Hyperpycnal sediment-laden river plumes in lakes: flow-sediment-bathymetry interactions (HARP)

PhD-LAB

Proposal defence

Kingsley Obinna EZE

October 10, 2024

Supervisors: Koen Blanckaert[1], Eletta Negretti[2], Julien Chauchat[2]
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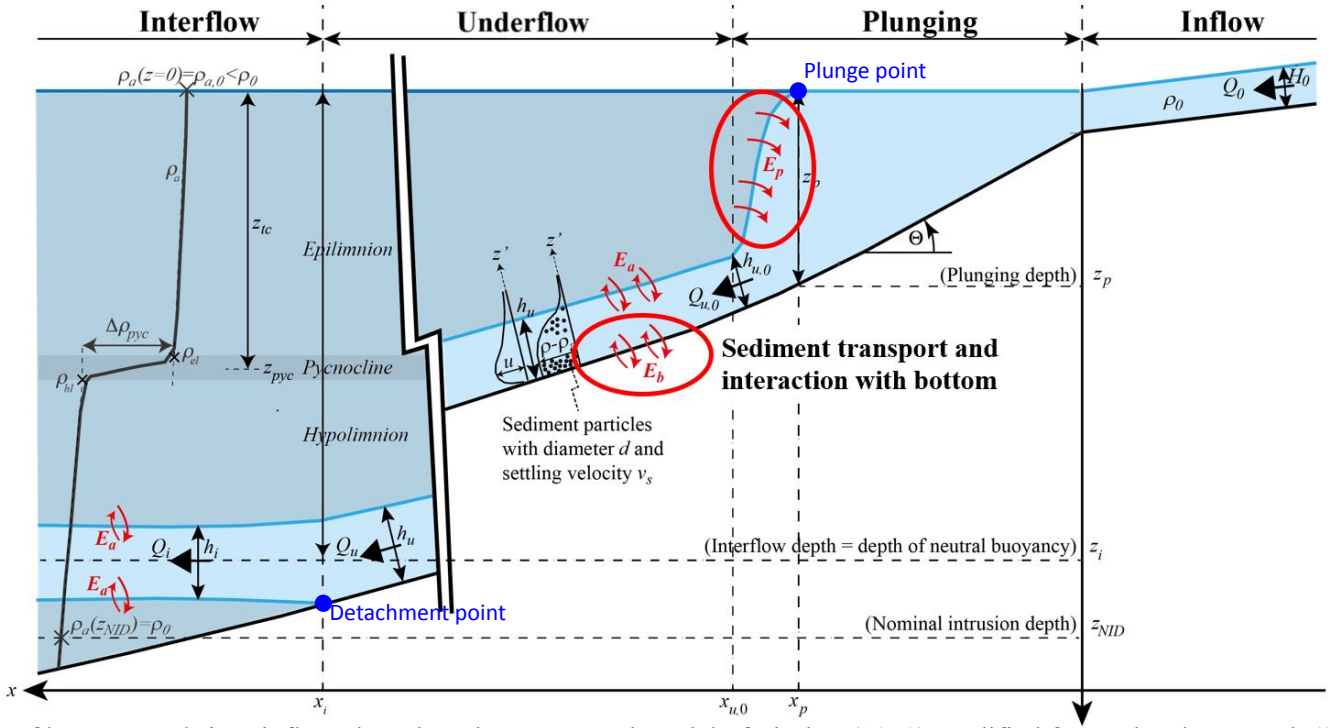
[2]Laboratoire des Ecoulements Géophysiques et Industriels (LEGI)

TU WIEN TECHNISCHE UNIVERSITÄT WIEN
FWF Austrian Science Fund
anr agence nationale de la recherche AU SERVICE DE LA SCIENCE
LEGI LABORATOIRE DES E... GEOPHYSIQUES ET I...

Introduction

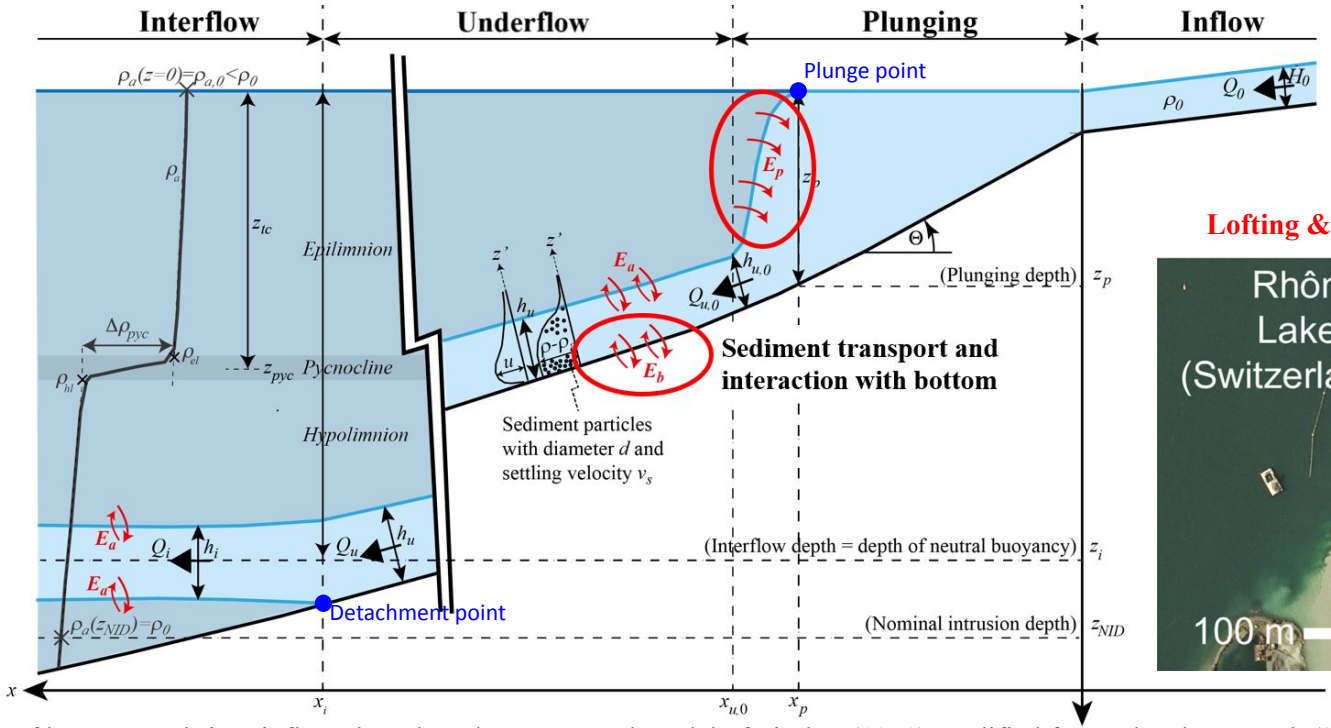
Hyperpycnal inflows in lakes



Pathway of hyperpycnal river inflows based on the conceptual model of Fischer (1979) modified from Blanckaert et al. (2024)

Introduction

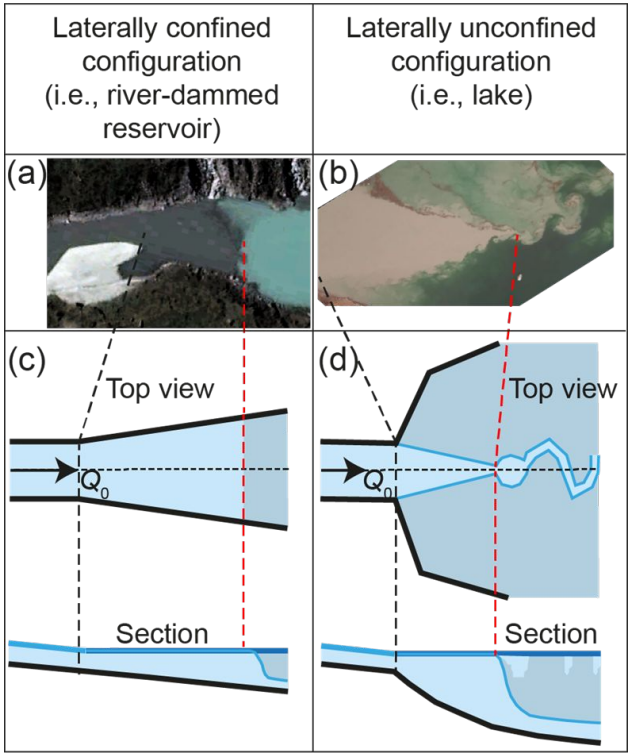
Hyperpycnal inflows in lakes



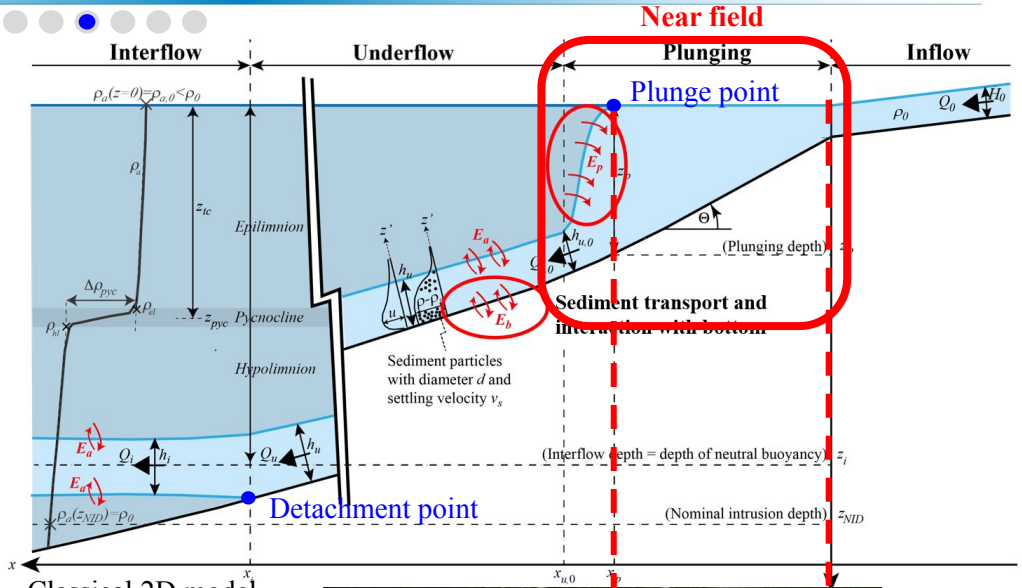
Lofting & surface leakage

Pathway of hyperpycnal river inflows based on the conceptual model of Fischer (1979) modified from Blanckaert et al. (2024)

Introduction



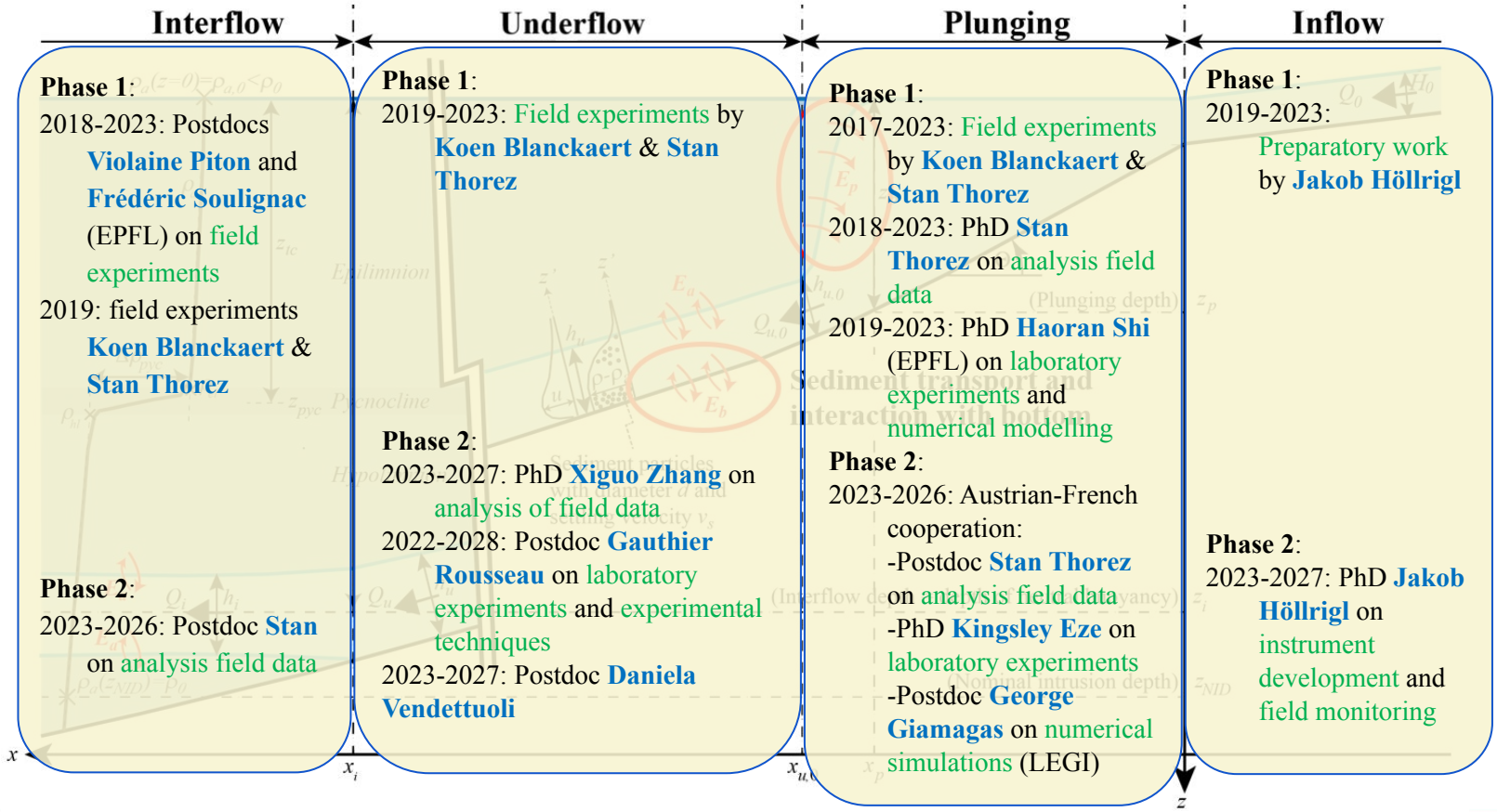
(source: Thorez et al. 2024)



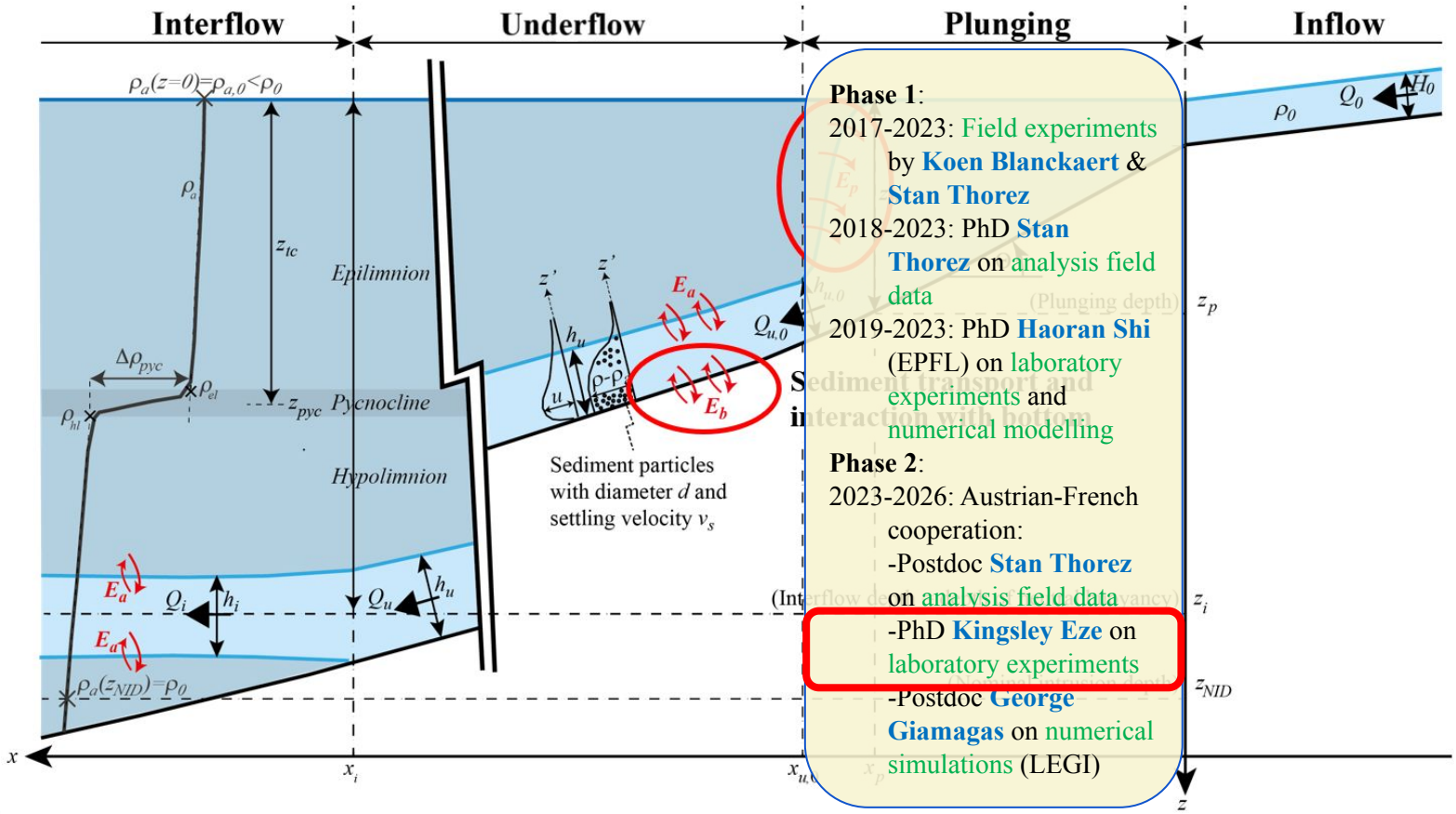
Classical 2D model

Confined Dranse de Bagnes inflow into Lake Mauvoisin (Switzerland)

Introduction



Introduction



Phase 1:

2017-2023: Field experiments by **Koen Blanckaert** & **Stan Thorez**

2018-2023: PhD **Stan Thorez** on analysis field data

2019-2023: PhD **Haoran Shi** (EPFL) on laboratory experiments and numerical modelling

Phase 2:

2023-2026: Austrian-French cooperation:

-Postdoc **Stan Thorez** on analysis field data

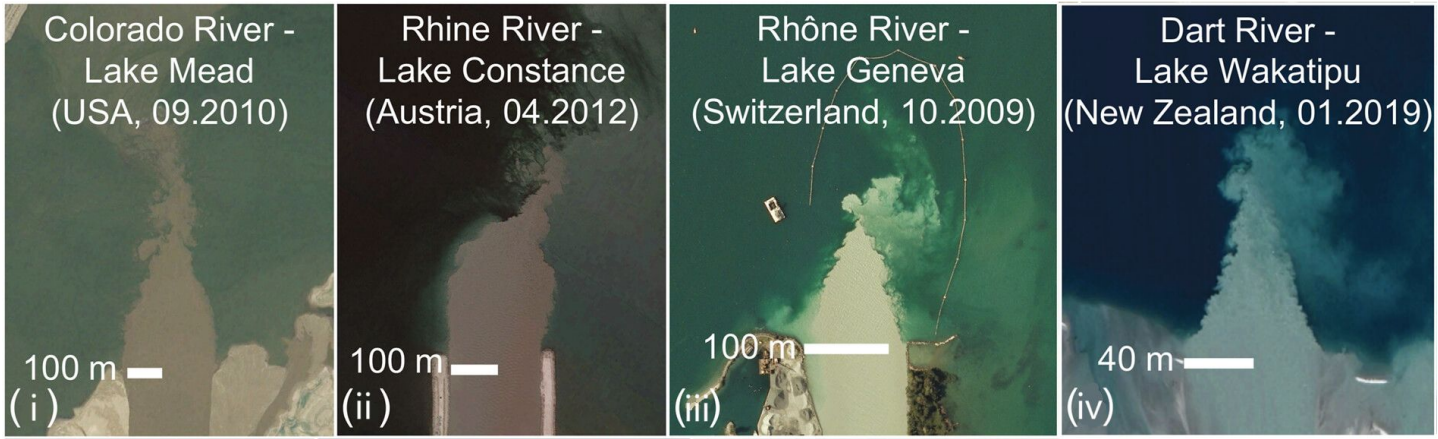
-PhD **Kingsley Eze** on laboratory experiments

-Postdoc **George Giamagas** on numerical simulations (LEGI)

Relevance

Hyperpycnal inflows transport sediments, nutrients, oxygen and contaminants etc., into lakes.

- ➔ Water quality
- ➔ Reservoir storage capacity
- ➔ Ecological status of the lake
- ➔ Hazards



Unconfined field examples (modified from Thorez et al. 2024).

Background of the study

Dominant control parameter: Fr_d (Densimetric Froude number)

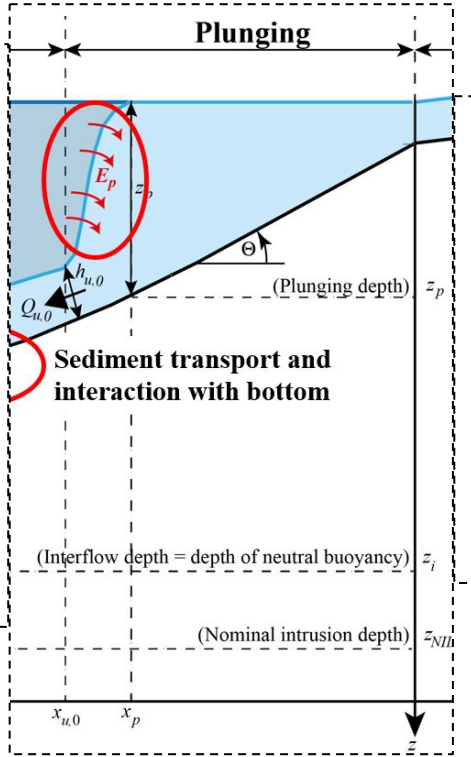
$$\mathrm{Fr}_d = \frac{U}{\sqrt{g'h}}$$

Momentum

Buoyancy

where reduced gravity

$$g' = g\frac{\triangle\rho}{\rho_w}$$



Dominant process in the near field: Plunging

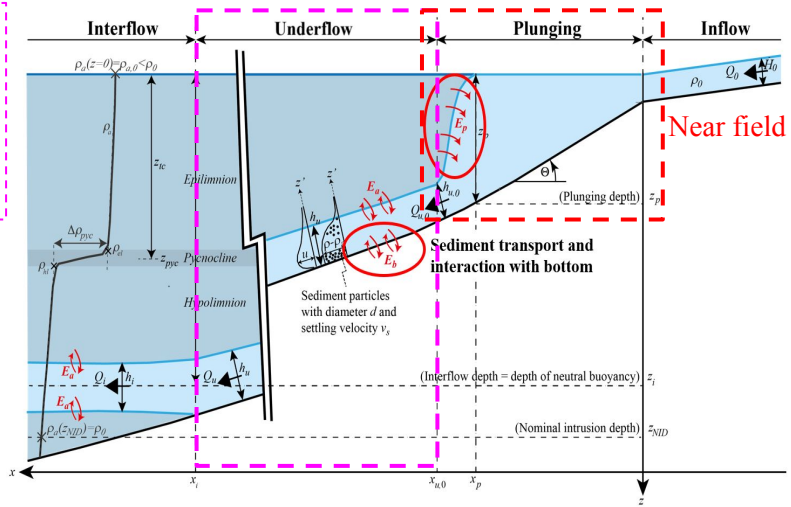
Mixing & entrainment E_p

Discharge increase $Q_{u,0} = (1 + E_p)Q_0$

Dilution of the density excess $\rho_u - \rho_a = \frac{\rho_0 - \rho_a}{1 + E_p}$

State of the art

Plunging open-channel inflow led to different underflow behaviour than an inflow introduced under a sluice gate at the bottom.
(Sequeiros et al. 2009)



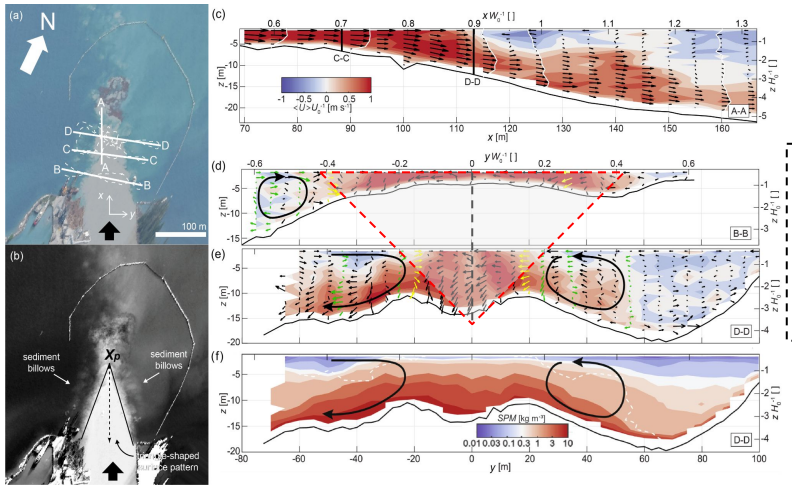
Hydraulic processes in unconfined configurations are more complex

➔ **Geometry**, bottom slope and $Fr_{d,0}$

Unconfined E_p > confined E_p
Unconfined field E_p >> Unconfined lab E_p

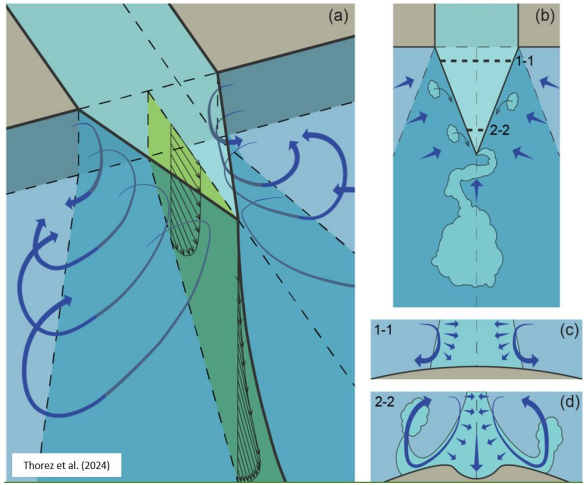
➔ Hardly any attention given to sediment transport and morphological processes in the near field region

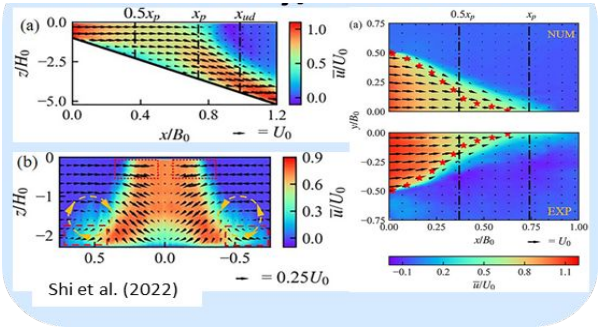
State of the art



Field (Thorez et al. 2024)

- ➔ Flow structures
- ➔ Transient storage hypothesis





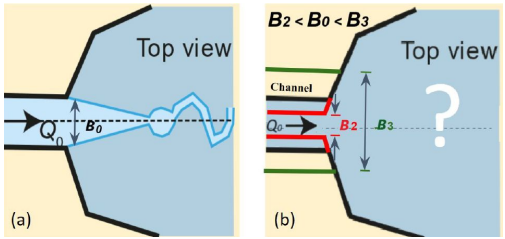
Laboratory/Numerical (Shi et al. 2022)

- ➔ Control parameters
- ➔ Extended geometry

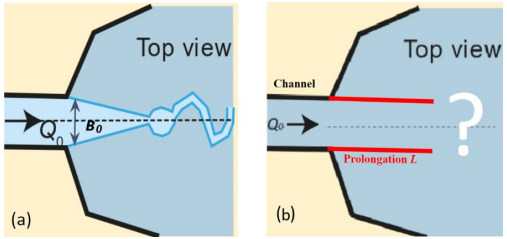
Only one width (2 m) and one aspect ratio (25), no sediments, confinement modelled numerically.

Research questions

RQ.1 How does the inlet aspect ratio (B_0/H_0) affect the hydrodynamics of plunging?



RQ.2 How does the extended longitudinal confinements of the inlet affect the hydrodynamics of plunging?

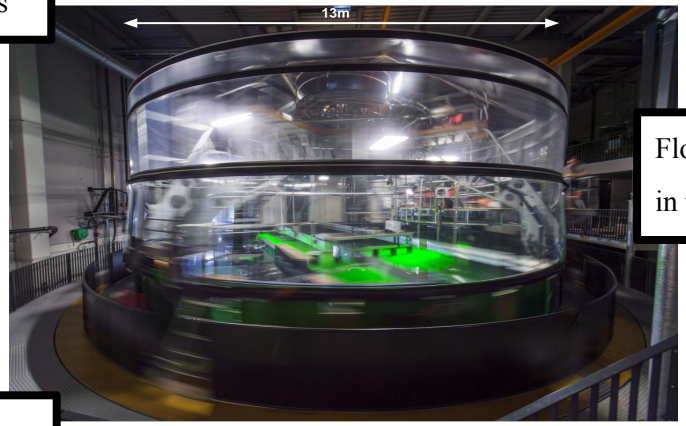


RQ.3 What is the influence of sediments on the flow and mixing processes and how can this be quantified?

RQ.4 What are the dominant interactions between the flow, sediments and the bathymetry?

Innovation

Parametric space of geometries

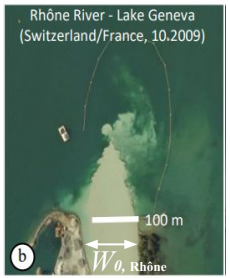


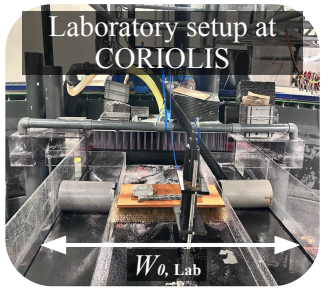
Flow-sediment-bathymetry interactions in the near field region

Riverine inputs pathway manipulation

Unique Coriolis platform

Methodology





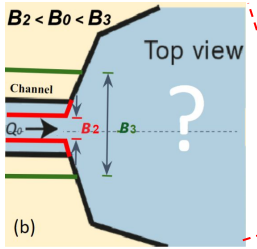
Froude number scaling: $Fr_{d,\,Rhône} = Fr_{d,\,Lab}$

Geometric scaling: $W_{0,\,Rhône} = 60 \times W_{0,\,Lab}$

Laboratory Experiments

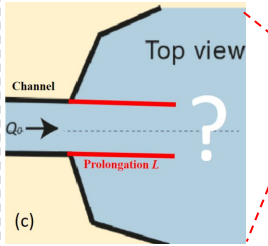
Saline plumes (**SAL**)

Sediment-laden plumes (**SED**)



Aspect ratio
27, 13.5, 9 and 5.4
(Paper 1 - RQ.1)

Trial



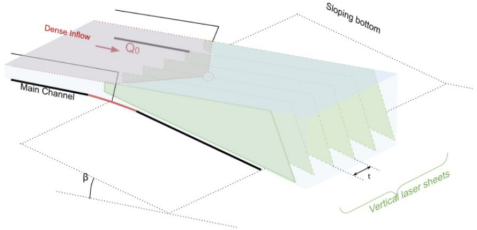
Confinement
0 m, 1 m, 1.5 m and 2.5 m
(Paper 2 - RQ.2)

Depositional-erosional plumes
(Paper 3 - RQ.3 & RQ.4)

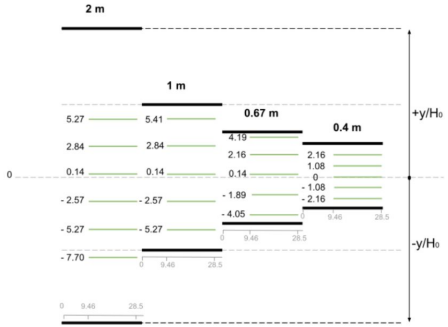
Methodology

SAL Set-up

V - Vertical

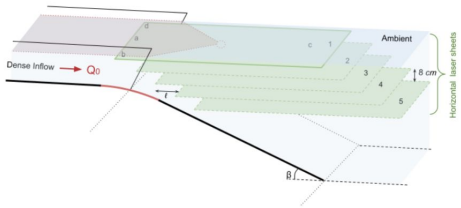


(a)



(b)

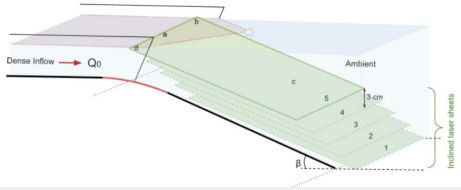
H - Horizontal

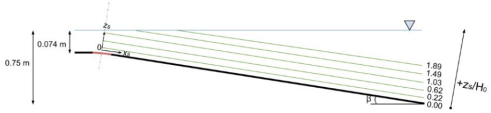


(c)

(d)

S - Inclined





Prolongation \ Width	0.4 m	0.67 m	1 m	2 m
0 m	(0.4-0-H1) (0.4-0-V1)	(0.67-0-H1) (0.67-0-V1) (0.67-0-S1)	(1-0-H1) (1-0-H2) (1-0-H3) (1-0-V1) (1-0-V2) (1-0-V3) (1-0-V4) (1-0-V5) (1-0-S1) (1-0-S2)	(2-0-H1) (2-0-V1)
1 m	(0.4-1-H1) (0.4-1-V1)	(0.67-1-H1) (0.67-1-V1)	(1-1-H1) (1-1-V1) (1-1-V2)	(2-1-H1) (2-1-V1)
1.5 m			(1-1.5-H1) (1-1.5-V1)	(2-1.5-H1) (2-1.5-H2) (2-1.5-V1)
2.5 m	(0.4-2.5-H1) (0.4-2.5-V1)	(0.67-2.5-H1) (0.67-2.5-S1)	(1-2.5-H1) (1-2.5-S1) (1-2.5-S2)	(2-2.5-H1) (2-2.5-V1) (2-2.5-V2)

SAL Data

➔ **Inflow verification and data quality assessment**

Methodology

SED - Trial**:** Adapting and testing the Coriolis for sediment laden flows

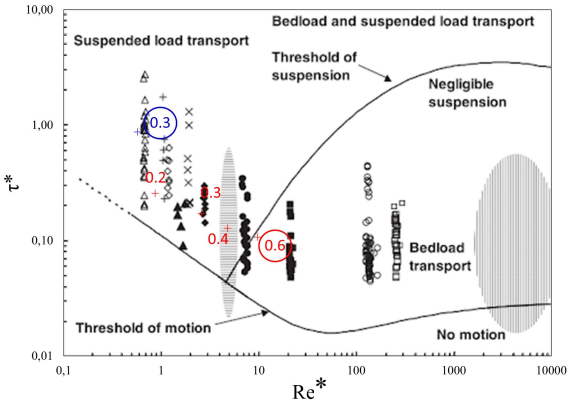
Shield's scaling

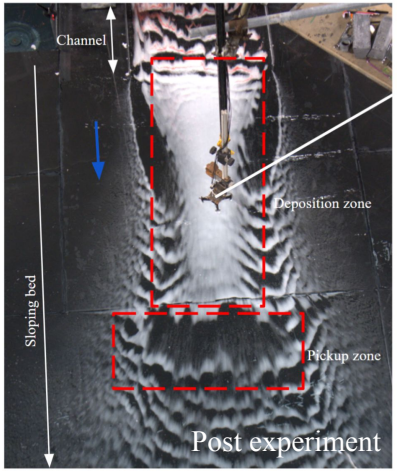
Rouse number $\frac{w_s}{u^*}$

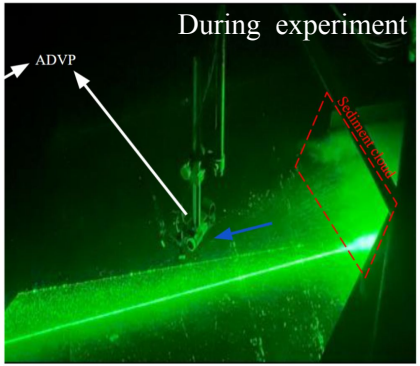
$\mathrm{Re}^* = \frac{u^* d}{\nu}$

d(mm)	ρ_s	$w_s * 10^{-3}(\mathrm{m.s^{-1}})$	Rouse No(P)
0,3	1040	1,50	0,37
0,2	1200	3,20	0,79
0,3	1200	6,40	1,58
0,4	1200	10,00	2,47
0,6	1200	17,60	4,35

Shields Diagram (Sequeiros et al., 2010)







Deposition-pickup patterns

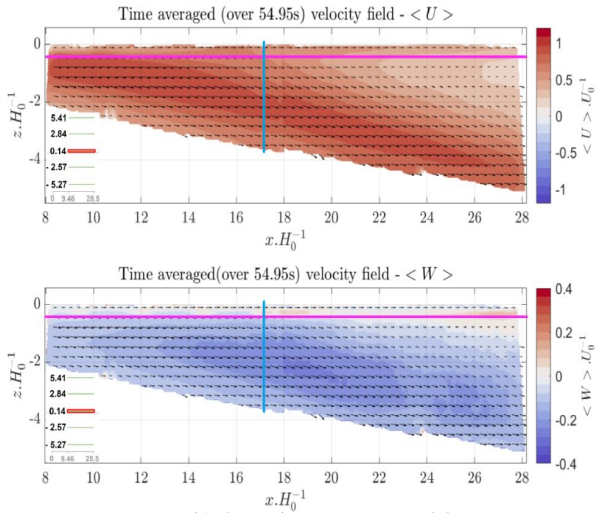
SED - Depositional-erosional experiments

1. Low Q_0 and SSC_0 (repeatedly)
   ➔ Deposition

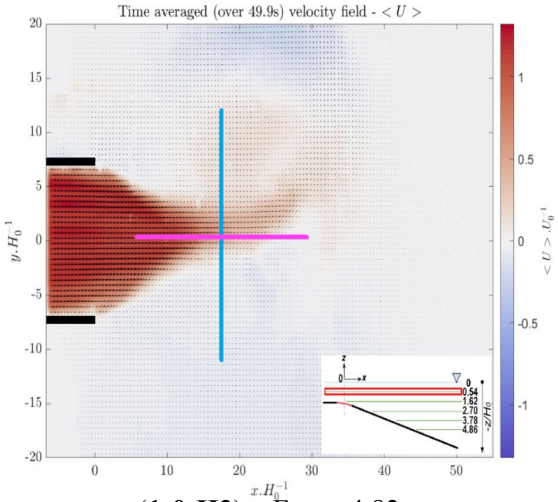
2. High Q_0 and SSC_0
   ➔ Pickup

Lofting and surface leakage - slightly positively buoyant inflow

Preliminary results



(1-0-V5) _ $Fr_{d,0} = 5.23$

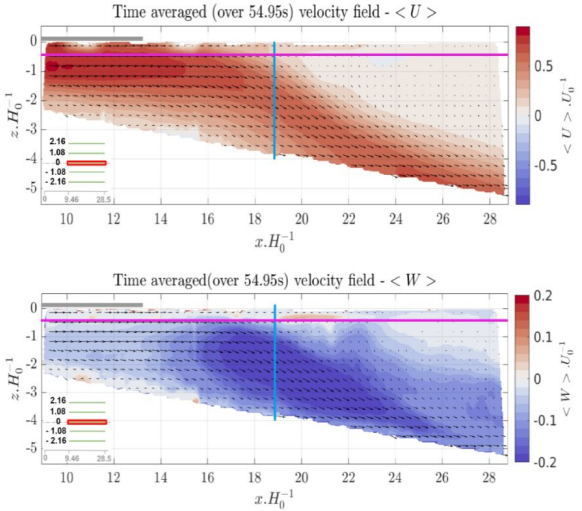


(1-0-H2) _ $Fr_{d,0} = 4.82$

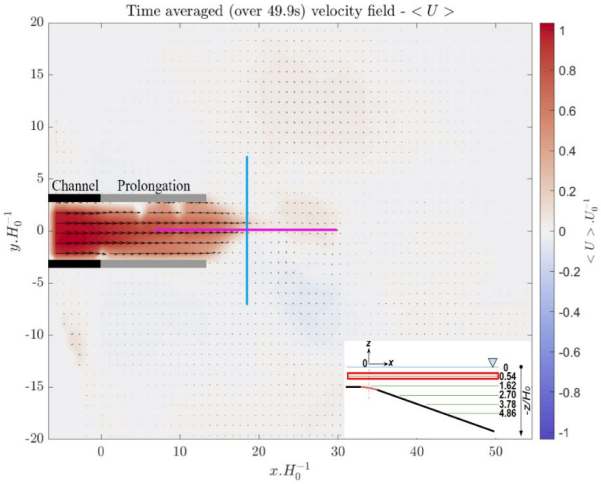
(0.4-0-V1) _ $Fr_{d,0} = 4.49$	**(0.4-0-H1)** _ $Fr_{d,0} = 4.96$
(0.67-0-V1) _ $Fr_{d,0} = 4.04$	**(0.67-0-H1)** _ $Fr_{d,0} = 3.54$
(2-0-V1) _ $Fr_{d,0} = 4.40$	**(2-0-H1)** _ $Fr_{d,0} = 3.96$

SAL 1 - Aspect ratio influence (RQ.1)

Preliminary results



(0.4-1-V1) _ $Fr_{d,0} = 4.96$



(0.4-1-H1) _ $Fr_{d,0} = 4.96$

(0.4-0-V1) _ $Fr_{d,0} = 4.49$

(0.4-0-H1) _ $Fr_{d,0} = 4.96$

(0.4-2.5-V1) _ $Fr_{d,0} = 4.71$

(0.4-2.5-H1) _ $Fr_{d,0} = 4.71$

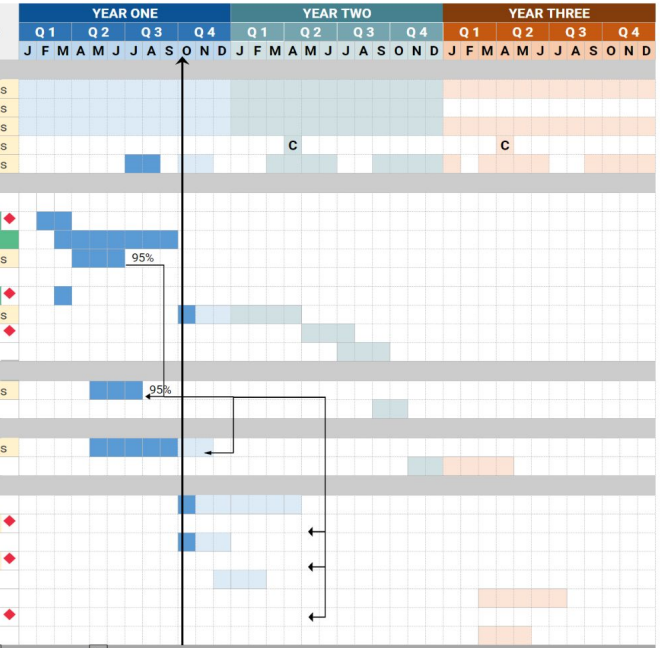
SAL 2 - Confinement influence (RQ.2)

Planning

PROGRESS UPDATE - 24HARP

PROJECT TYPE	Research	UNIVERSITY	Technische Universität Wien, Österreich
PROJECT TITLE	Hyperpycnal sediment laden plumes in lakes: flow-sediment-bathymetry inte	INSTITUTE	Institute for hydraulic engineering and water resources m
SUPERVISOR	Blanckaert, Koen	START DATE	13/11/23

NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION (days)	STATUS
1	**General**					
1.1	Acquaintance with research topic	Eze K	01/01/24	31/12/26	1080	In progress
1.1.1	Review paper	Eze K	15/03/24	31/12/25	646	In progress
1.2	Literature review	Eze K	01/01/24	31/12/26	1080	In progress
1.3	Conferences	Eze K	01/04/25	31/12/26	630	In progress
1.4	Academic courses/seminars	Eze K	01/10/24	31/12/26	810	In progress
2	**Laboratory Experiments**					
2.1	**Saline plume**					
2.1.1	Main experiment: : WP 3.1	Eze K/Eletta	08/02/24	24/03/24	45	Done
2.1.2	Acquaintance with data treatment tools	Eze K	29/02/24	30/09/24	214	Done
2.1.3	Data pre-processing	Eze K	01/04/24	30/06/24	90	In progress
2.2	**Sediment-laden plume**					
2.2.1	Trial experiments : WP 3.2.1	Eze K	14/03/24	20/03/24	6	Done
2.2.2	Planning for main experiment	Team	01/10/24	15/04/25	196	In progress
2.2.3	Main experiment: WP 3.2.2	Eze K	01/05/25	01/07/25	61	Pending
2.2.4	Data pre-processing	Eze K	01/07/25	30/09/25	91	Pending
3	**Data Quality Assessment**					
3.1	Saline plume	Eze K	08/05/24	31/07/24	84	In progress
3.2	Sediment laden plume	Eze K	01/09/25	31/10/25	60	Pending
4	**Data Analysis**					
4.1	Saline plume	Eze K	08/05/24	30/09/24	145	In progress
4.2	Sediment laden plume	Eze K	01/11/25	01/04/26	151	Pending
5	**Deliverables**					
5.1	Saline plume	Eze K	01/10/24	01/04/25	182	
5.1.1	Scientific paper 1					In progress
	Initial manuscript draft					
5.1.2	Scientific paper 2					In progress
	Initial manuscript draft					
5.2	Sediment laden plume	Eze K	01/03/26	30/06/26	121	
5.2.3	Scientific paper 3					Pending
	Initial manuscript draft					



Important Dates	Event
13-Nov-2023	PhD start date
31-May-2024	HARP project 1-year update

Planning

PROGRESS UPDATE - 24HARP

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2.1.3	Data pre-processing	Eze K	01/04/24	30/06/24	90	In progress
2.2	**Sediment-laden plume**					
2.2.1	Trial experiments : WP 3					
2.2.2	Planning for main exper					
2.2.3	Main experiment: WP 3.					
2.2.4	Data pre-processing					
3	**Data Quality Assessme**					
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3.2	Sediment laden plume					
4	**Data Analysis**					
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4.2	Sediment laden plume	Eze K	01/11/25	01/04/26	151	*Pending*
5	**Deliverables**					
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5.1.1	Scientific paper 1					In progress
	Initial manuscript draft					
5.1.2	Scientific paper 2					In progress
	Initial manuscript draft					
5.2	Sediment laden plume	Eze K	01/03/26	30/06/26	121	
5.2.3	Scientific paper 3					*Pending*
	Initial manuscript draft					

Important Dates	Event
13-Nov-2023	PhD start date
31-May-2024	HARP project 1-year update

YEAR ONE | YEAR TWO | YEAR THREE

Q1 Q2 Q3 Q4 | Q1 Q2 Q3 Q4 | Q1 Q2 Q3 Q4

J F M A M J J A S O N D | J F M A M J J A S O N D | J F M A M J J A S O N D

C C 95% 95%

Influence of **Aspect ratio** and **Confinement.**

Influence of **Sediment** and **Interactions between flow, sediment and bathymetry.**

Milestone | Current status | Expectation | Dependencies | C Conferences

Outlook

- Completion of data processing and analysis
- Preparations for the main **SED** experiment (Depositional - erosional experiments)
- Manuscript preparation for the proposed papers

The proposed papers include:

Paper 1: Effect of inflow aspect ratio, B_0/H_0 on the hydrodynamics of plunging.
➔ **RQ.1** using **SAL**

Paper 2: Effect of confinement on the hydrodynamics of plunging.
➔ **RQ.2** using **SAL**

Paper 3: The influence of sediment on the flow and mixing processes and the dominant interactions between the flow, sediments and the bathymetry.
➔ **RQ.3** & **RQ.4** using **SED**


THANK YOU
GRACIAS
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SHUKURIA
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BOLZÏN
MERCI
BÏYAN
SHUKRIA
TINGKI
YAQHANYELAY
TASHAKKUR ATU
SUKSAMA
EKHMET
SPASSIBO
SNACHALHUYA
NUHUN
CHALTU
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KOMAPSUMNIDA
PALDIES
MERASTAWHY
GAEJTHO
LAH
AGUYJE
FAKAAUE
SANCO
TAVTAPUCH
MEDAWAGSE
BAIKA

Questions