CEDREN

Centre for Environmental Design of Renewable Energy

HydroPEAK user group meeting

Trondheim 30.10.2014

WP 7
Physical effects of load fluctuations in rivers

Stephan Spiller

Nils Rüther

NTNU

Norwegian University of Science and Technology

Research schedule:

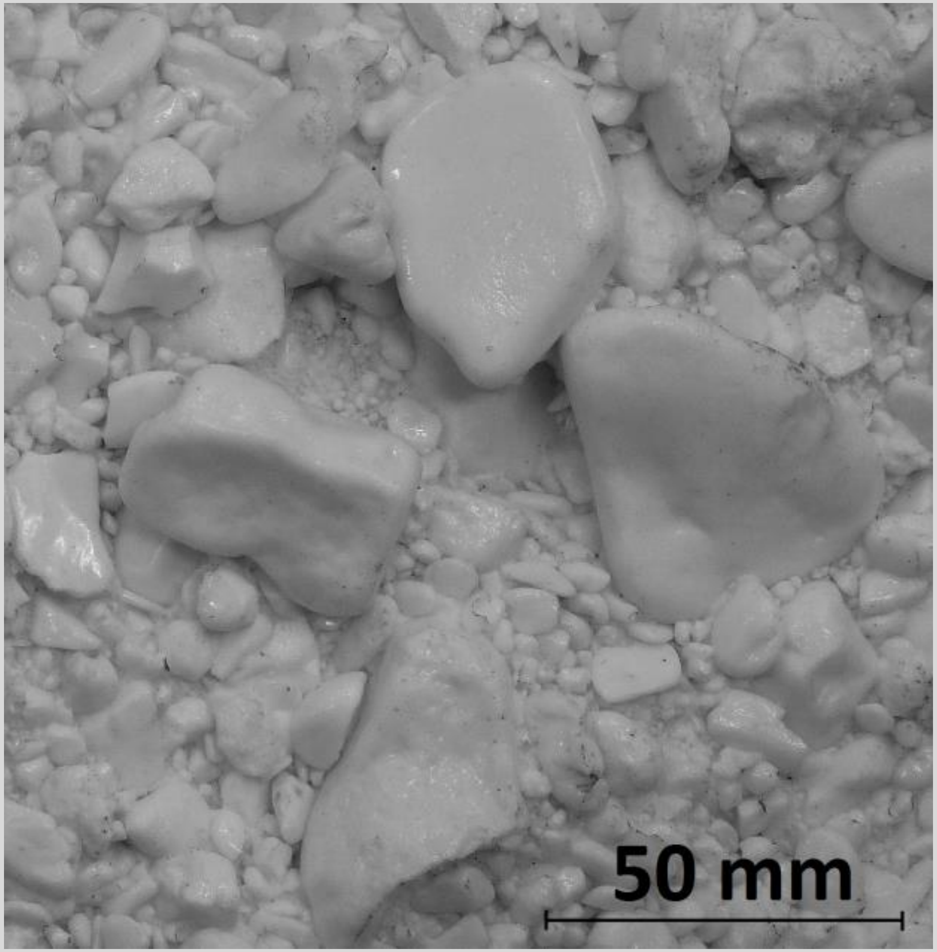
Milestone / type of deliverable	Description	Reached by (month & year)	
PhD start up	Welcome Stephan Spiller at the Department and within CEDREN	11-2010	Ok
Research plan	reviewing literature and demands of end user to establish a research plan	06-2011	Ok
Exams demaded within the PhD regulations	3 PhD level courses and 1 MSc level course	12-2011	Ok
Research start	Establish plan for measurement campaign in field & laboratory	03-2011	Ok
Progress report	Evaluation of progress by interims report	10-2012	Ok
Publishing; peer-reviewed conferance papers	It is planned to participate in 4-6 international conferences	12-2013	8 first author 3 co-author papers
Publishing; peer-reviewed journal paper	3 journal paper submissions are planned	06-2014	1 accepted 1 in review 1 in progress
Final report	Dissemination of final results to the end users	08-2014	
Thesis	Defending the thesis	08.12.2014	

Motivation:

- *Increased importance of hydropower peaking due to flexible energy market*
- *How is bed stability affected by rapid flow fluctuations?*
- *How can effects on flow fluctuations be mitigated?*

Tinfos power plant; hydropower reservoirs in Norway represent a great potential for a future European power system.
Photo: © Ånund Killingtveit, NTNU

Static armor layer



Artificial copy

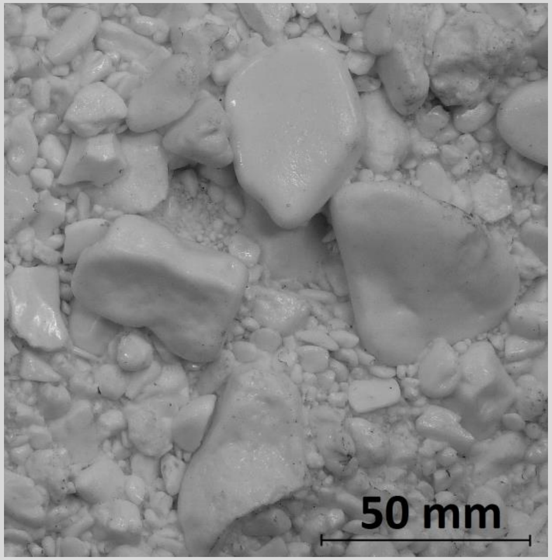
Artificial streambed :

Pro

- *Same prerequisite conditions for every experiment*
- *Possible to include discharges larger than the critical without destroying the bed.*
- *Streambed can be moved to other facilities (Germany, Norway, New Zealand)*

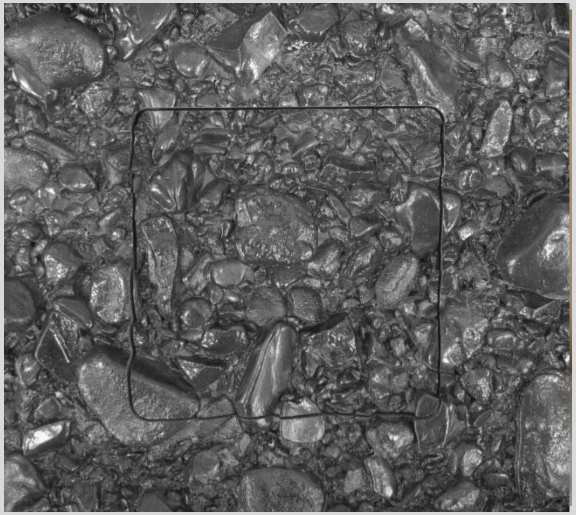
Contra

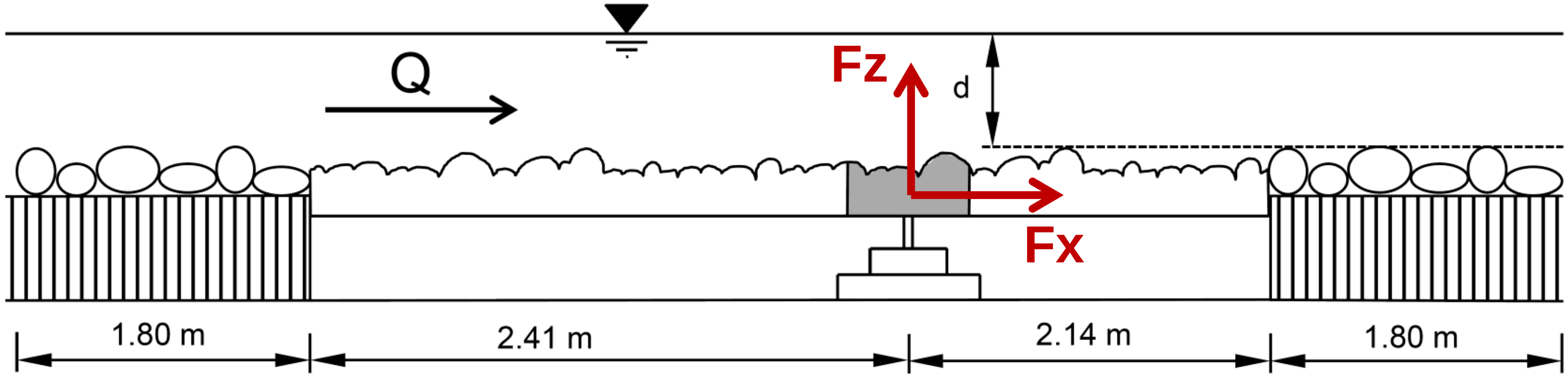
- *No porosity*



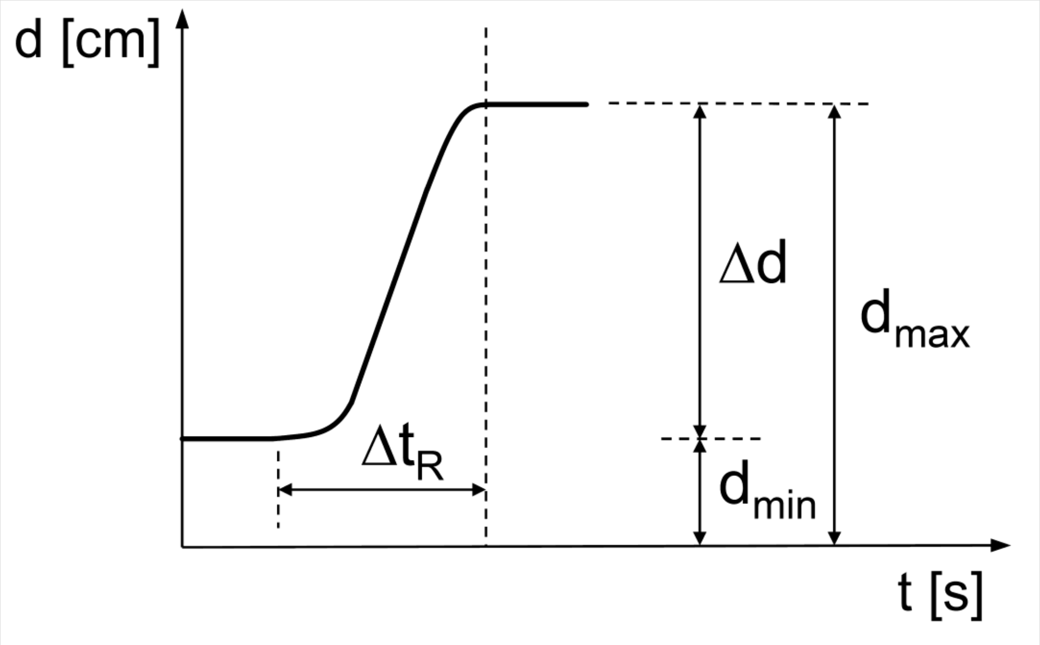
<u>*Experimental setup:*</u>

- *Flume: 18.5m long , 0.46m wide , slope 0.5%*
- *Artificial streambed*
- *10cm x 10cm target piece supported by force sensor*



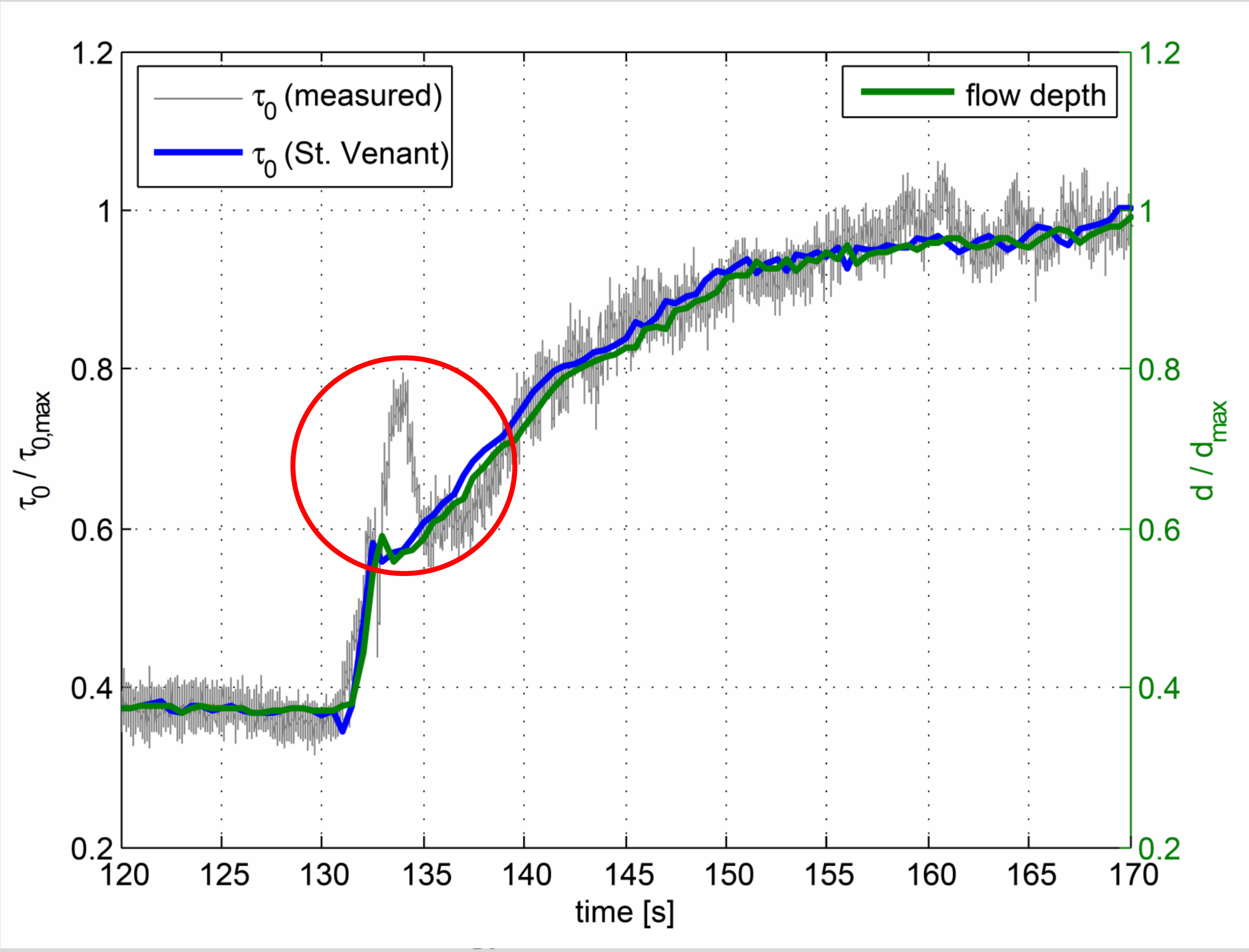


Experimental procedure:



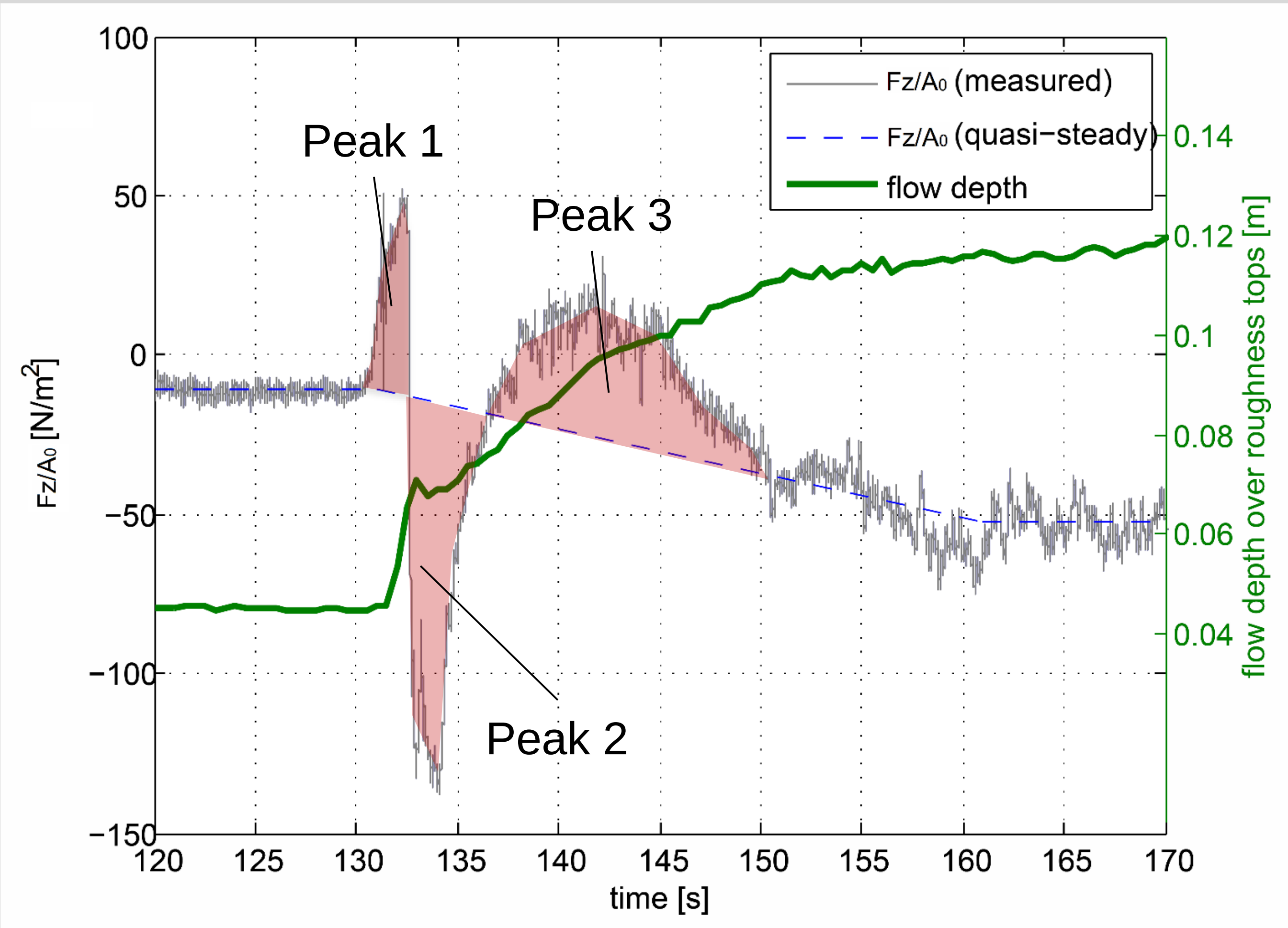
- Certain flow increase in a certain amount of time.
- >200 different hydrographs

Results – Shear stress:



- 6.5 l/s to 41.8 l/s in 24 seconds
- Relatively extreme example!
- Still no extreme difference between quasi steady and unsteady.

Results – Lift Force:

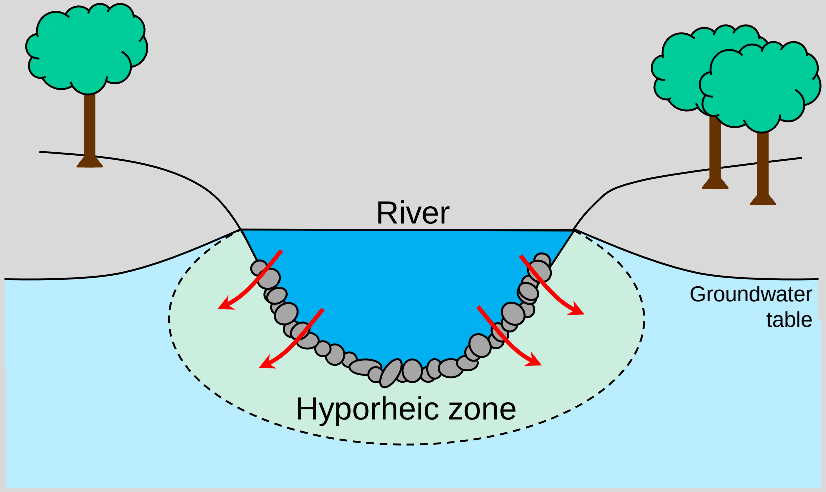


- 6.5 l/s to 41.8 l/s in 24 seconds
- Relatively extreme example!
- Severe lift forces 50N/m² (≈5kg/m²)

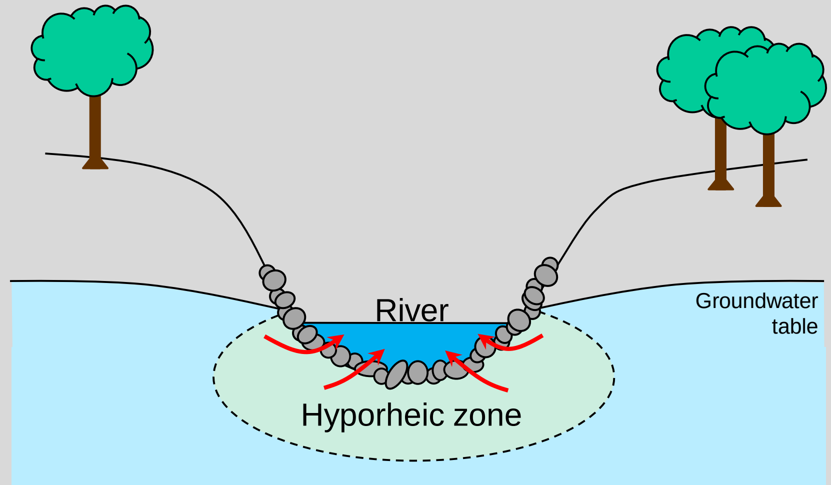
The hyporheic zone during hydropower peaking

(hyporheic zone = mixing zone of surface- and ground water)

Situation 1:
Surface water stage > groundwater stage
"DOWNWELLING"

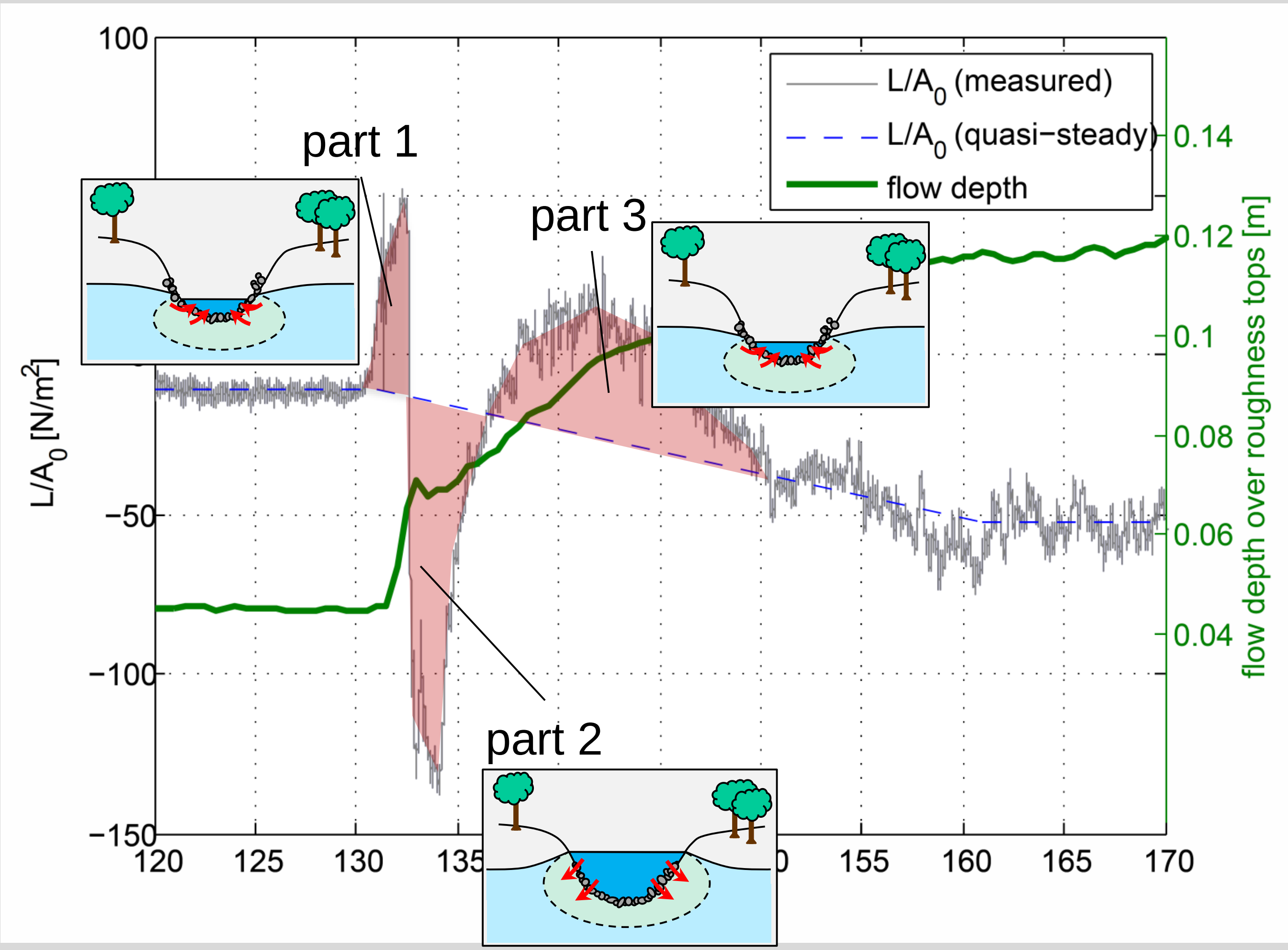


Situation 2:
Surface water stage < groundwater stage
"UPWELLING"



- Upwelling and downwelling are responses to the hydrostatic pressure difference between ground water table and surface water stage. They can be described as ***"quasi-steady effects"*** of hydropower peaking
- Are there additional ***"dynamic" or "unsteady effects"*** during hydropower peaking, affecting the hyporheic zone?

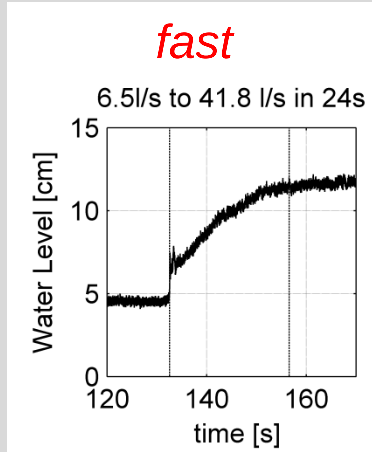
Results – Lift Force:

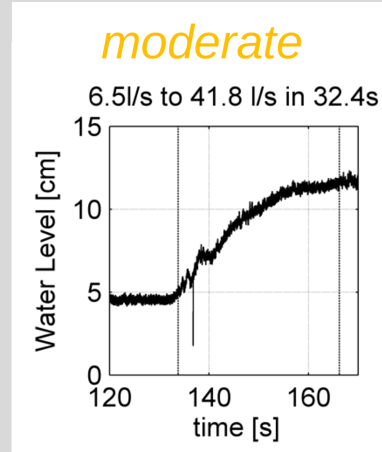


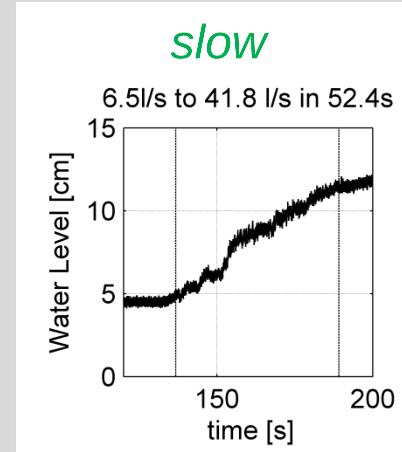
- 6.5 l/s to 41.8 l/s in 24 seconds
- Relatively extreme example!
- Severe lift forces 50N/m² (≈5kg/m²)

Results:

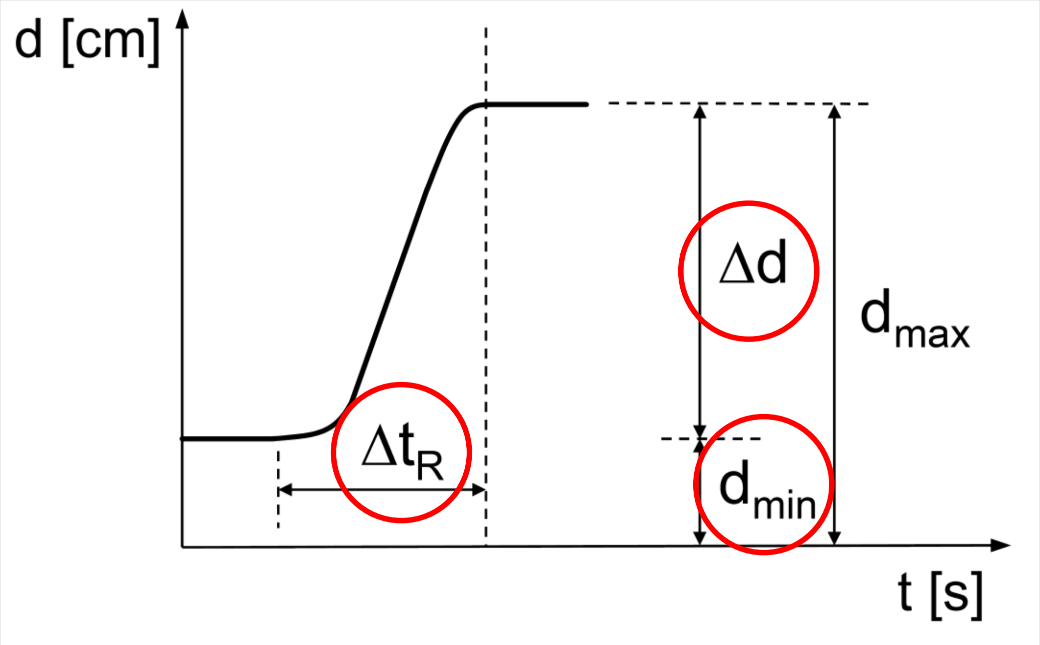
Same change in discharge in three different “speeds”







Results:

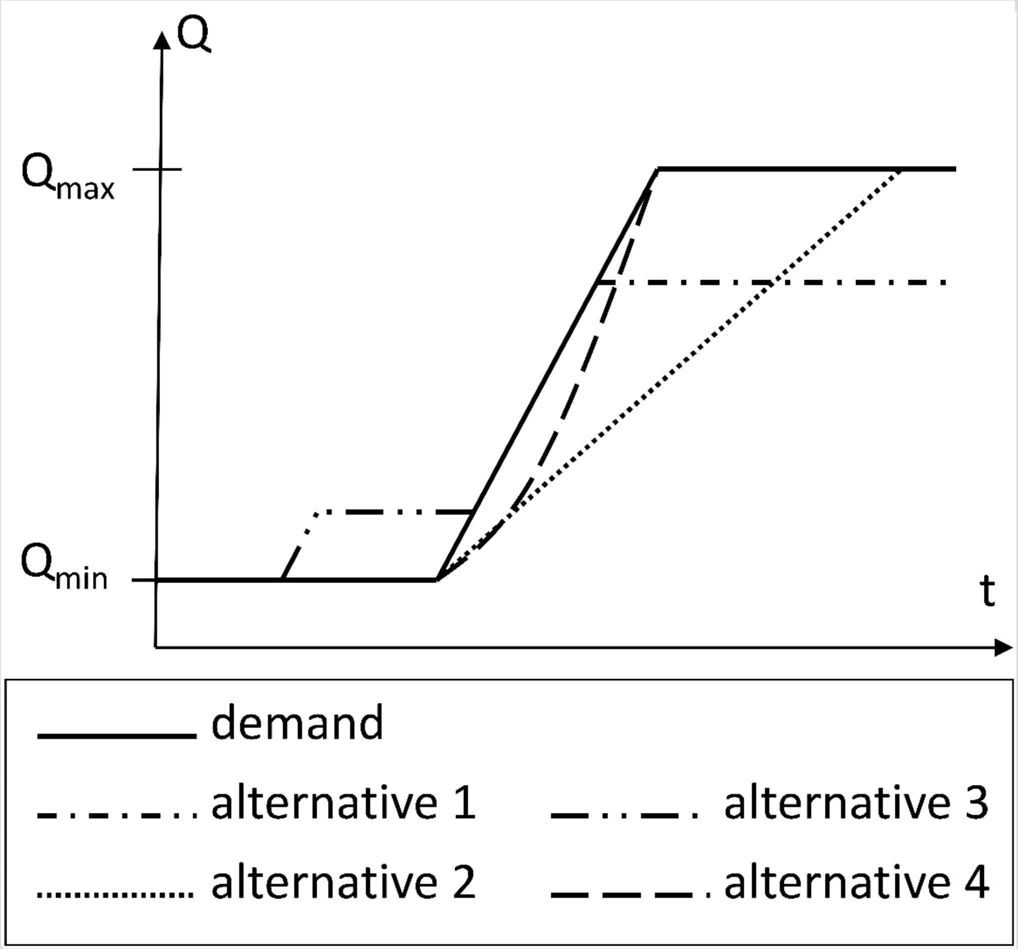


Three hydrograph characteristics affect the results:

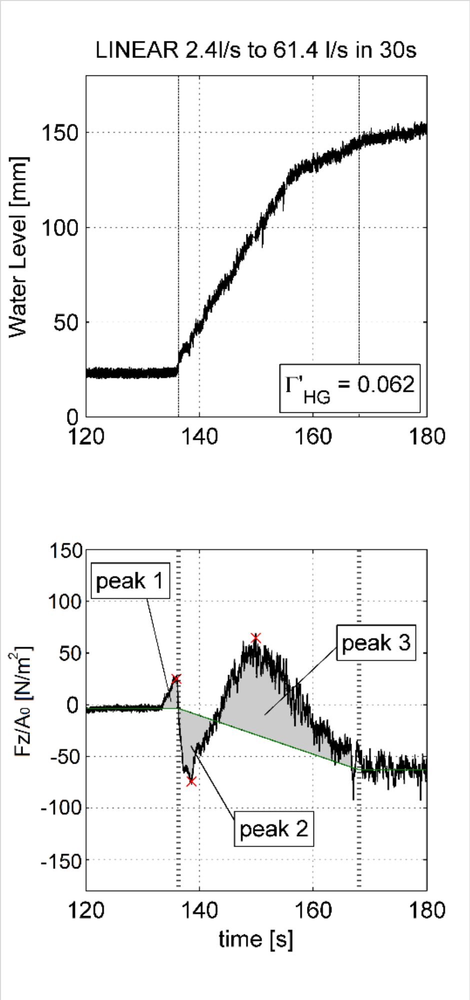
Δt_R , Δd and d_{min}

→ With more than 200 hydrographs, these can be isolated…

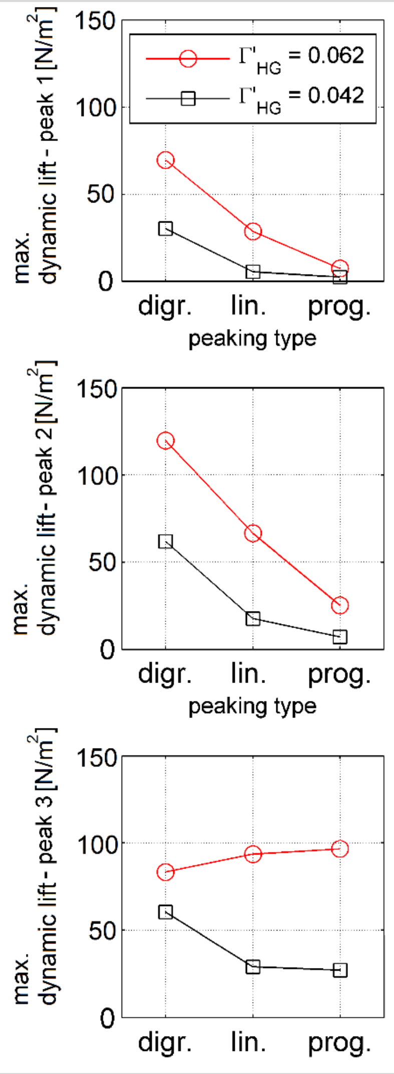
Results:


Q
Q_{max}
Q_{min}
t
demand
alternative 1
alternative 2
alternative 3
alternative 4

Results:


LINEAR 2.4l/s to 61.4 l/s in 30s
Water Level [mm]
150
100
50
0
120
140
160
180
Γ'HG = 0.062
Fz/A0 [N/m2]
150
100
50
0
-50
-100
-150
peak 1
peak 2
peak 3
120
140
160
180
time [s]

Results:


max. dynamic lift - peak 1 [N/m²]
Γ'HG = 0.062
Γ'HG = 0.042
150
100
50
0
digr.
lin.
prog.
peaking type
max. dynamic lift - peak 2 [N/m²]
150
100
50
0
digr.
lin.
prog.
peaking type
max. dynamic lift - peak 3 [N/m²]
150
100
50
0
digr.
lin.
prog.

Conclusions:

- Unsteady flow can have significant dynamic effects on the lift acting on a streambed compared to the bed-shear stress.
- Operational mitigation measures during hydropower peaking reduce the dynamic lift but often interfere with the hydropower plant's production schedule
- Non-Linear (progressive) peaking can be an operational mitigation measures that effectively reduces dynamic lift during flow increases without interfering with the production schedule of hydropower plants.

Recent MSc Student in HydroPEAK WP7:

NTNU – Trondheim
Norwegian University of Science and Technology

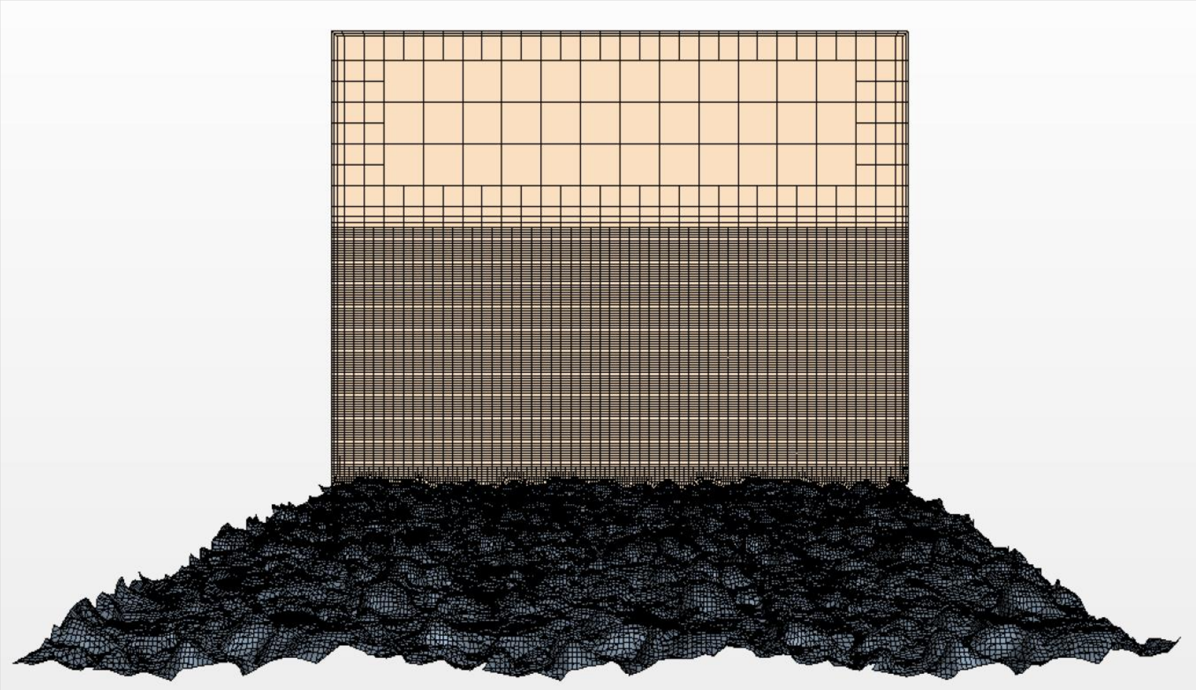
3D Numerical modeling of flow over an artificial gravel bed

Vincenzo Sessa

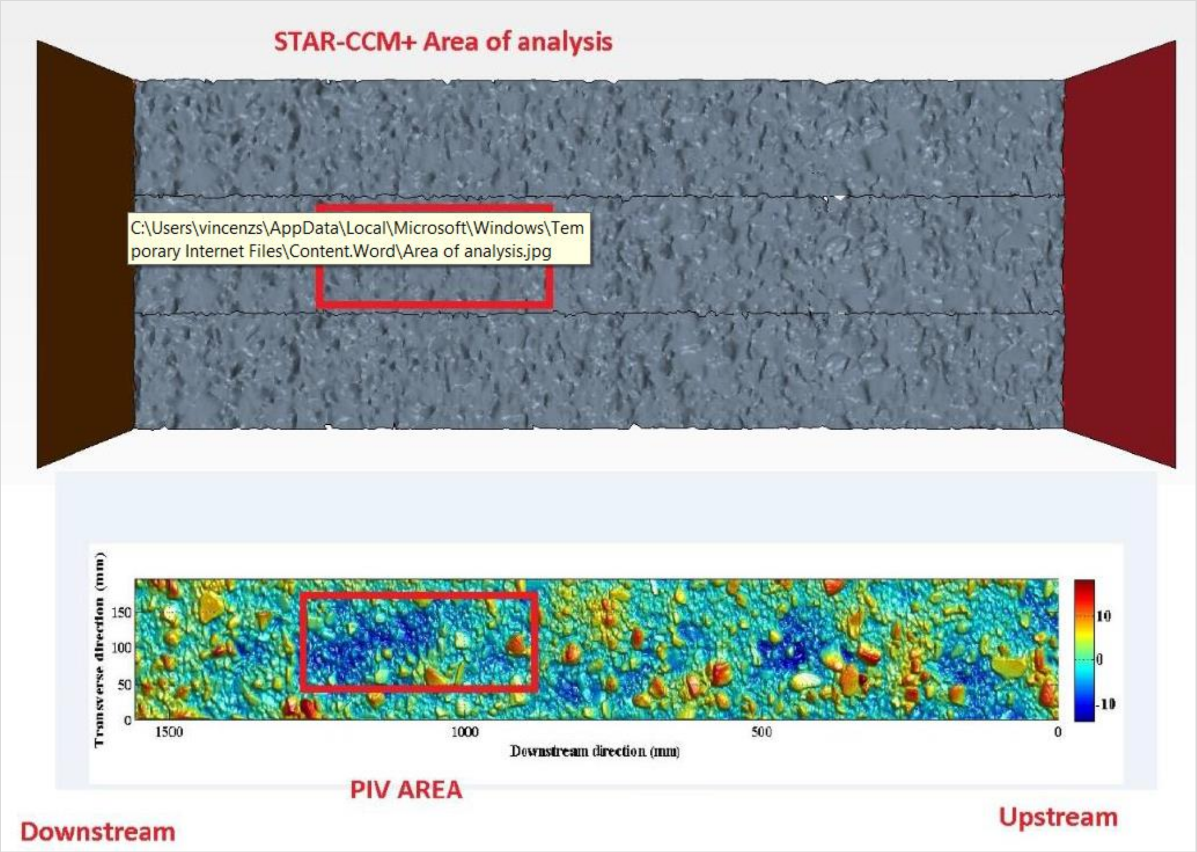
Civil and Environmental Engineering
Submission date: September 2014
Supervisor: Nils Rüther, IVM

Norwegian University of Science and Technology
Department of Hydraulic and Environmental Engineering

Recent MSc Student in HydroPEAK WP7:



Recent MSc Student in HydroPEAK WP7:

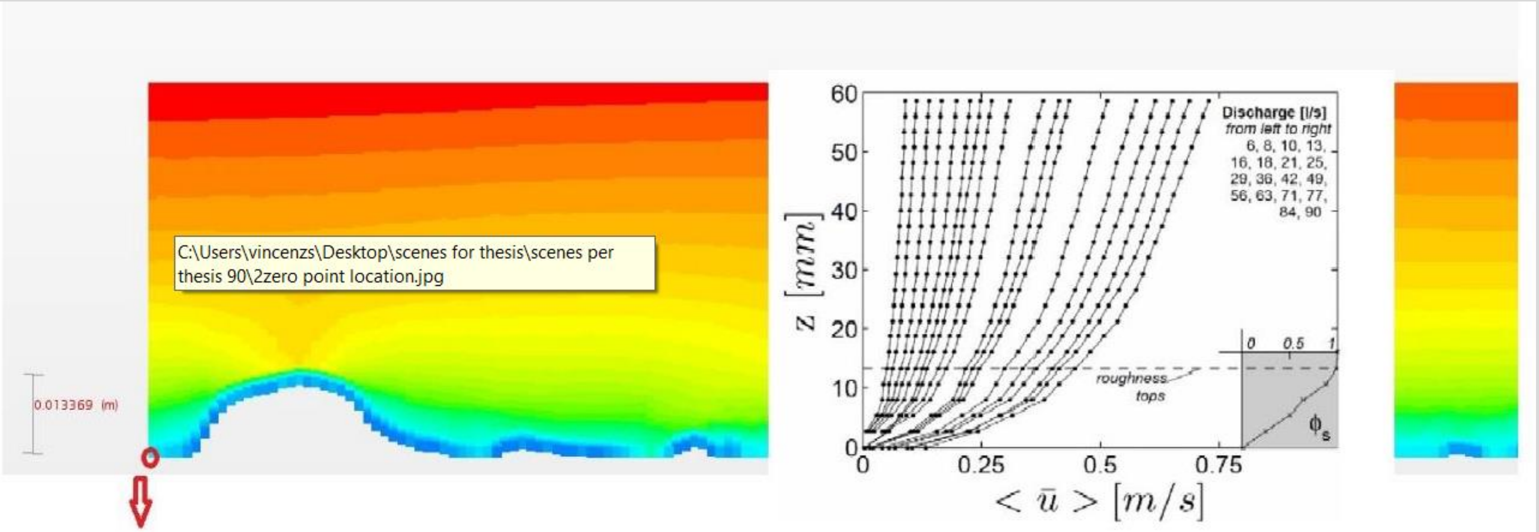


CEDREN

Centre for Environmental Design of Renewable Energy

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

Recent MSc Student in HydroPEAK WP7:



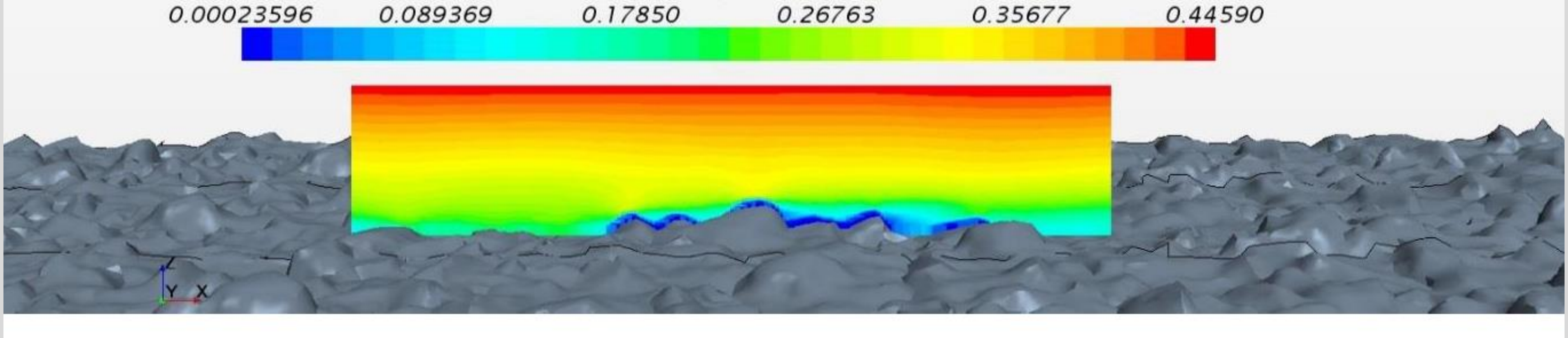
zero point (z=0.000)

Exact location of zero point by roughness tops (13,3 mm) matching

NTNU

Norwegian University of Science and Technology

Recent MSc Student in HydroPEAK WP7:



CEDREN

Centre for Environmental Design of Renewable Energy

Recent MSc Student in HydroPEAK WP7:

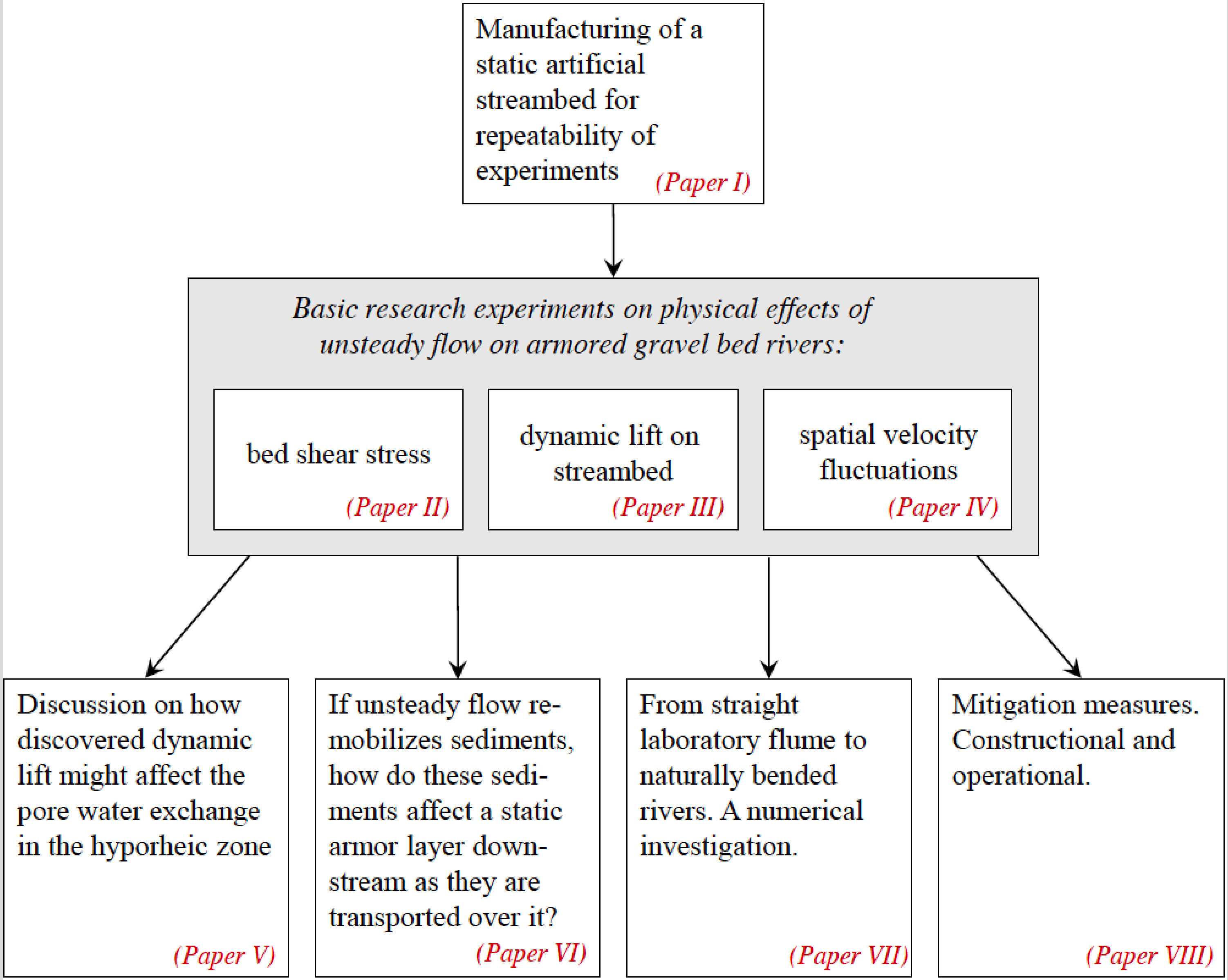
NTNU

Norwegian University of Science and Technology

4 years of work!
outcome…

HydroPeak WP7 finished??!!

- *PhD finished → Public defence on 8th of December → Rådsalen Gløshaugen*
- *Nils Rüther applied for transfer of money to continue in 2015 → use of blue flume*


Manufacturing of a static artificial streambed for repeatability of experiments (Paper I)
Basic research experiments on physical effects of unsteady flow on armored gravel bed rivers:
bed shear stress (Paper II)
dynamic lift on streambed (Paper III)
spatial velocity fluctuations (Paper IV)
Discussion on how discovered dynamic lift might affect the pore water exchange in the hyporheic zone (Paper V)
If unsteady flow re-mobilizes sediments, how do these sedi-ments affect a static armor layer down-stream as they are transported over it? (Paper VI)
From straight laboratory flume to naturally bended rivers. A numerical investigation. (Paper VII)
Mitigation measures. Constructional and operational. (Paper VIII)

13 papers

2014

Spiller, Stephan; Ruther, Nils; Friedrich, Heide.
Dynamic lift on an artificial static armor layer during highly unsteady flow. *Journal of Hydraulic Engineering (ASCE)* In review

Spiller, Stephan; Ruther, Nils; Baumann, Benjamin.
Form-induced stress in non-uniform steady and unsteady open channel flow over a steady rough bed. *International Journal of Sediement Research.* Accepted for publication

Spiller, Stephan; Ruther, Nils; Friedrich, Heide.
Mitigation measures for unsteady flow effects on riverbeds during hydropower peaking. I: *Proceedings of the River Flow 2014 International Conference on Fluvial Hydraulics*. CRC Press 2014 ISBN 978-1-138-02674-2. s. 1807-1812

Spiller, Stephan; Ruther, Nils; Casas-Mulet, Roser; Friedrich, Heide.
PORE WATER EXCHANGE IN GRAVEL BED RIVERS DURING HYDROPOWER PEAKING EVENTS. 10th International Symposium on Ecohydraulics 2014; 2014-06-23 - 2014-06-27

Friedrich, Heide; Spiller, Stephan; Ruther, Nils.
Near-bed flow over a fixed gravel bed. I: *Proceedings of the River Flow 2014 International Conference on Fluvial Hydraulics*. CRC Press 2014 ISBN 978-1-138-02674-2. s. 279-285

Török, G.T.; Baranya, S; Ruther, Nils; Spiller, Stephan.
Laboratory analysis of armor layer development in a local scour around a groin. I: *Proceedings of the River Flow 2014 International Conference on Fluvial Hydraulics*. CRC Press 2014 ISBN 978-1-138-02674-2. s. 1455-1462

2013

Spiller, Stephan; Ruther, Nils.
The Impact of Hydropower Peaking on Gravel Beds. Hydro2013 International Conference; 2013-10-07 - 2013-10-09

Spiller, Stephan; Ruther, Nils; Baumann, Benjamin.
PIV Measurements of Steady Flow over an Artificial Static Armor Layer. I: *Proceedings of the 35th IAHR World Congress*. China: Tsinghua University Press 2013 ISBN 978-7-89414-588-8.

Ruther, Nils; Huber, Sonja; Spiller, Stephan; Aberle, Jochen.
Verifying a Photogrammetric Method to Quantify Grain Size Distribution of Developed Armor Layers. 35th IAHR World Congress; 2013-09-08 - 2013-09-13

2012

Spiller, Stephan; Ruther, Nils; Baumann, Benjamin.
Artificial Reproduction of the Surface Structure in a Gravel Bed. München: IAHR 2012 (ISBN 978-3-943683-03-5) 6 s

Spiller, Stephan; Ruther, Nils; Killingtveit, Ånund.
Physical Effects of Load Fluctuations in Rivers. *Berichte des Lehrstuhls und der Versuchsanstalt für Wasserbau und Wasserwirtschaft* 2012 (125) s. 52-59

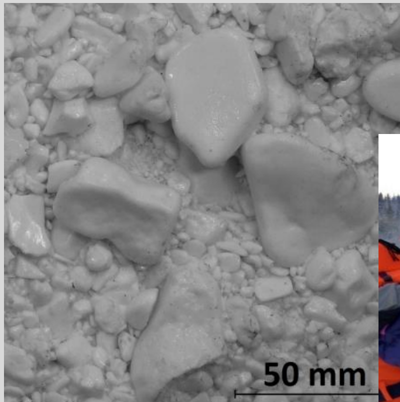
Spiller, Stephan; Ruther, Nils; Koll, Klaus; Koll, Katinka.
Bed load movement over a fully developed armor layer – A tracer experiment. I: *River Flow 2012*. Taylor & Francis 2012 ISBN 978-0-415-62129-8. s. 465-471

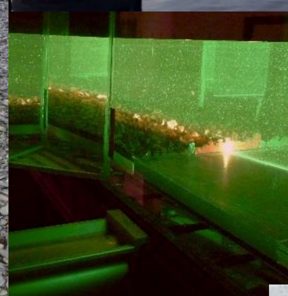
2011

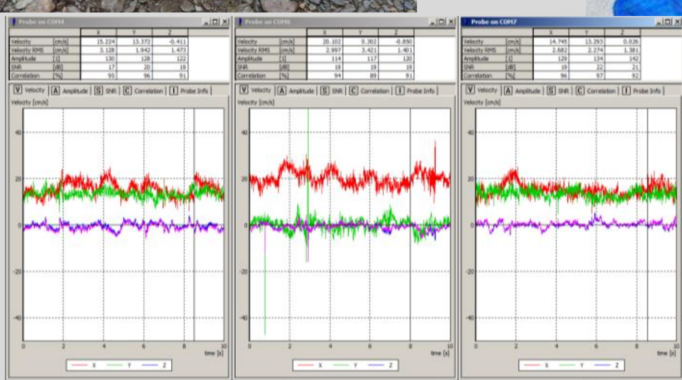
Spiller, Stephan; Ruther, Nils; Belete, Kiflom Wasihun; Strellis, Brendon.
Assessing environmental effects of hydropower peaking by 3D numerical modeling. *Flow simulation in hydraulic engineering : Dresdner wasserbauliche Mitteilungen* 2011 ;Volum 1.(1) s. 79-86

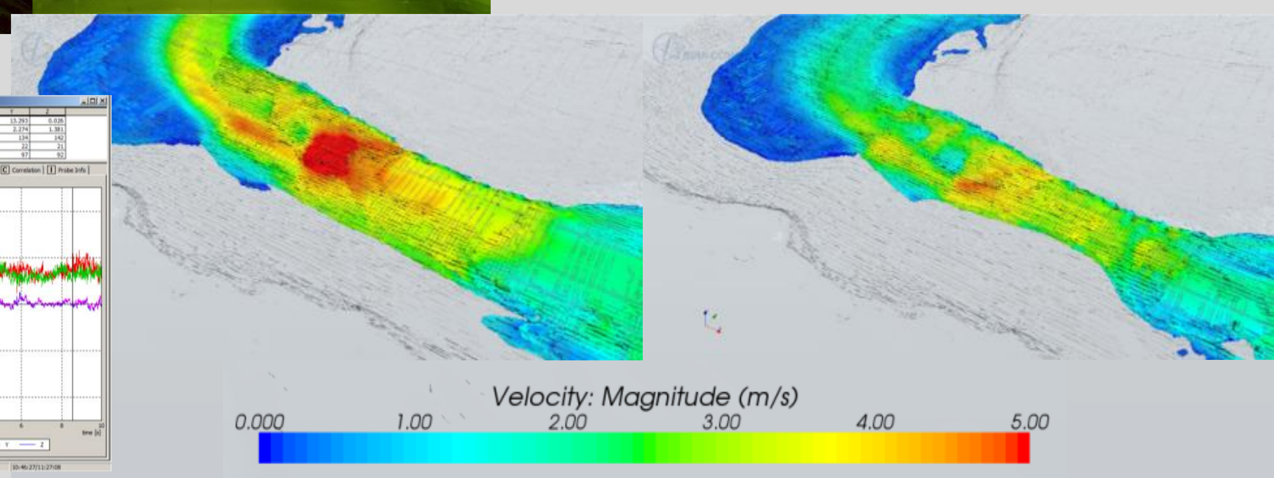
Methods and measurement devices

- Artificial gravel bed
- Direct force measurement
- Freeze cores
- Suspended sediment
- Particle Image Velocimetry (PIV)
- Acoustic Doppler Velocimetry (ADV)
- Numerical methods







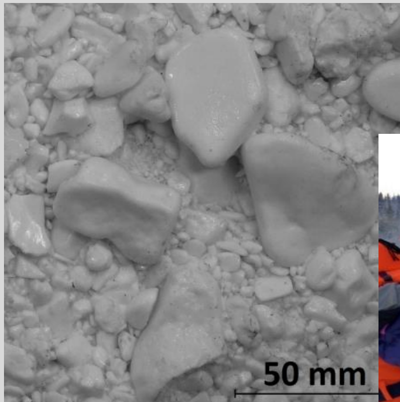


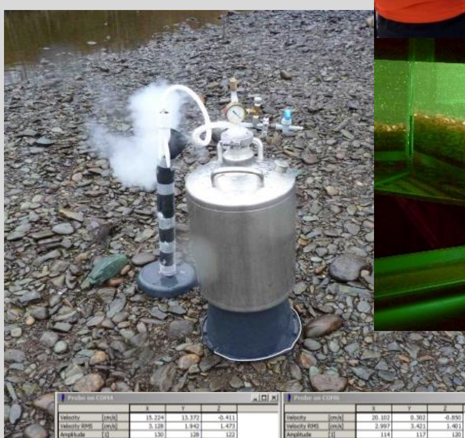
CEDREN

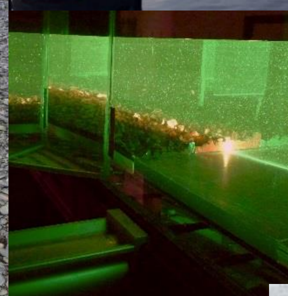
Centre for Environmental Design of Renewable Energy

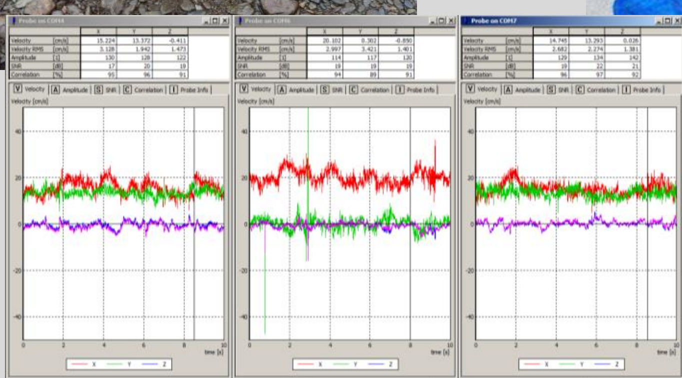
CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

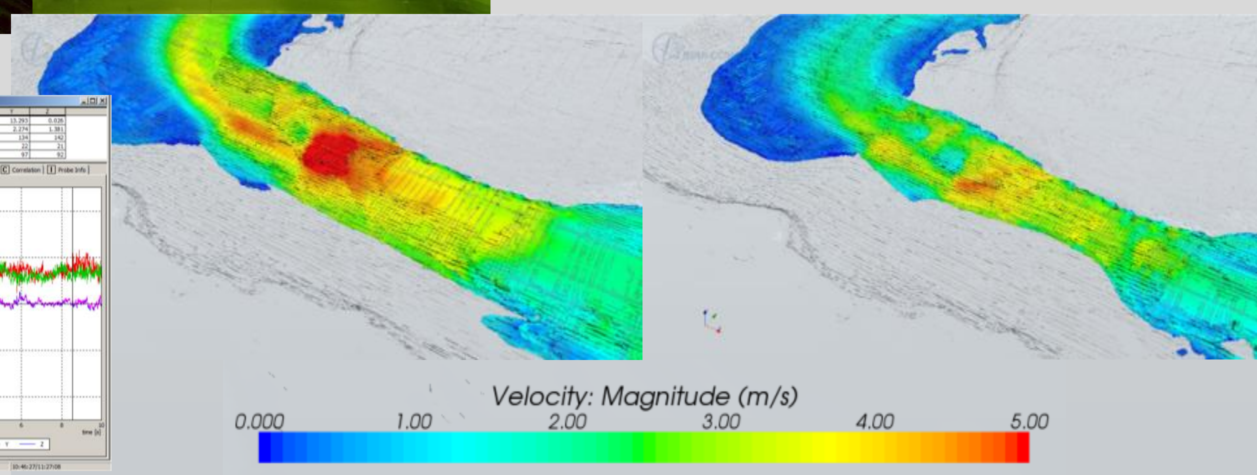
Basis for further research











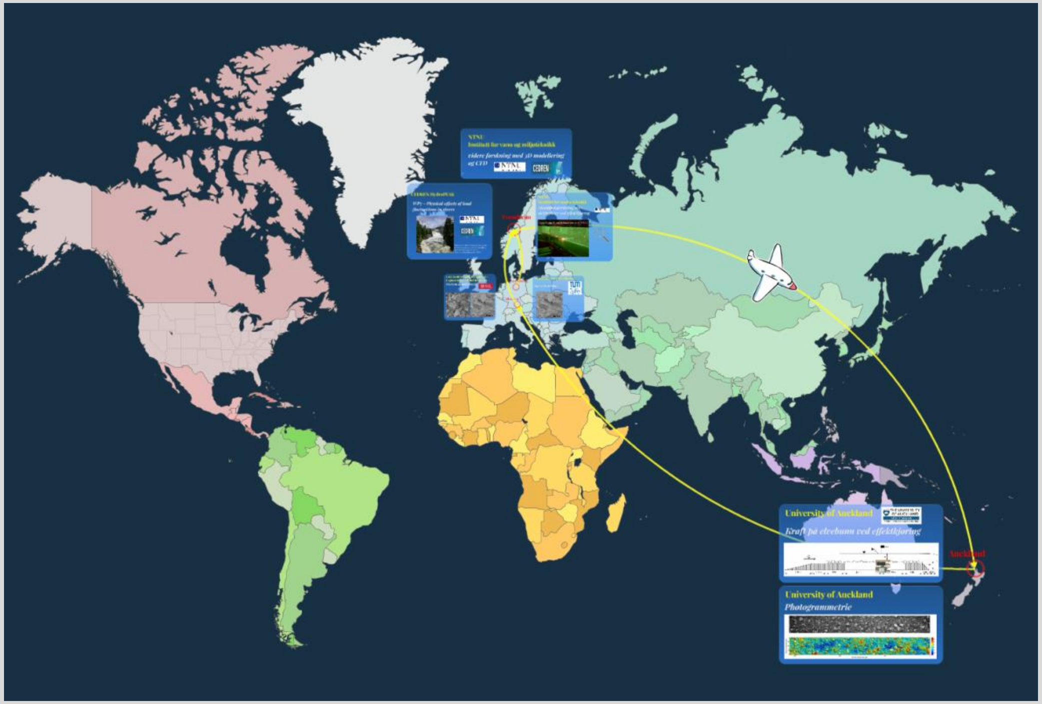
- New PhD student at NTNU
- Master students
- Projects at other institutes in Norway, Germany, New Zealand

CEDREN

Centre for Environmental Design of Renewable Energy

FME – Centre for Environment-Friendly Energy Research

networking



THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

Technische Universität Braunschweig

TUM
TECHNISCHE UNIVERSITÄT MÜNCHEN

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA A.D. 1088

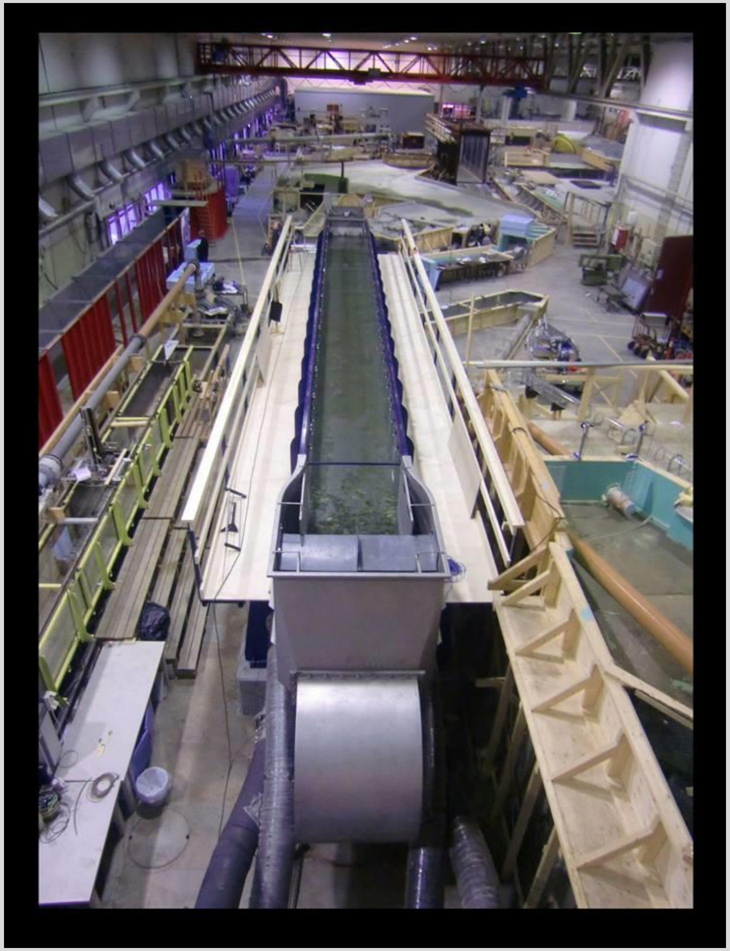
MŰEGYETEM 1782

- 9 conferences
- 3 workshops
- 2 research exchanges

Connections within CEDREN and NTNU

- Nils → EnviPEAK
  many project collaborations
- Roser Casas-Mulet is co-Author in Ecohydraulics paper
- Marine Technology PIV group

New flume installed at NTNU



- Flume installed
- gangway
- working platform
- staircase
- downstream weir
- 5 tons of sediments
- Automatic valves
- Inductive discharge measurement
- Connection to high reservoir
- Connection to low reservoir
- Traverse

- ➢ Several Master theses
- ➢ 4 Months cooperation with Hungarian PhD student
- ➢ Collaboration with MARINTEK
- ➢ New PhD Student at NTNU

Thank you very much for your attention

Stephan Spiller
Nils Rüther

NTNU
Norwegian University of Science and Technology