Session C8: Development of Criteria for the Design and Dimensioning of Fish-Friendly Intakes for Small Hydropower Plant

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Pôle Ecohydraulique ONEMA – IRSTEA – IMFT (Toulouse)

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Institut P' de Poitiers

Development of criteria for the design and dimensioning of fish-friendly intakes for small hydropower plant

COURRET D[1], LARINIER M, DAVID L[2] and CHATELLIER L[2]

Several studies funded by :

Context in France

- **Downstream migration is taking into account for :**
  - **Salmon : smolts** (+ adults)
  - **Sea trout : smolts** + adults
  - ➔ Can have a lot of hydropower plants on their migration route
  - **Silver eels**
  - ➔ Suffered high mortality
  - **Brown trout** at medium or high head hydropower plant

Smolts : (12) 15 - 20 (22) cm

Silver eels :
- Male 30-45 cm
- Female 50-90 (110) cm

- **A lot of small hydropower plants on migration route (old mills)**
  - Run-of-river operation
  - Turbine discharge mostly < 50 m^3/s, some between 50 - 100 m^3/s
  - A few big plants :
    - » Dordogne and Garonne river : 300-500 m^3/s
    - » Rhine and Rhone river : 1000 – 1500 m^3/s

Brief overview of solutions and ONEMA positions

4 main types of solutions

- **Fish friendly turbine** (VLH, Screw) ➔ Good solutions, but limited to low height dam and discharge, mostly for new equipment, not really cost-effective on existing plant

- **Behavioral device** (sound, light, electricity) ➔ No system approved until now, except light to attract smolts

- **Targeted shutdown of turbines** ➔ Foreseen for eels at biggest dams where other solutions are not feasible, difficult to define, ongoing research

- **Material barriers which can induce both behavioral or physical effects :**
  - Louver ➔ Not implemented due to maintenance constraints
  - Surface guiding wall with bypasses ➔ Reserved to biggest dams (1 case)
  - **Bypass in association with trashrack ➔ Main solution implemented at small plants in France**

Studies conducted

- **1992 – 2005 : Assessment of the efficiency of bypasses in association with existing trashracks (EDF R&D – CSP – Cemagref)**

➔ A satisfactory solution in some cases

➔ But difficulties to obtain regularly good efficiencies, especially for eels

Halsou

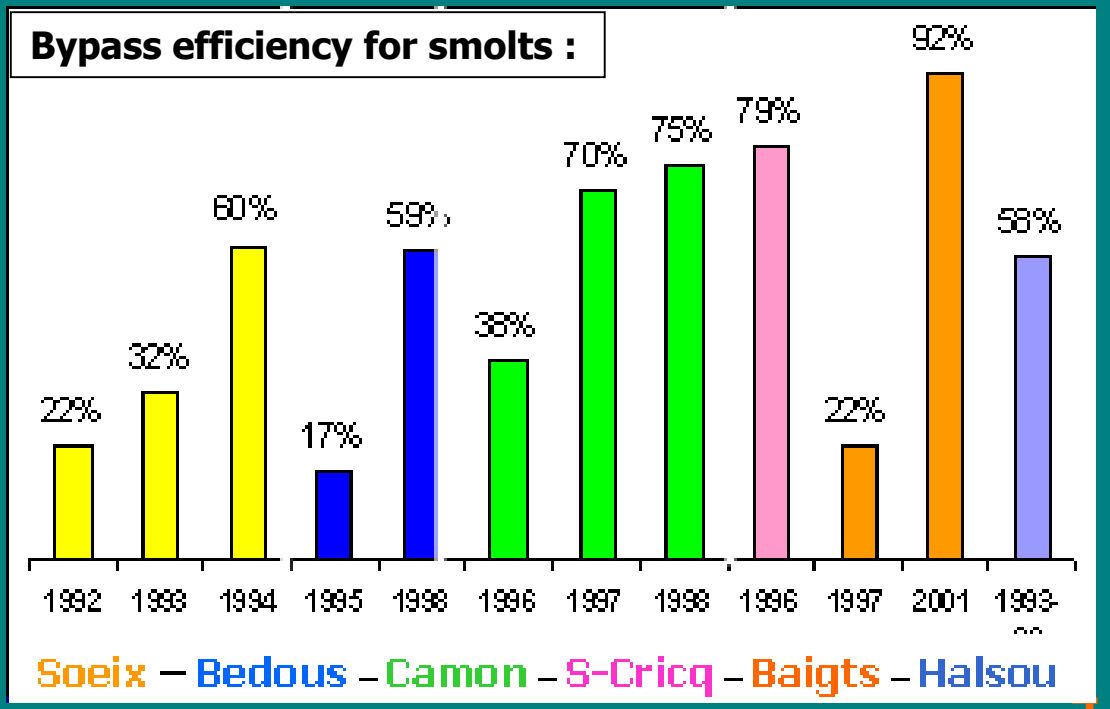
Baigts

Bypass efficiency for silver eels :

- Baigts : ≈ 20% (surface), very low (bottom)

- Halsou : 56 – 64 %

Bypass efficiency for smolts :



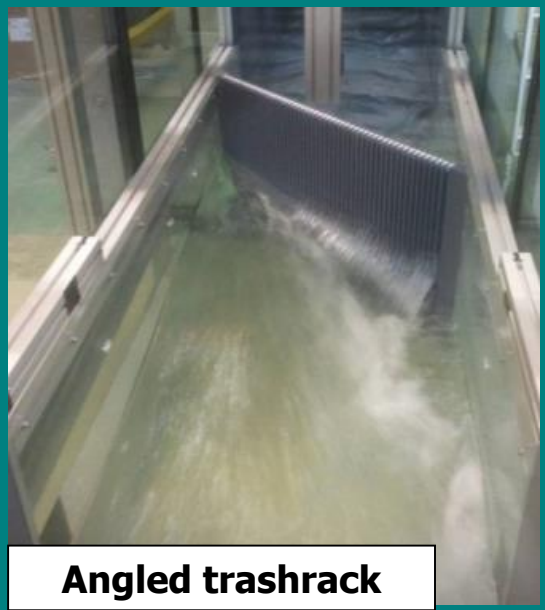
Studies conducted

- **2007-2008 : Synthetize the feed-back of all efficiency assessment and intake design in France and abroad (mainly USA) to define criteria for systems of racks and bypasses with high efficiency (> 90%)**

➔ So-called "fish friendly intakes"

➔ Production of a technical guide in 2008

- **2010 – Until now : hydraulic studies, mainly on down-scaled physical model + numerical simulation :**
  - Characterize head-losses through racks in fish-friendly configurations
  - Verification of guiding conditions and adaptation of criteria
  - Precise criteria for the design of bypasses (attractivity in function of position, flow, …)



Angled trashrack

3 fundamentals functions

1) Stop fish and avoid their passage through turbine

- **Smolts :**
  - Possible to obtain good efficiency with a behavioral effect

  ➔ Bar spacing : ≤ 25 mm

- **Silver eels :**
  - Necessity to install a physical barrier : bar spacing ≤ head diameter

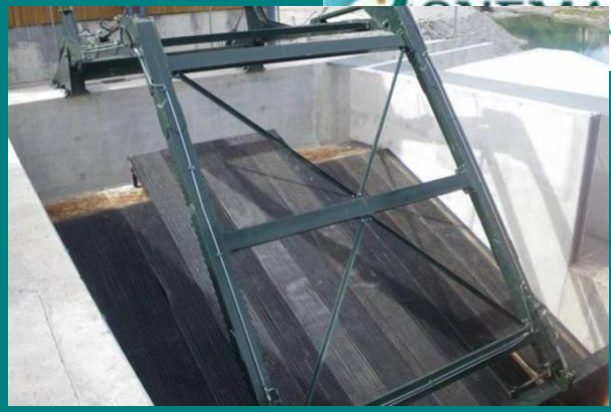
    ➔ Bar spacing : 15 - 20 mm to stop eels longer than 50 - 60 cm

- **Velocities upstream the rack low enough to :**
  - Allow fish swimming during the time necessary to find bypasses
  - Do not induce rapid passage through or impingement of fish against the rack

  ➔ Normal velocity (flow divided by the wetted rack surface) ≤ 50 cm/s for eels and smolts

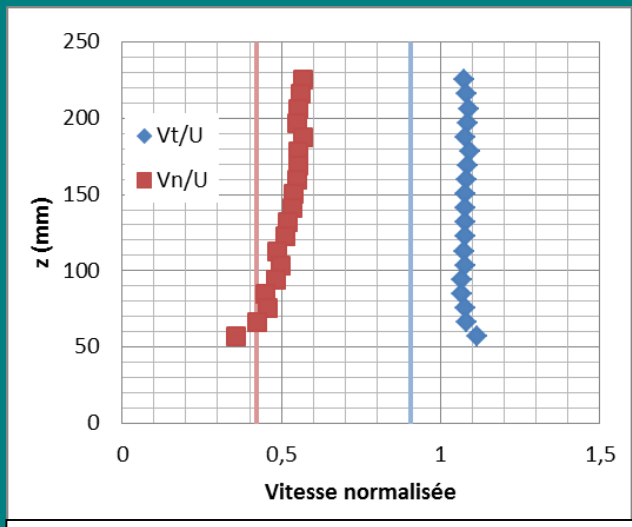
  ➔ Give a minimal surface of the rack for a given turbine discharge : at least 2 m^2 of rack for 1 m^3/s of turbine discharge

3 fundamentals functions



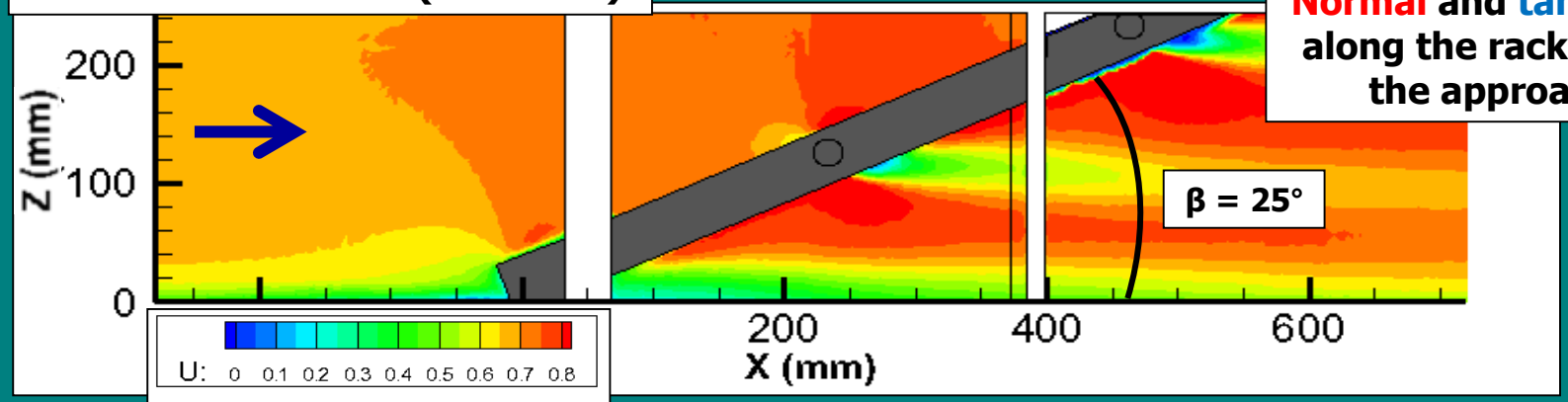
2) Guide fish towards bypasses ➔ Inclined trashrack perpendicular to the flow :

- **Moderate acceleration of velocities along the rack** (≈ +10% at the top of the rack)
- **Minimal inclination at β ≤ 26** to obtain Vt ≥ 2 Vn and guide fish to the surface
- **Approach velocity acceptable up to ≈ 0.80-0.85 m/s à β = 26°** ➔ higher inclination in case of higher velocities



Normal and tangential velocity along the rack (normalized to the approach velocity)

Measured velocities (side view)

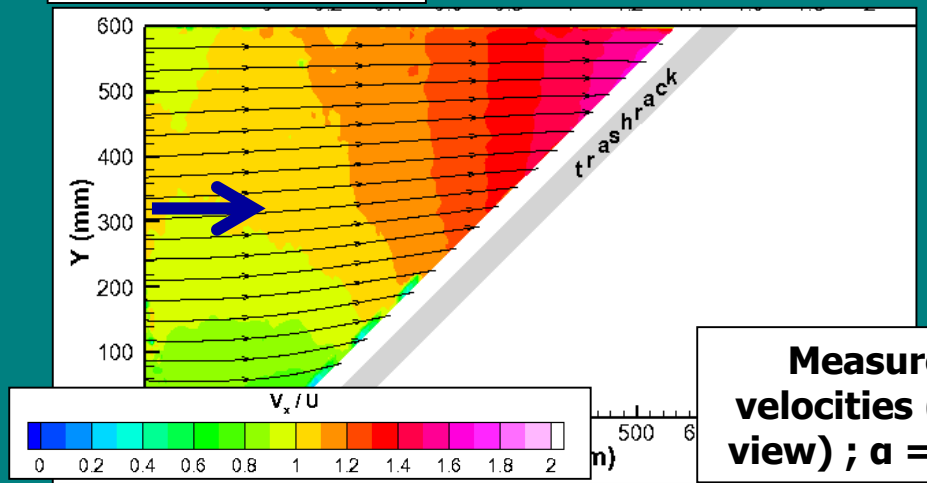


3 fundamentals functions

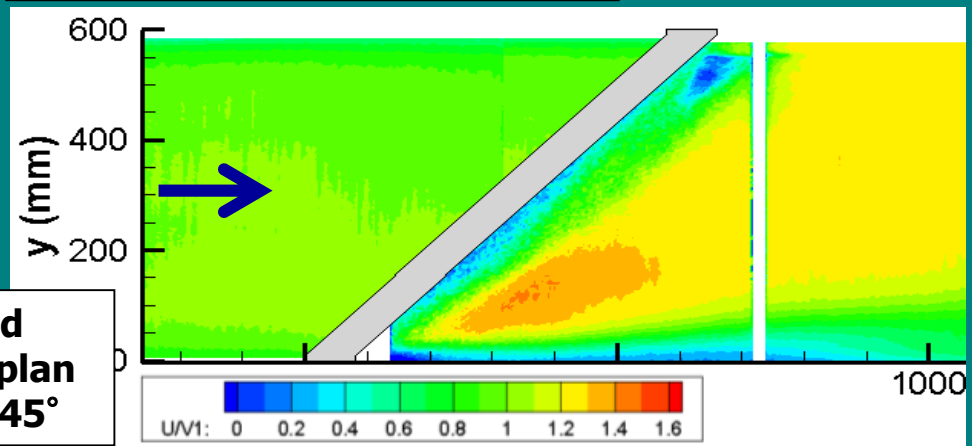
2) Guide fish towards bypasses ➔ Angled vertical trashrack :

- **Minimal angle α ≤ 45° to obtain Vt ≥ Vn**
- **Conventional rack (bar perpendicular to the rack axis)**
  - Flow acceleration along the rack + head-losses increasing with angulation
  - Approach velocity acceptable limited to 0.5 m/s at α = 45° ➔ Low gain on acceptable approach velocity with an increase of the angulation
- **Rack with streamwise bars (experimental configuration)**
  - Homogeneous velocities upstream the rack + reduction of head-losses
  - Approach velocity acceptable up to 0.6 m/s à α = 45° ➔ higher angulation in case of higher velocities, but solution to find to clean the rack

Conventional rack



Rack with streamwise bars

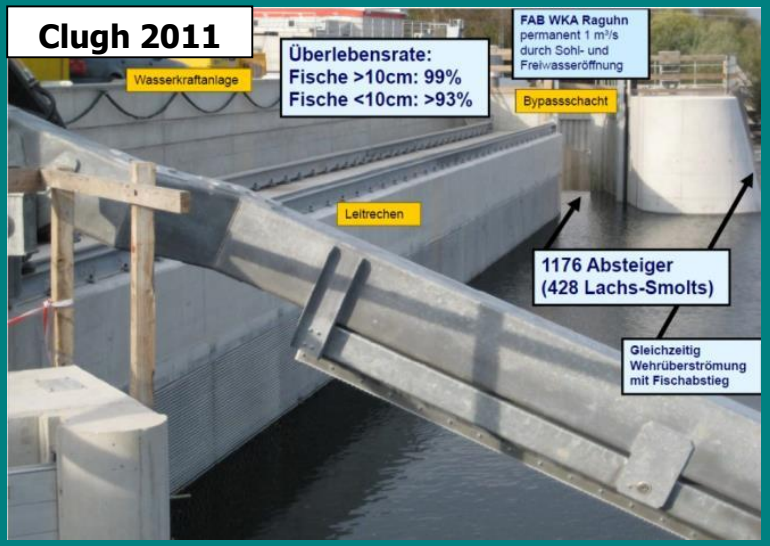


Measured velocities (plan view) ; α = 45°

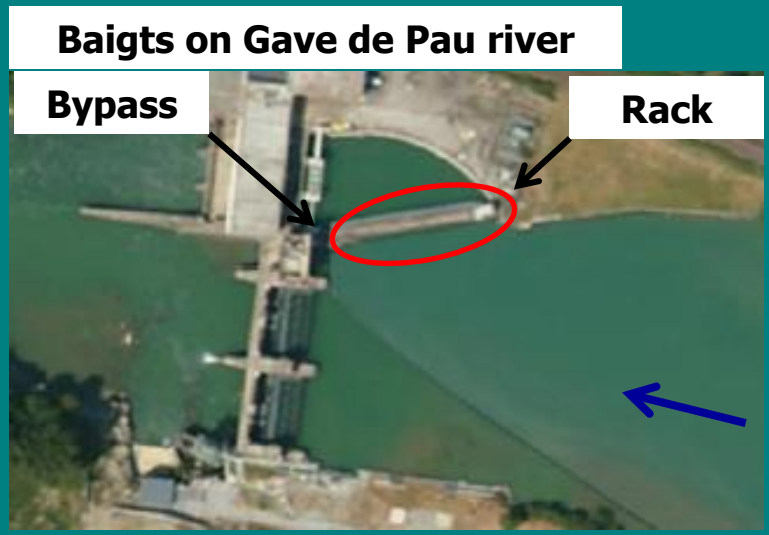
3 fundamentals functions

2) Guide fish towards bypasses ➔ Angled vertical trashrack :

- **Angled rack with horizontal bars are interesting :**
  - no installation in France ; several installations in Deutschland and Sweden
  - Looking for studies and feedback on this configuration



- **Rack in bank alignment are favorable configuration for fish guidance**



3 fundamentals functions

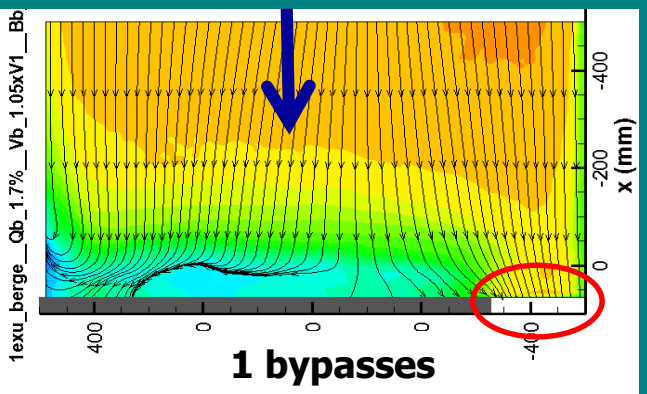
3) Downstream transfer of fish ➔ Inclined rack

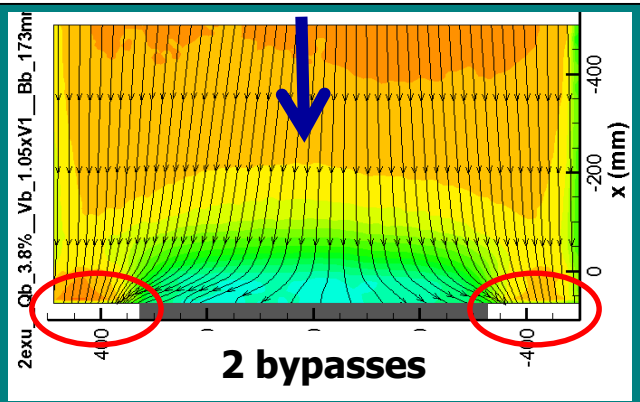
$$Q_b = V_b * H_b * (N_b * B_b)$$

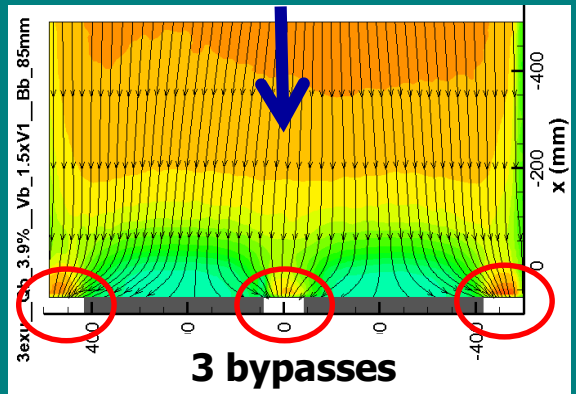
- **Surface bypasses at the top of the rack**
- **Criteria to determine bypass number and flow :**
  - Velocity at the bypass entrance V_b = 1.1 V_A
  - Minimal dimensions recommended : 1 m wide (B_b) and 0.5 m deep (H_b)
  - Obstruction of the top of the rack, between bypasses, over the same depth ➔ to generate transversal velocities
  - Maximal distance between bypasses : 4-5 m ➔ Determination of the number of bypasses N_b

➔ From 5-6% of turbine discharge for small intakes, down to 2-3% for intakes > 50 m³/s

Near surface velocities (plan view) at the top of inclined rack ; β= 26°







3 fundamentals functions

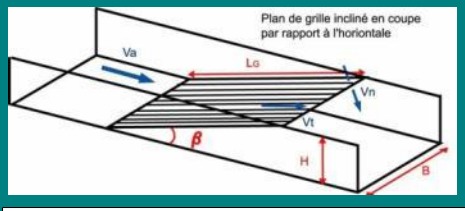
3) Downstream transfer of fish ➔ Angled rack

- **Bypass positioned at the downstream end of the rack**
- **Not a complete set of criteria nowadays :**
  - Surface bypass : as deep as possible, ideally same depth as the intake ➔ high flow ; difficulties to create a such deep bypass on existing site
  - Interrogation about bottom bypass, notably for eels :
    - » Sensible to clogging and difficult to clean
    - » Necessity ? ➔ Eels seem to prospect all the water column if they are stopped by the rack.
  - Velocity at the bypass entrance V_b of about velocities at the downstream end of the rack :
    - » $\mathbf{V_b}$ = 1.7 $\mathbf{V_A}$ for a "conventional" angled rack à 45° ➔ high flow
    - » $\mathbf{V_b}$ = 1.0 $\mathbf{V_A}$ for a angled rack with streamwise bars
    - » Criteria for an angled rack with horizontal bars and rach in bank alignment ?

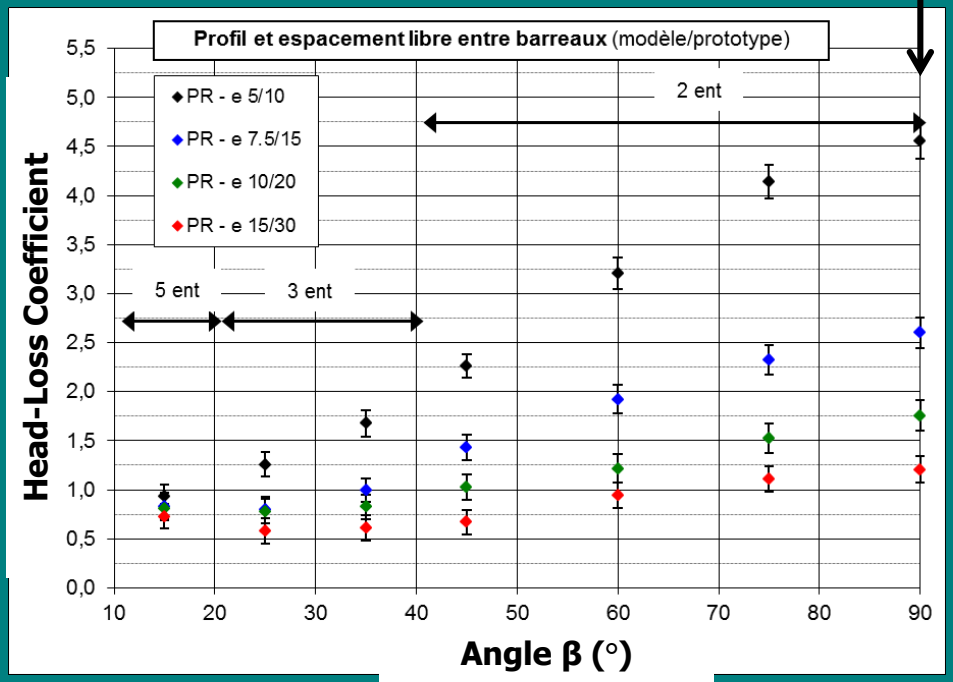
Head-losses and clogging issues

- Experimental measurement of head-losses
- Existing formulae not adapted to fish-friendly configurations

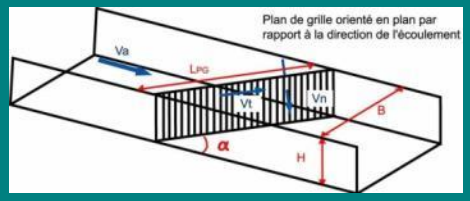
➔ Production of new formulae (Raynal et al. 2013)



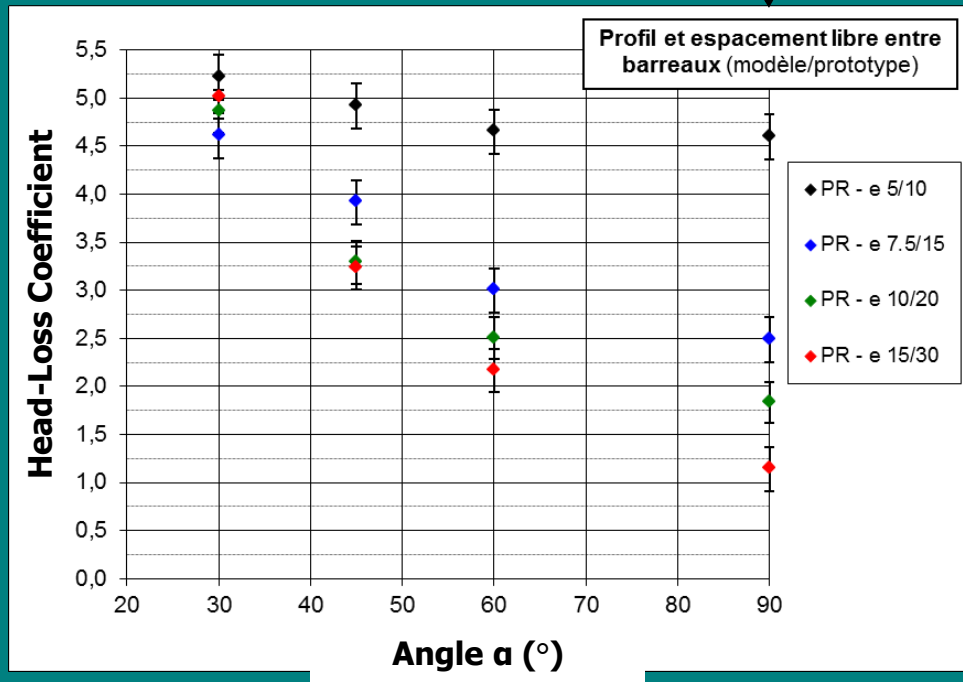
Vertical



Decreasing head-losses with inclination



Perpendicular



Increasing head-losses with angulation

Conclusions

- **Preference for inclined rack :**
  - Lower head-losses
  - Compatible with high approach velocity
  - Existing solutions for rack cleaning ➔ Except for deep intakes and long racks
  - Bypass design criteria well-defined
  - But not adapted to forebay with water level fluctuations
- **Angled rack reserved to deep intakes, or intake with fluctuating water levels, or in bank alignment**
  - « Conventional » rack constraining (head-losses, admissible approach velocity)
  - Rack with stream-wise bars ➔ interesting solution, trashrake design to find
  - Rack with horizontal bars ? ➔ Feed back in Deutschland and Sweden
  - Design criteria for bypass to complete
- **Absolute necessity to adapt the trashrake**
- **Feed back to acquire on operation and biological efficiency (ongoing)**

Thank you for your attention