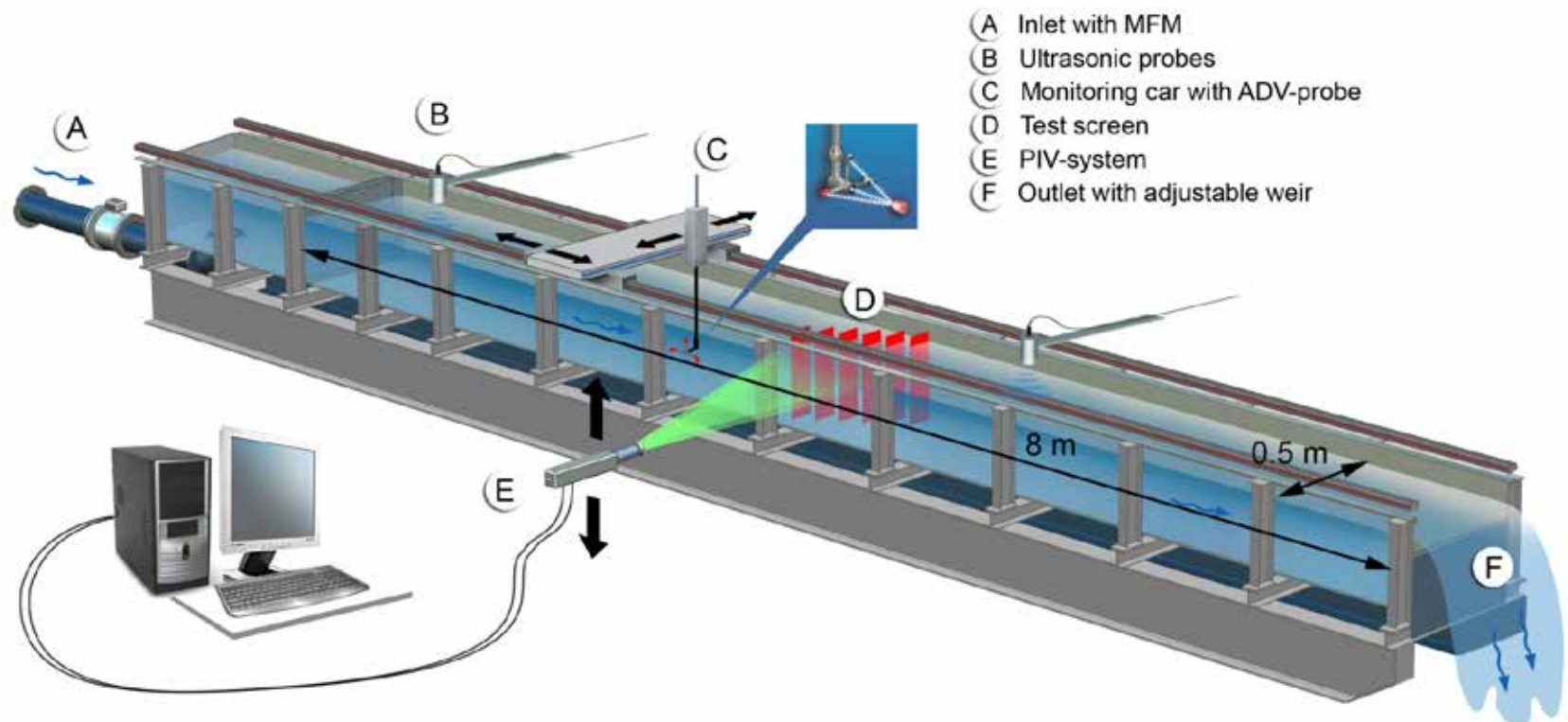


Physical Model Investigations

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

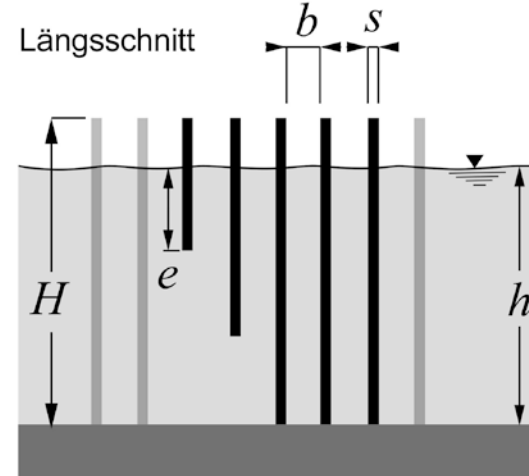
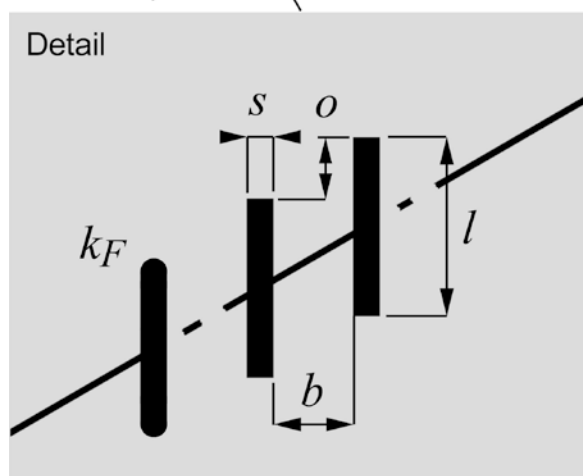
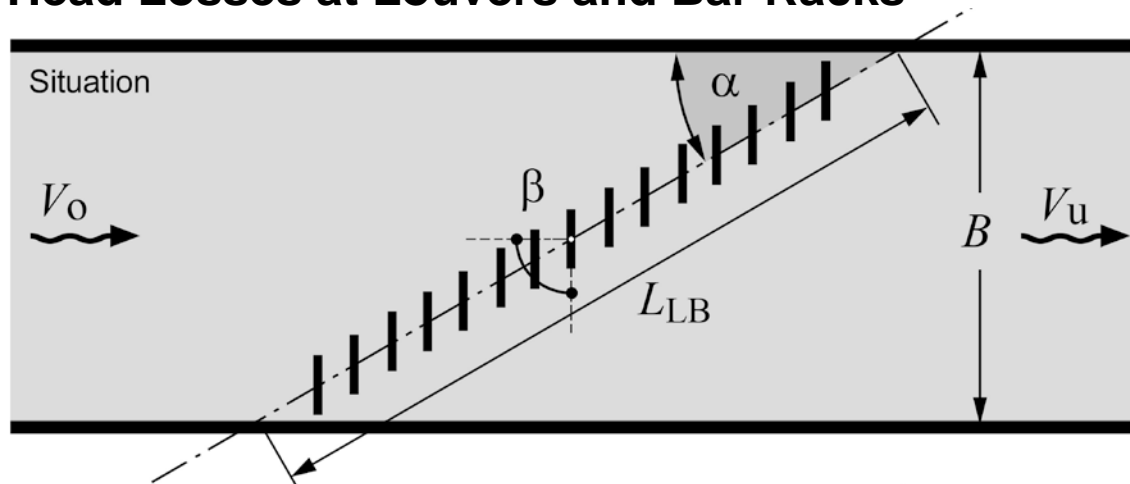
### Detailed Model Tests of Louver and Bar Racks - Scales 1:1 & 1:2

- § Determination of the energy losses → Ultrasound sensors
- § Measurements of mean and turbulence flow characteristics → Particle Image Velocimetry (PIV)



# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Head Losses at Louvers and Bar Racks



### Parameters

*Main angle*

$\alpha$ : 45, 30, 15 [°]

*Bar angle*

$\beta$ : 90, 67.5, 45 [°]

*Bar opening*

$b$ : 5, 11, 23 [cm]

*Bar thickness*

$s$ : 1, 0.5 [cm]

*Bar length*

$l$ : 7.5, 10, 12.5 [cm]

*Water depth*

$h$ : 10, 20, 40, 80 [cm]

*Mean velocity*

$v_0$ : 0.1 – 1.0 [m/s]

*Bar shape*

$k_F$ : rectangular, round

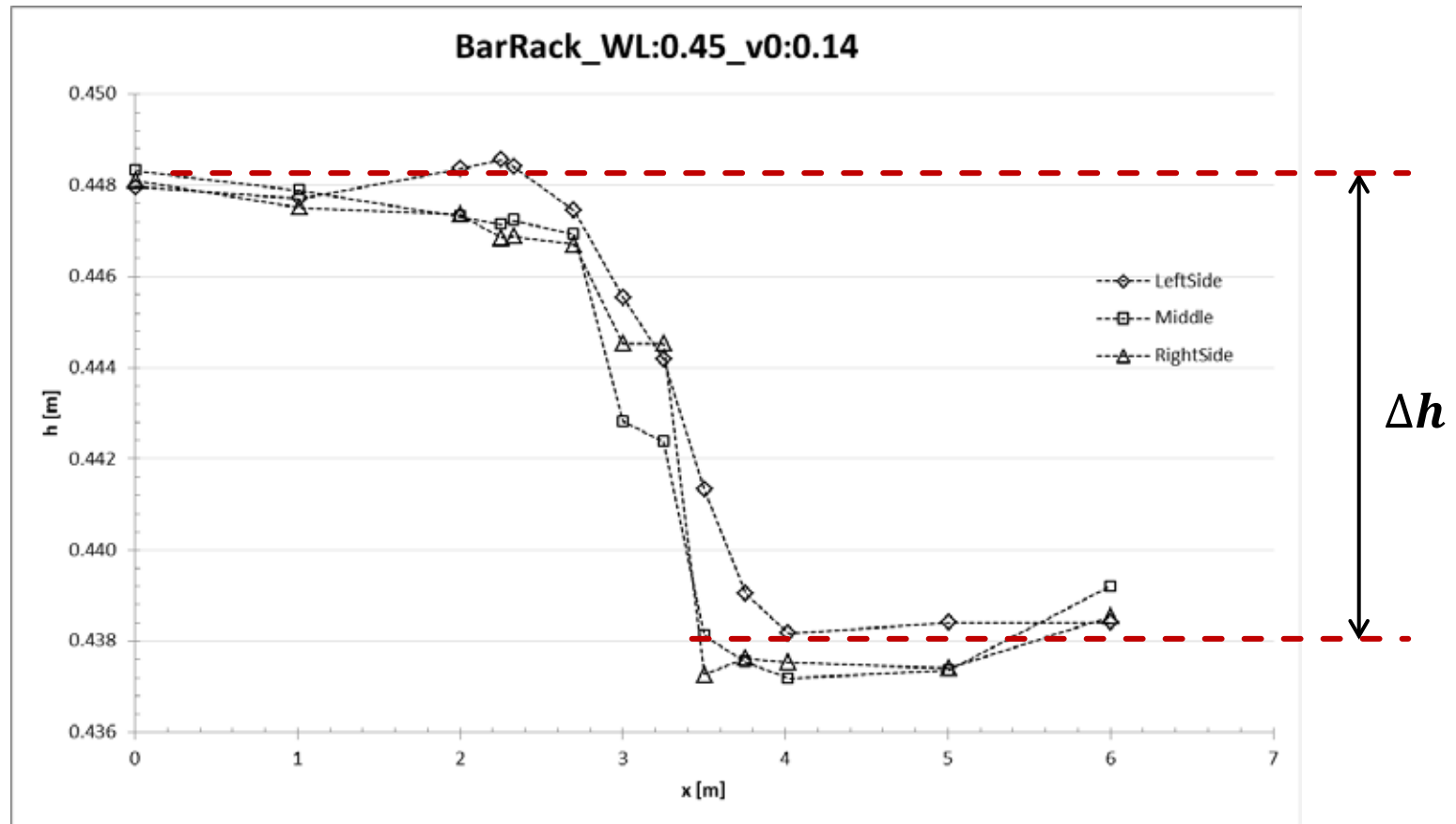
*Submergence*

$k_F$ : rectangular, round

Detailed Model Investigation

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Preliminary Results: Calculation of Head-losses





## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Calculation of Head-loss Coefficient

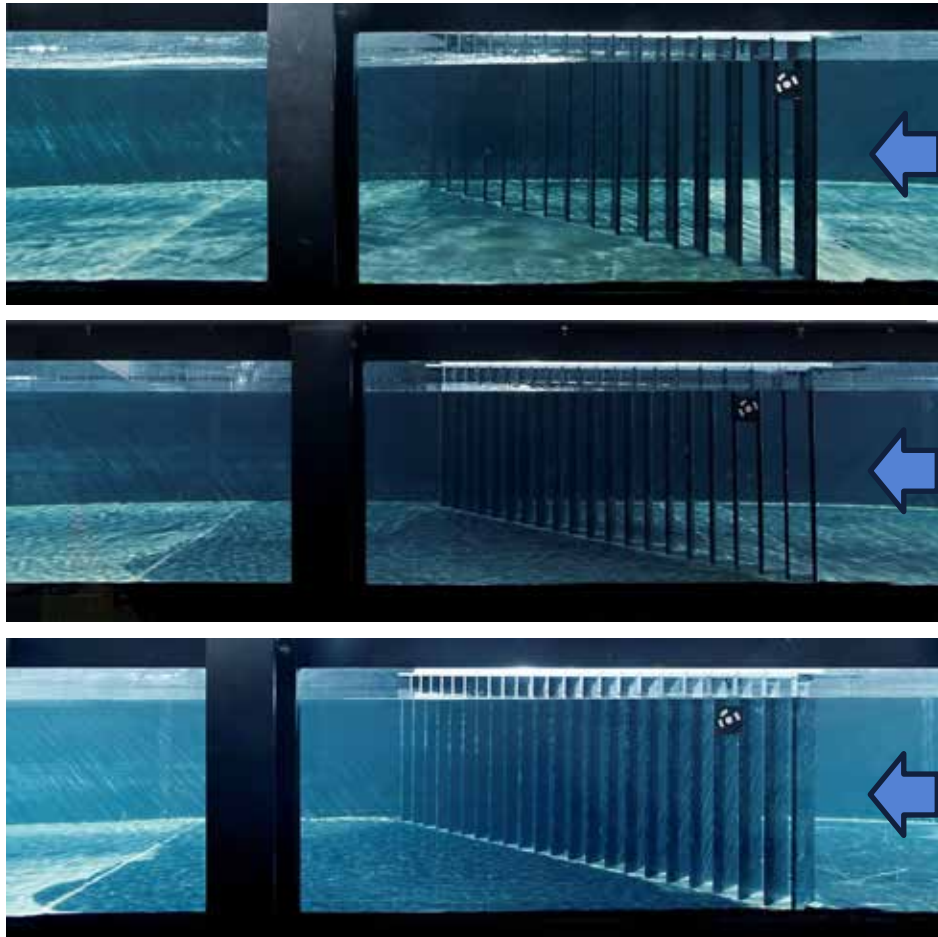
measured  $\leftarrow \boxed{\Delta h} = \xi_R \times \frac{v^2}{2g}$

calculated  $\leftarrow \boxed{\xi_R} = f(\text{Parameters}, Fr, Re)$

Measures to facilitate safe downstream fish migration at large Central-European Rivers

Preliminary results: Effect of bar orientation  $\beta$  on  $\xi_R$  ( $\alpha = 45^\circ$ )

Detailed Model Investigation



90°  
à «Louver»

67.5°

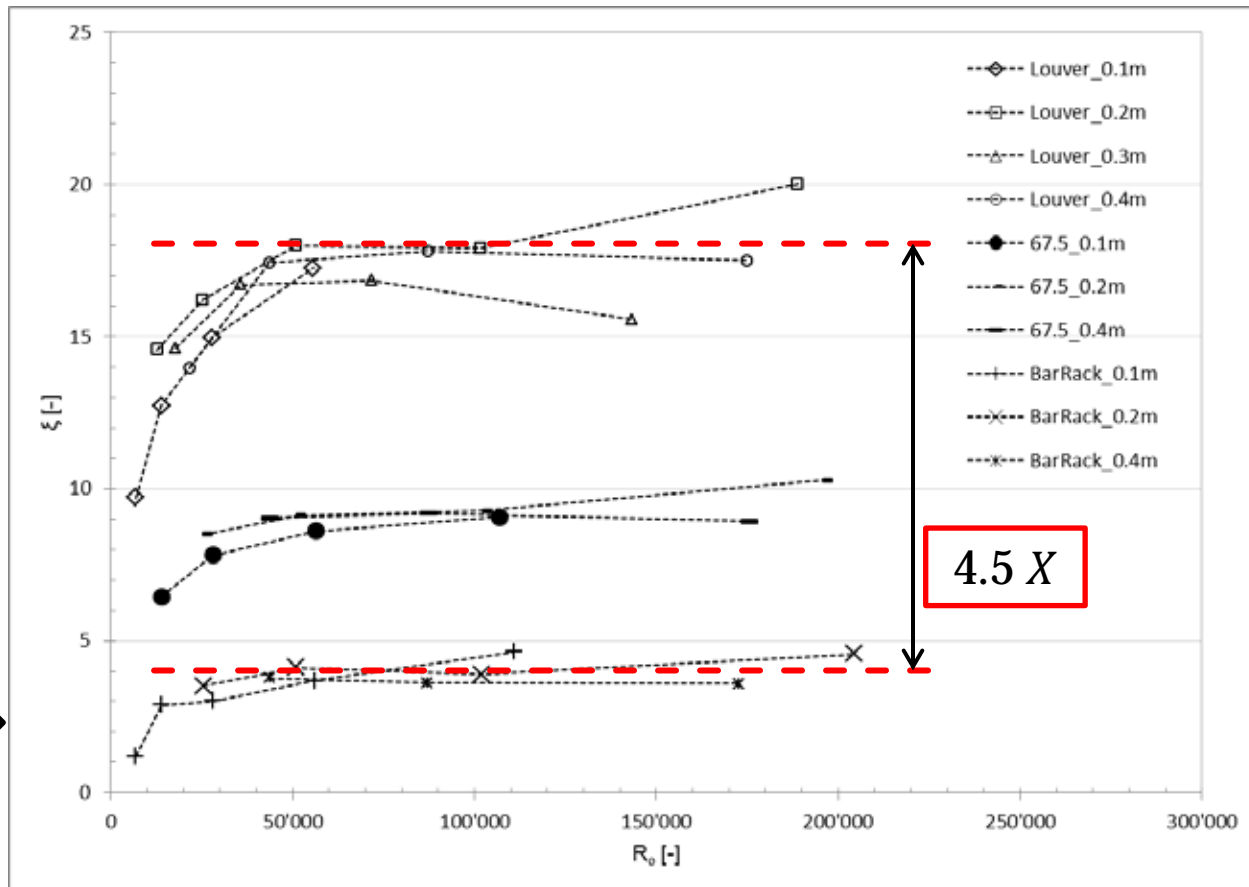
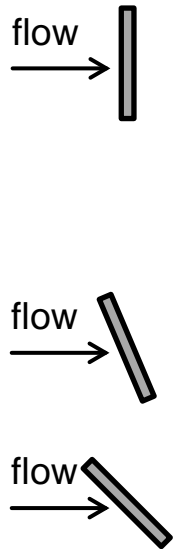
45°  
à «bar rack»

$\beta$

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Preliminary results: Effect of bar orientation $\beta$ on $\xi_R$ ( $\alpha = 45^\circ$ )

Detailed Model Investigation



$$Re = \frac{\textit{inertial } F}{\textit{viscous } F}$$

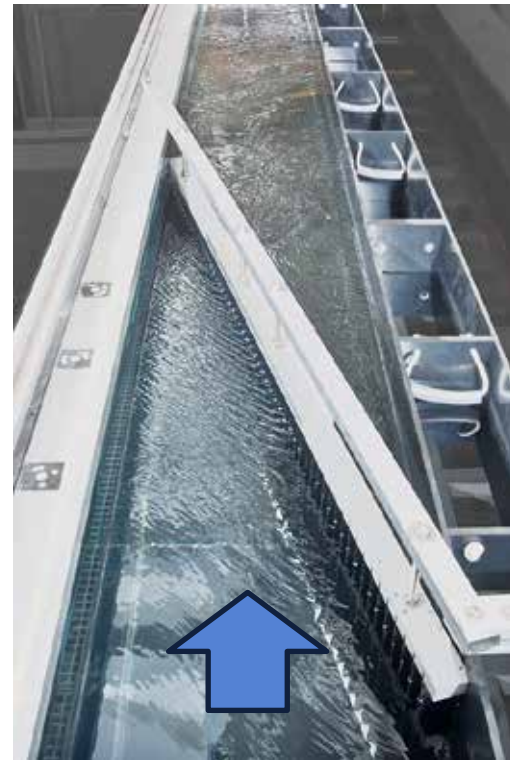
$$Re = \frac{vL}{\nu}$$

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Preliminary results: Effect of main angle $a$ on $\xi_R$ ( $b=90^\circ$ )



45°

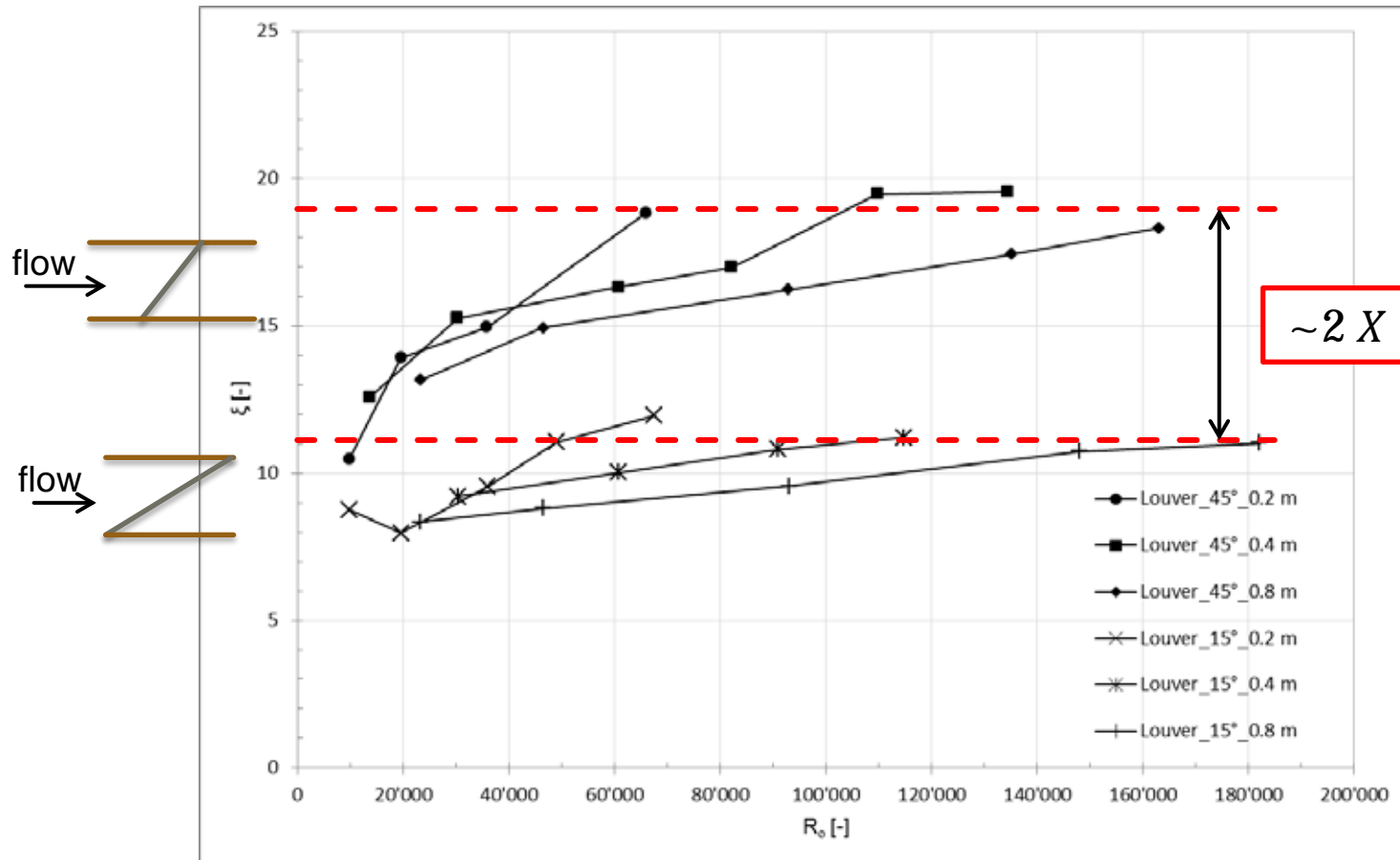


15°

$\alpha$

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Preliminary results: Effect of main angle $a$ on $\xi_R$ ( $b=90^\circ$ )



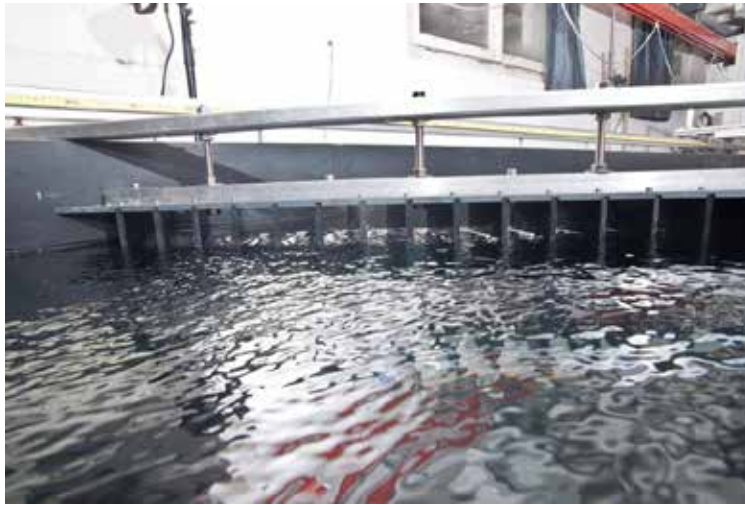
Detailed Model Investigation

$$Re = \frac{\text{inertial } F}{\text{viscous } F}$$

$$Re = \frac{vL}{\nu}$$

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Preliminary results: Effect of bar opening $b$ on $\xi_R$



5 cm



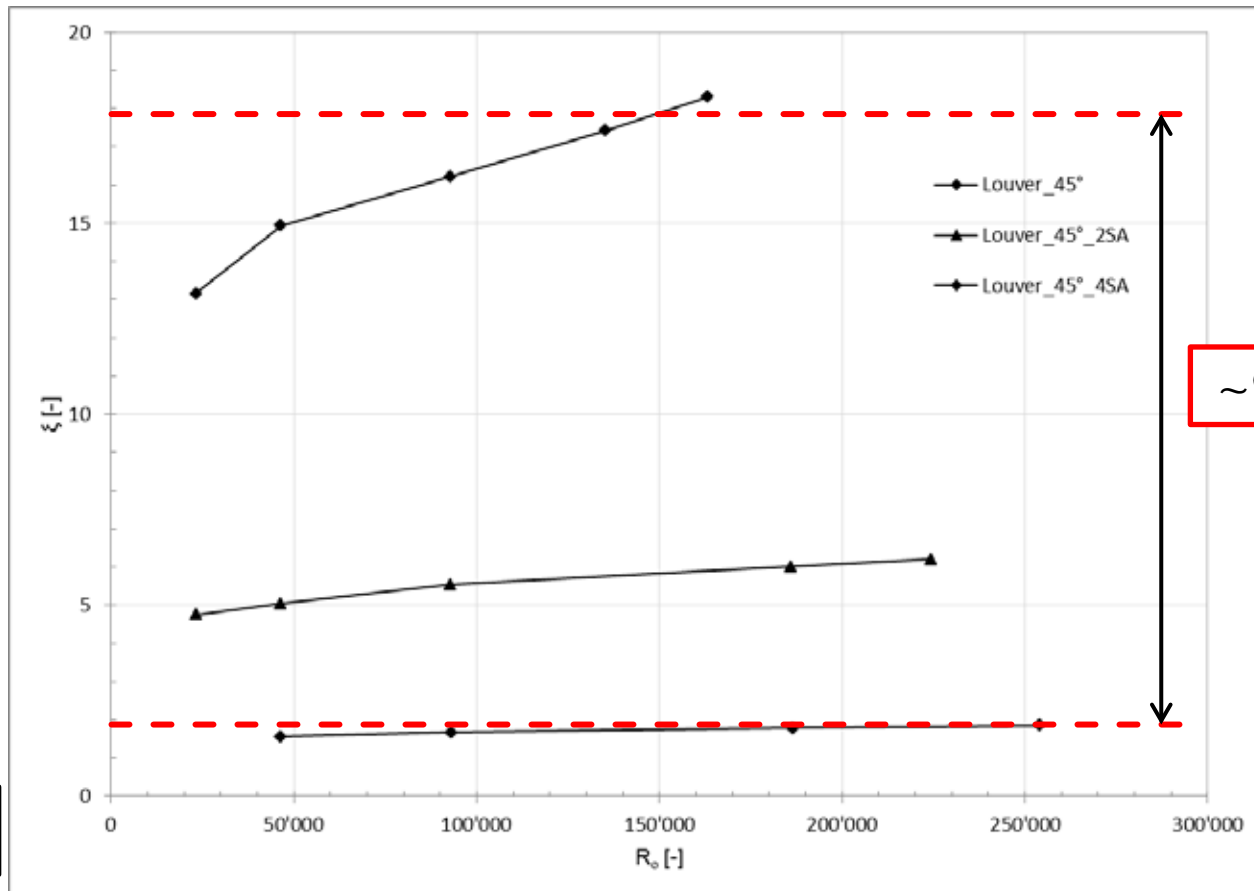
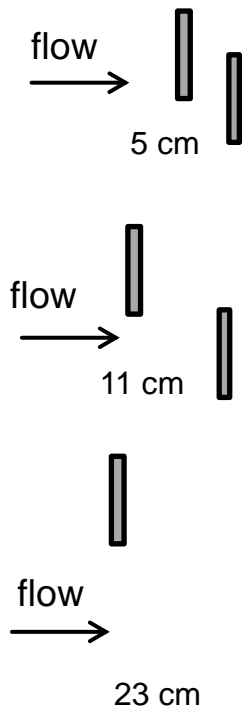
23 cm

$b$

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Preliminary results: Effect of bar opening $b$ on $\xi_R$

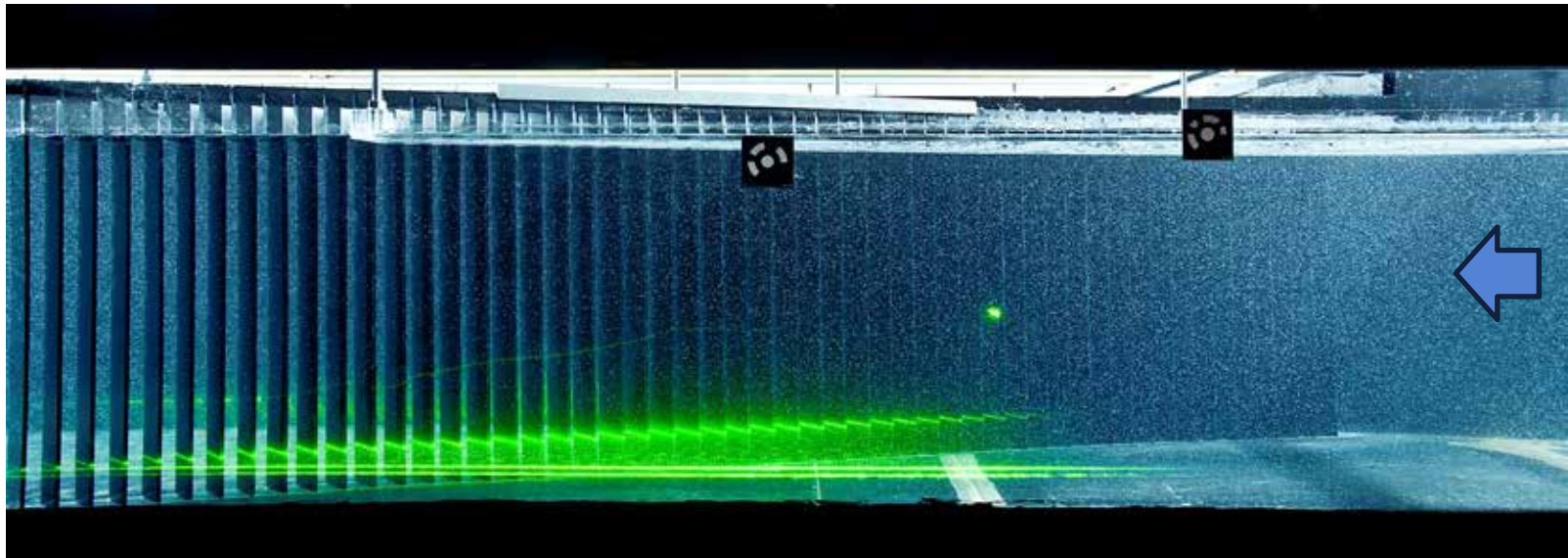
Detailed Model Investigation



## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Flow field experiments

- § Particle Image Velocimetry (PIV)
- § Velocity components in the horizontal plane

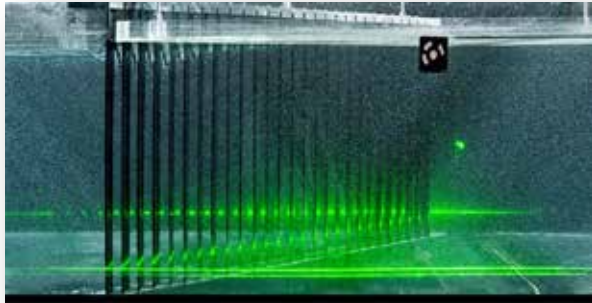




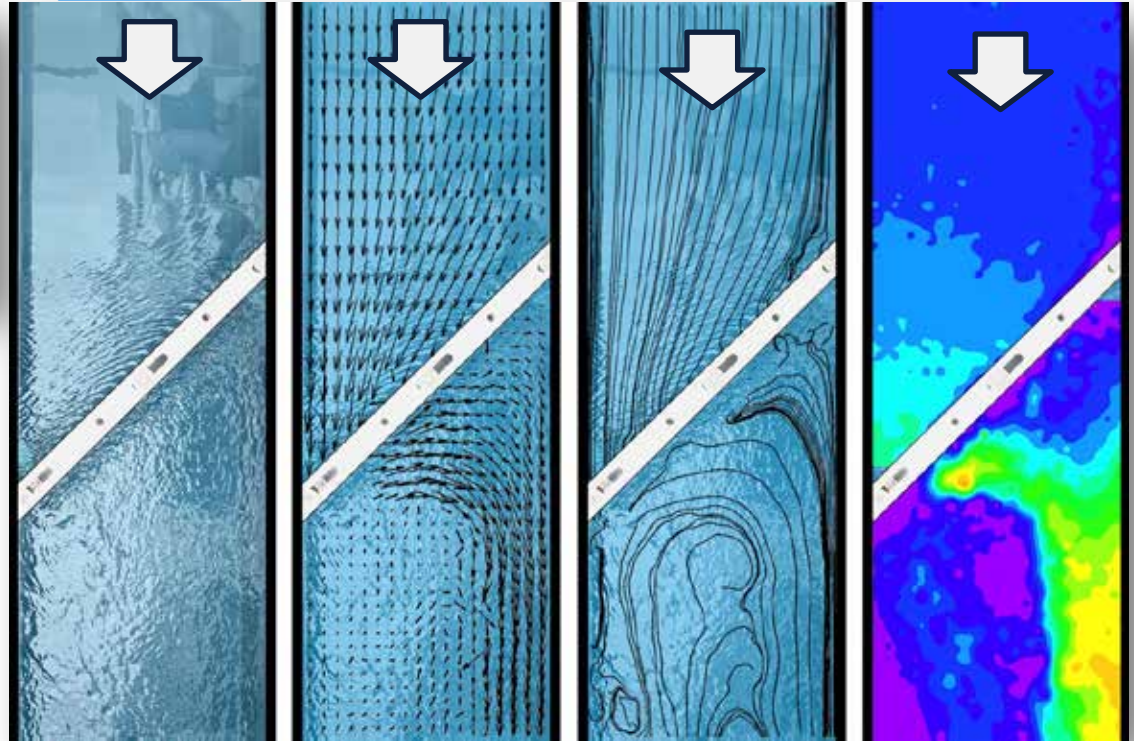
# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Preliminary results: Flow field experiments

0.2 m/s



$\alpha = 45^\circ$   
 $\beta = 90^\circ$   
 $b = 5 \text{ cm}$



Flow

2D Vel. Vectors

Streamlines

Vel. Magnitude

Detailed Model Investigation

Measures to facilitate  
at large Central-Euro

Large scale mod

Objectives

Impact of differen  
measures on:

Hydraulic conditio

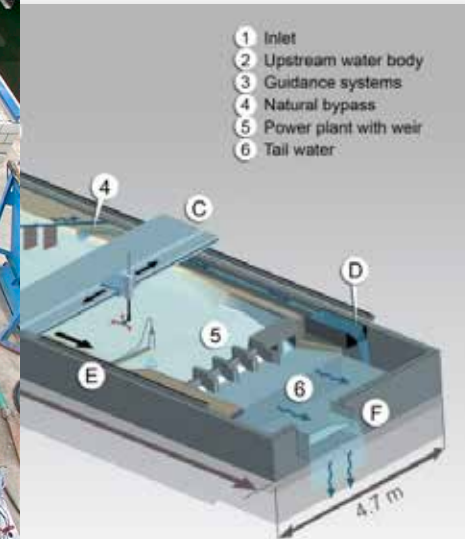
- Head losses
- Flow structures a
- Flow field near fis

Operational aspect

- Flood security
- Driftwood behavi
- Possible scour fo

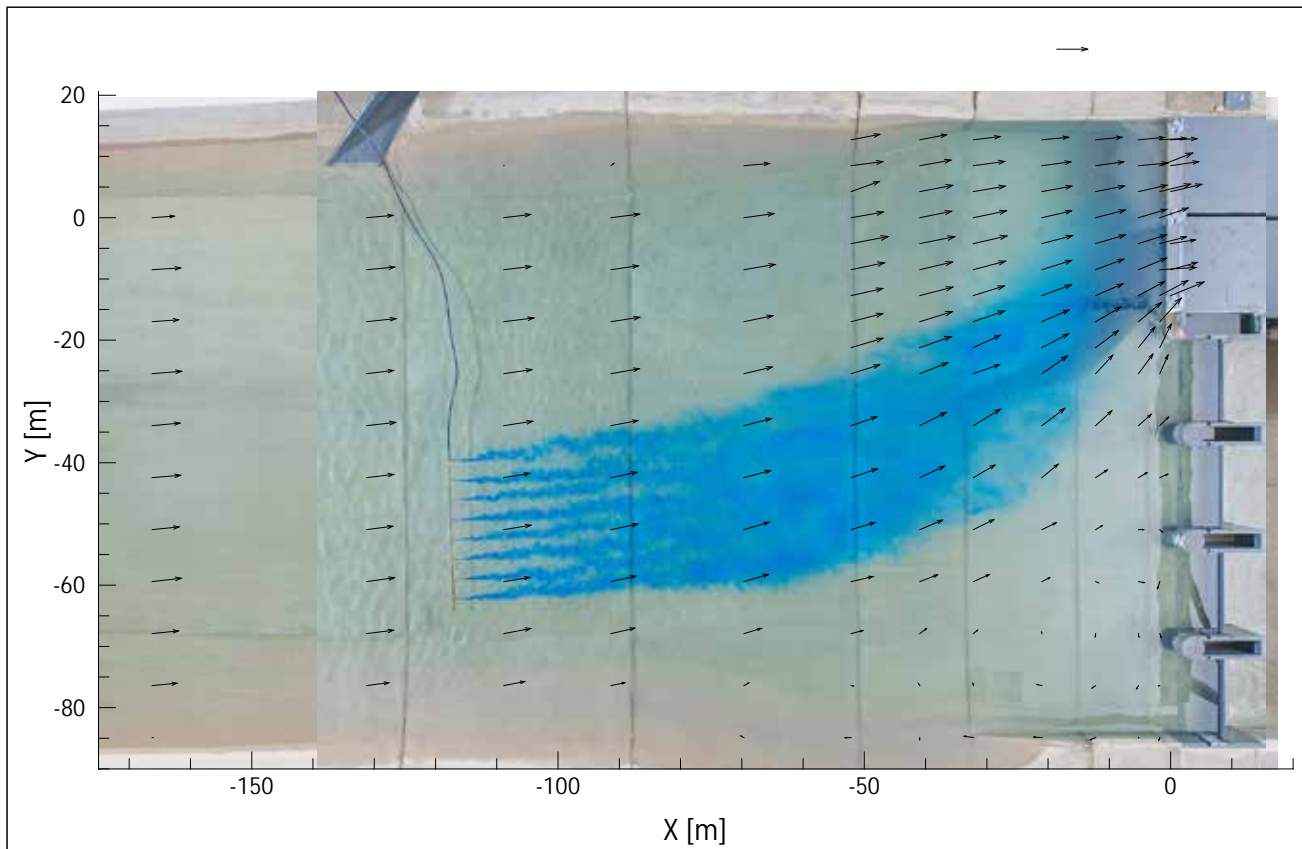


plant



## Measures to facilitate safe downstream fish migration at large Central-European Rivers

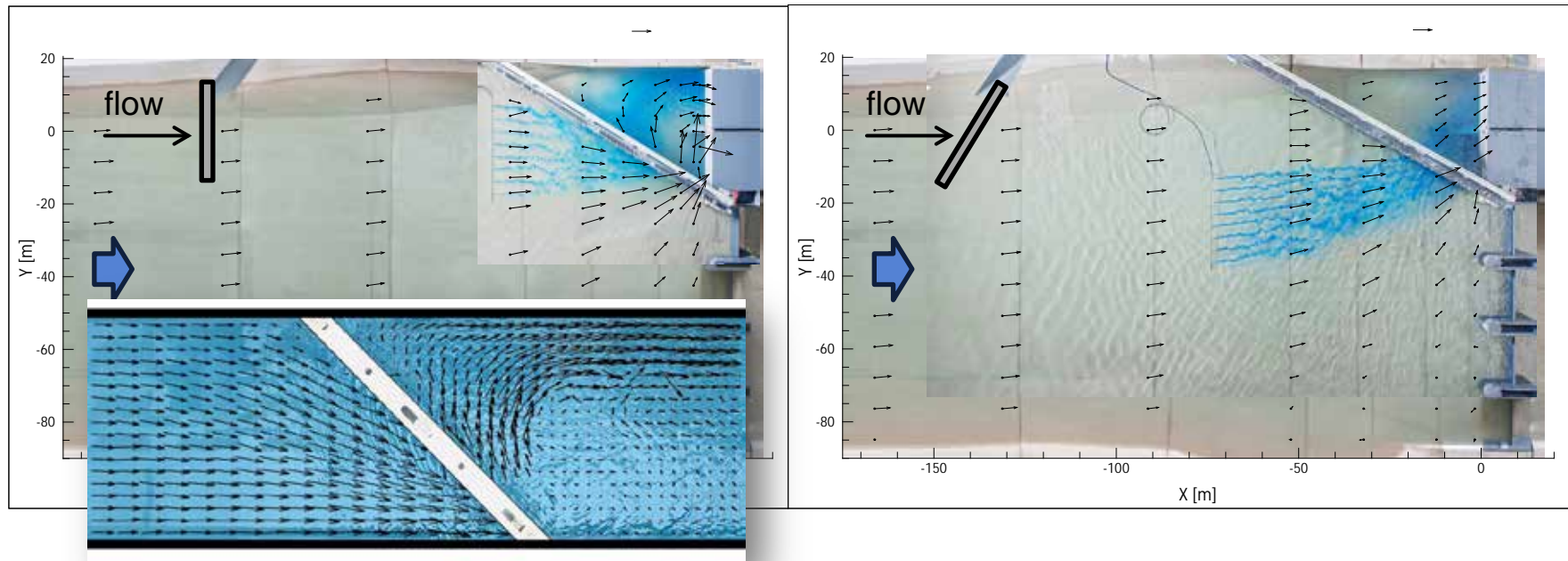
### Large scale model tests: Velocity experiments - no structure installed



## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Large scale model tests: Velocity experiments - Louver and bar rack

Louver and bar rack at 30° main angle

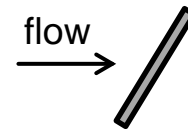
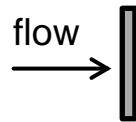
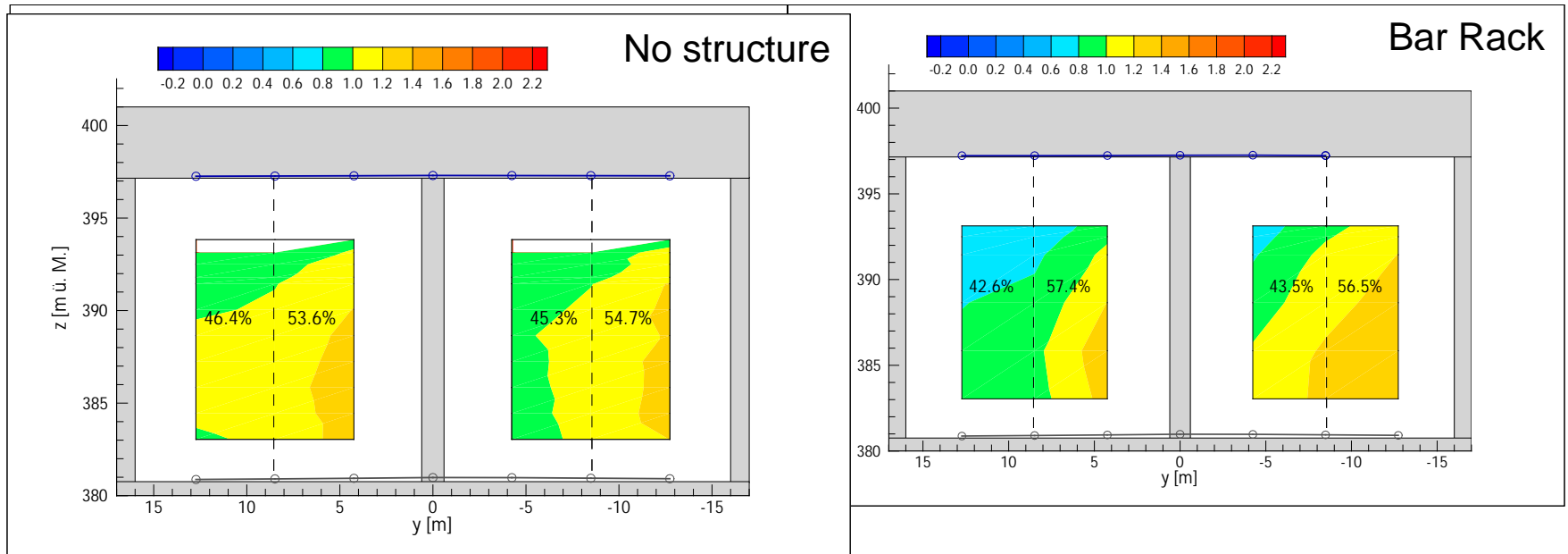


- § Both structures fully redirect flow in slat direction
- § Louver causes severe head losses and flow distortion

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Large scale model tests: Velocity experiments - Louver and bar rack

### Velocity distribution at turbine intakes



Large Scale Model Investigation

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Large scale model tests: optimization of velocity field at turbine intakes

Louver at 15 ° main angle



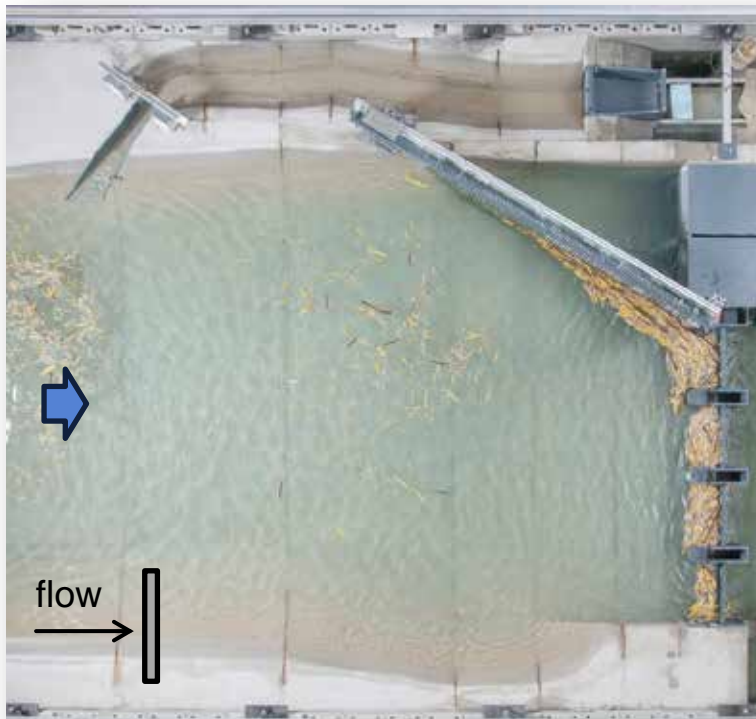
Large Scale Model Investigation

- § Pillar extension does not improve the velocity distribution
- § Pillar extension and guidance wall does improve the velocity distribution
- § Just a guidance wall is a promising measure

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Large scale model tests: Drift wood experiments

Louver at 30 ° main angle



- § No turbine operation, driftwood is transported downstream via spillway
- § During turbine operation the screen becomes jammed with driftwood

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Ethohydraulic model tests with fish

### Objectives

*Fish behaviour and guidance efficiency:*

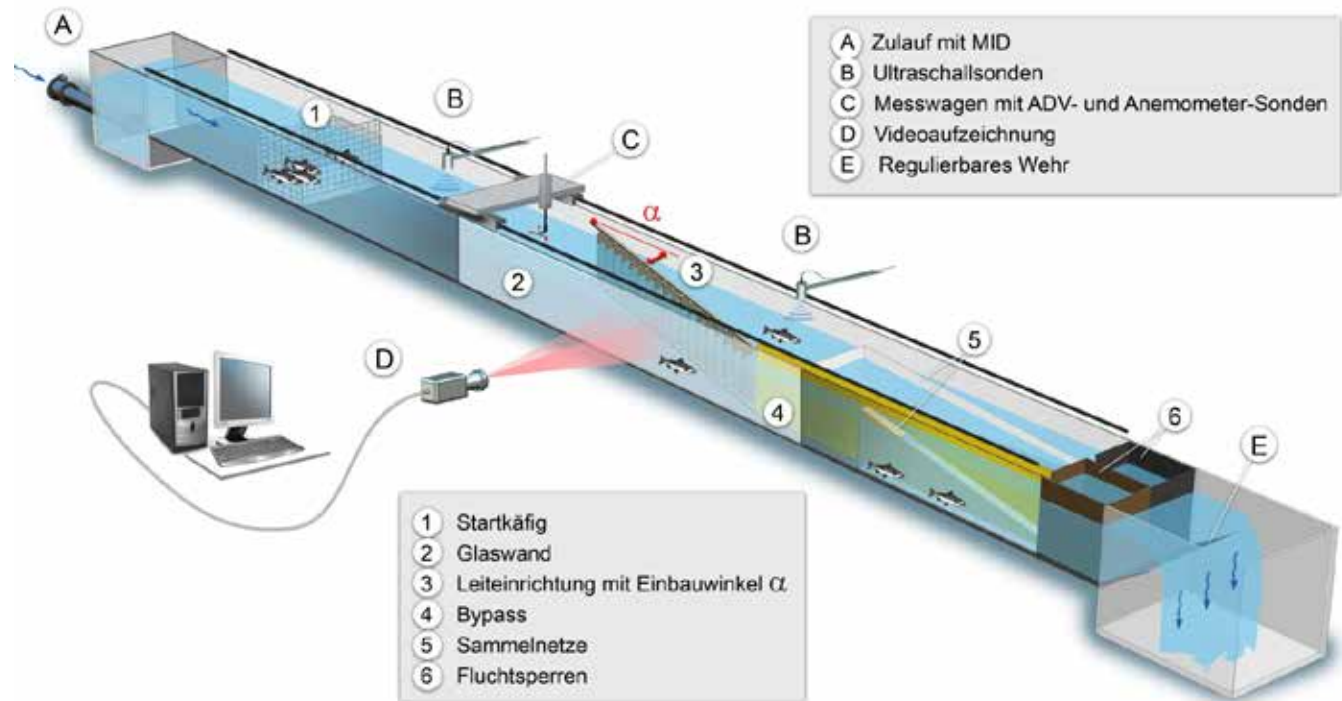
§ Flow velocity

§ Structure main angle

§ Slat angle

§ Bar distance

§ Bypass



Ethohydraulic Model Investigation

Tamara Boes, David Flügel



## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Ethohydraulic model investigation



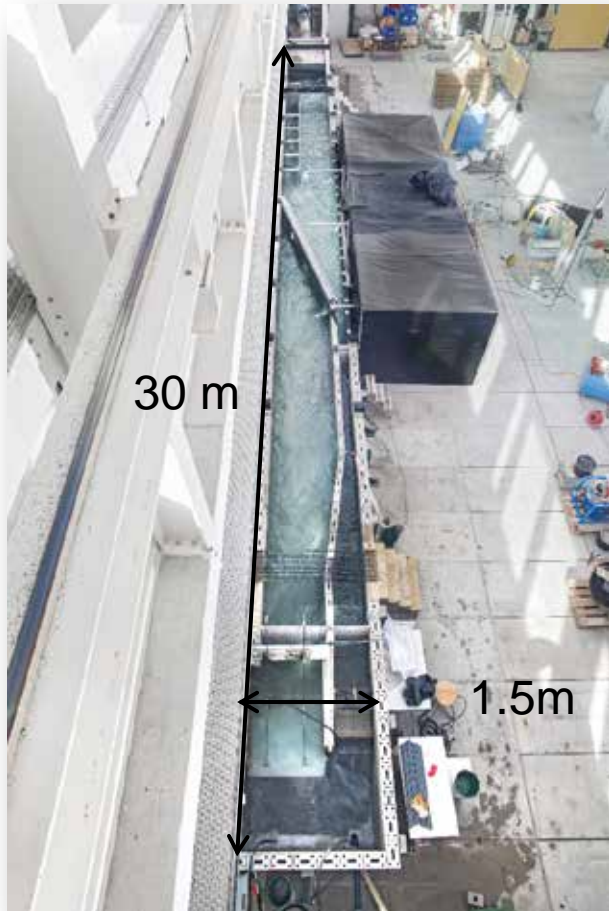
Ethohydraulic Model Investigation

~ 6 months to get the permission

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Ethohydraulic model investigation: Experimental set-up

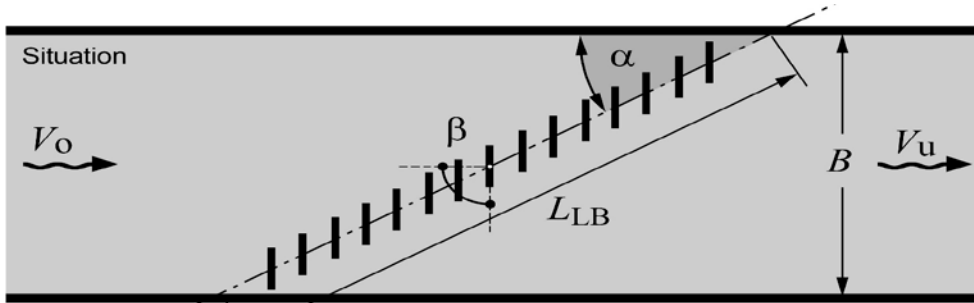
Ethohydraulic Model Investigation



$$Q_{\max} = 1200 \text{ l/s} = 1.2 \text{ m}^3/\text{s} !!!$$

# Measures to facilitate safe downstream fish migration at large Central-European Rivers

## Ethohydraulic model investigation: Experimental set-up



### Parameters

$\alpha$ : 30, 15 [°]

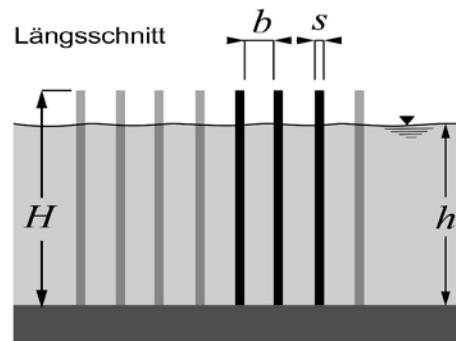
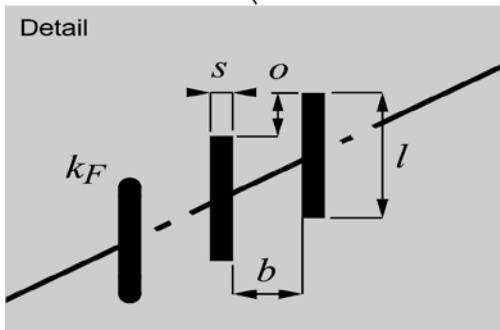
$\beta$ : 90, 45 [°]

$b$ : 5, 11 [cm]

$h$ : 90 [cm]

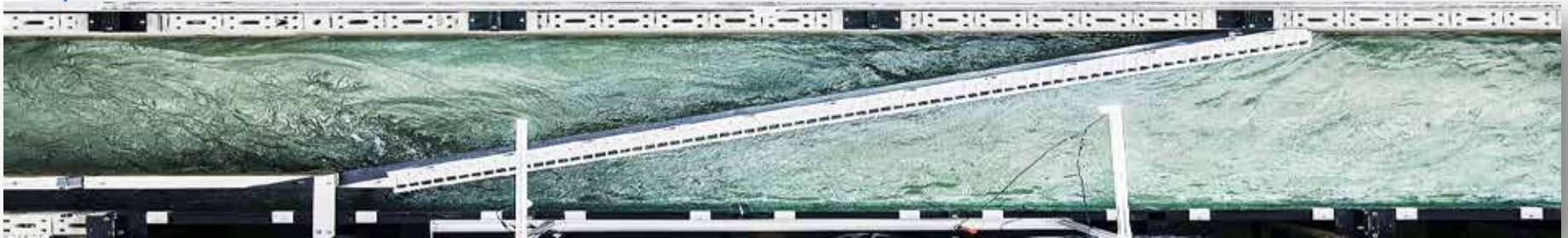
$v_o$ : 0.3 – 0.6 [m/s]

$k_F$ : rectangular



## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Ethohydraulic model investigation: Results from first experiments



§ Barbe (Barbel)



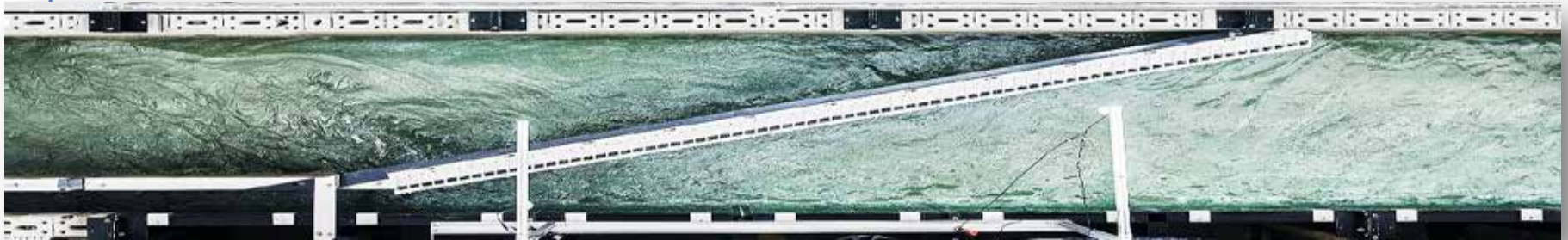
#### Parameters

$\alpha$ : 15 [°],  $\beta$ : 90 [°],  $b$ : 5 [cm]

$h$ : 90 [cm],  $v_o$ : 0.6 [m/s]

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Ethohydraulic model investigation: Results from first experiments



§ Schneider (Spiralin)



#### Parameters

$\alpha$ : 15 [°],  $\beta$ : 45 [°],  $b$ : 5 [cm]

$h$ : 90 [cm],  $v_o$ : 0.6 [m/s]

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

# Conclusions

### § Detailed model experiments:

- § Smaller main and bar angle à lower head losses
- § Larger bar opening à lower head losses
- § ...Effect of all parameters individually identified
- § Universal formula to be formulated

### § Large Scale Model Experiments

- § Louver negatively effects flow field at turbine intakes
- § Bar rack has less pronounced effect on flow field
- § Optimization with guidance walls can improve the situation
- § Without turbine operation driftwood is transported to the spillway

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

# Conclusions

### § Ethohydraulic model investigation (preliminary results)

- § Bar rack system guides fish as effective or better than louver system
- § Bypass optimization promising for further improvement
- § Spirlins and Barbels show equal guidance efficiencies
- § ...This is only the tip of the iceberg! More tests necessary.

## Measures to facilitate safe downstream fish migration at large Central-European Rivers

### Outlook

#### § Ethohydraulic model investigation

- § More experiments with different configurations
- § Passage time and swimming paths of fish will be analyzed
- § Data analysis using fish tracking
- § Temperature and Light effects need to be investigated

#### § A guideline for downstream fish migration will be prepared

#### § Fish monitoring and further optimization of guidance structure are necessary at prototype scale (site specific)



## Measures to facilitate safe downstream fish migration at large Central-European Rivers

# Thank you for your attention!

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