HIDROINŠTITUT
INŠTITUT ZA HIDRAVLIČNE RAZISKAVE

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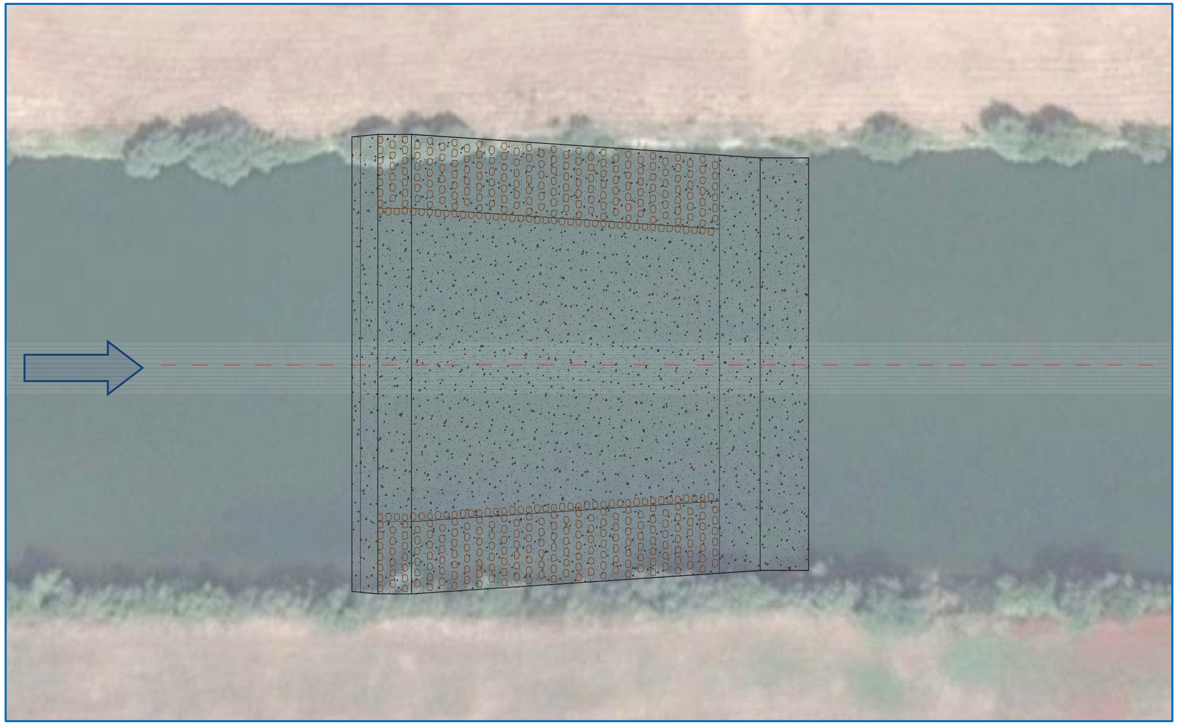
ANALIZA PROJEKATA I PRIJEDLOG DALJNJIH KORAKA ZA PROJEKTIRANJE PRAGOVA U KORITU RIJEKE SAVE



Naručilac: HRVATSKE VODE
VODNOGOSPODARSKI ODJEL
ZA GORNJU SAVU
10000 Zagreb, Ulica grada Vukovara 271/VIII

Zagreb, 26.4.2017

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

S pojmom Ribja steza, Prehod za ribe oz. Ribji prehod, označujemo naprave/konstrukcije na ali ob pregradnih objektih (ki pregrajujejo celotno širino vodotoka), ki omogočajo prehod/migracijo rib preko pregradnih objektov.

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Pragovi tipa a in b:

- **Jarun**
- **Kajzerica**
- **Bundek**
- **Mičevac**
- **Ščitarjevo**
- **Hruščica**

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

A. Predlog zasnove prehodov za ribe na pragovih na Savi v Zagrebu

Pragovi naj se zgradijo z manjšim vzdolžnim nagibom dolvodne klančine 1:35, na katerih se vzpostavita po dve strukturirani površini - **drči**, ob vsakem bregu po ena v širini 15 m, ki služita za prehode rib, na katerih so strukturirano vgrajene skale na točno določenih medsebojnih razdaljah v prečni in vzdolžni smeri.

Zasnova s strukturirano površino, z večjo hrapavostjo in manjšimi hitrostmi vodnega toka, omogoča zgraditev funkcionalno učinkovitega prehoda za ribe v obliki drče.

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Ihtiofauna Save na širšem vplivnem območju pragov – biološke podlage

Študija (Mrakovčić) je pokazala, da je na območju posega

(a)kvalitativna struktura ribjih vrst in
(b)skupno število zabeleženih vrst,

značilen odsek reke Save v katerem je, v ihtiološkem smislu, prehodno območje (krapovskih) vrst med cono **mrene** i cono **ploščiča**, z mešano ihtiofauno, kar (predstavlja) je **osnova** za projektiranje učinkovitega ribjega prehoda.

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Učinkovit ribji prehod – definicija

Učinkovit prehod je tisti, ki je zasnovan tako, da so v njem zagotovljene take hidravlične razmere, da:

- je omogočen prehod vsem ribam ki želijo preiti oviro in
- ribe to lahko storijo sigurno, brez nepotrebnega stresa, poškodb in z najmanjšo zamudo

(DWA-M 509, po Clay 1960, 1995, modificirano)

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Učinkovit ribji prehod – projektni kriteriji

- Vhod v RP – zaznavnost / atraktivnost, da ribe najdejo vhod:
  - Koridor migracij: vrste rib, migracijsko obnašanje
  - Vrsta i velikost reke, mesto vhoda, pretok, spremembe nivojev gladine spodnje in zgornje vode, povezava RP s spodnjo vodo
- Ribji prehod (RP) - Prehodnost – kategorije: ribje vrste - njihove značilnosti in plavalne sposobnosti, geometrija in morfologija prehoda, hidravlične razmere v prehodu:
  - Največje ribje vrste ?
  - Ribje vrste z najmanjšo kapaciteto plavanja ?
  - Nagib ribjega prehoda, velikost bazena, širina odprtin, substrat dna
  - Hitrosti toka (največja, najmanjša), pretok, turbulenca, globina (najmanjša), gostota razsipanja (disipacije) kinetične energije
- Izgradnja
  - Čas in termin del v reki in ob njej

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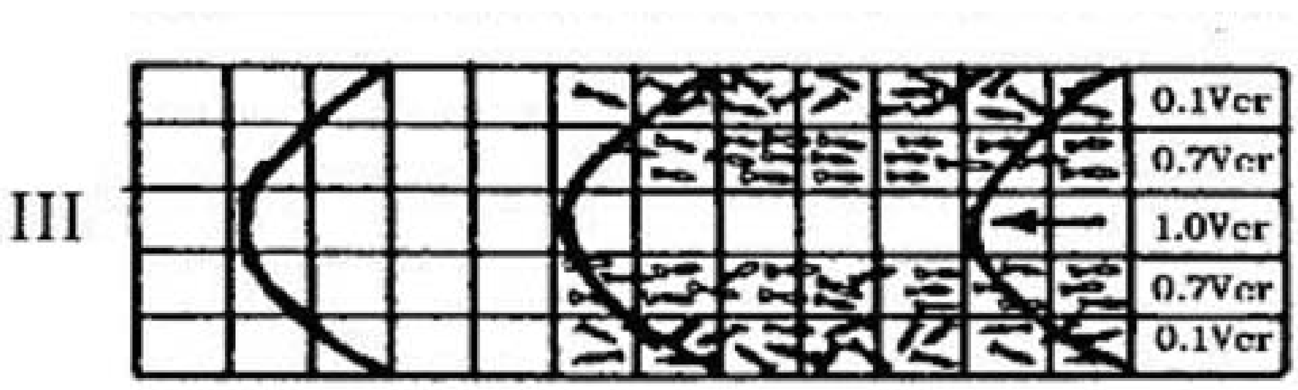
A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Učinkovit ribji prehod – Vhod v RP- Najdenje vhoda: zaznavnost / atraktivnost

- **Koridor migracij**: **vrste rib**, **migracijsko obnašanje**, mesto vhoda, pretok, **hitrost vodnega toka**

hitrost vodnega toka



Prikaz obnašanja rib pri migraciji v pasovih z različnimi hitrostmi vodnega toka z ozirom na kritično hitrost Vcr (Pavlov)

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A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Učinkovit ribji prehod – Najdenje vhoda – zaznavnost / atraktivnost

- **Koridor migracij**: vrste rib, **migracijsko obnašanje, mesto vhoda**

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A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Učinkovit ribji prehod – Najdenje vhoda: zaznavnost / atraktivnost

- **Koridor migracij**: **povezava s spodnjo vodo**

Drče na Mirni: napačna povezava s spodnjo vodo

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A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

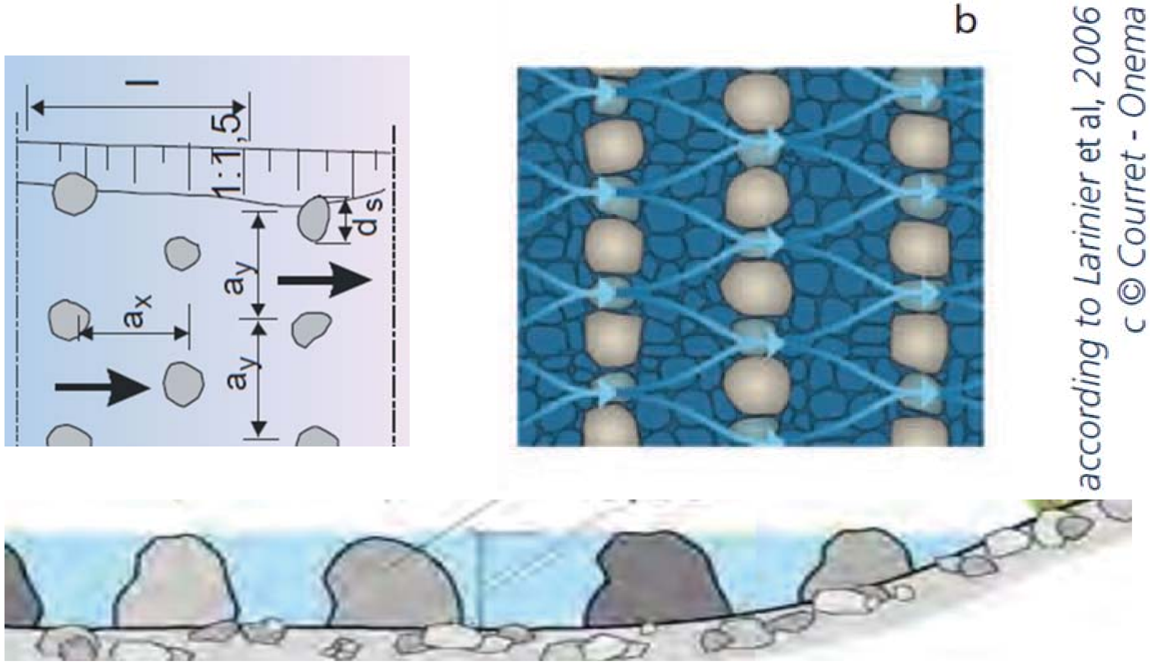
Učinkovit ribji prehod – Najdenje vhoda: zaznavnost / atraktivnost

- **Koridor migracij**: **povezava s spodnjo vodo**

Drče na Mirni : pravilna povezava s spodnjo vodo

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

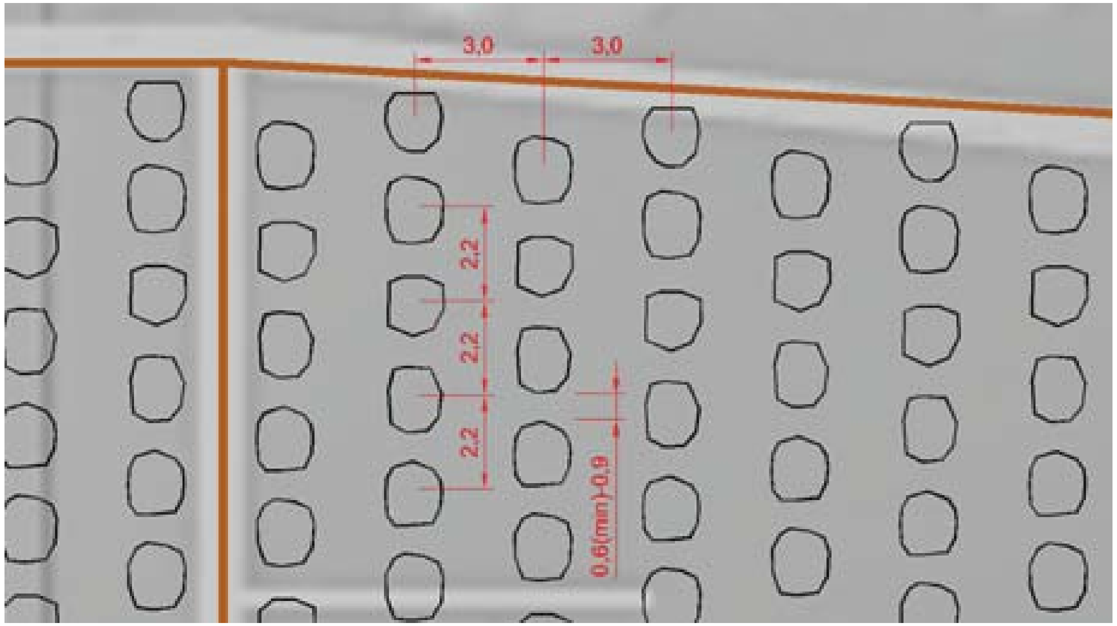
Učinkovit ribji prehod – Prehodnost ribjega prehoda – princip strukturiranosti



Shematski prikaz razporeda skal v tlorisu (zgornji sliki) i prečnem prerezu (spodnja slika) - po DWA-M 509, 2014, Larinier, 2006.

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Učinkovit ribji prehod – Prehodnost ribjega prehoda – strukturiranost drč



Razpored skal na strukturiranem ribjem prehodu

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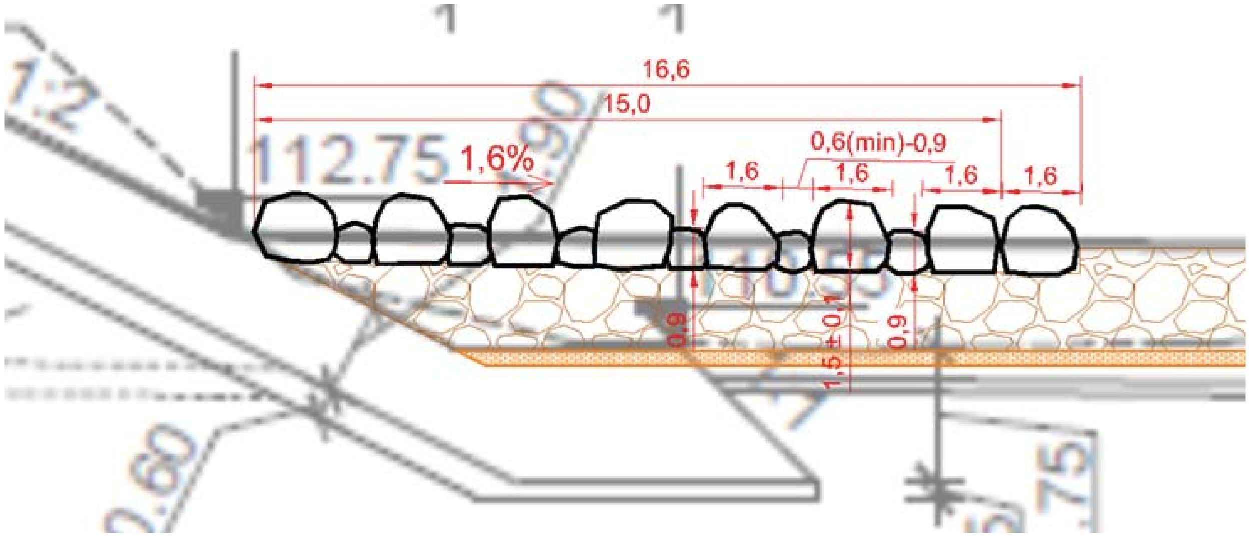
A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

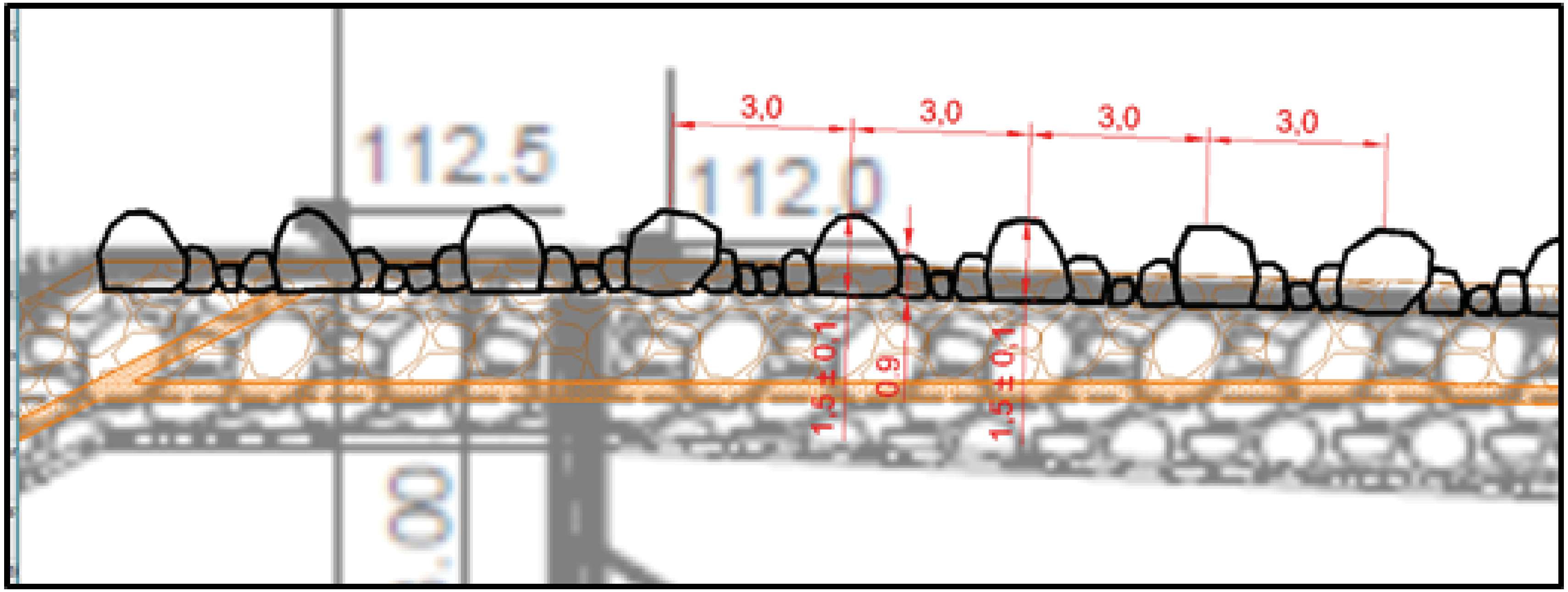
Učinkovit ribji prehod – Prehodnost ribjega prehoda – strukturiranost drč



Prečni razpored skal na strukturiranem ribjem prehodu

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Učinkovit ribji prehod – Prehodnost ribjega prehoda – strukturiranost drč



Vzdolžni razpored skal na strukturiranem ribjem prehodu - drči

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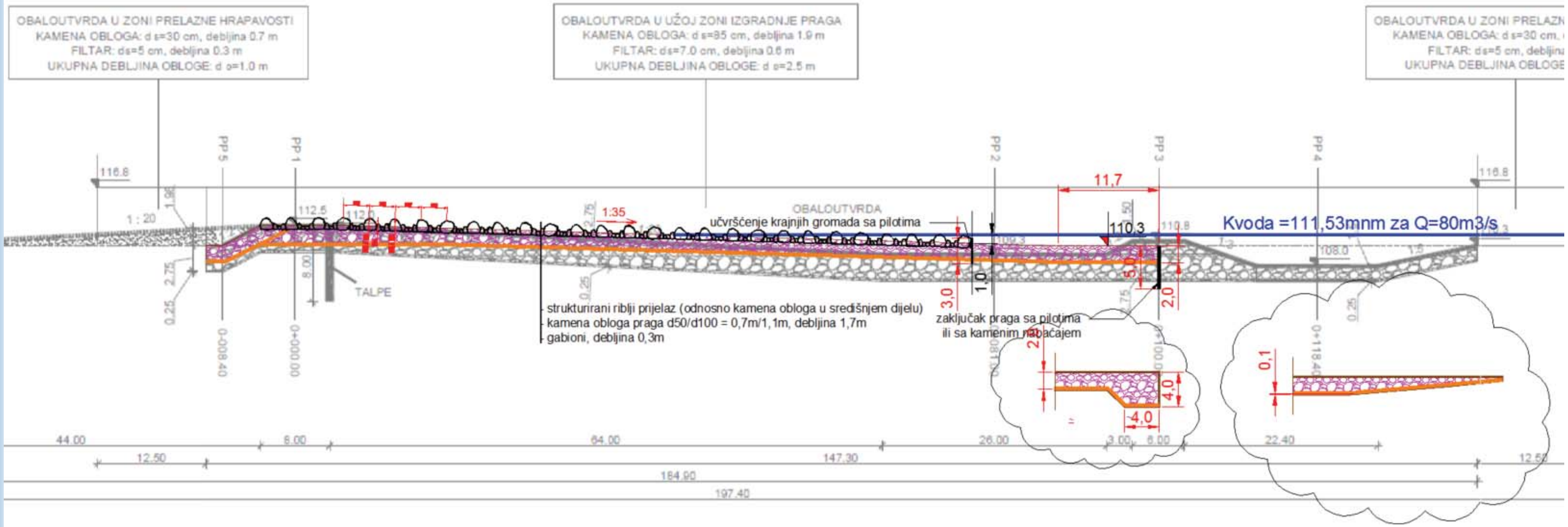
A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Učinkovit ribji prehod – Prehodnost ribjega prehoda:

- Največja (migrirajoča) vrsta rib: mrena
- Ribje vrste z minimalno kapaciteto plavanja: krapovske
- Nagib ribjega prehoda: dH/dL = 8,5 cm/3 m (1 : 35)
- dimenzije bazena (bruto): 3 x 2,2 m
- širina odprtin vrzeli: od 0,6 (min) do 0,9 m
- največja hitrost toka : Vmax = 1,6 m/s
- minimalna globina: 0,6 m
- podloga dna: substrat d= 2 – 6 cm / 10 – 30 cm
- gostota sipanja (disipacija) kinetične energije: < 100 W/m^3

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu



Vzdolžni prerez praga Jarun (tip a) z nagibom 1:35

A. Zasnova prehodov za ribe na pragovih na Savi v Zagrebu

Vzdolžni prerez praga Ščitarjevo (tip b) z nagibom 1:35

C. Priporočila za izgradnjo pragov

Opomba: Postopek pregrajevanja Save je nujno preizkusiti na fizičnem hidravličnem modelu!

- Pregrajevanje z obeh bregov proti sredini struge Save
- Pregrajevanje od sredine struge proti strukturiranim delom praga
- Izgradnja praga po celotni širini struge
- Drugi mogoči načini (iz prakse)

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3. PREDLOG NADALJNJIH KORAKOV ZA PROJEKTIRANJE

D. Fizični hidravlični model za optimizacijo projekta pragov

V okviru naloge je bil predviden program hidravlične modelne raziskave na prostorskem fizičnem hidravličnem modelu

Prehod za ribe pri HE Arto - Blanca

Prehod za ribe pri HE Brežice

Prehod za ribe pri HE Brežice

Prehod za ribe pri HE Brežice

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Prehod za ribe pri HE Brežice

Prehod za ribe pri HE Brežice

FISH MIGRATION WORKSHOP

"Fish passage theoretical and practical approach"

10 -11 September 2015

Hotel Loop, Župančićeva 18, Zagreb

Fish pass

BLANCA HYDROPOWER PLANT ON THE SAVA RIVER

Fish pass design by
DUŠAN CIUHA
Certified Engineer

IBE, Consulting Engineers
Hajdrihova ulica 4
1001 Ljubljana, Slovenia

"Fish passage theoretical and practical approach"
10 -11 September 2015
Hotel Loop, Župančićeva 18, Zagreb

**Description of the fish fauna*

The Sava River inhabits a wide spectrum of fish species totalling in 37 fish species and one lamprey species. The fish fauna is dominated by cyprinid species but also encompasses salmonids, percids and others. Most of the species are rheophilous species, i.e. adapted to the flowing conditions of the riverine habitat. In total, 13 species are protected according to the Habitats Directive.

****Description of the fish fauna provided by Prof. Dr. Metka Povž prof. biol.***
****Fish-ecological assessment from Final Report for Fish pass at HPP Blanca provided by Ao.Univ.Prof. DI Dr. Stefan Schmutz***


27.10.2014: Field hydraulic measurements by Hidroinstitut, Ljubljana


• 1.2 … 24.2.2009


• 24.03.2009


01.04.2009

2009

• 2009

Nature-like fish pass at HPP Arto-Blanca (7)

- 01.06.2009

Nature-like fish pass at HPP Arto-Blanca (12)

- 17.06.2009

Nature-like fish pass at HPP Arto-Blanca (16)

- 2009


Nature-like fish pass at HPP Arto-Blanca (18)
• 2009

Nature-like fish pass at HPP Arto-Blanca (20)

- 2009

Nature-like fish pass at HPP Arto-Blanca (26)

- 2013


Nature-like fish pass at HPP Arto-Blanca (27)
• 2013


Nature-like fish pass at HPP Arto-Blanca (28)
• 2013

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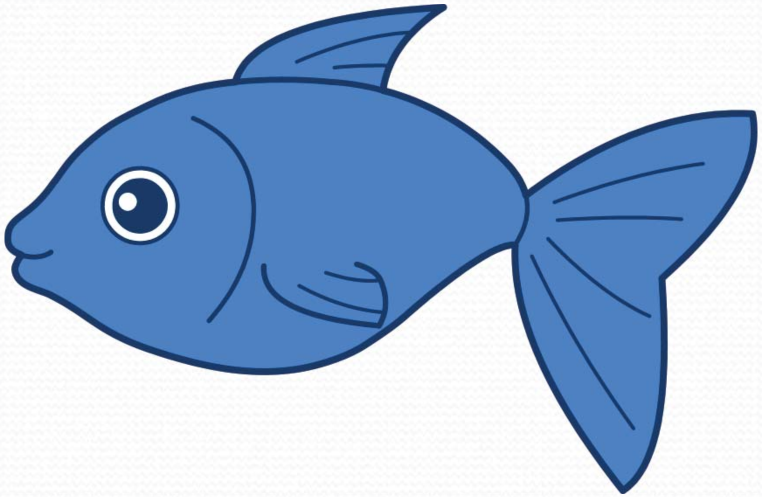
UNIVERZA V LJUBLJANI
FAKULTETA ZA GRADBENIŠTVO IN GEODEZIJO
KATEDRA ZA MEHANIKO TEKOČIN

Vertical slot fishway – measurements of flow, validation of mathematical model and optimization of vertical baffles in VSF

dr. Martin Bombač



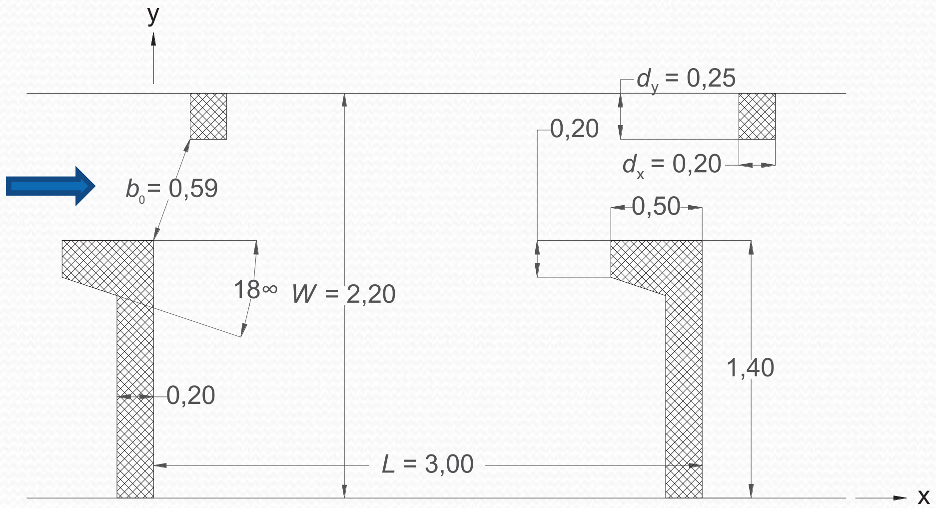
Ljubljana, 11.9.2015

Fishway at HPP Arto-Blanca

- *Artificial barriers such as dams interupt fish migration*
- *With the aim to enable fish to pass such obtracles, fishway at HPP Arto-Blanca was build in 2009*
- *Saddly, up to now this is the only effective fishway at large dams in Slovenia*

Fishway at HPP Arto-Blanca – upper concrete reach

- *height difference between upstream and downstream water levels is 9,4 m*
- *total fishway length is 680 m*
- *upper technical reach is composed of two intake reaches at different levels*
- *discharge is regulated with gates*
- *longitudinal slope of technical reach is I_0 = 1,7 %*
- *depth difference between two adjecent pools is Δh = 5 cm*
- *pool dimensions: b_0 = 0,59 m; L = 3,0 m; W = 2,2 m*



Upper intake reach with vertical slots

Fishway at HPP Arto-Blanca – natural bypass reach

- *after the technical reach, a close to natural bypass reach follows*
- *length of this reach is 570 m*
- *it has 106 sills, longitudinal slope is $I_o = 2$ %*
- *channel width is 4,7 m*
- *distance between sills is 5 m*
- *height difference between sills is Δh = 10 cm*

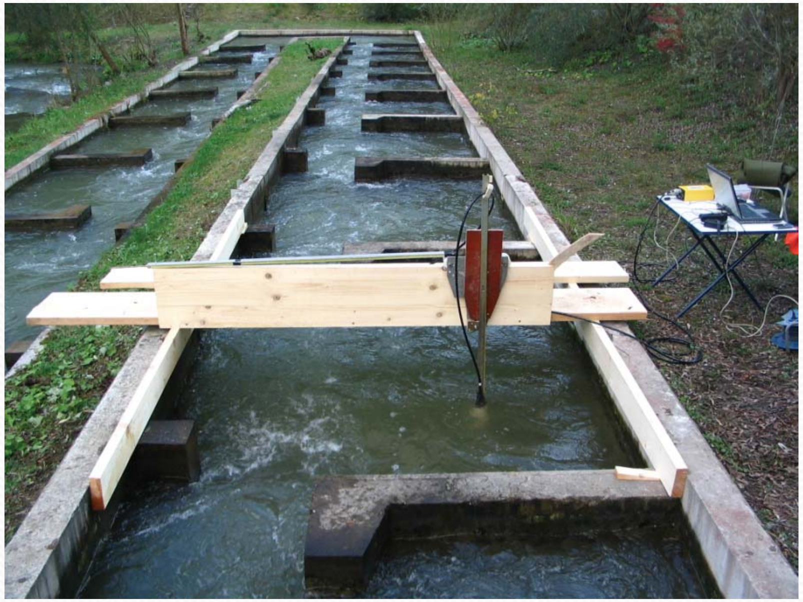
Outlet reach

Natural bypass reach

Field measurements of water levels and velocities at VSF

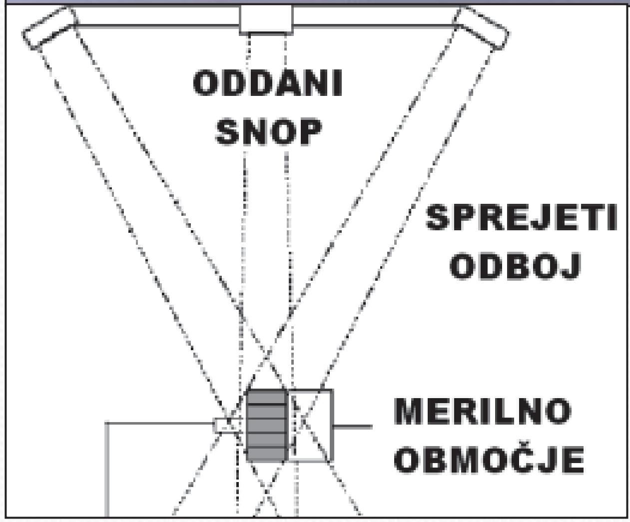
- *hydrodynamics of flow in the fishway have been determined for information purposes only on the basis of analytical calculations*
- *conditions in the fishway had to be verified by measurements in the field (water depth, velocity)*
- *In 2014 Hydroinstitute carried out detailed measurements in the central pool of the upper technical reach*

Water depth measurements at VSF



Velocity measurements with a 3D ADV probe

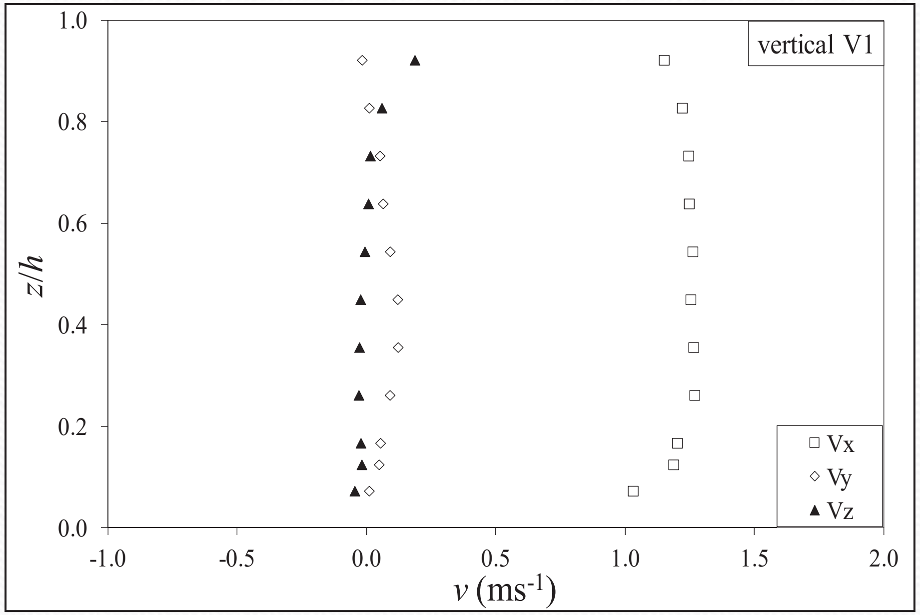
Measurements of water levels and velocities at VSF



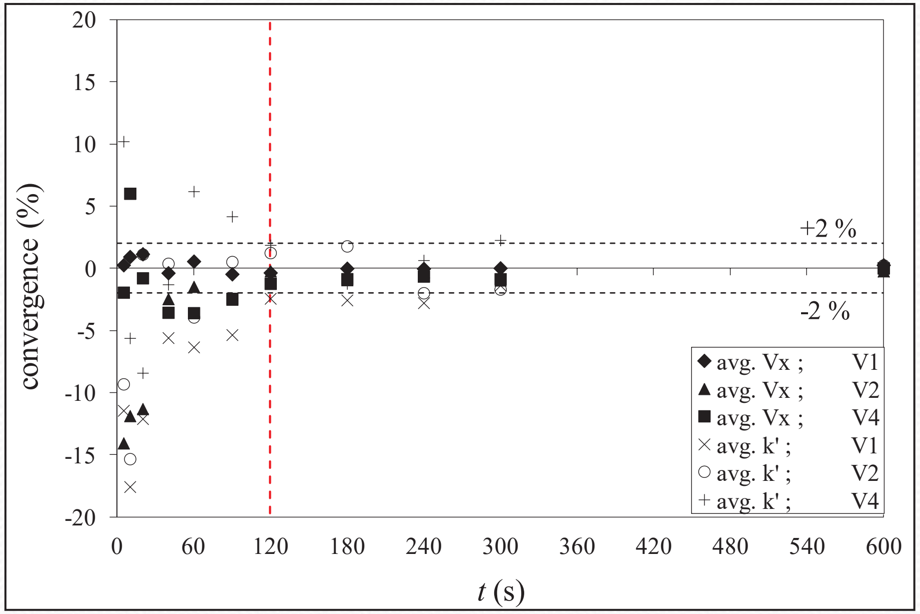
- *3D Micro ADV ultrasonic velocity probe*
- *Sampling frequency 50 Hz*
- *Sample volume the size of 0,1 cm³ is located 5 cm in front of probe*
- *The accuracy of measurements up to 1% of the measuring range (selected range 2.50 m/s)*
- *water level measurements using point gauge*

Velocity measurements of flow in VSF

❖ *preliminary measurements in 4 verticals* ➡ *determining the time necessary for each individual measurement, confirmation of two-dimensional nature of the flow*



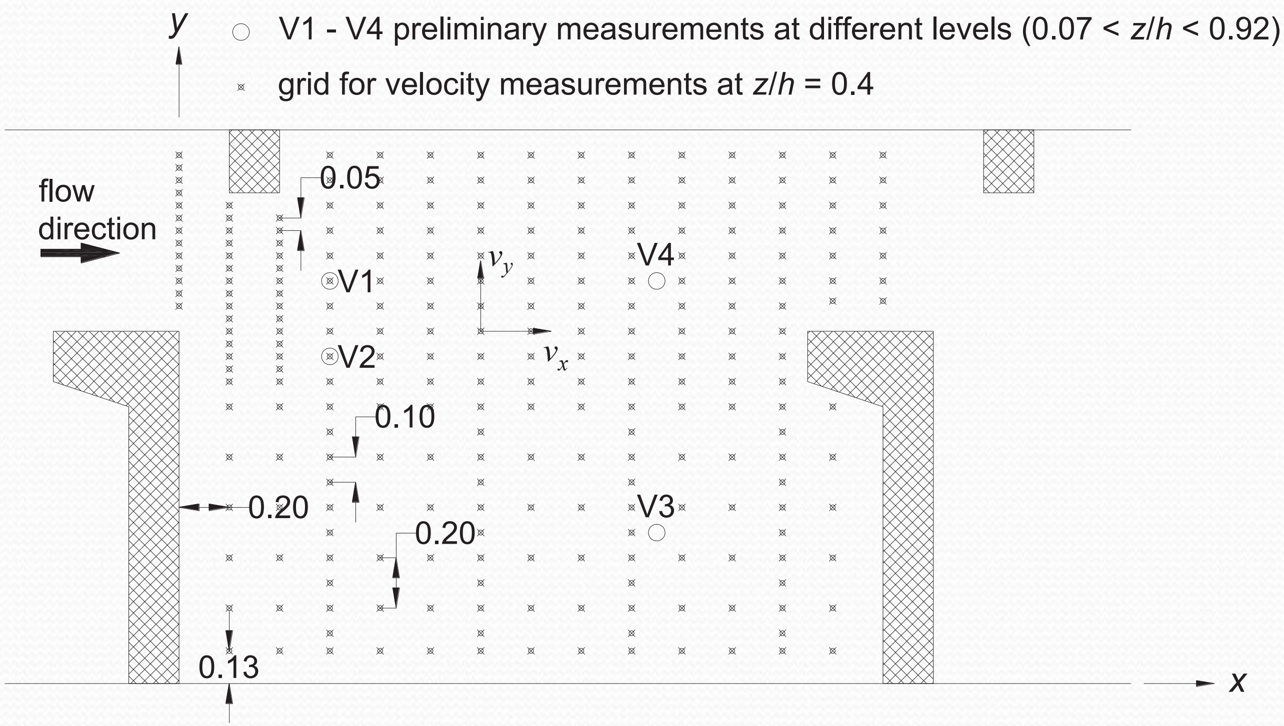
Measured velocities prove the two-dimensional nature of the VSF flow



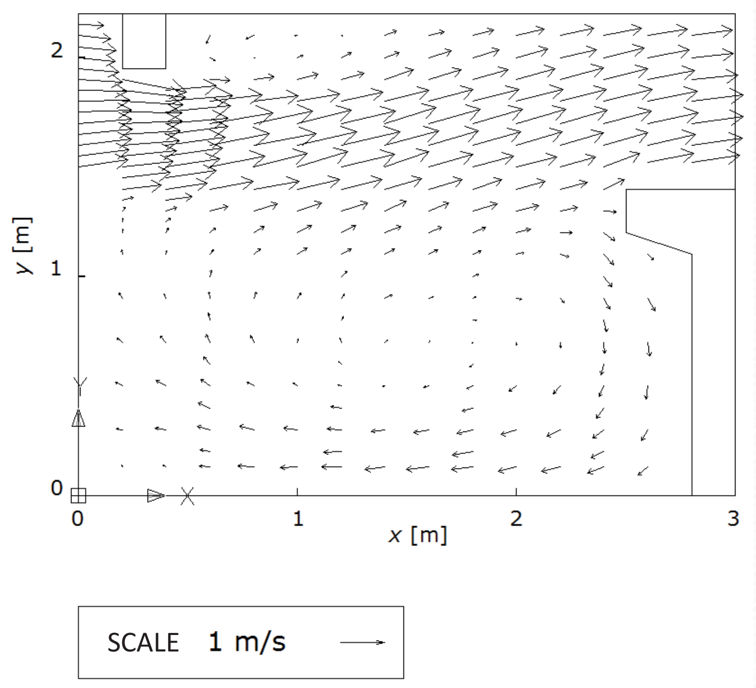
The convergence of the measured longitudinal velocity component v_x and turbulent kinetic energy per unit mass *k'*

Velocity measurements of flow in VSF

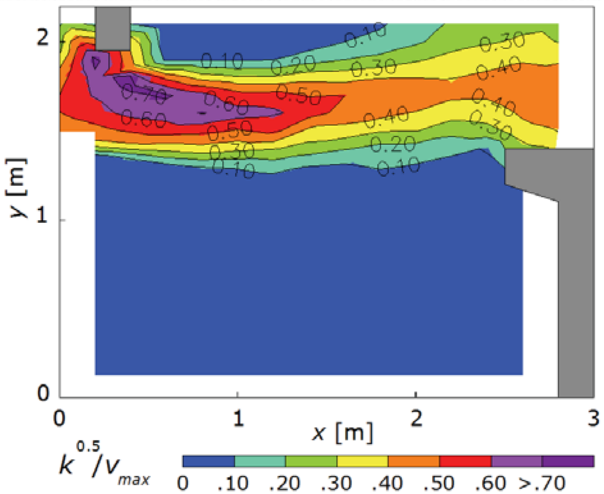
- *on the basis of both previous findings, detailed velocity measurements were performed in one horizontal plane (255 points)*
- *15 cross sections in a distance of 0,20 m*
- *the distance between points in the transverse direction ranges from 0.05 m to 0.20 m*



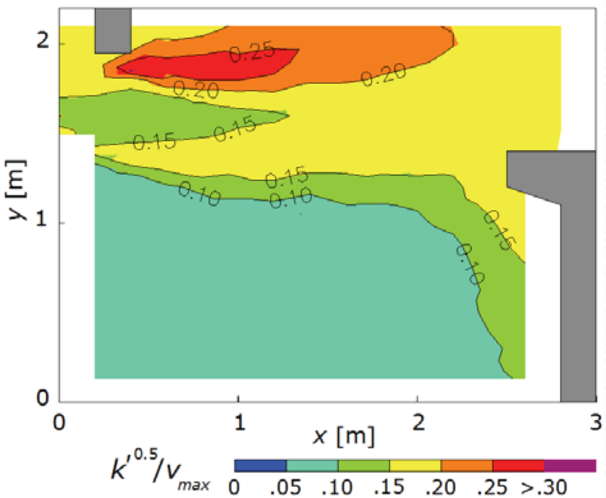
The results of measurements of flow field in VSF



Measured velocity vectors in the central pool of VSF Arto - Blanca



Square root of mean flow kinetic energy per unit mass *k* normalized by maximum measured velocity v_{max}



Square root of turbulent kinetic energy per unit mass *k'* normalized by maximum measured velocity v_{max}

v_{max} = 1,5 m/s > v_{max_dim} = 1,0 m/s
Q = 1000 l/s > Q_{dim} ≈ 660 l/s

Mathematical model of VSF at HPP Arto-Blanca

- *in order to establish a tool that enables accurate determination of the hydraulic characteristics of the flow in VSF, a mathematical model has been established*
- *numerical simulations were performed with the PCFLOW2D model, which solves the depth-averaged shallow water equations coupled with a turbulence model*
- *k – ε turbulence model was used*
- *mathematical model was validated with field measurements at VSF at HPP Arto-Blanca*

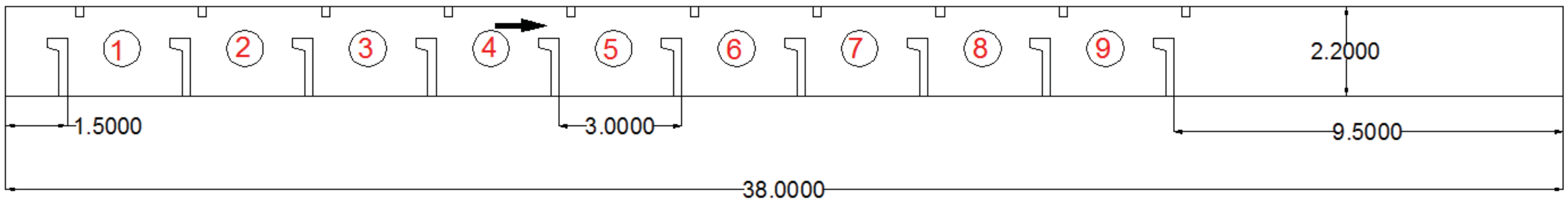
$$\frac{\partial h}{\partial t} + \frac{\partial \left(h v_x\right)}{\partial x} + \frac{\partial \left(h v_y\right)}{\partial y} = 0$$

$$\frac{\partial \left(h v_x\right)}{\partial t} + \frac{\partial \left(h v_x^2\right)}{\partial x} + \frac{\partial \left(h v_x v_y\right)}{\partial y} = -gh\frac{\partial h}{\partial x} - gh\frac{\partial z_b}{\partial x} - ghn_g{}^2\frac{v_x\sqrt{v_x^2 + v_y^2}}{h^{\frac{4}{3}}} + \frac{\partial}{\partial x}\left(h\nu_T\frac{\partial v_x}{\partial x}\right) + \frac{\partial}{\partial y}\left(h\nu_T\frac{\partial v_x}{\partial y}\right)$$

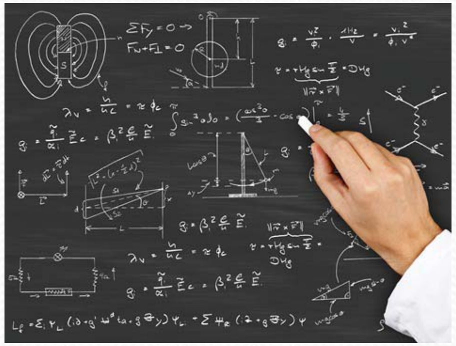
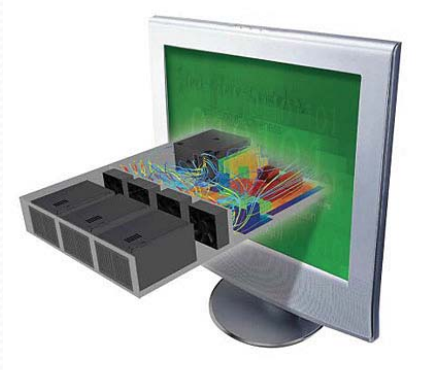
$$\frac{\partial \left(h v_y\right)}{\partial t} + \frac{\partial \left(h v_x v_y\right)}{\partial x} + \frac{\partial \left(h v_y^2\right)}{\partial y} = -gh\frac{\partial h}{\partial y} - gh\frac{\partial z_b}{\partial y} - ghn_g{}^2\frac{v_y\sqrt{v_x^2 + v_y^2}}{h^{4/3}} + \frac{\partial}{\partial x}\left(h\nu_T\frac{\partial v_y}{\partial x}\right) + \frac{\partial}{\partial y}\left(h\nu_T\frac{\partial v_y}{\partial y}\right)$$

Mathematical model of VSF at HPP Arto-Blanca

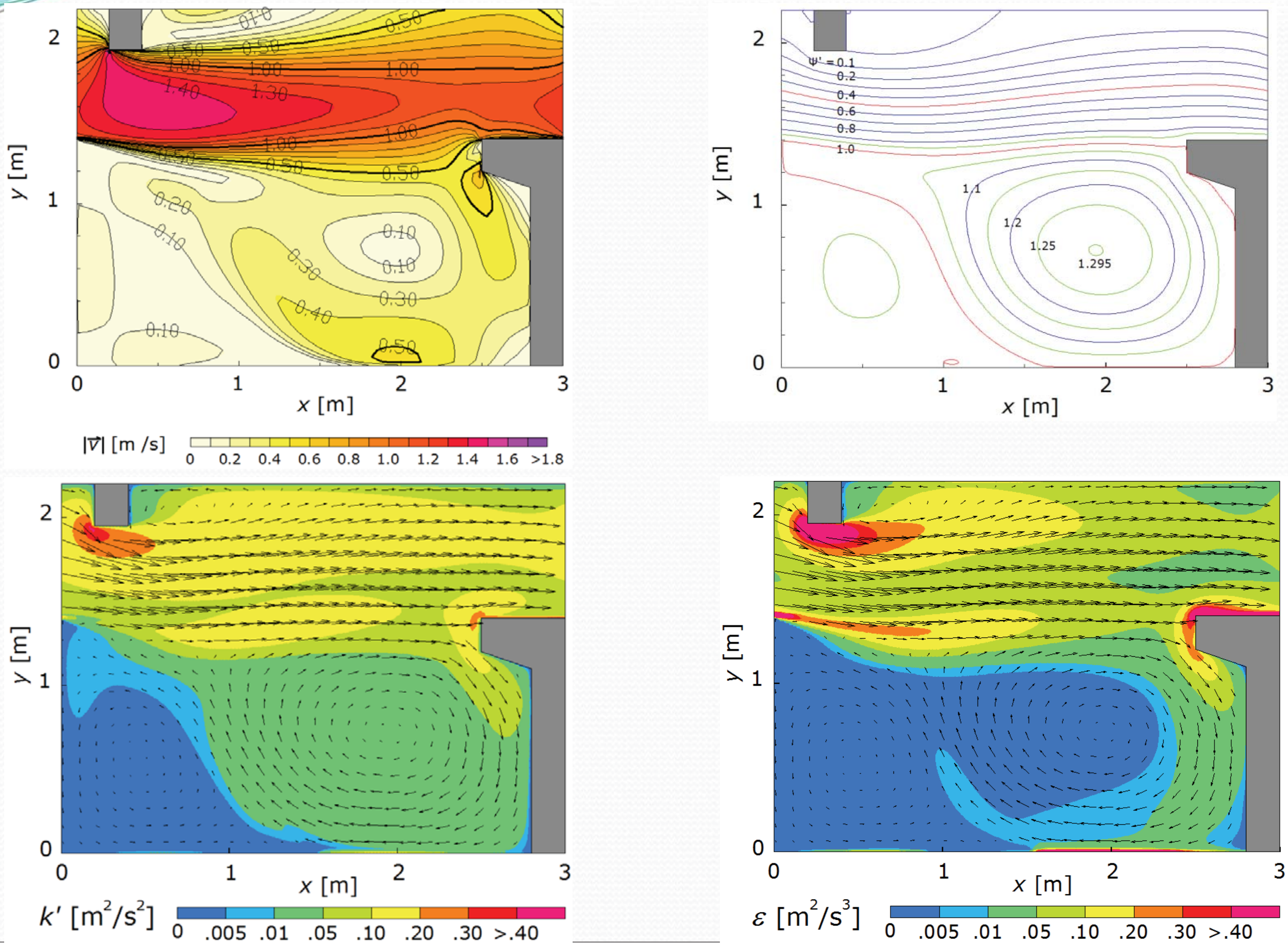
- *9 pools + inlet and outlet reach*
- *all presented numerical results refer to the fifth (middle) pool, which is not affected by the boundary conditions*



- *dense numerical mesh was used (Δx = 1 cm; Δy = 2 cm) ➡ an exact description of geometry + numerical diffusion is sufficiently low*
- *Δt = 0,1 s; t_{max} = 2 h = 7.200 s ➡ 72.000 time steps*

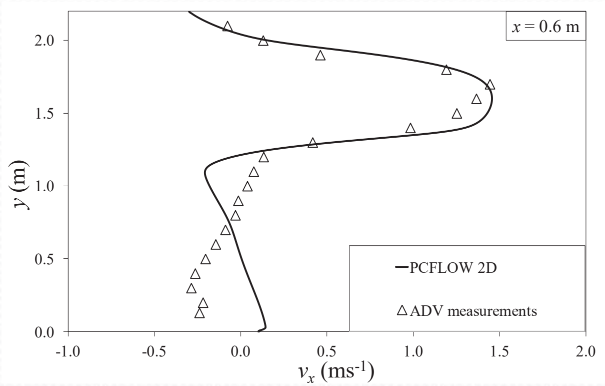



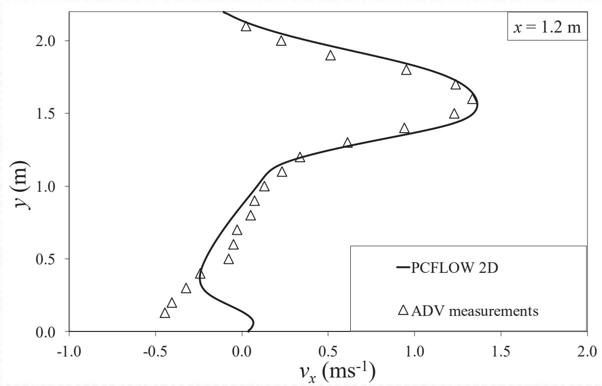

The results of mathematical model of VSF at HPP Arto-Blanca

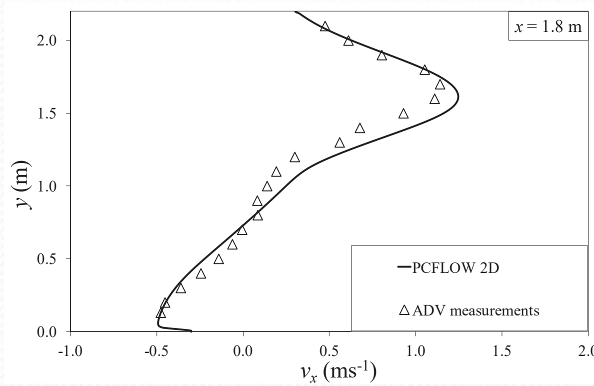


Validation of mathematical model of VSF

- *comparison of results between mathematical model and measurements show very good agreement*
- *point out that the mathematical model was not calibrated to measurements, measurements were used solely for verification*
- *only calibration of MM was iterative search for the appropriate outlet boundary condition, which gives the corresponding water level difference Δh = 5.0 cm*





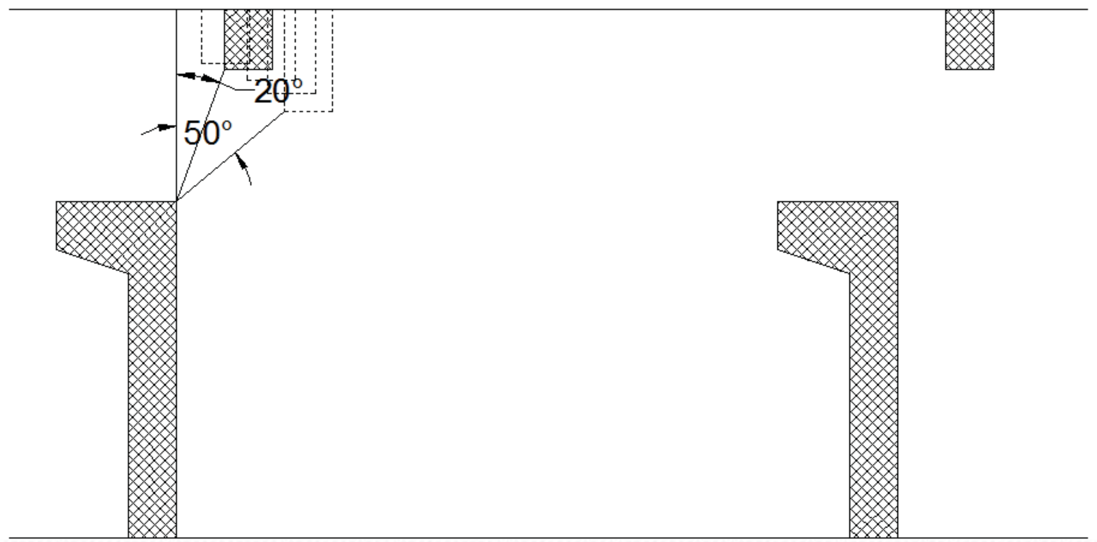


- *mathematical model PCFLOW2D proved to be a reliable tool for accurate simulation and optimization of vertical slot fishways*

<u>*Optimization of VSF*</u>

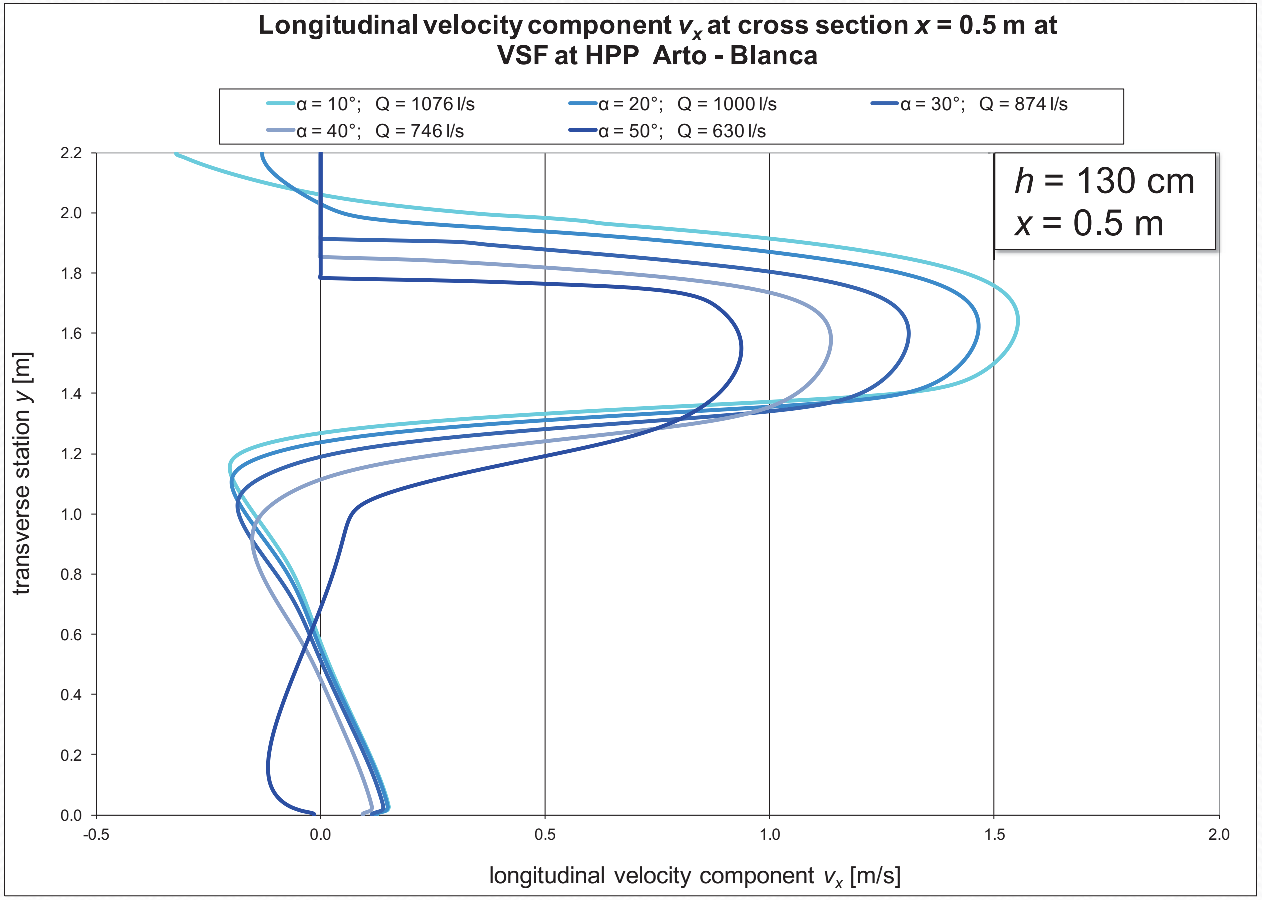
- *measurements (and numerical simulation) proved that v_{max} are higher than planned*
- *analitical equation proposed in the design manuals* $v_{max} = \sqrt{2 * g * \Delta h}$ *is not necessary correct as it is based on somewhat unrealistic assumption that the upstream flow velocity in negligible*
- *optimization of VSF geometry was carried out with the angle between vertical baffles α being varied (**α = 20°, 30°, 40°, 45°, 50°**)*

v_{max} = 1,5 m/s > v_{max_dim} = 1,0 m/s

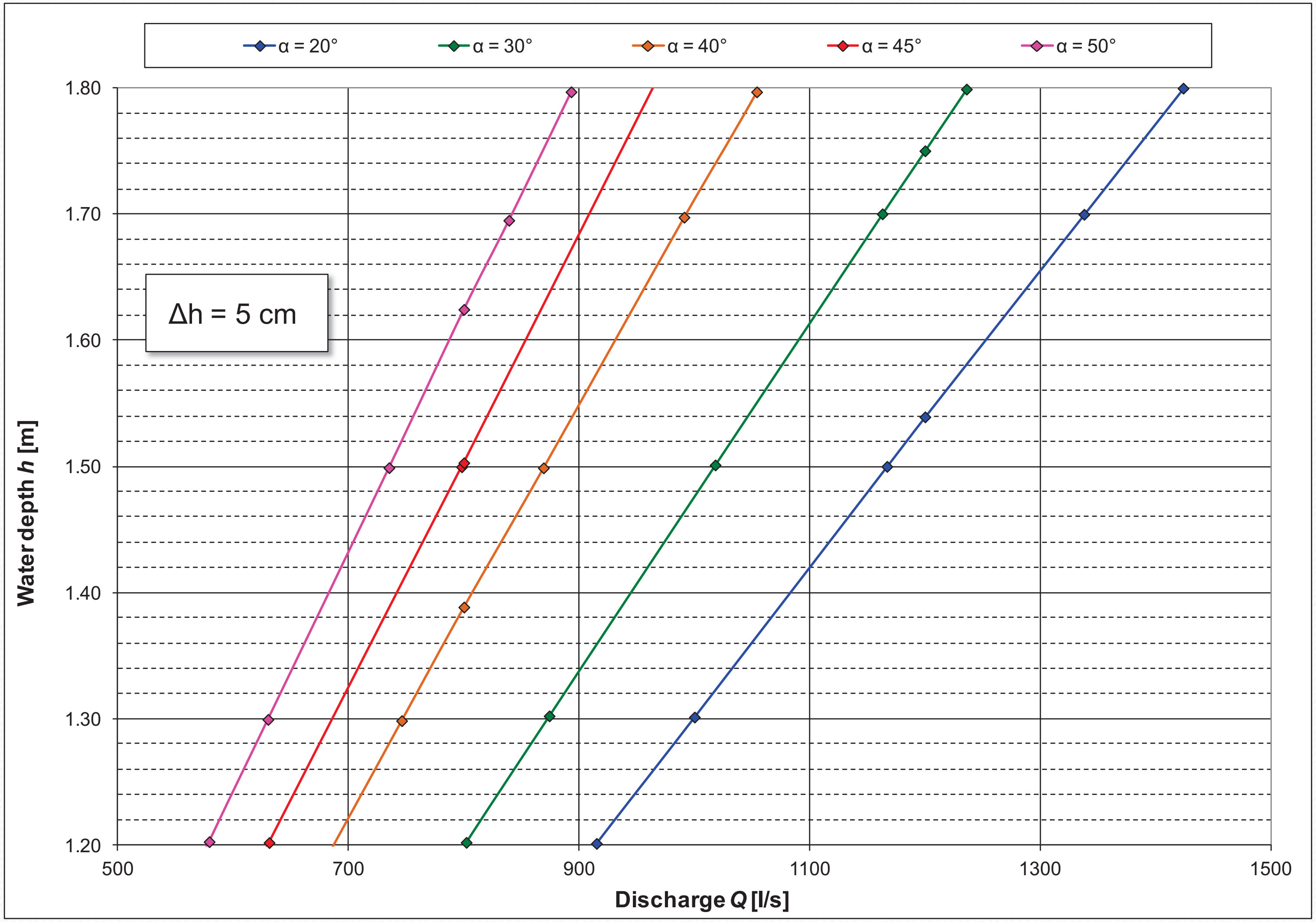


Optimization of VSF

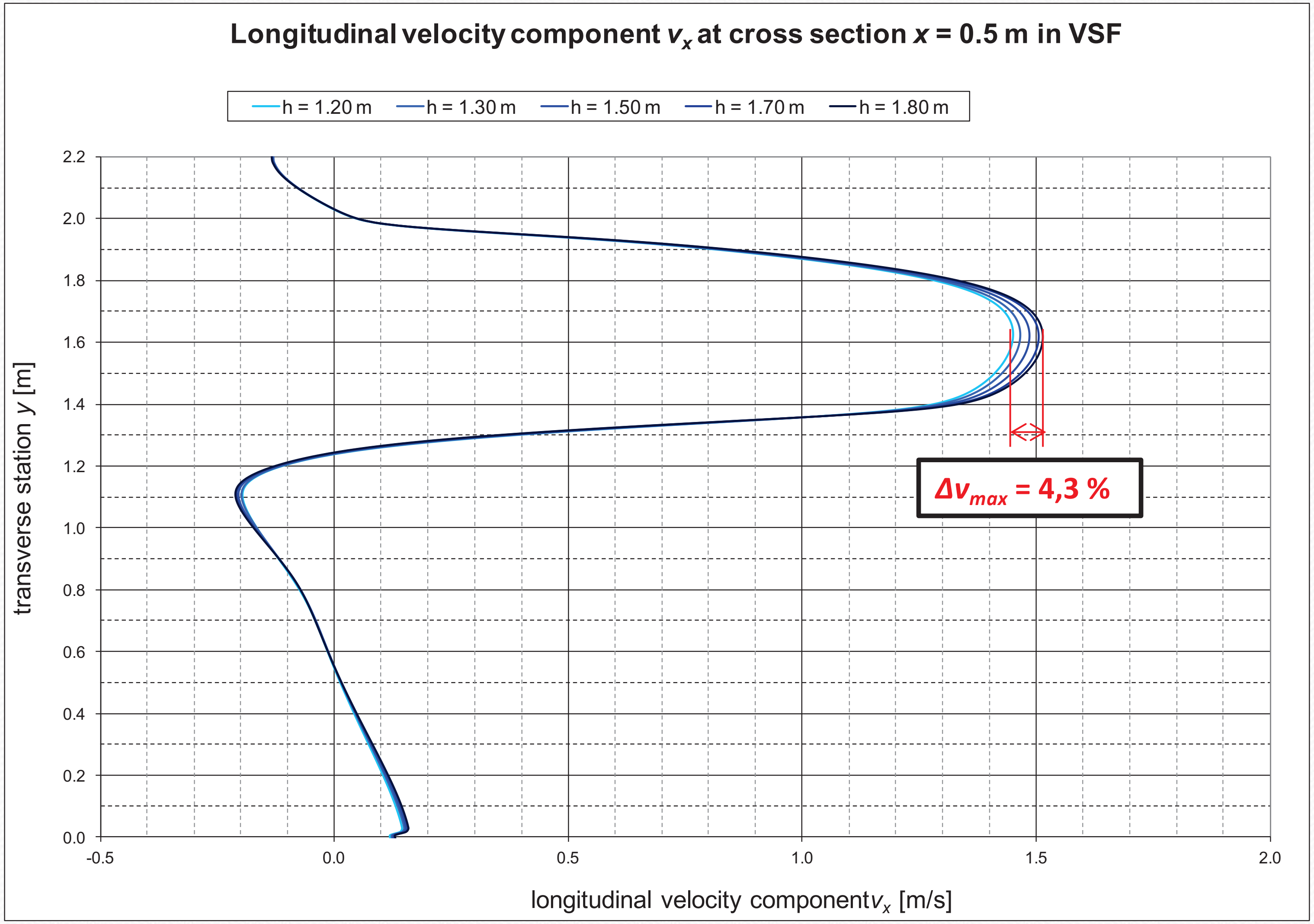
v_{dim} = 1,00 m/s; Q_{dim} = 660 l/s; h_{dim} = 1,30 m

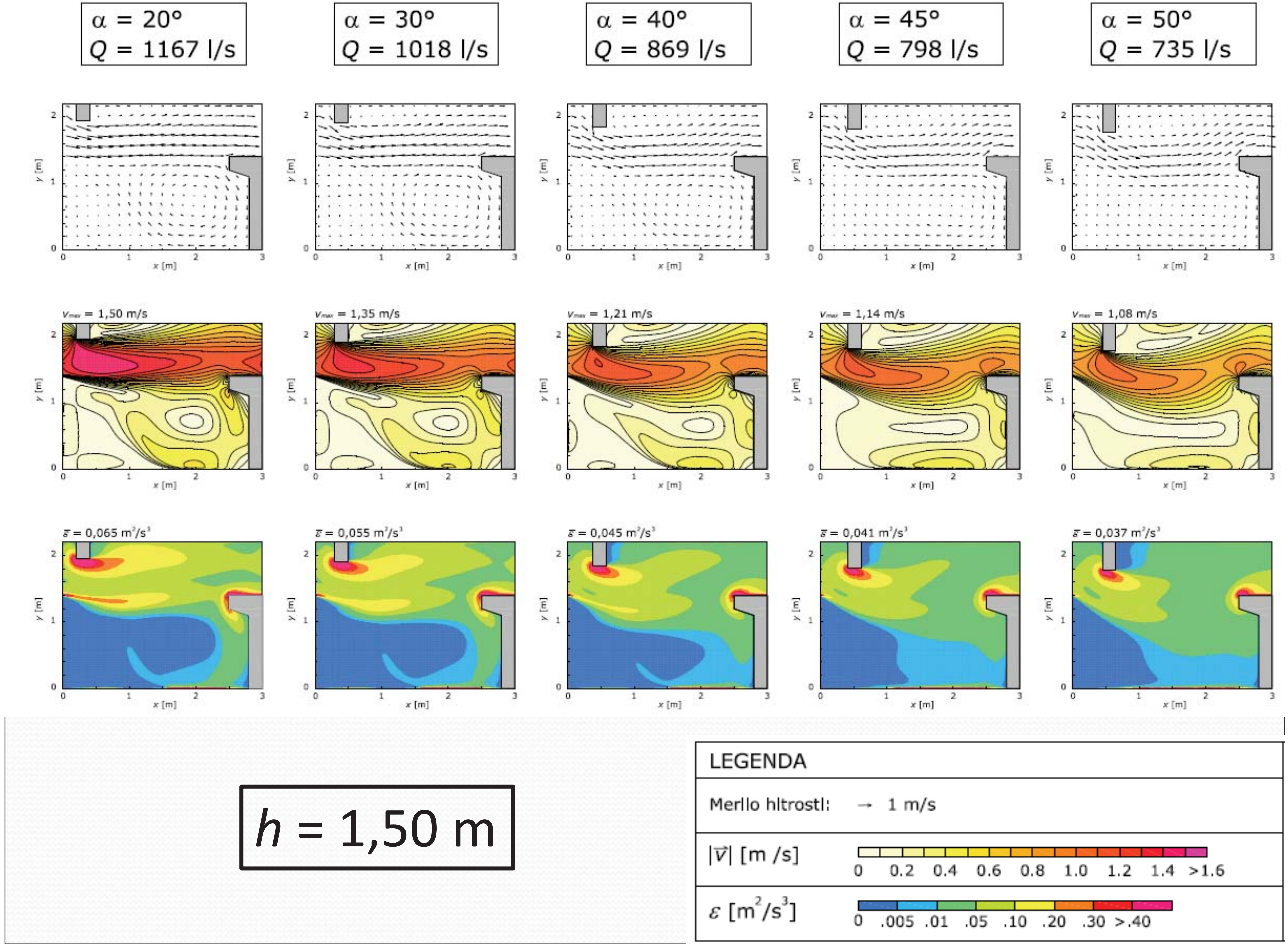


Optimization of VSF – depth discharge curves



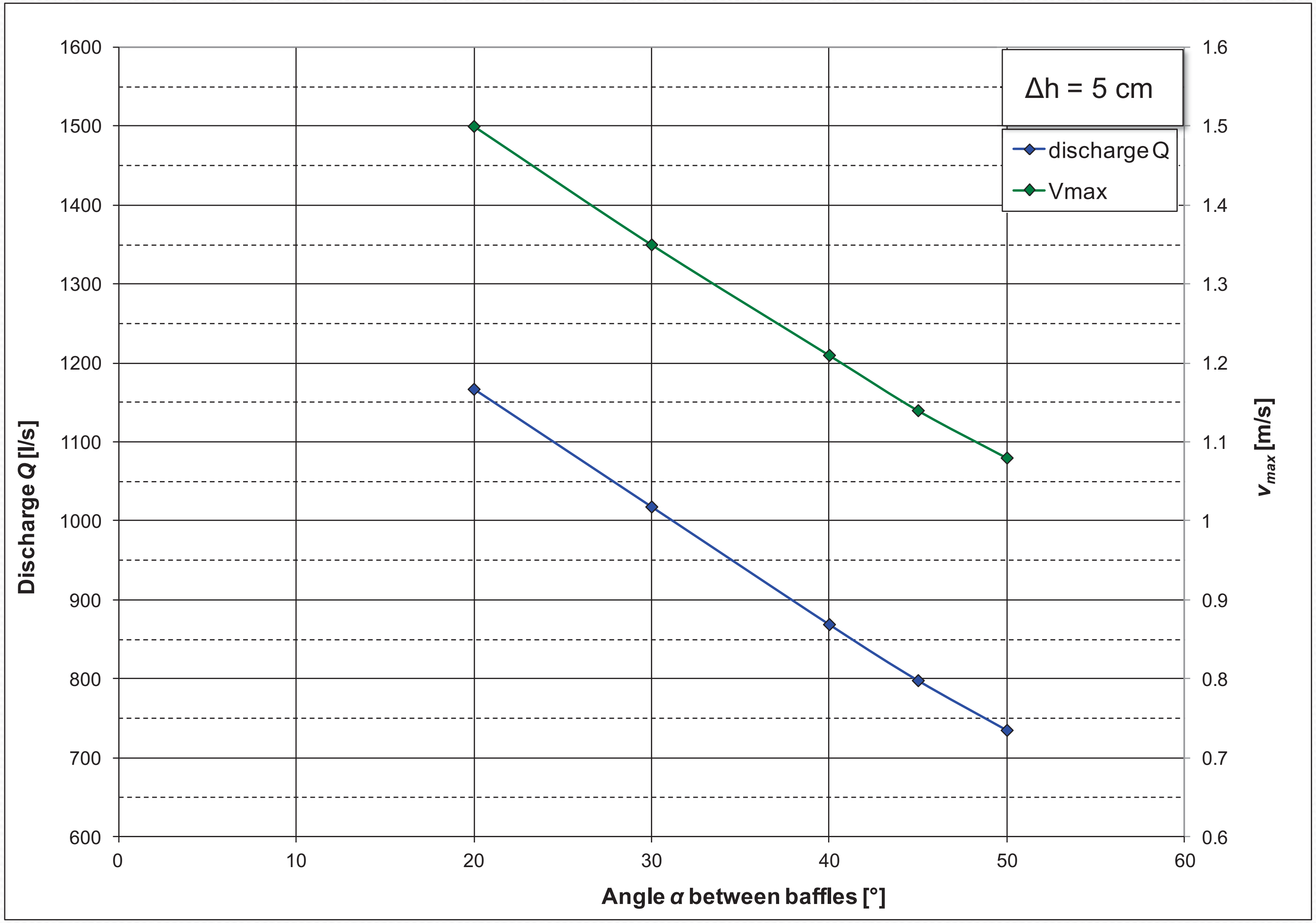
Optimization of VSF – $v_x = f(h)$?



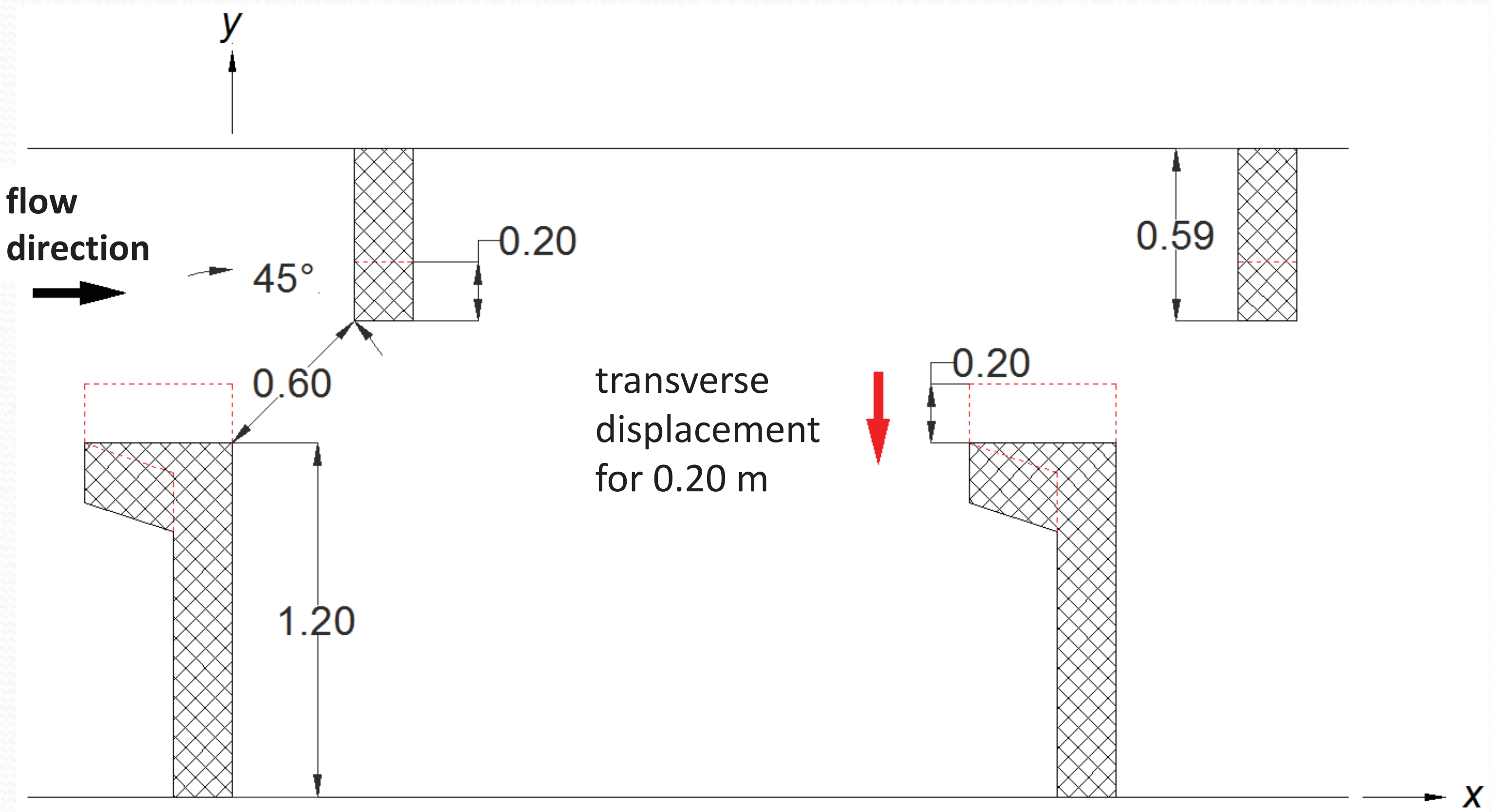


α = 20° Q = 1167 l/s
α = 30° Q = 1018 l/s
α = 40° Q = 869 l/s
α = 45° Q = 798 l/s
α = 50° Q = 735 l/s
x [m]
y [m]
v_{max} = 1,50 m/s
v_{max} = 1,35 m/s
v_{max} = 1,21 m/s
v_{max} = 1,14 m/s
v_{max} = 1,08 m/s
$\bar{\varepsilon}$ = 0,065 m²/s³
$\bar{\varepsilon}$ = 0,055 m²/s³
$\bar{\varepsilon}$ = 0,045 m²/s³
$\bar{\varepsilon}$ = 0,041 m²/s³
$\bar{\varepsilon}$ = 0,037 m²/s³
h = 1,50 m
LEGENDA
Merilo hitrosti: → 1 m/s
$|\vec{v}|$ [m /s] 0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 >1.6
ε [m²/s³] 0 .005 .01 .05 .10 .20 .30 >.40

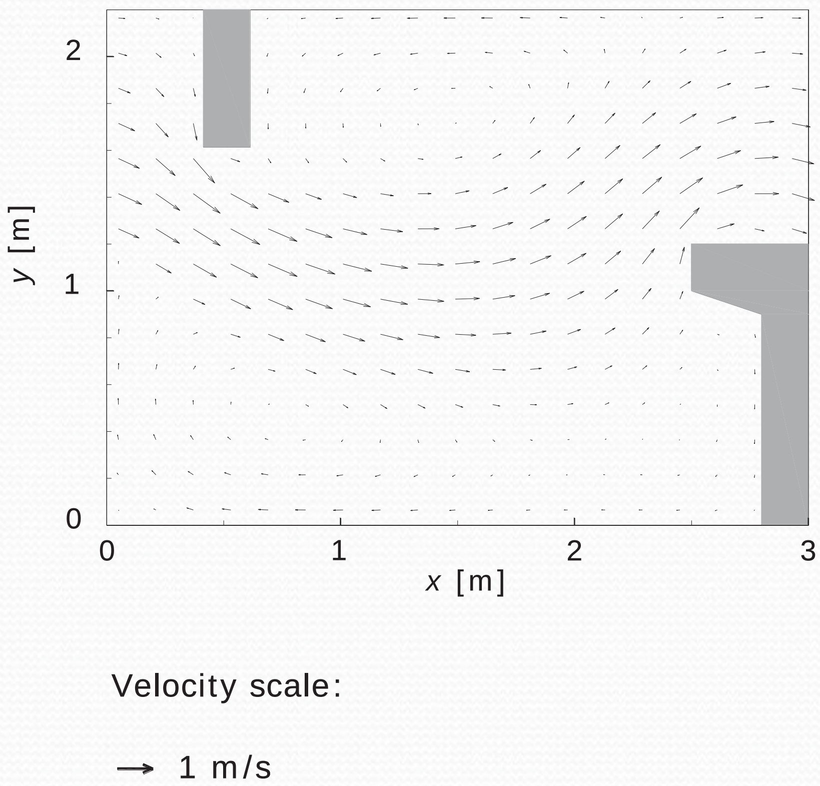
Optimization of VSF – v_{max} and Q

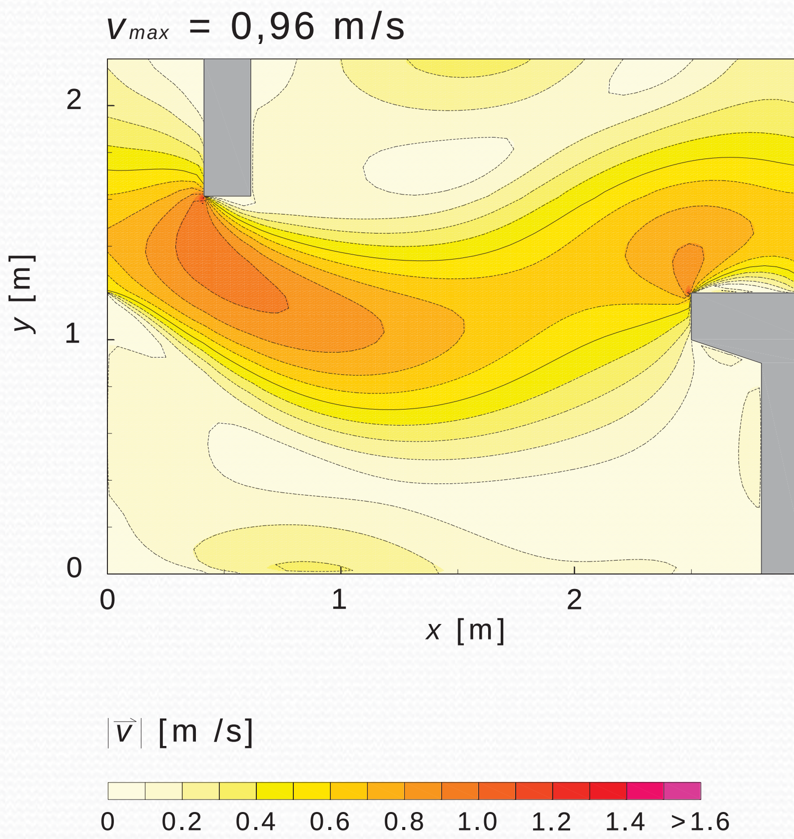


Optimization of VSF – final variant



Optimization of VSF – final variant





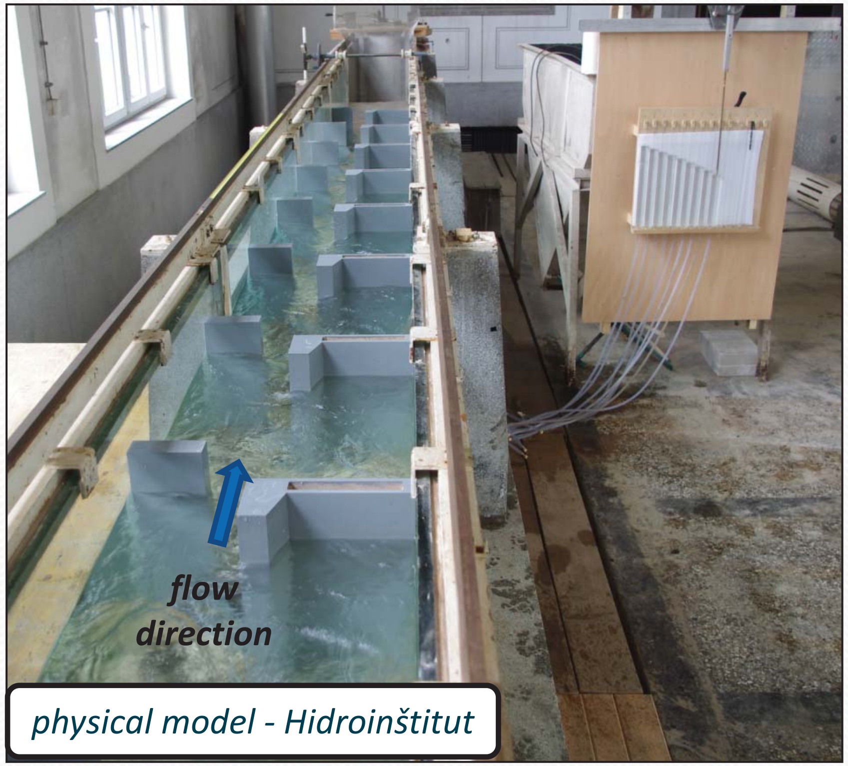
transverse displacement for 0.20 m → **- 13 % Q**
- 16 % v_{max}

Physical model of vertical slot fishway

- flow in VSF is highly turbulent ➡ precise and accurate turbelence modelling is necessary
- a 1:4.4 scale physical model of VSF with 9 pools was built in a 0.5 m wide rectangular glass flume

prototype – HPP Arto-Blanca

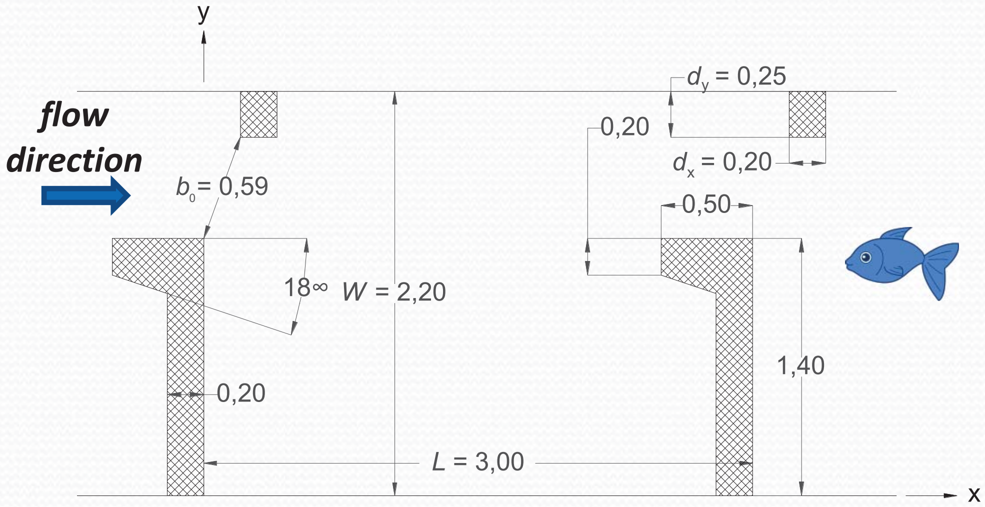
M 1:4,4 ➡



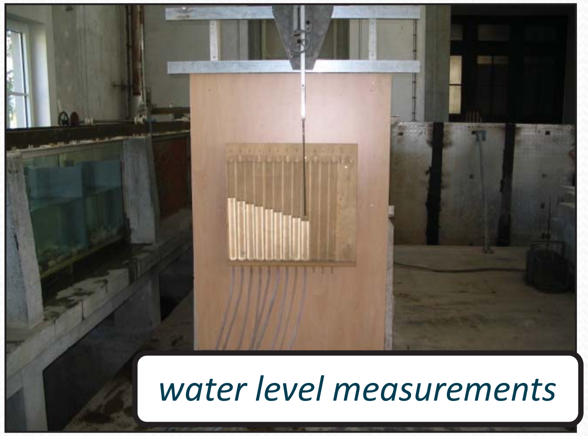
physical model - Hidroinštitut

Measurements at physical model of vertical slot fishway

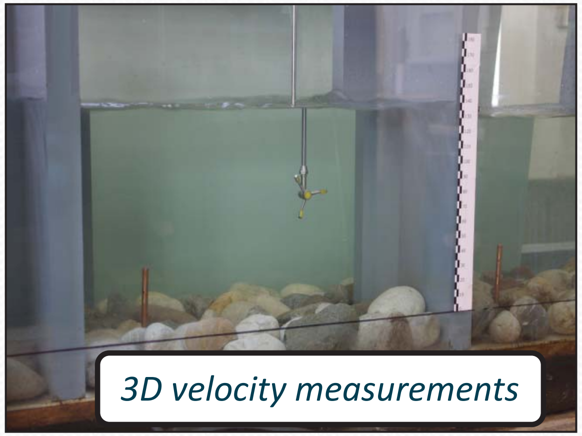
- *water level measurements with point gauge*
- *3D velocity measurements*
- *measurements at 6 cross sections*
- *measurements at 2 depths*



Geometry of pool and slot at VSF Blanca, ΔH = 5 cm

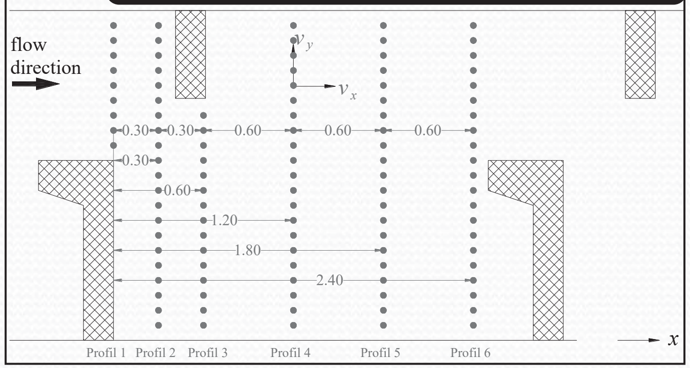


water level measurements



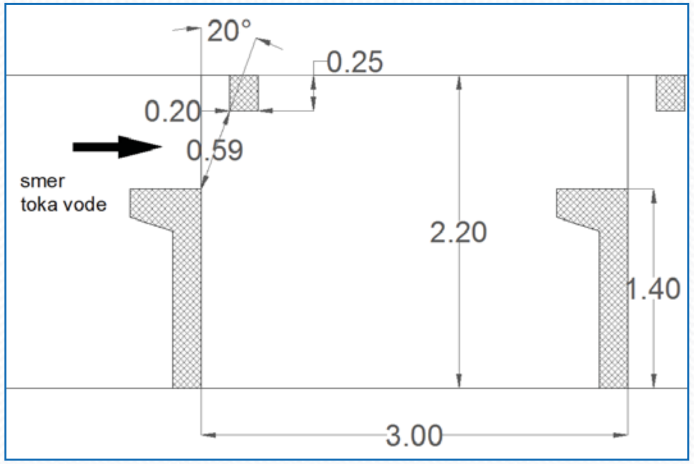
3D velocity measurements

cross sections for velocity measurements

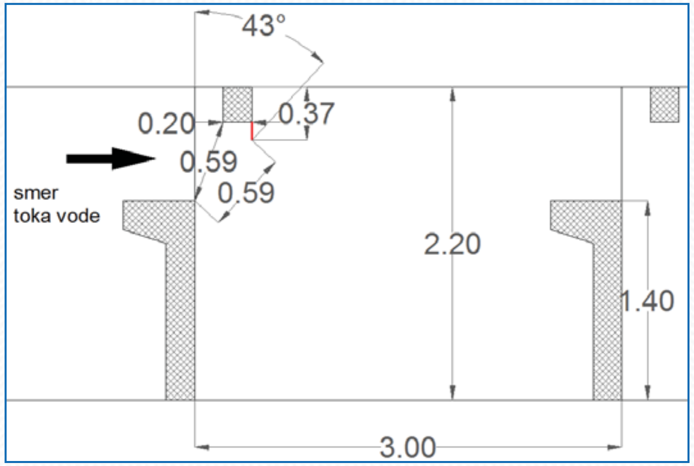


Physical model of VSF – studied variants

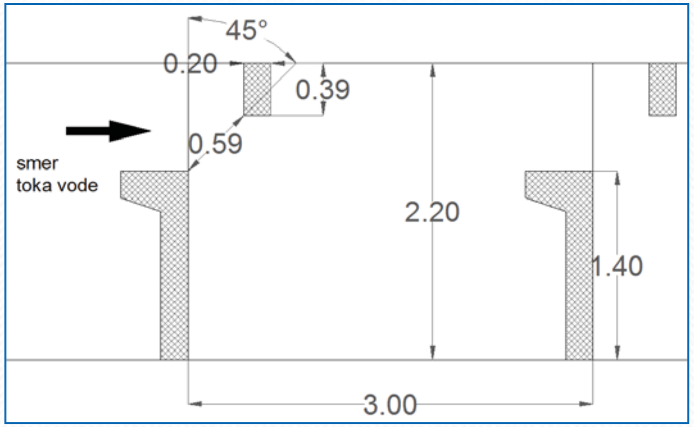
variant I



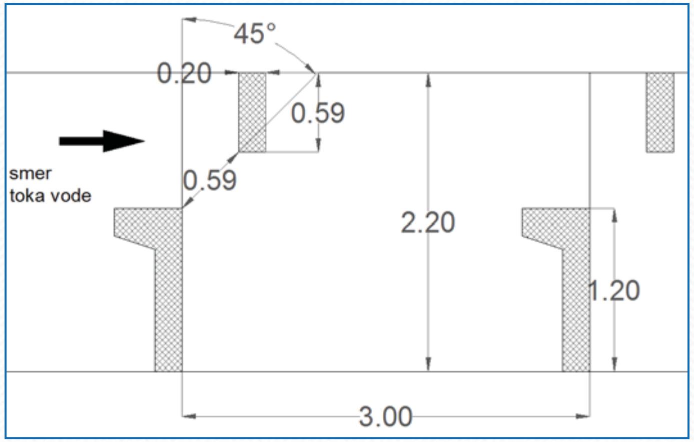
variant II



variant III

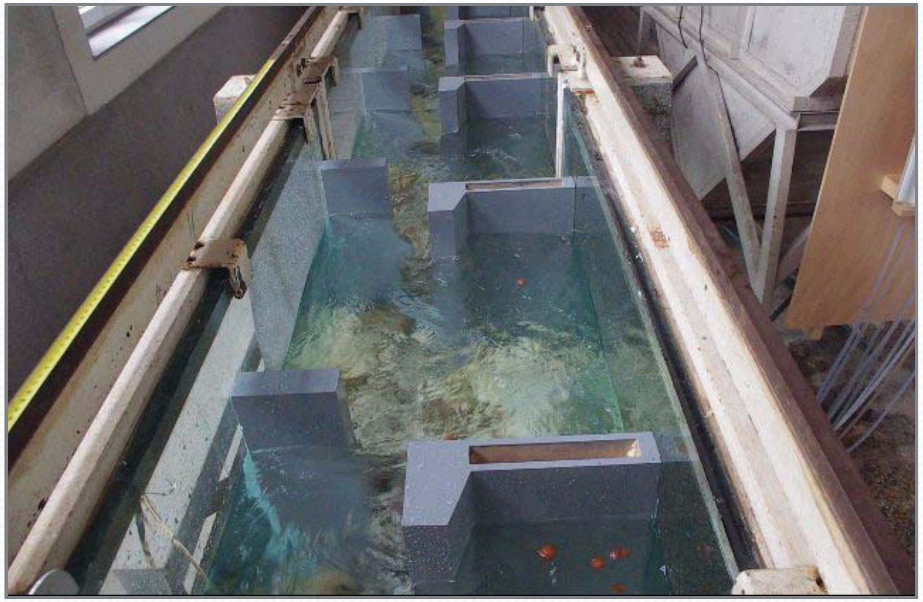


variant IV



Physical model of VSF – studied variants

- ✓ *good agreement between mathematical and physical model ($v_{max\ MM}$ = 0,96 m/s; $v_{max\ PM}$ = 0,97 m/s)*
- ✓ *confirmation of 2D nature of flow in VSF (minor differences between measured velocities at two depths)*
- ✓ *some minor differences between MM and PM in flowfield, probably caused by imperfect mathematical modeling of turbulence*



Conclusions

- ✓ *measured velocities in VSF at HPP Arto-Blanca confirmed that the flow in such fishway types is two-dimensional*
- ✓ *maximum velocities were significantly higher than dimensioned (calculated analytically:* ~~$v_{max} = (2g\Delta h)^{1/2}$~~*)* → *difficult passage for weaker swimmers*
- ✓ *consequently, the discharge in VSF is greater than planned, which adversely affects the hydrodynamics of flow in the inlet and in the natural bypass reach*
- ✓ *validated mathematical model PCFLOW2D proved to be a reliable tool for accurate simulation and optimization of vertical slot fishways*
- ✓ *final optimized variant of VSF with angle $\alpha = 45°$ and transverse displacement of slot for 0.20 m to the center reduces discharge from original for 40% and v_{max} for 36%*
- ✓ *precise measurements on a physical model confirmed the appropriateness of the proposed format of VSF and give more detailed information on flow in the technical part of the fishway which will be used for dimensioning of new fishway at HPP Brežice*

Thank you

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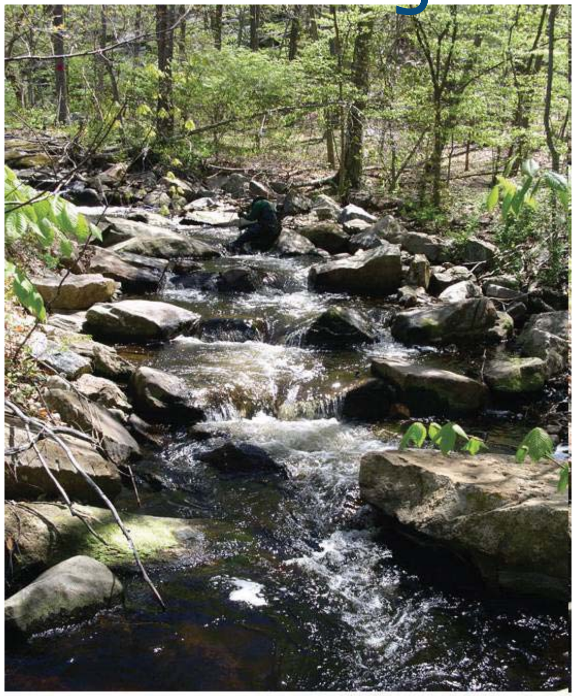
Fishway Evaluations: Past, Present and Future

American Fisheries Society
Nashville, TN – August 31 2009

Christopher Bunt – Biotactic Inc.

Early Attempts: Pre 20th Century

- The need for upstream fish passage first documented in China near the end of the Ming Dynasty (~1500s)
- Precursors to modern structures first built in 17th Century France
- First documented patent in 1837 by Richard McFarlan to bypass water-powered lumber mill in Bathurst, NB



Nature-like bypass channel, East River, Guilford, Connecticut.
Photo credit: J. Turek, NOAA.

Early 20th Century

- Hiram M. Chittenden (Ballard) Locks, Lake Washington Ship Canal, Seattle, WA, USA (1906, rebuilt 1976)

- Royal Roads University Japanese Garden fish ladders, Esquimalt Lagoon, Victoria, BC, CAN (1914, restored 2009)

http://www.royalroads.ca/news-release/fish-ladder-restoration-project-japanese-gardens

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Mid 20th Century

- Pitlochry Fishway, River Tummel, Pitlochry, Scotland, 1943
- Robert E. Barrett Fishway, Holyoke Dam, Connecticut River, Holyoke, MA, USA, 1955 (Dam built in 1849, blocking fish migration)

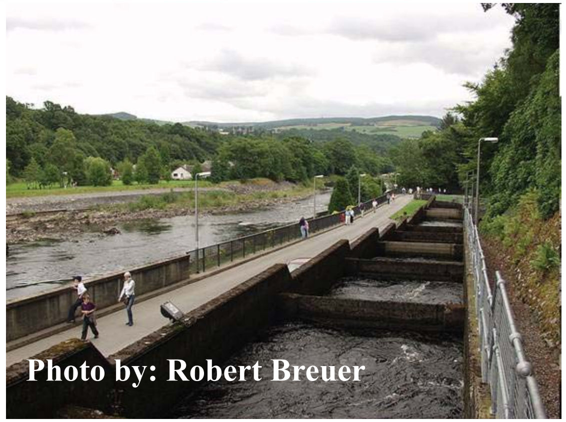
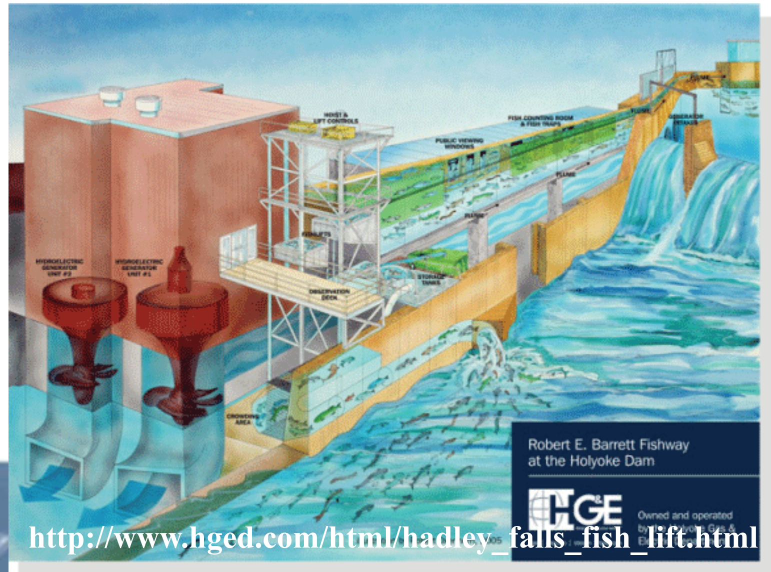


Photo by: Robert Breuer


Photo by: Dave Roback



http://www.hged.com/html/hadley_falls_fish_lift.html

Early Evaluations

- The effectiveness of fishway structures began to be "properly" studied in the 1970s; trapping fish at entrances/exits, mark-recapture
- Many structures are site, species and size-specific in their effectiveness
- Early focus on anadromous salmonids, major food and sport species

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Fish Counting Technology

Resistive – differences in electrical resistance

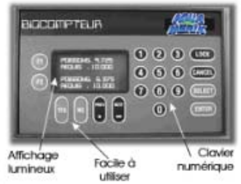
Optical – broken laser beam

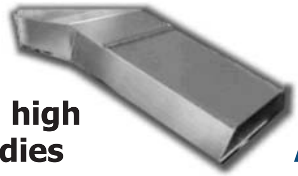
Accurate over small distances due to poor water penetration, suited to narrow passages

Smith-Root

Must install electrodes at site, good for long term monitoring in narrow passages

Hydroacoustic – sonar reflections





Requires skilled operators, difficult to obtain high accuracy, more suited to short term field studies

Aquamerik

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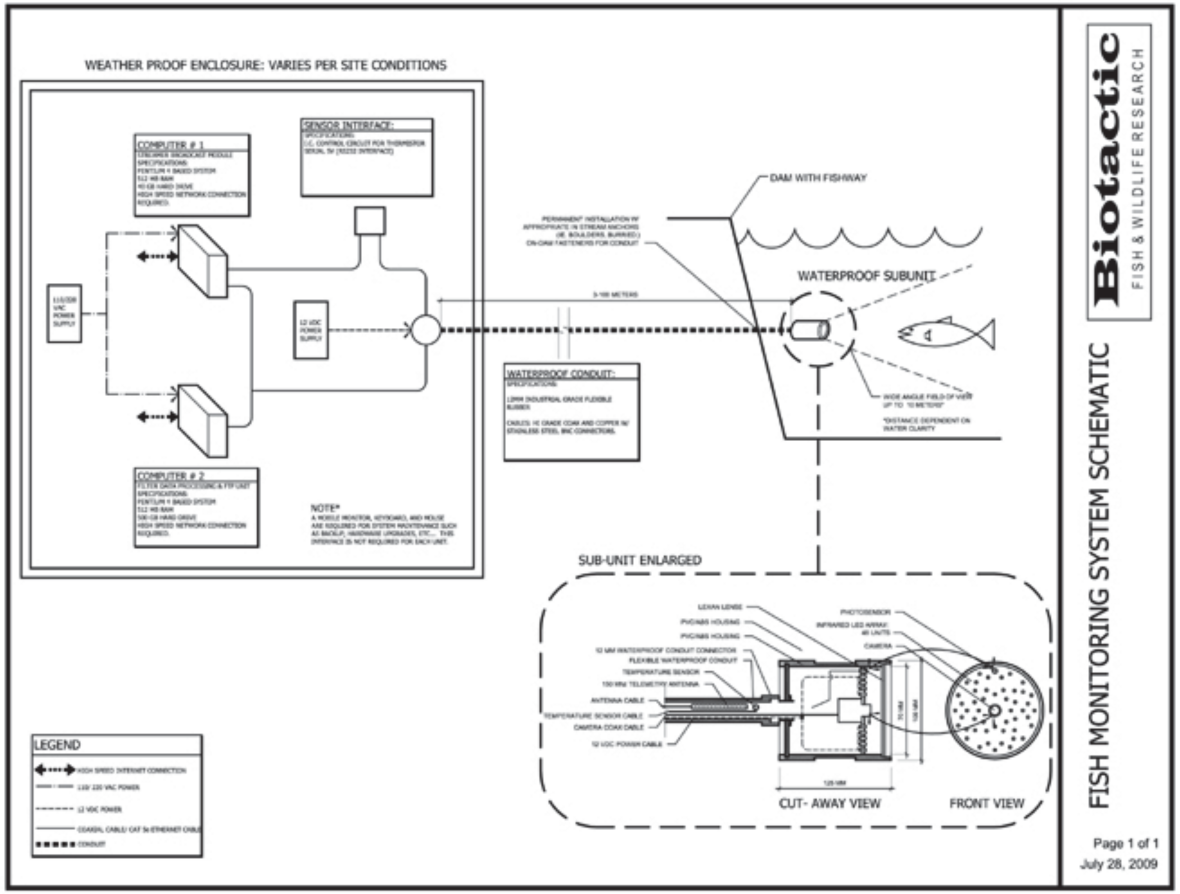
Underwater Fish Monitoring Systems - Video



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SMB in turbulent Denil flow

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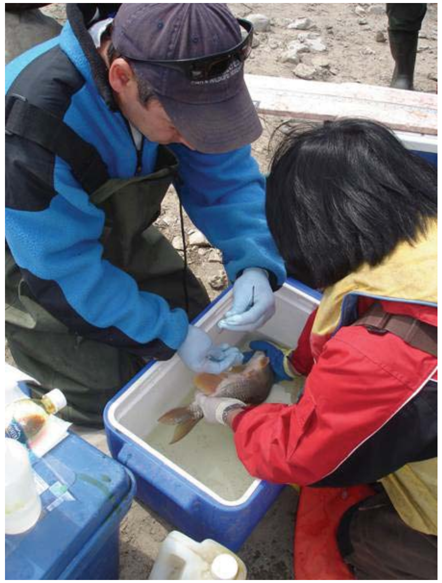
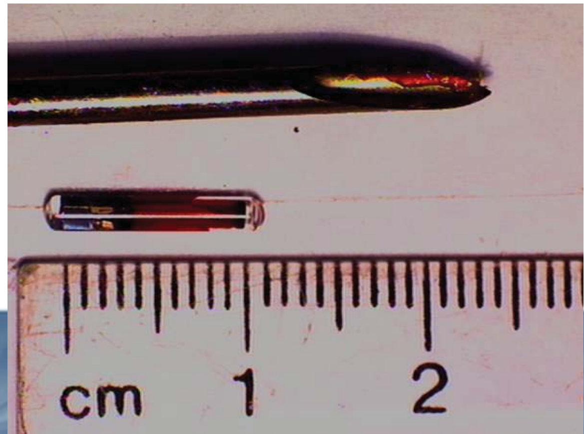
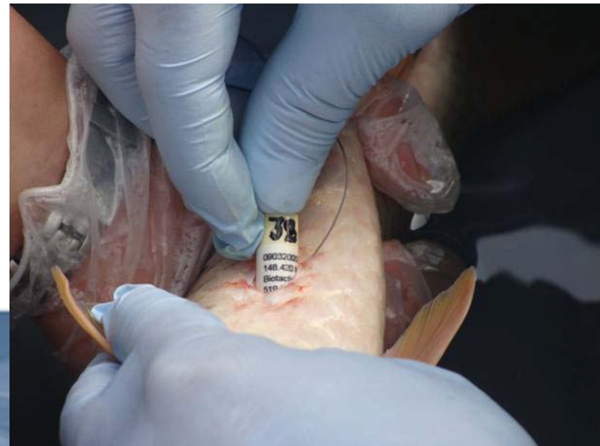
Breakthroughs: Individual Fish Tracking

- PIT/RFID, Sonic and Radio Telemetry became widely available in the 1980's
- Permits detailed tracking of individual fish
- Evaluations of passage success and passage failure







Monitoring Protocol

- Individual tracking, no corralling or coercion to enter passage
- Correlated with hydraulic and thermal data
- Elevation, slope, guidance, attraction and passage efficiency

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Standard Definitions

- Attraction efficiency: proportion of individuals that approach a fishway entrance
- Passage efficiency: proportion of individuals that passed through a fishway
- Elevation: difference in height between entrance and exit of structure
- Slope: difference in height/ distance between entrance and exit of structure

Fish Passage Effectiveness

- Monitor Movement & Behaviour and swimming performance of individual fish
- Attraction Efficiency
- Passage Efficiency
- Timing and Delay

Denil Fishway Effectiveness

Number of Studies: 6
Attraction Efficiency: 31%
Passage Efficiency: 32%
Structure Height: 2.02 m
Elevation Change: 1.99 m
Slope: 15%
n Total: 478
n Entered: 149
n Exited: 48

Vertical-Slot Fishways

Number of Studies: 6
Attraction Efficiency: 83%
Passage Efficiency: 20%
Structure Height: 1.48 m
Elevation Change: 0.67 m
Slope: 7%
n Total: 2019
n Entered: 1666
n Exited: 335

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Pool & Weir Fishway Effectiveness

Number of Studies: 14
Attraction Efficiency: 58%
Passage Efficiency: 44 %
Structure Height: 10.99 m
Elevation Change: 10.59 m
Slope: 7%
n Total: 1723
n Entered: 999
n Exited: 436

Naturelike Bypass Channels

Number of Studies: 19
Attraction Efficiency: 27%
Passage Efficiency: 79%
Structure Height: 11.35 m
Elevation Change: 7.01 m
Slope: 3%
n Total: 670
n Entered: 180
n Exited: 143

Open Dam Effectiveness

Number of Studies: 6
Attraction Efficiency: 90%
Passage Efficiency: 71%
Structure Height: 0m
Elevation Change: 0m
Slope: 0%
n Total: 120
n Entered: 108
n Exited: 77

Springbank Dam, Upper Thames, London, ON

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Efficiency/Elevation Change

		Mean	
Main Structure Type	n	Passage Efficiency/ Elevation Change (m)	Total Efficiency/ Elevation Change (m)
Bypass channels	19	0.11	0.03
Denil	6	0.16	0.05
Eel ladder	2	0.01	0.003
Lift/lock/other	7	0.3	0.3
Open Dam Gates	6	1.78	1.6
Pool/weir	14	0.04	0.02
Siphon Complex	1	-	-
V-slot	6	0.3	0.25

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Centrarchidae

Number of Studies: 5
Attraction Efficiency: 68%
Passage Efficiency: 42%
Structure Height: 1.12m
Elevation Change: 1.1m
Slope: 7%
n Total: 199
n Entered: 136
n Exited: 57

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Efficiency/Elevation Change

		Mean	
Species Family	**n**	**Passage Efficiency/ Elevation Change (m)**	**Total Efficiency/ Elevation Change (m)**
Anguillidae	2	0.01	0.002
Catostomidae	9	0.35	0.28
Centrarchidae	5	0.38	0.26
Clupeidae	17	0.03	0.02
Cyprinidae	6	0.08	0.02
Esocidae	3	0.26	0.16
Lotidae	1	0.06	0.05
Multiple	3	0.12	0.08
Percidae	4	0.08	0.02
Salmonidae	11	0.12	0.05

Fish Passage Synopsis

- Multiple logistic regression analysis
- 100 studies examined - useful data extracted from 20 multi-year or multi-structure evaluations from 7 countries
- Data broken down by specific structure or study year for a total of comparable 61 studies
- Fishway performance by 22 individual species (9 families) with three studies of combined fish species.

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Fish Passage Synopsis

Logistic Regression Model: Type, Height, Slope, Family, Slope*type
Model Predictions – probability of passage taking into effect height and slope

Nature-like: 2-95%
Denil: 28-53%
Ice Harbor: 13-99%
V-slot: 6-83%

Performance decreases with steepness (economics)

Sig. diff: among types and families
Can't justify design criteria based on available data

Bunt, Castro-Santos and Haro (2009), in prep.

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Future Fish Passage Research

- Is 100% attraction efficiency necessary?
- Is 100% passage efficiency necessary?

} Optimum efficiency?

- Fishways require maintenance, redesigns and retrofits - modifiability
- Standardize protocol for capture, tracking, release
- Standardize protocol for measuring attraction and passage efficiency
- MORE DATA

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Acknowledgements & Sources

Acknowledgements: Stephanie Choo-Wing, Tyler Socha,

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Salmonidae: Salmon and Trout

Number of Studies: 11
Attraction Efficiency: 35%
Passage Efficiency: 83%
Structure Height: 9.07m
Elevation Change: 6.78m
Slope: 4%
n Total: 646
n Entered: 229
n Exited: 190

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Percidae: Walleye and Perch

Number of Studies: 4
Attraction Efficiency: 28%
Passage Efficiency: 42%
Structure Height: 10.72m
Elevation Change: 5.31m
Slope: 4%
n Total: 68
n Entered: 19
n Exited: 8

Lotidae: Burbot

Number of Studies: 1
Attraction Efficiency: 83%
Passage Efficiency: 60%
Structure Height: 14.5m
Elevation Change: 9.25m
Slope: 3%
n Total: 6
n Entered: 5
n Exited: 3

Burbot (*Lota lota*)
from Fisheries of the Great Lakes Region
by Hubbs and Lagler

Esocidae:
Pike, Pickerel

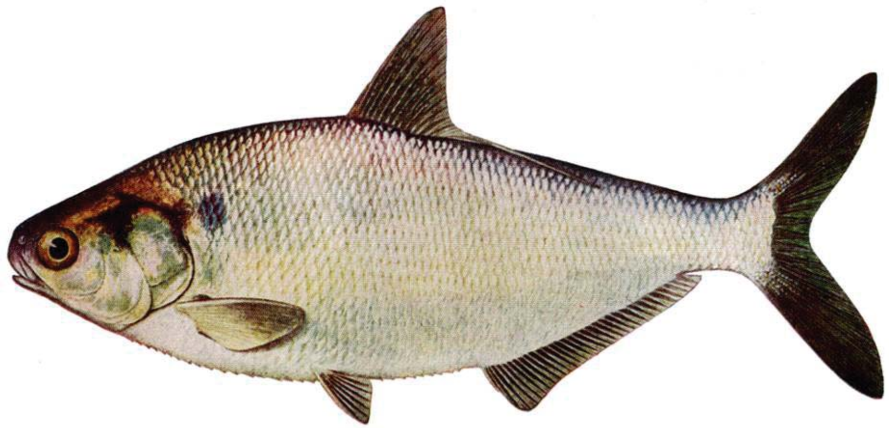
Number of Studies: 3
Attraction Efficiency: 61%
Passage Efficiency: 93%
Structure Height: 5.38m
Elevation Change: 3.63m
Slope: 3%
n Total: 23
n Entered: 14
n Exited: 13

Cyprinidae: Carp, Minnow

Number of Studies: 6
Attraction Efficiency: 25%
Passage Efficiency: 74%
Structure Height: 14.50m
Elevation Change: 9.25m
Slope: 3%
n Total: 137
n Entered: 34
n Exited: 25

Clupeidae: Herring, Shad, Sardines

Number of Studies: 17
Attraction Efficiency: 70%
Passage Efficiency: 34%
Structure Height: 13.18m
Elevation Change: 12.32m
Slope: 46%
n Total: 2415
n Entered: 1702
n Exited: 587



Gizzard Shad (*Dorosoma cepedianum*)
from Fisheries of the Great Lakes Region
by Hubbs and Lagler

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Catostomidae: Suckers and Redhorse

Number of Studies: 9
Attraction Efficiency: 80%
Passage Efficiency: 28%
Structure Height: 1.53m
Elevation Change: 0.8m
Slope: 16%
n Total: 941
n Entered: 757
n Exited: 215

Anguillidae: Freshwater Eels

Number of Studies: 2
Attraction Efficiency: 28%
Passage Efficiency: 31%
Structure Height: 25.00m
Elevation Change: 29.50m
Slope: 29%
n Total: 684
n Entered: 191
n Exited: 59

American Eel (*Anguilla rostrata*)
from Fisheries of the Great Lakes Region
by Hubbs and Lagler

Multiple Species

Number of Studies: 3
Attraction Efficiency: 72%
Passage Efficiency: 18%
Structure Height: 2.07 m
Elevation Change: 1.53 m
Slope: 11%
n Total: 1411
n Entered: 1013
n Exited: 186

Biotactic
FISH AND WILDLIFE RESEARCH

Lift and Lock Effectiveness

Number of Studies: 7
Attraction Efficiency: 85%
Passage Efficiency: 55%
Structure Height: 10.86 m
Elevation Change: 8.95 m
Slope: 73%
n Total: 117
n Entered: 114
n Exited: 35