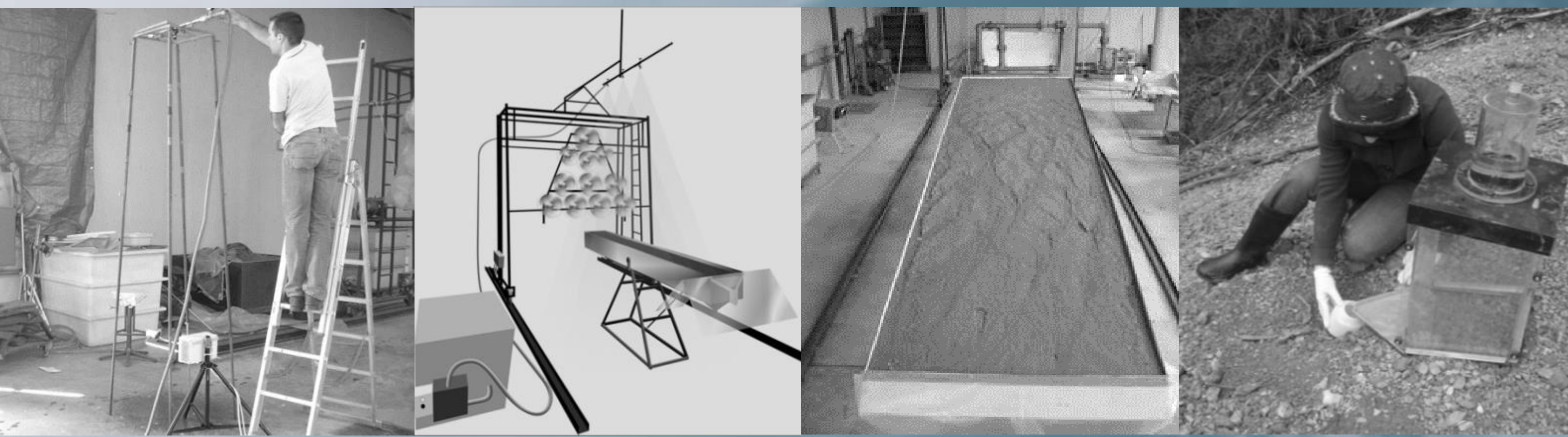
BOOK OF ABSTRACTS

2nd RAINFALL SIMULATOR WORKSHOP

Towards harmonisation in the use of rainfall simulators



22-24 May, 2023
Coimbra, Portugal

***Edited by*:**
M. Isabel P. de Lima
João L. M. P. de Lima
Jorge M. G. P. Isidoro

Department of Civil Engineering
Faculty of Sciences and Technology of the University of Coimbra
MARE – Marine and Environmental Research Centre
ARNET – Aquatic Research Network

2nd Rainfall Simulator Workshop

Towards harmonisation in the use of rainfall simulators

Book of Abstracts

22-24 May, 2023

Coimbra, Portugal

Edited by:

M. Isabel P. de Lima
João L. M. P. de Lima
Jorge M. G. P. Isidoro

Organized by:

Department of Civil Engineering, Faculty of Science and Technology, University of Coimbra
MARE – Marine and Environmental Research Centre / ARNET – Aquatic Research Network

2nd Rainfall Simulator Workshop
Towards harmonisation in the use of rainfall simulators
Book of Abstracts
22-24 May 2023, Coimbra, Portugal

Faculty of Sciences and Technology of the University of Coimbra, Department of Civil Engineering
Editors: M. I. P. de Lima, J. L. M. P. de Lima e J. M. G. P. Isidoro

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Águas do Centro Litoral
Grupo Águas de Portugal

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Welcome

Welcome address to Participants

Dear Participants of the 2nd Rainfall Simulator Workshop,

It is our pleasure to welcome you in Coimbra and to this second gathering of the Rainfall Simulator Workshop series.

Over the years, a core group of researchers has stimulated the exchange of ideas and expertise on using rainfall simulators, as a way of improving our understanding of hydrological processes, including their observation, estimation, modelling and prediction. The first Rainfall Simulator Workshop held in 2011 in Trier, Germany, showed that a Rainfall Simulator Workshop series could potentially provide an important forum to discuss ongoing research based on rainfall simulators experiments with a focus on the characteristics of the rainfall simulators and implications for research and comparison of results.

This workshop aims at contributing to the identification and discussion of harmonised best practices in rainfall simulation studies (e.g., alignment in design criteria, working procedures and data collection), while recognizing the importance of embracing diverse design characteristics, as it is crucial to ensure that rainfall simulators are tailored to meet the specific research objectives effectively. Such understanding would considerably enhance our capacity to characterise and compare rainfall simulators and experimental results. Harmonisation of simulated rainfall-based research is likely to enhance its value by facilitating the comparison of different studies and unlocking potential synergies, which has been hindered so far. Different research experiences and viewpoints will be shared and discussed during the workshop, pursuing further developments in this field.

These issues will be discussed during the **2nd Rainfall Simulator Workshop**, with the special theme "***Towards harmonisation in the use of rainfall simulators***", with the objective of promoting a focused interdisciplinary exchange on the present state of knowledge. We hope the workshop will provide an opportunity for the participants to reflect on the past accomplishments and discuss the future challenges.

The workshop will allow participants to share their work and exchange ideas to advance the field of simulated rainfall-based research in hydrology and geosciences.

The conveners of this meeting wish all Participants a pleasant stay in Coimbra, a stimulating workshop and fruitful discussions.

Conveners
João de Lima
Isabel de Lima
Jorge Isidoro

General information on the Workshop series

Beginning with the first workshop held in 2011 in Trier, Germany, this workshop aims at bringing together researchers whose interest includes rainfall simulation studies.

Rainfall simulators are important experimental tools in hydrology and geomorphology studies and have been widely used both in the laboratory and in the field for accomplishing a wide range of research objectives and purposes. The literature reveals the existence of more than 250 different rainfall simulator setups. These exhibit a significant diversity in the simulators' type, sizing, form and operation methodologies, which have been developed and adapted to address specific research demands. While often regarded as a significant advantage, the flexibility of rainfall simulators can also introduce several drawbacks, notably encompassing challenges in comparing results and outputs across studies that employ different simulators' designs.

The main objectives of this Workshop series are:

- To increase relationships between participants, research teams and universities, and to promote exchanges of data, research methods and models;
- To facilitate collaborative research;
- To promote the discussion of ideas and experiences related to the design and use of rainfall simulators, and explore the key benefits and drawbacks associated with the harmonisation of data collection and processing techniques.

These events are very important platforms for presenting and discussing research, facilitating the exchange of experiences. Notably, young scientists can benefit from these meetings as they can showcase their (PhD) research, discuss their ideas and collaborate with peers to test hypotheses and improve model concepts.

Organization

The Workshop is organized by the Department of Civil Engineering of the Faculty of Sciences and Technology of the University of Coimbra and MARE – Marine and Environmental Sciences Centre / ARNET – Aquatic Research Network, Portugal.

Sponsorship & Collaboration

The Workshop has been sponsored by:

ACIV – Associação para o Desenvolvimento da Engenharia Civil
(*Portugal*)

Águas de Coimbra, E.E.M.
(*Portugal*)

Águas do Centro Litoral, S.A.
(*Portugal*)

Câmara Municipal de Coimbra
(*Portugal*)

Itecons – Institute for Research and Technological Development in Construction, Energy, Environment and Sustainability
(*Portugal*)

The Workshop also secured the collaboration of:

Federal University of Alfenas, *Brazil*

Heriot-Watt University, *United Kingdom*

Newcastle University, *United Kingdom*

Trier University, *Germany*

Universidade Federal Rural de Pernambuco, *Brazil*

University of Algarve, *Portugal*

General Information

Location and Workshop Address

The 2nd Rainfall Simulator Workshop is being held at the Department of Civil Engineering of the University of Coimbra, Coimbra, Portugal. The history of the University of Coimbra dates back to the century following the one in which the Portuguese nation itself was founded, since the University was established in 1290.

The workshop is organized by the Department of Civil Engineering of the Faculty of Sciences and Technology of the University of Coimbra, and MARE – Marine and Environmental Research Centre / ARNET – Aquatic Research Network, Portugal.

***Workshop Venue*:**

Department of Civil Engineering
Faculty of Science and Technology
Rua Luís Reis dos Santos - Pólo II Univ. Coimbra
3030-788 Coimbra, Portugal

Workshop Themes

The objective of this second edition of the Rainfall Simulator Workshop series is to continue promoting a focused interdisciplinary discussion of the present state of knowledge, and of the necessary advances in research and application disciplines related to experimental studies based on the use of rainfall simulators. This edition of the workshop is centred around a special theme:

Towards harmonisation in the use of rainfall simulators.

The workshop sessions will be dedicated to oral and porter presentations and to open discussions on the special theme.

The following main topics will be addressed:

1. Insights on rainfall simulators
2. Applications of rainfall simulators
3. Field and laboratory experiments
4. Scale issues in rainfall simulation studies
5. Harmonisation on the use of rainfall simulators

Workshop Organization

The workshop is organized by the Department of Civil Engineering of the Faculty of Sciences and Technology of the University of Coimbra and MARE – Marine and Environmental Sciences Centre / ARNET – Aquatic Research Network with the support of ACIV – Association for the Development of Civil Engineering, Portugal.

Conveners

João de Lima, MARE/ARNET, *University of Coimbra, Portugal*
Isabel de Lima, MARE/ARNET, *University of Coimbra, Portugal*
Jorge Isidoro, MARE/ARNET, *University of Algarve, Portugal*

Local Organising Committee

Isabel Pedroso de Lima (*team leader*), *Portugal*
João Pedroso de Lima, *Portugal*
João Rafael Abrantes, *Portugal*
Romeu Gerardo, *Portugal*
Soheil Zehsaz, *Portugal* (student)
Thayná Almeida, *Brazil* (student)

International Organising Committee

Jorge Isidoro (*team leader*), *Portugal*
Alexandre Silveira, *Brazil*
Daniel Green, *United Kingdom*
Ian Pattison, *United Kingdom*
Isabel Pedroso de Lima, *Portugal*
João Pedroso de Lima, *Portugal*
Miriam Marzen, *Germany*
Ross Stirling, *United Kingdom*
Thomas Iserloh, *Germany*

International Scientific Committee

João Pedroso de Lima (*coordinator*), *Portugal*
Abelardo Montenegro, *Brazil*
Antonio Paz-González, *Spain*
Artemi Cerdà, *Spain*
Carla Ferreira, *Sweden*
Demetrius David da Silva, *Brazil*
Jan Jacob Keizer, *Portugal*
Jesús Rodrigo-Comino, *Spain*
Johannes B. Ries, *Germany*
Karl Manuel Seeger, *Germany*
Sergio Prats Alegre, *Portugal*

Registration & Information Desk

Information Desk

The Workshop Information and Registration Desk is located in the main Entrance Hall of the Department of Civil Engineering building (workshop venue), on the 2nd floor.

Pre-registration

Participants who have already fully registered for the workshop can collect their badge and workshop material at the registration desk.

Participants who have pre-registered for the workshop can pay the registration fee at the registration desk and collect their badge and workshop material there. On-site rates are charged.

On-site registration

On-site registration is possible, at the registration desk.

Registration fee of Participants includes:

Full access to scientific sessions
Book of the accepted Abstracts
Workshop documents, bag, certificate of attendance
Refreshments, coffee and lunches (Monday and Tuesday)
Guided visit: Coimbra UNESCO World Heritage Sites (historical centre of Coimbra)
The Workshop Dinner
Technical Visits 1 and 2

Registration of Accompanying Persons is also possible but limited to the Workshop Dinner. Depending on availability accompanying persons could participate in the Technical Visit 3 (fees are charged). Pre-registration is required.

Registration & Information Desk opening time:

Day	Opening time
Monday, 22 May	8:30-16:00
Tuesday, 23 May	9:00-15:00

Abstract & Programme Management

See information at the Workshop website:
https://www.rainfallsimulatorworkshop.com/
If you have any queries, please contact:
rainfall.simulator.workshop@gmail.com

Workshop Publications

A book of abstracts of oral and poster presentations will be available at the workshop.

After the workshop, a review paper will be prepared with contributions from participants, for publication in an international journal.

Guidelines

Oral

Authors are kindly asked to upload their presentations in the 30 minutes preceding the actual time block of the session. A lecture room assistant will be available to help.

Poster

The general Display Time is from Monday, 9:00, to Tuesday, 16:00, during the workshop hours. Authors are kindly asked to put up their posters as soon as possible.

The Authors in Attendance Time is when the authors' posters must be on hand at their display for presentation. This will be on Monday, 22 May, 12:00-13:00.

Authors are kindly asked to take down their posters on Tuesday, before 16:00.

Special Events

All registered Participants of the 2nd Rainfall Simulator Workshop are invited to join the following events:

- Lunches (Monday and Tuesday, 22-23 May)
- Workshop Dinner (Monday, 22 May)
- Technical Visit 1 (Monday, 22 May)
- Technical Visit 2 (Tuesday, 23 May)
- Technical Visit 3 (Wednesday, 24 May)
- Guided visit in the historical centre of Coimbra (Wednesday, 24 May)

<u>Lunches</u>:

Lunches are offered from 13:00 to 14:30 in the University Restaurant "*Casa da Pedra*" - Campus II, Rua Sílvio Lima (a short walk from the Workshop Venue).

Meal vouchers for Monday and Tuesday will be distributed beforehand to the Participants.

<u>Workshop Dinner</u>:

The Workshop Dinner will be on Monday, 22 May, at 19:30. The Participants and Accompanying Persons should register for the Workshop Dinner at the Registration Desk before 10:00, on Monday, 22 May.

Directions:
Restaurant "Piscinas", Parque Verde do Mondego
(left bank of the River Mondego, about 100 m upstream of the Pedestrian Bridge over the Mondego River, downtown).

<u>Technical Visits</u>:

The Workshop includes three Technical Visits; their programmes are included in this book:

Technical Visit 1 (*Monday, 22 May*)

Laboratory of Hydraulics, Water Resources and Environment, of the Department of Civil Engineering of the University of Coimbra: experimental hydrology

Technical Visit 2 (*Tuesday, 23 May*)

Itecons - Institute for Research and Technological Development in Construction, Energy, Environment and Sustainability

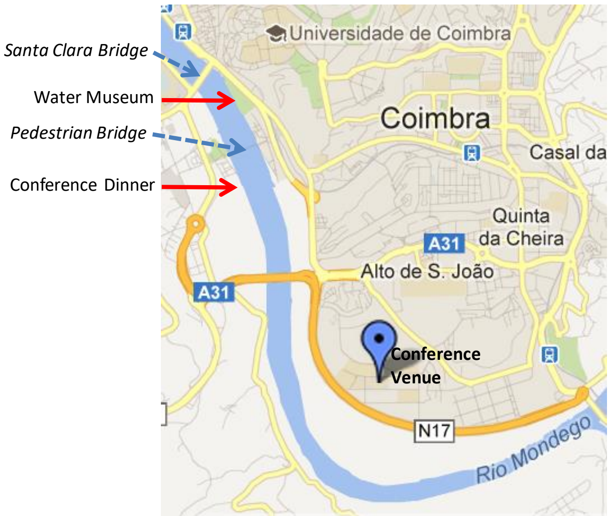
Technical Visit 3 (*Wednesday, 24 May*)

Insight into the fluvial environment of the River Mondego upstream of Coimbra

Departure from Casal da Misarela, at 9:45
(approx. duration: 4 h, kayak trip; additional 2 h for optional lunch).

Any participants who have not registered prior to the workshop are kindly asked to register for this visit by Monday morning, 22 May, at the Workshop Help Desk. Requests will be processed on a first come, first served basis.

Location of the University Restaurant "Casa da Pedra" (lunches)



Location of the Restaurant "Piscinas" (Workshop Dinner)

<u>Guided Visit: Coimbra UNESCO World Heritage Sites</u>

This visit is a courtesy of the Coimbra Municipality. It will start at 17:00, from the Largo D. Dinis (Campus I of the University of Coimbra) with a duration of about 1.5 h.

Coordinates, meeting point: 40°12'28.30"N; 8°25'22.53"W

The visit will guide the participants through Coimbra UNESCO World Heritage Sites (old University buildings, downtown Coimbra and historical sites).

More details about the special events will be available at the Information Desk during the workshop.

<u>Coordinates</u>

Workshop Venue: 40º 11' 07,55" N; 8º 24' 55,04" W
University Restaurant (Lunch): 40º 11' 09,86" N; 8º 25' 01,97" W
Meeting point Guided Visit: 40°12'28.30"N; 8°25'22.53"W
Workshop Dinner: 40°11'51.60'' N; 8°25'38.81'' W

About Coimbra

Coimbra has long held an important place in Portugal's history since it was the first capital of the country from 1139 to about 1260; it is the birthplace of six Portuguese kings. The main part of Coimbra is essentially clustered on and around the hill overlooking the River Mondego, although newer parts of the town are spread out all around it below. Coimbra is a place full of tradition and beauty. It's a cosmopolitan city that has developed into an important cultural centre, mainly because of the University of Coimbra, founded in 1290, and it has notable monuments from that era and beyond.

The University of Coimbra was the first in Portugal, is one of the oldest universities in Europe, and due to its monumental buildings and history attracts tourists from around the world. St Peter College ("Colégio de S. Pedro"), the delightful St. Michael Chapel ("Capela de S. Miguel"), the Rector's Palace ("Reitoria"), The Grand Hall ("Sala dos Capelos"), the King John Library ("Biblioteca Joanina"), a magnificent Baroque building from the 18th century, profusely decorated with gilt carved wood and various exotic woods, and containing a collection of around 300 thousand volumes) are world-renowned landmarks situated on the main campus. The university town maintains its century-old academic traditions, as seen in the black-caped students and in the soulful tones of the "fado de Coimbra" (traditional songs sung by students to the accompaniment of guitars). The students' houses and liveliness are present all over Coimbra and permeate its festivities and daily life.

With such a rich history, Coimbra has much to offer and see. Several monuments hark back to the beginnings of the Portuguese kingdom in the 12th century, such as the Old Cathedral ("Sé Velha") and the São Tiago, São Salvador and Santa Cruz (with the tombs of the first two kings of Portugal) churches. But many other monuments evince the historical magnitude of Coimbra: the Santa-Clara-a-Velha and Santa-Clara-a-Nova Convents, the Santo António dos Olivais Church, Celas Monastery, the Manga Garden (or Cloister) and even the new Cathedral ("Sé Nova"). In Coimbra there are also pleasant green spaces, like the Parque Verde do Mondego, the beautiful Botanical Garden, the Dr. Manuel Braga Park and the romantic Penedo da Saudade Garden.

Coimbra is home to a fascinating historical heritage, and there are several important archaeological sites within a short distance of the city, which are well worth visiting.

UNESCO's World Heritage Committee decided in 2013 that the University of Coimbra has unquestionable exceptional universal value and that therefore deserved to be classed as World Heritage.

View of the city of Coimbra and River Mondego, with the historical buildings of the University of Coimbra at top of the hill

Historical buildings of the University of Coimbra.

Programme Overview

Time	Monday, 22 May	Tuesday, 23 May	Wednesday, 24 May
9:00-9:15	*Registration and welcome to participants*	**Technical Visit 2** Itecons (incl. rainfall simulation installation)	
9:15-9:30			*Participants pick-up and travel to departure location (Casal da Misarela)*
9:30-9:45	**Opening session**		
9:45-10:00			**Technical Visit 3** Field trip down the river Mondego from Penacova to Casal da Misarela
10:00-10:15	***Keynote lecture***		
10:15-10:30			
10:30-10:45	Coffee Break	Coffee Break	
10:45-11:00		Walk (Itecons → Venue)	
11:00-11:15	***ORAL session 1***		
11:15-11:30		***ORAL session 3***	
11:30-11:45			
11:45-12:00			
12:00-12:15	***Poster session***		
12:15-12:30			
12:30-12:45			
12:45-13:00			
13:00-13:15	Lunch	Lunch	
13:15-13:30			
13:30-13:45			Lunch
13:45-14:00			
14:00-14:15			
14:15-14:30			
14:30-14:45	***ORAL session 2***	**OPEN DISCUSSION**	
14:45-15:00			
15:00-15:15			
15:15-15:30			
15:30-15:45		**Closing session**	*Travel to Coimbra*
15:45-16:00	**Technical Visit 1** Rainfall simulator demonstration (Lab - LHRHA)		
16:00-16:15			
16:15-16:30			
16:30-16:45			
16:45-17:00			
17:00-17:15			**Guided Visit:** Coimbra UNESCO World Heritage Sites
17:15-….			
19:30-….	Workshop Dinner		

<u>Session rooms and meeting points</u>:

Oral sessions: Auditório Laginha Serafim, 3rd Floor, Department of Civil Engineering of the University of Coimbra.

Poster session: Hall, 4th Floor, Department of Civil Engineering of the University of Coimbra.

Technical Visit 1: LHRHA, Laboratory of Hydraulics, Water Resources and Environment (4th Floor, block E), Department of Civil Engineering of the University of Coimbra.

Technical Visit 2: meeting point at Itecons (*address*: Rua Pedro Hispano s/n; coordinates: 40.190167; -8.413305).

Technical Visit 3: meeting point at Restaurante Mariazinha (*address*: Rua General Humberto Delgado 1, Casal da Misarela, Coimbra; coordinates: 40.20593, -8.36328); transport available, contact organization.

Guided Visit: meeting point at Campus I University of Coimbra (*address*: Largo D. Dinis; coordinates: 40.20805; -8.42316).

Oral Programme

Monday, 22 May 2023

9:00-9:30
Registration and welcome to Participants

Opening Session

9:30-10:00
Room: Auditório Laginha Serafim

Vice-Director - Department of Civil Engineering, Univ. Coimbra
Thomas Iserloh (*former Workshop organizer*)
Workshop Conveners: João de Lima
Isabel de Lima
Jorge Isidoro

Keynote lecture

10:00-10:30
Room: Auditório Laginha Serafim
Chairperson: Isabel Pedroso de Lima

Keynote speaker: João Pedroso de Lima
How useful are rainfall simulators in experimental hydrology?

10:30-11:00 Coffee break

Oral Session 1

Room: Auditório Laginha Serafim
Chairperson: Abelardo Montenegro

11:00-11:15: RFW2023-5
On-demand raindrop generator with photogrammetric drop size and fall velocity validation
E. Chinchella, A. Cauteruccio, L.G. Lanza

11:15-11:30: RFW2023-7
Single drop measurements as a supplement to rainfall simulator research
A. Bieganowski, M. Beczek, R. Mazur, A. Sochan, C. Polakowski, K. Gibała, M. Ryżak

11:30-11:45: RFW2023-10
Determination erosion properties of mining residues - Transfer of field-scale sprinkler experiments to the lab
A. Routschek, D. Wienhold, C. Jackisch, A. Kassahun

11:45-12:00: RFW2023-13
Bringing rain into soil research: 15 years of experimental studies on vegetation and erosion with the portable Tübingen Rainfall Simulator (TRS)
S. Seitz, C. Gall, C. Geissler, P. Goebes, N. Riveras-Munoz, P. Kühn, Z. Song, T. Scholten

12:00-13:00 POSTER SESSION
(see Poster Workshop Programme)

13:00-14:30 Lunch break

Oral session 2

Room: Auditório Laginha Serafim
Chairperson: Ross Stirling

14:30-14:45: RFW2023-3
Evaluating soil and water conservation techniques with laboratory rainfall simulator
A.A.A. Montenegro, T.A.B. Almeida, C.A. de Lima, J.R.C.B. Abrantes, J.L.M.P. de Lima, D. Silva

14:45-15:00: RFW2023-6
Advancing surface hydrology research with large-scale rainfall simulators: Opportunities and challenges
J.M.G.P. Isidoro, A. Silveira

15:00-15:15: RFW2023-8
Wildfire ash mobilisation by rainfall-runoff using a rainfall simulator under controlled laboratory conditions: Qualitative analysis
R. Martins, J.J. Keizer, L. Simões, L.M. Godoy, I.P. de Lima, J.L.M.P. de Lima

15:15-15:30: RFW2023-1
Applicability of fluorescent tracers in rainfall experiments on particle transport in raindrop impacted thin surface flows
W. Fister, C. Evéquoz

15:30-15:45: RFW2023-2
Estimating sheet flow velocities using fluorescent quinine tracer under simulated rainfall
S. Zehsaz, T.A.B. Almeida, J.L.M.P. de Lima, M.I.P. de Lima, A.A. de A. Montenegro

END OF ORAL PROGRAMME *TOPIC 1*

15:45-17:15 Technical Visit 1
Meeting point:
(see Technical Visits' Programme)

Contact person: João de Lima

Welcome: José Lopes de Almeida - Director of the Laboratory of Hydraulics, Water Resources and Environment, Univ. Coimbra

Workshop Dinner: 19:30

Tuesday, 23 May 2023

9:00-10:30 Technical Visit 2

Meeting point: Itecons
(see Technical Visits' Programme)

Contact person: João Abrantes

10:15-10:45 Coffee break (at Itecons)

11:45-11:00 Walk to the Venue

Oral session 3

Room: Auditório Laginha Serafim
Chairperson: Isabel de Lima

11:15-11:30: RFW2023-18
Using portable field rainfall simulator for experimental research of soil resistance
N. Živanović, V. Rončević, S. Ćorluka, V. Čebašek, M. Kašanin-Grubin, S. Štrbac, N. Antić

11:30-11:45: RFW2023-16
Rainfall simulators application for assessment of effectiveness of soil erosion control measures
M. Neumann, J. Krása, J.Stašek, P. Kavka, T. Dostál

11:45-12:00: RFW2023-4
Mulch water retention and absorption under simulated rainfall
I. Lopes, J.L.M.P. de Lima, A. Montenegro, A.A. de Carvalho

12:00-12:15: RFW2023-24
Design and development of a novel automated 'runoff simulator' system
D. Green, R. Stirling

12:15-12:30: RFW2023-14
Using the Rainfall Simulators to Test Rolled Erosion Control Products and Other Applications
P. Kavka, M. Neumann, T. Laburda, J.-F. Kubát, A. Tejkl, J. Krása, T. Dostál

12:30-12:45: RFW2023-17
Need of methodological harmonization of rainfall simulation experiments to enhance soil conservation research
T. Dostál, J. Krása, M. Neumann, P. Kavka, J. Devátý, A. Bieganowski, S. Seitz

13:00-14:30 Lunch break

14:30-15:30 Open discussion session

Room: Auditório Laginha Serafim
Chairperson: João de Lima

Closing Session

Room: Auditório Laginha Serafim

15:30-16:30

Isabel de Lima, *Convener*
Jorge Isidoro, *Convener / Workshop rapporteur*
Daniel Green, *Workshop rapporteur*
Thomas Iserloh, *Workshop rapporteur*

Wednesday, 24 May 2023

9:45-15:30

Technical Visit 3

(see Technical Visits' Programme)

Contact person: João de Lima

Departure to **Technical Visit** from the city: 9:15-9:30
Departure to **Technical Visit** from meeting point: 9:45

Meeting point, at the village Casal da Misarela
Address: Rua General Humberto Delgado, 1, Casal da Misarela
Coordinates: 40.20593; -8.36328

View of meeting point, at Casal da Misarela

17:00-18:30

Guided Visit
Coimbra UNESCO World Heritage sites

Departure to Guided Visit from Campus I of the University of Coimbra (city centre).

Meeting point: Largo D. Dinis
Coordinates: 40.20805; -8.42316

View of Largo D. Dinis

Aerial view of Coimbra city centre with the University of Coimbra at top of the hill.

Poster Programme

Poster Exhibition Hall: 4th Floor

Display time:

Posters will be on display during the Workshop (from Monday, 9:30, to Tuesday, 16:00).

Authors in Attendance Time:

Monday, 22 May, 12:00-13:00

Chairperson: Jorge Isidoro

P1: RSW2023-11

Rainfall simulations to compare the effect of mulch and biochar on different soil ecosystem services

S. Prats, G. Basch, C. Bastos, C. Brígido, M.J. Cabrita, F. Cachapa, A. Caetano, L. Coelho, J.M. de la Rosa, A. Dias, I. Campos, N. Guiomar, O. Gonzalez Pelayo, A. Miller, J. Muñoz-Rojas, J.P. Nunes, P. Palma, T. Pinto-Correia, M. Rivera, A.R. Sousa, F. Silva, L. Tarelho, A. Tomaz, F. Verheijen

P2: RSW2023-15

Study the influences of environmental drivers on N_2O emissions under semi-controlled conditions using a rainfall simulator

M. Cadel, I. Cousin, M. Lacoste, L. Cottenot, A. Grossel

P3: RSW2023-12

Evaluations of rill and interrill erosion using rainfall simulators, SfM and mini-JET

J. Krása, S. Seitz, M. Neumann, P. Kavka, T. Laburda, A. Tejkl, M. Vrána, T. Dostál

P4: RSW2023-9

Dripping rainfall simulators for soil research–performance review

V. Rončević, N. Živanović, J.H. van Boxel, T. Iserloh, S. Štrbac

P5: RSW2023-19

The influence of rainfall simulators dripper size, type and dripping speed on generated drop size

V. Rončević, N. Živanović, J.H. van Boxel, T. Iserloh, S. Štrbac

P6: RSW2023-20

Assessment of the effects of land use changes on surface runoff and soil erosion in a southern Alpine valley using a portable rainfall simulator device

M. Maerker, S. Vogel, M. Bettoni

P7: RSW2023-21

Spray nozzle simulators and drop properties: the role of meshes in acting on drop kinetic energy and size distribution

J.L.M.P. de Lima, M.I.P de Lima

P8: RSW2023-22

Using a portable rainfall simulator to understand sediment loss and runoff on an abandoned mine tailing in Alagoa, Portugal

R. Gerardo, J.L.M.P. de Lima, I.P de Lima

P9: RSW2023-23

Studying the combined effect of wind and rain using rainfall simulators

J.L.M.P. de Lima, J.M.G.P. Isidoro, M.I.P de Lima

END OF POSTER PROGRAMME

Abstracts

RSW2023-Keynote Lecture

How useful are rainfall simulators in experimental hydrology?

João L.M.P. de Lima*

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Over the past few decades, significant research efforts have been dedicated to investigating the relationship between rainfall and runoff, particularly focusing on the study of overland flow and associated transport processes. Year after year, researchers have presented new developments, innovative techniques, and breakthroughs in this field, which is noteworthy. In this context, rainfall simulators have played a key role in advancing our understanding of these processes.

While experimental hydrology has contributed significantly to these studies, it is important to acknowledge the inherent difficulties, limitations, and challenges, but also the advantages and opportunities associated with this experimental approach, both in the laboratory and in the field settings. Rainfall simulators have emerged as vital tools in studying the rainfall-runoff transformation process. These simulators enable researchers to simulate rainfall patterns and intensity, facilitating a better understanding of how precipitation interacts with the land surface. By mimicking natural rainfall events, rainfall simulators can help predict the response of different land covers and soil types to precipitation, which is fundamental for a wide range of studies.

Drawing from more than three decades of personal involvement in experimental surface hydrology, which has contributed to enhancing our understanding of several hydrological processes such as overland flow, sediment transport, rill and interrill erosion, and infiltration, this keynote lecture briefly addresses the main issues related to the experimental aspects of this work. The experiments conducted focused primarily on the study of rainfall-runoff, overland flow, and associated transport processes, particularly water erosion. These experiments encompassed natural, agricultural, and urban surfaces under both disturbed and undisturbed conditions or samples. Special attention was given to factors such as mulching, wind-driven rain (Figure 1), stony soils, as well as the use of thermal and fluorescent tracers. Rainfall simulators and/or runon were employed in laboratory-based experiments and field-based studies. The adaptability of rainfall simulators to different temporal and spatial scales enabled the design of specific experiments to suit various research objectives.

This lecture highlights the inherent problems and difficulties encountered when studying such diverse situations observed in natural and human-modified surfaces. However, the main objective is to stimulate discussion and enhance understanding of the requirements of experimental research using rainfall simulators, both in the laboratory and in the field, as this can contribute to further advancements in surface hydrology. For instance, the understanding of diffuse pollution resulting from runoff responses of urban, rural, and peri-urban areas remains limited due to the complexity of the variables involved. Rainfall simulators also play an essential role in multidisciplinary approaches aimed at improving our knowledge on the transport of various pollutants associated with runoff, such as, litter, viruses, microplastics, microbial contaminants, and emerging chemicals found in pharmaceuticals, personal care products, pesticides, industrial and household products, surfactants, and metals. In summary, rainfall simulators serve as important tools for hydrologists, engineers, and environmental scientists in their endeavours to better comprehend the complex relationships within surface hydrology.

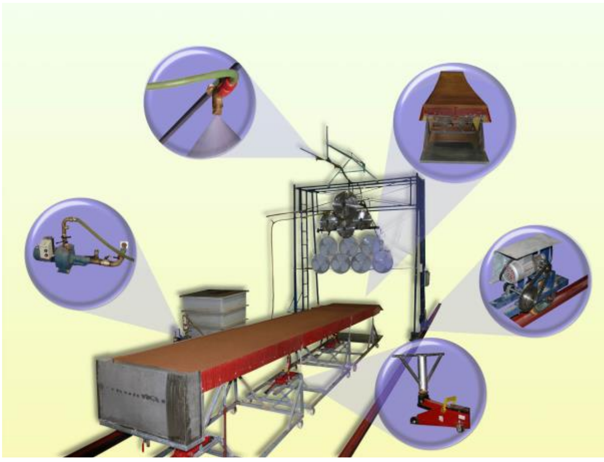

Figure 1: Experimental setup for wind-driven rainfall in the Laboratory of Hydraulics, Water Resources and Environment at the University of Coimbra.

RSW2023-1

Use of fluorescent tracers in rainfall experiments to study particle transport in raindrop-impacted thin surface flows

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Laboratory rainfall experiments on particle detachment and transport in raindrop- impacted thin surface flows often lack the accuracy and reproducibility of rainfall and flow conditions necessary to distinguish between different transport modes. Therefore, a high-precision droplet-type rainfall simulator, combined with a soil flume capable of precisely controlling flow velocity and flow depth, was used to assess the applicability of fluorescent tracers as a means of accurately measuring particle transport distances and velocities in thin surface flows. The rainfall simulator consists of an aluminium tank with internal dimensions of 0.9 m × 0.9 m × 2.5 cm. 1225 hypodermic needles (Braun Medical AG; type: Sterican® size 16, blue, 23G × 1'', 0.6 × 25 mm) were placed in a square grid with a spacing of 2.5 cm apart. The median drop diameter generated during the experiments was 2.6 mm and the average rainfall intensity was between 60 and 80 mm h^{-1}. The rainfall simulator (Figure 1) is mounted on a hydraulic hoist that allows drop heights from 0.05 m to a maximum of 7 m. For the experiments in this study, the drop height was set at 3 m. In order to minimise spatial heterogeneity, a rack and pinion system with two 12V DC electric motors was installed to move the tank longitudinally and transversely. In this study, a methodological setup was developed to appropriately use the tracers and to facilitate the processing and analysis of the resulting images, using open-source particle tracking software.

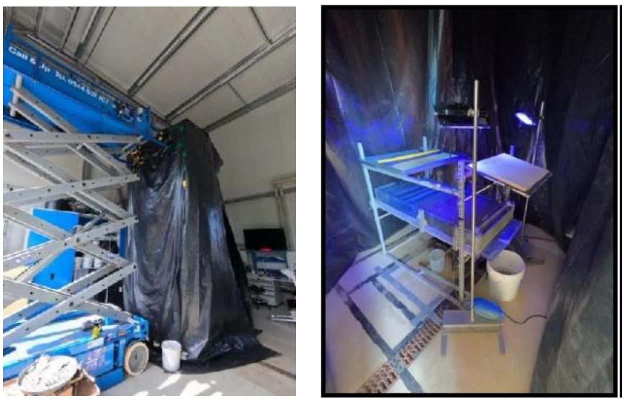

Figure 1: Experimental setup in the rainfall laboratory at Basel University. Left: Overview of rainfall simulator; Right: Inside view of flume and light setup under light protection cover.

RSW2023-2

Estimating sheet flow velocities using fluorescent quinine solution tracer under simulated rainfall

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Tracing methods have been widely used in hydrology for measuring surface velocity of overland flow. However, selecting the appropriate tracer for specific conditions and its performance in estimating sheet flow velocities is important. For example, previous studies have shown that quinine solution tracer when exposed to UVA light, can be used to estimate sheet flow surface velocities over various soil and urban surfaces in low luminosity conditions. In this study the use of fluorescent quinine solution to estimate sheet flow velocities was tested for flow disturbed by rainfall of different intensities. For this purpose, a series of laboratory experiments were conducted using a flume and a rainfall simulator, for studying flows under simulated rainfall, different hydraulic conditions and fed also by run-on (upstream discharge). The rainfall simulator was comprised of one hydraulic downward-oriented full-cone nozzle, from Spraying Systems Co., a support structure, in which the nozzles were installed, and a hydraulic circuit connected to a water pump, water reservoir and tap water supply system from the public network. The nozzles were positioned at an average height of 2.5 m from the geometric centre of the flume soil surface. The working pressure on the nozzles was kept approximately constant at 50 kPa, producing rainfall at a maximum intensity of 211 mm h^{-1} just below the nozzle. The uniformity coefficient of rainfall intensity spatial distribution at the soil surface, calculated according to Christiansen, was 64.6%. Flow velocities were estimated by injecting a quinine solution into the overland flow. The surface velocity of the flow was estimated by tracking the leading-edge of the tracer plume and calculating the travel distance of the tracer's leading edge over a certain time lapse. The results show that, for measurements carried out under high rainfall intensities, this technique based on the use of fluorescent quinine solution as a visual tracer of surface flows had visibility limitations due to the disturbance of the water surface by the rainfall drops.

RSW2023-3

Evaluating soil and water conservation techniques with a laboratory rainfall simulator

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This study aims to investigate the performance of coir dust mulch (*Cocos nucifera* L.) and cover crop Palma cactus (*Opuntia ficus indica* Mill.) as soil and water conservation techniques, in a laboratory soil flume under simulated rainfall.

The rainfall simulator has an oscillating single downward-oriented flat-spray H–3/8–U–80–100 Veejet nozzle from Spraying Systems Co., with an orifice diameter of 6.2 mm, positioned 2.9 m above the geometric centre of the soil flume surface. A 0.75 horse power centrifugal pump supplied the rainfall simulator with tap water at an operating pressure of 0.6 bar at the nozzle, producing a total discharge of 17.5 L min^{-1} with a spray angle of 75°. The Christiansen uniformity coefficient of the rainfall intensity spatial distribution at the soil surface was 89%. Raindrops mean diameter, estimated using the flour method, was 2.3 mm. The rainfall intensity at the soil surface is adjusted through variation of the oscillating movement of the nozzle, which in turn is controlled by an electrical motor.

Palma cactus plants were positioned on the soil flume, oriented at 90° and 30° angles with respect to the slope direction. Simulations comprised uniform advanced and delayed rainfall patterns. Runoff hydrographs and soil loss were measured at the downstream end of the flume. Soil moisture and flow velocity were measured, and several hydraulic parameters of runoff were estimated.

Results show that both coir dust mulch and cover crop Palma cactus were effective in reducing runoff and soil loss and increasing soil moisture content, thus being both suitable soil and water conservation techniques for semiarid environments. Coir dust was more effective than Palma cactus. Palma cactus oriented at a 90° angle was slightly more effective than Palma cactus oriented at a 30° angle. Differences between advanced and delayed rainfall patterns on the hydrological and erosive response were more pronounced for the mulch cover condition.

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RSW2023-4

Mulch water retention and absorption under simulated rainfall

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The amount of mulch interception is highly relevant for the understanding of the impact of rainfall on runoff generation and sediment transport. The objective of this study was to investigate the process of interception, retention and absorption of rainwater by different types, sizes and densities of organic mulch covers. Six organic coverings mulches were used, largely available at the Brazilian semiarid: Coconut leaf, cashew leaf, elephant grass, corn leaf, brachiaria grass and sugar cane leaf, under simulated rainfall condition. The rainfall simulator had a single oscillating downward-oriented flat-spray H–3/8–U–80–100 Veejet nozzle from Spraying Systems Co., with an orifice diameter of 6.2 mm, positioned at 2.9 m above the mulch. A 0.75 hp centrifugal pump supplied the rainfall simulator with tap water at an operating pressure of 0.6 bar at the nozzle, producing a total discharge of 17.5 L min^{-1}. The uniformity coefficient of rainfall intensity spatial distribution at the soil surface, calculated according to Christiansen, was 89%. Raindrops' mean diameter, estimated using the flour method, was 2.3 mm. The rainfall intensity at the soil surface was adjusted through variation of the oscillating movement of the nozzle, which in turn was controlled by an electrical motor. The experimental scheme used 6 types, 3 sizes (50, 100 and 200 mm) and 4 densities (1, 2, 4 and 8 t ha^{-1}) of mulch. The adopted experimental mulch support area was a planar horizontal rectangle with 270 × 420 mm^2, allowing for the positioning of mulches with different sizes and densities in adequate uniformity manner. Water adsorption and retention curves were constructed to estimate the interception capacity of the different mulch materials. It was observed that an increase in density systematically led to an increase by more than water retention and absorption. Comparing densities of 8 t ha^{-1} and 2 t ha^{-1}, rainfall retention and absorption increased by more than 100%. Cashew and brachiaria grass showed higher values, with brachiaria grass promoting better water retention and cashew leaves promoting better water absorption. Coconut leaves promoted only 83% retention and 67% water absorption when compared to cashew leaves and brachiaria grass.

RSW20234-5

On-demand raindrop generator with photogrammetric drop size and fall velocity validation

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The precipitation process is made of an ensemble of a wide variety of hydrometeors, that derive from the complex atmospheric processes of nucleation, accretion, melting and interactions. Microphysical properties of precipitation are often measured using dedicated instruments called disdrometers. Calibration of such gauges is, however, still an open challenge, since the hydrometeor characteristics like particle size, shape and fall velocity must be carefully reproduced to provide a traceable reference precipitation. Instrument calibration is usually declared by the manufacturer, using undisclosed internal procedures, since no standard calibration methodology exists (Lanza *et al*., 2021).

To meet the need for disdrometer calibration, a device is presented in this work to achieve individual drop generation on demand and in-flight measurement of the released drops. Water drops in the range from 0.6 to 5 mm in diameter are generated to mimic natural raindrops. A high-precision syringe pump, mostly 3D printed, is used to form the drop of the desired volume at the tip of a calibrated nozzle. A high-voltage power supply is then used to apply a large potential difference between the nozzle and a metallic ring positioned just below it, so that the resulting electric field would release the drop. A precision motorized gantry moves the generator across the horizontal plane, to cover different releasing positions within the instrument sensing area. By varying the release height, different fractions of the terminal velocity can be achieved, depending on the drop size. A second gantry, just above the gauge under test, aligns the plane of focus of a high-resolution digital camera with the fall trajectory of the drop. The release of the drop and the camera shutter are synchronized so that three images of the same drop are captured in a single picture, using speedlights triggered at a 4.2 ms fixed interval. The picture is then post-processed by means of photogrammetric techniques, providing the shape, size and fall velocity of the drop. Each released drop is therefore characterized to a traceable standard before it reaches the instrument sensing area (Baire *et al*., 2022). By comparison with the disdrometer measurement, the instrumental bias is then obtained. Performance of the calibration device are validated, in terms of the drop size, by comparing the output of the photogrammetric procedure with direct measurements of the drop mass from a high-resolution scale.

This calibration device is used to evaluate the performance of the Thies LPM, a laser disdrometer commonly deployed in the field. Tests are conducted considering six different drop diameters, and two different telegrams as provided by the instrument. At least 50 drops are released for each diameter, from a height of 1.2 m. Results show a general underestimation of the drop size, with the smallest drops reporting, on average, larger errors. The dispersion of the results in terms of the drop size is similar for all diameters, except for the smallest one showing a higher value. The instrumental bias on the drop velocity is on average more limited, meaning that the instrument provides a better measure of fall velocity than of the drop size. A strong variability in the results is however observed for both small and large diameters.

The difference between results obtained for the two output telegrams is quite large in terms of the drop diameter, while it is more limited for the fall velocity. This fact suggests that the instrument firmware applies different forms of correction on the drop size, depending on the telegram settings. Differences in the drop velocity are instead compatible with the error introduced by the binning operation performed by the instrument when computing the drop size and fall velocity distribution matrix.

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RSW2023-6

Advancing Surface Hydrology Research with Large-Scale Rainfall Simulators: Opportunities and Challenges

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Rainfall simulators have become an essential tool for hydrological and geoscientific research, providing researchers with the flexibility to simulate a wide range of rainfall intensities, durations, and patterns to meet the specific needs of their studies. However, the lack of harmonisation in rainfall simulator design and operation procedures has made it difficult to compare results between studies. There is a need for greater consistency in the use of these simulators to allow for effective comparisons and synergy between studies while recognising that variations in design characteristics can exist to cater to different research purposes.

Rainfall simulators typically operate at small scales, which means that the results may not be representative of what occurs at larger scales. As so, the development of large-scale rainfall simulators (LSRS) gave researchers an opportunity to reduce some scale-derived issues, such as spatial and temporal variability of rainfall, and plot size and plot edge effects. Nonetheless, the construction and operation of LSRS come with significant challenges, including high cost and technical complexity. As such, their use has remained limited, and there is a need for continued innovation in their design and operation.

By reducing scale-related issues regarding the use of physical models, LSRS can better reflect a wider range of conditions and provide more accurate data for model calibration and validation. Additionally, the use of LSRS can help bridge the gap between laboratory experiments and field observations, allowing researchers to conduct controlled experiments with larger and more representative plot sizes. Overall, the development of LSRS is a promising avenue for advancing our understanding of surface hydrology and improving the accuracy of physical simulation under artificial rainfall. The development of LSRS presents new opportunities to gain valuable insights into surface processes, thus playing a critical role in advancing our understanding of surface hydrology and geosciences.

One such LSRS has been designed, developed, and constructed at the Federal University of Alfenas, in Poços de Caldas (MG), Brazil. This rainfall simulator consists of a pressurised water supply system that supplies a set of 16 full-cone nozzles. Artificial rainfall with different intensities can be produced over a V-shape area of 100 m^2. The assembly is housed in an acrylic structure to eliminate the influence of wind and natural rainfall. Runoff is collected and measured at the outlet of the experimental plot, from where it is pumped to a storage tank that enables the reuse of water. This LSRS has been used to investigate the effects of urbanisation on the rainfall-runoff process. Specifically, it has been employed, e.g., to explore how different building arrangements can impact surface runoff and the transport of pollutants.

In this workshop, we will be presenting the LSRS facility in Poços de Caldas, Brazil, discussing its design, construction, and operation. We will also explore the potential of LSRS in advancing our understanding of surface hydrology and geosciences. Furthermore, we will examine the challenges and opportunities associated with the use of LSRS and discuss ways to promote greater consistency in the use of these facilities for effective comparisons and synergy between studies. Our goal is to raise awareness of the importance of LSRS as a critical tool for advancing our understanding of surface hydrology and geosciences and to encourage their use in research.

RSW2023-7

Single drop measurements as a supplement to rainfall simulator research

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Measurements using rainfall simulators provide a large amount of information about the course of water erosion in reproducible conditions. However, elucidation of some of the mechanisms behind erosion, especially in its early stages, may require analysis of the interaction of even single drops with the soil surface. The use of rainfall simulators in such studies can be at least difficult or even impossible. A solution might be the inclusion of other methods. Such an approach will allow extending the interpretation of results and facilitate precise studies of splash erosion and soil deformation after the splash. Hence, it may be possible to investigate the basic mechanisms and processes related to detachment and ejection of soil particles. Thus, it will provide a more complete understanding and description of the phenomenon.

The paper presents a set of measurement methods that are used in the laboratory of the Institute of Agrophysics of the Polish Academy of Sciences in Lublin (Poland) for analyses of the impact of a single water drop on the soil surface. These include (*i*) a set of three integrated high-speed cameras with PTV (Particle Tracking Velocimetry) software used to identify, track, and characterize splashed particles; (*ii*) a surface scanner with 3D reconstruction capabilities; (*iii*) “splash cups” for determining the mass ratio of the solid and liquid phases in splashed material; (*iv*) microtomography for investigations of the shape of the crater and the compaction under the crater; (*v*) the laser diffraction method and light microscopy for determination of the size of splashed particles; (*vi*) IRMS (Isotope-ratio mass spectrometry), i.e., deuterium labelled water to the define the origin (from a water drop or from a soil solution) of the splashed liquid phase.

RSW2023-8

Wildfire ash mobilisation by rainfall-runoff using a rainfall simulator under controlled laboratory conditions: Qualitative analysis

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Extreme rainfall/runoff events are triggering high erosion hazards worldwide, with ashes and char resulting from wildfires being the first particles to be mobilized and washed-out. However, the contribution of the ash/char layer to the overall erosion process remains uncertain and unknown, mainly because separating the ash and char fraction from other components such as litter, soil, and eroded sediments is often challenging. The ASHMOB project (CENTRO-01-0145-FEDER-029351) aimed to address this knowledge gap by investigating the mobilisation of wildfire ash by wind and water erosion in both controlled laboratory and field conditions. Specifically, this study focuses on the physical process underlying the mobilisation of ashes and char under rainfall-runoff conditions. The rainfall simulator located at the Laboratory of Hydraulics, Water Resources, and Environment of the University of Coimbra (Portugal) is a flexible and variable outflow rainfall simulator. It can generate rainfall intensities ranging from 30 mm/h to 800 mm/h using different full-cone nozzles and pressure settings.

In this study, a flume with a section of 1.2 x 0.3 m^2 was used to characterize ash and char mobilisation. The flume was placed under a rainfall simulator with a variable flow inlet upstream of the flume to simulate flow incoming from outside of the study area. We simulated a mid/end-slope plot with a constant rainfall intensity of approximately 100 mm/h using a Fulljet 3/8 HH 9.5 nozzle situated 2.5 m above the flume, set at 0.5 bar and increasing discharge from 0.5 to 3.5 L/s (i.e., incoming discharge from upstream). The flume bed was tilted at 20% slope, filled with soil, sealed with a surfactant so that only ash particles were transported, thus avoiding infiltration and soil transport. The soil's surface characteristics, namely friction and texture were kept intact to accurately simulate soil surface hydraulic roughness. The study analysed two major variables: (*i*) type of ashes from local vegetation (ashes from *Arbutus unedo* and *Eucalyptus globulus*), and (*ii*) use of mulch to reduce ash mobilisation during the events.

The experiments resulted in four significant findings: Firstly, the initial sediment yield and concentration were observed to be higher for lower flows, indicating that the availability of particles is a critical factor in the transport process. Secondly, the application of mulch was found to be a crucial factor in delaying the occurrence of the first flush and reducing the overall amount of ashes mobilized, leading to higher retention of the ashes. Thirdly, the type of burnt vegetation significantly affects the mobilisation process. Smaller particle size distributions such as the Arbutus unedo tend to mobilize faster and more uniformly, whereas uneven distributions such as the Eucalyptus globulus tend to facilitate the formation of micro-dams and barriers. Finally, the use of mulch demonstrated similarities with the presence of larger particles in a sample, creating small barriers in flow, such as micro-dams, allowing the retention/protection of smaller particles by reducing localised flow velocity upstream of the barrier and an overall decrease in mobilisation.

RSW2023-9

Dripping rainfall simulators for soil research–performance review

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Rainfall simulators represent often used equipment for soil research. Depending of their performance they could be appropriate for some soil research or not. The aim of this research is to provide insight into the capabilities of existing dripping rainfall simulators (DRS) to mimic natural rainfall and frequency of simulated rainfalls of certain characteristics, to facilitate the selection of rainfall simulators that would best meet the needs of soil research and to reach step closer to standardization of rainfall simulators. DRS performance was analysed integrally, for simulators with more than one dripper (DRS>1) and with one dripper (DRS=1). A statistical analysis of the performance of DRS, wetted area, drop size, rainfall intensity, duration and kinetic energy (KE) was performed. The analysis showed that DRS can provide rainfall that resembles natural rainfall, except in terms of drop size distribution and wetted area. However, usually there are more factors that do not correspond to the natural rainfall, such as median drop size, volume and kinetic energy. The sizes of the drops generated by drippers are mostly in the range between 2 and 6 mm, while the number of drops smaller than 2 mm is relatively small. The intensity and duration of the simulated rain can be successfully produced to match natural values, with the most frequently simulated short-term rainfall of high intensity. The majority of the simulations was conducted at a fall height of up to 2 m; the other experiments were conducted at fall heights that increased from 2 m up to a fall height of 5 m. The KE of the majority of simulations (58.6%) occurred in the range between 20–90% of terminal KE, 33.0% in the range 90–100% and only 8.4% was lower than 20%.

RSW2023-10

Determination erosion properties of mining residues - Transfer of field-scale sprinkler experiments to the lab

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Tailings and other fine-grained mining residues are usually deposited in the different forms of landfills in the surroundings of raw material extraction plants and are exposed to erosion by wind and water - at least until they are covered or re-cultivated. With the discharge of the tailings, ecotoxic and harmful substances may enter the environment and could spread ubiquitously by the transport media wind and water.

The substrate properties (texture, aggregate stability, water content, bulk density, elution), the climatic conditions (especially wind speeds and directions, heavy rain frequencies and intensities) and the landfill geometries determine how much material is removed from the surface and/or transported to the aquifer as eluate with the leachate. The complexity of these processes requires the use of models to simulate wind and water erosion. Such models have usually been developed for natural soils. In order to apply these models to quantify the discharge of mining residues, the specific substrate properties of the mining residues with respect to their exposure to erosion (by water and wind) must be measured.

Within the framework of the BMBF project ReAK (Reduction of arsenic in copper concentrates), the working group “Flow and Transport Modelling in the Geosphere” of the TU Bergakademie Freiberg (Germany) in cooperation with Wismut GmbH developed a laboratory tool with capillary sprinkler and wind module to determine the erosion properties of dumped mining residues. The tool was tested first for the transferability of the measured variables for natural soils, for which comprehensive data sets from routinely applied field sprinkler experiments are available. After optimization of the measurement procedure, erosion measurements were carried out on various grained materials with different precipitation intensities, slope inclinations, moistures and wind speeds.

The measurement results with the laboratory sprinkler (and the wind module) were plausible for both water and wind erosion, but shall be discussed at the workshop. For the natural loess soils, a good comparability of the sediment concentrations with the field tests on larger plots (1×3 m^2 and 2×22 m^2) could be demonstrated. For the dumped mining residues, the input parameters for the physically based erosion model Erosion-3D (water erosion) could be obtained. In the next step, the model will be applied to different landfill geometries and weather scenarios.

RSW2023-11

Rainfall simulations to compare the effect of mulch and biochar on different soil ecosystem services

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The recent introduction of super intensive irrigated olive groves in the Mediterranean, with up to 2000 olive trees per ha, poses new concerns about soil and water resources. Unsustainable management practices will trigger desertification, and lead to land degradation by soil erosion and soil fertility losses, compromise long-term food security as well as water availability through the silting of water bodies. Desertification is anticipated to intensify, with climate models predicting warmer and drier scenarios, with more frequent extreme rainfall events. At the same time, the oleic sector faces a great challenge in dealing with olive mill waste, requiring the development of new technologies to neutralize and/or valorise these phytotoxic residues. The recently approved SOLVO project aims to simultaneously address both these problems by engineering innovative nature-based solutions that combine mulch, derived from olive residues, with biochar, derived from olive mill wastes (OMW), to reverse soil degradation in low fertility olive orchards (very low soil olive mulch (SOM) and highly vulnerable to soil threats). SOLVO will take advantage of the availability of olive residues, the easy and economic surface application of mulches, and the instant increase of soil carbon through a single application of biochar, as a low-turnover, recalcitrant carbon source. There is already proof that this method is effective at reducing soil erosion and increasing SOM, and it is now important to assess the effects on other soil-mediated ecosystem services (ESs) at wider spatio-temporal scales. Preliminary results show that mulch and biochars from different olive mill agro-wastes, at application rates and schemes that maximize the soil restoration capacity of the treatment, can be identified using an indoor rainfall simulation facility. Mulch of olive pruning were surface-applied, while biochar was surface-applied and soil-incorporated in the rainfall simulation soil trays. Mulching alone strongly reduced runoff and soil erosion. Biochar was effective at reducing runoff and erosion, but it was much more effective, either surface-applied and soil-incorporated, if protected from rain splash with a layer of mulch.

RSW2023-12

Evaluations of rill and interrill erosion using rainfall simulators, SfM and mini-JET

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One of the key questions in soil erosion modelling is to distinguish between rill and interrill runoff, hence the rill erodibility steeply rises in many cases compared to the sheet flow process. Another uncertainty is then defining the volumes of soil loss initiated by splash, sheet flow, and concentrated flow. Several approaches can be used to measure soil loss initiated by rainfall simulators. Direct methods of erosion monitoring include measurement of the erosion process by sampling surface runoff or soil particles directly in droplet erosion, followed by laboratory analysis of the amount of dried soil particles. These values are usually taken as reference values. Indirect methods include the use of Structure from Motion - Multi-View Stereo (SfM-MVS). Especially rill erosion can be realistically estimated using SfM-MVS. The problem remains in defining exact rill definitions in shape for cases when pre-experiment data are not available. For these applications, we are testing machine learning approaches to define rill boundaries only based on imagery of the resulting eroded surfaces.

The experiments utilized CTU Prague lab RS (Kavka *et al*., 2019) and Stable Rain Simulators of plot sizes from 1×1 m^2 size to 2×8 m^2 sizes (Kavka *et al*., 2018).

A third method to define soil surface erodibility 'in the spot' is the Mini-JET device. The JET device was used in recent decades mostly to define the erodibility of cohesive surfaces such as stream banks and stream bed. Mini-JET is a small copy of the original device. The stream of water, which is generated by constant pressure, passes through the nozzle and strikes perpendicular to the soil surface. The soil surface is flooded with water during the experiment; the nozzle is completely immersed in water, so subsequent calculations of erosion parameters are based on the dynamics of the immersed jet. The measured data from the Mini-JET will be compared with other methods to determine soil erodibility. This comparison will verify whether the device can be used as a suitable method to determine the characteristics of erodibility on agricultural land. These data can then be used as input parameters in several computational models.

Different approaches to estimate soil erodibility and soil erosion will be presented with their pluses and minuses as seen in all experiments conducted by CTU in Prague in recent years. In 2023 our team started a new cooperation with the Group of Soil Sciences and Geomorphology at the University of Tübingen. Both teams will benefit from the expansion of datasets of measured data with simulators of larger scales and experience gained from multiscale experiments focused on different forms of erosion process (splash erosion, interrill erosion, rill erosion preferential pathways).

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RSW2023-13

Bringing rain into soil research: 15 years of experimental studies on vegetation and erosion with the portable Tübingen Rainfall Simulator (TRS)

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A key feature of rainfall simulators is the formation of replicable precipitation patterns with appropriate kinetic energy corresponding to natural rainfall events. Portable small-scale (1 m^2 – 5 m^2) devices provide scientists with a tool to investigate complex interconnections experimentally. Despite not measuring the complete process chain of water erosion, they can shed light on individual phenomena of hydrological and sediment transport in detail. In particular, specific effects of vegetation (such as structure or traits) and soil fauna (such as litter treatment) on soil erosion still have high investigation potential.

Here we summarize conclusions from field simulations with the Tübingen Rainfall Simulator (TRS, single-nozzle, <1–2 m^2) on the influence of plant diversity, individual species, soil covering vegetation as well as soil fauna in different forest and agricultural ecosystems. Results show, among others, that higher forest vegetation not necessarily has an erosion-reducing effect. Impacts on sediment transport are often species-specific and depending strongly on individual plant traits. Therefore, surface-near soil covering vegetation layers and contained mesofauna play a larger role than expected. Important reducing impacts can be initiated by biological soil crusts as pioneer stages after disturbance, which also show severe impacts on water fluxes and infiltration in woodlands. Furthermore, impacts of vegetation are transferable to agriculture, where a positive impact of modern organic farming systems with short fallow periods and reduced soil-turning techniques on soil erosion control can be underlined.

In summary, we can illustrate the reliability of mobile simulator systems even under difficult operating conditions in the field when appropriate technical standards regarding design, maintenance and replicability are met. For a better comparability and use of more extensive data sets between researchers, a harmonization of the different field measurement approaches would be desirable.

RSW2023-14

Using the rainfall simulators to test rolled erosion control products and other applications

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Rainfall simulators (RS) are widely used in research to study the effects of rainfall on runoff, infiltration, and sediment transport in the landscape. Research includes the key impact mechanisms of overland flow (sheet and rill runoff), soil erosion types, and the influence of soil surface conditions and its changes by rainfall. Due to the high number of research goals, various types of RS use are available to meet different research needs and challenges.

This contribution presents unique experiments designed to address specific non-standard research applications. These include:

(*i*) Impact of Rolled erosion control products (RECP) on artificial steep slopes:

Linear structures, such as roads, railways, and watercourse training, with surrounding landscaping features such as steep embankments and cuts, and rill erosion can occur on relatively short sections. To protect these surfaces, technical measures (RECPs) are used to temporarily stabilize the slope until vegetation takes root. A series of tests were carried out on plots divided into different types of RECP to evaluate the effectiveness and protection provided by these measures. The effectiveness was evaluated in terms of the impact of measures on surface runoff and sediment flow. This allowed the evaluation of individual measures during rainfall-runoff events. The project resulted in the evaluation of the effectiveness of different geotextiles, with natural materials showing better properties than plastic geotextiles. Furthermore, the research focuses on developing a method to detect topsoil movement based on fiber-optic sensors using rainfall simulators, which will lead to increased safety in traffic infrastructure. The study also aims to investigate the propagation of rills on steep slopes using SfM (Structure from Motion) methods. The slope of the rain plots is greater than 22°.

The experiments utilized CTU Prague lab RS (Kavka *et al*., 2019) and Stable Rain Simulators (SRS), a unique type of rainfall simulator that combines both mobile and laboratory rainfall simulators. Unlike traditional rainfall simulators, SRS maintains experimental plots in a fixed location under natural conditions, onto which simulated rainfall is repeatedly applied. This approach offers several advantages, including the natural growth of vegetation and soil development, as well as reduced demands for operational staff and experiment preparation time. Additionally, the experimental setup remains consistent between simulations as the layout of nozzles and rainfall characteristics remain unchanged.

(*ii*) Plot scaling:

This research focuses on the effect of plot size on the formation of surface runoff and soil loss. The effect of plot size has been tested several times in the past, comparing plots of 1×1 m^2 with plots of 2×8 m^2 on bare soil, grasslands, and once also on vineyards. A large rainfall simulation (8 m long × 2 m width) (Kavka *et al*., 2018) was divided into four plots with lengths of 1, 2, 4, and 8 m (with widths of 1 m) under two conditions (grass and bare soil). Soil moisture sensors were placed at various depths in the plots to monitor the evolution of soil moisture over time. The results showed that the plot length is more important for soil loss than for surface runoff processes and that the heterogeneity of the infiltration soil properties would play a significant role in the experiment results.

(*iii*) Surface and vegetation condition:

In this case RS (Kavka *et al*., 2018) was used in rotated position with the longer side along the contour for parallel measuring study of the effects of different surface and vegetation conditions on surface runoff and soil loss. Four surface types (bare soil, rolled bare soil, patterned grass and mowed grass) were tested on four 2×2 m^2 plots that were rained simultaneously. The results provided a comparison of the effect of vegetation and surface conditions.

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RSW2023-15

Study of the influences of environmental drivers on N_2O emissions under semi-controlled conditions using a rainfall simulator

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Understanding the dynamics of N_2O emissions, the third anthropogenic greenhouse gas, is a major environmental issue. N_2O atmospheric concentration, mainly due to soil emissions, rises globally resulting from human activities, especially agricultural practices related to N fertilisation. Microbial denitrification is considered as the major contributor of N_2O production, responsible for 40% to 85% of global emissions. Denitrification rate in field is influenced by several regulating factors interacting with time at the scale from the microsite to the landscape (availability of inorganic nitrogen, soil structure and aeration in relation to volumetric water content, organic carbon, pH and temperature). In this work we aimed at analysing the relationships between N_2O emissions dynamics and hydric functioning of a cultivated fertilised soil, to better understand N_2O production hotspots and hot moments to help reducing uncertainty in N_2O emissions estimation. The effect of some environmental parameters, like topography, are hard to assess in the field because of the number of regulating factors involved in N_2O production and emissions. Oppositely, laboratory studies can easily isolate one factor but they are generally conducted in conditions very different from field, on small samples. Many replicates are necessary to assess studied effects, but it is impossible to reproduce spatial interaction and the effect of distal factors such as topography.

In this study, a 10 m² sloped soil model (0.3 m depth) was installed inside an experimental hall under a rainfall simulator located at INRAE Val-de-Loire Research Centre, which results in an intermediate scale between soil cores and field. This equipment was built in accordance with the rainfall simulator design of the National Soil Erosion Research Laboratory (USDA-ARS, West Lafayette, IN), with 2 rows of 5 swiping nozzles located at 5.1 m above the soil model. Rainfall characteristics can be modified through changes in nozzle type, water pressure and sweep frequency. For this experiment, 10 Veejet flat spray nozzles were used (on each row: 2×8070, 2×8060 and 1×8050) with a pressure of 0.85 bar for a rainfall intensity of 17 mm h^{-1}. The soil model was cropped (spring barley) and fertilized to reproduce field conditions (3.5° slope). N_2O emissions were measured for 70 days at 16 locations, using a fast-box chamber and a quantum cascade laser spectrometer. Soil characteristics (nitrogen, pH, bulk density, water content) were measured up, mid and downstream. We aimed at assessing the temporal and spatial variability of N_2O emissions at the model scale, in semi-controlled conditions (fertilisation and rainfall events), considering the interaction of two distal factors (topography and plants).

The N_2O emissions measured were in accordance with field measurements. On all points, a first N_2O peak was observed after a 24 mm rainfall following a nitrogen application (two conditions favouring denitrification), and a second but lower peak was observed after an 8 mm rainfall. We observed a slope impact, affecting the dynamics of the water processes (lateral flows, accumulation of water at the bottom of the slope) and inducing stronger emissions at the downstream position. Plants also had an impact on N_2O emissions, which were significantly higher where the crops had grown better, which increased soil porosity and gas diffusion, limited soil of compaction caused by rainfalls and enhanced the organic matter inputs.

RSW2023-16

Rainfall Simulators Application for Assessment of Effectiveness of Soil Erosion Control Measures

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The USLE equation is the basic method for estimating soil loss in Europe. The model calculates long-term average values of soil loss over large areas, but requires accurate input parameters for reliable results. The method was developed many decades ago, and its parameters have been largely adopted from the United States without major revisions related to new crops and technologies. This paper focuses on one of the parameters of the equation, the c-factor, which describes the effect of plant cover. The c-factor has been determined on the experimental plots with natural rainfall for USLE and using rainfall experiments for RUSLE, but the data are outdated. The aim of constructing a large-scale rainfall simulator in the Czech Republic was to revise the c-factor values using the most common vegetation cover in the region. A FULLJET nozzle type rainfall simulator (kinetic energy 10 J/m2/mm) and experimental field plots of 8x2 m^2 with 9% slope were used for this research. During each experiment, two measurements were taken, the first on a plot with natural conditions and the second on a fully saturated plot after the first experiment. Natural conditions mean actual wetness of the soil in the day of the experiment; the soil moisture was recorded before and after the experiment. The experimental plots with crops were compared to the plots with bare soil. A revised catalogue of c-factor values for crop rotation was published after more than 300 experiments conducted on 8x2 m^2 plots over a period of 4 years (2015−2018). The ongoing study resulted in another 4 years of trials (2019−2022) and a catalogue of c-factor values based on agricultural methods was published. Now the measurement continues with additional crops and soil conservation practices. Based on the measurements, a database with the soil loss ratio calculated on a daily basis was created.

Experiments with a large rainfall simulator are very time consuming and required a lot of personnel. Since the beginning of 2022, a new small rainfall simulator has been used to estimate the c-factor values on 1×1 m^2 plots. Presently, we are looking for a comparison between large and small plots. This research is at an early stage, but if successful, will allow more experiments to be carried out during the day. The new large rainfall simulator, which is now in the initial testing phase, will be used in the 2023 season for field experiments. It allows the simulations to be run on four 4×2 m^2 plots or to combine plots into a larger one.

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RSW2023-17

Need of methodological harmonization of rainfall simulation experiments to enhance soil conservation research

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There are numerous teams across the world using rainfall simulators, to mimic natural processes related to rainfall-runoff, soil erosion, sediment transport, infiltration, subsurface lateral flow, nutrient and other chemical substances transport, preferential flow tracing and also to determine basic soil properties. Rainfall simulations can also very well indicate how effective various control measures and strategies can be. Typically, effectiveness of soil control measures, cover crops, crops residues, conservation tillage and other strategies can be quantified – for most effective agricultural policy.

However, experiments with rainfall simulators (regardless of the size, indoor or outdoor, raindrops generation principles, ….) are very much time and man power demanding and to collect large datasets is not easy for individual team. To be able to share measured data, two main conditions are necessary: (*i*) to harmonize experiment´s methodology (rainfall intensity, duration of experiment, initial conditions of experimental plot, kinetic energy of raindrops, sampling scheme, basic analysis of samples, ….) (*ii*) to build a database or at least a meta-database of recorded values from experiments for potential sharing by individual teams.

A database of results of field and laboratory rainfall experiments has already been developed at CTU Prague and data are shared with several other teams across Europe. The database structure will be presented within the presentation and other teams are very welcome to join.

Several common experiments to compare various rainfall simulators systems from individual teams in CZ, Germany and Austria has been performed under controlled conditions to test whether experimental results are replicable and comparable. Results showed that spatial soil variability and diverse technical parameters of individual devices and specific methodologies applied by individual teams, in fact exclude the possibility of sharing results of experiments to enlarge datasets without their essential harmonization and coordination.

Such methodological harmonization and data sharing is an essential step for effective pan-European soil conservation policy, proper GAEC systems calibration and also demonstration of effects of individual control measures to stakeholders.

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RSW2023-18

Using portable field rainfall simulator for experimental research of soil resistance

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Due to the action of erosion processes, degraded areas of forests have a reduced capacity to perform ecosystem services and a reduced production potential of wood mass. In an attempt to reduce such negative effects, one of the steps is to determine the elements of the mechanisms of erosion processes in order to achieve an appropriate solution for remediation by analysing the physical and mechanical parameters of the soil. Using a portable field rainfall simulator in the forest area in the gullies and the conditionally stable zone of the gullies' banks, experimental soil testing has conducted. The simulator that was used is based on the pop up sprinkler system described in detail by Živanović *et al*. (2022). The limited amount of water on the field, as well as the duration of the pouring rain for the study area, affected the duration of each test to be limited to 10 minutes. During the experiment, the effects of changes in soil moisture on changes in the parameters of soil shear resistance and resistance to penetration, as well as the formation of surface runoff and soil erosion, have been observed. Research has been conducted during the spring and autumn. It was established that the change in the current soil moisture affects the change in the mechanical parameters of the soil. Compared to tests on gullies' banks, the values of soil shear resistance and resistance to penetration are lower in tests in gullies. The presence of cracks and macropores influenced the appearance of rapid infiltration into the soil of part of the precipitation, which resulted in small amounts of runoff water on the exit profile (3.76–32.71% of the total volume of rain). Surface erosion occurs in the form of tearing off entire microaggregates and their transport via micro-furrows to the outlet profile. The concentration of sediments in the water, during tests on the banks, tended to decrease with each subsequent repetition. It's been determined that soils of the research area are sensitive to erosion processes when they are in a state of low natural humidity. With an increase in water content above 20%, the soil becomes more sensitive to erosion processes and other forms of physical degradation. After an increase in the current water content above 42% (the average value of the liquid limit), the soil was in a saturated state when the resistance forces cease to act.

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RSW2023-19

The influence of rainfall simulators dripper size, type and dripping speed on generated drop size

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The choice of drippers for dripping rainfall simulators (DRS) is often based on the experience of previous research or personal empirical knowledge, under the assumption that drippers in form of tubes and holes with a smaller internal diameter (ID) generate water drops of a smaller diameter and vice versa, neglecting other factors that affect the size of the drops. The aim of research is to provide insight into the influence of DRS dripper size, type and dripping speed (i.e., the number of water drops dripped out from a dripper per unit of time) on generating different water drop size. A search was conducted for all available scientific papers describing DRS and papers that include a wide range of thematically related papers to soil research in which DRS are used starting from 1941 until today. Out of a total of 188 scientific papers included in the analysis, 76 different types and 31 subtypes of DRS have been singled out. The analyses of DRS drippers design and performance was conducted in terms of the drops' sizes that they are able to generate. The analysis was conducted integrally, for simulators with more than one dripper and with one dripper. Metal and plastic tubes (MT and PT), which are the most common drippers' type, showed a strong relationship between the outer diameter (OD) with the drop size, while the ID relationship was moderate to weak. However, when increasing the range of MT drippers' diameter size, the relationship significance became very strong for both ID and OD. It is observed that with the increase of the ID of PT the relationship deviates from the logarithmic curve that represents all dripper types together. Although the applied dripping intensity difference is quite big for MT, drop size does not differ much. On the other hand, PT generate much bigger difference in drop size for a less drastic change in intensity. It is suggested that a possible reason for such a deviation and difference in the functional forms that describes drop and drippers size relations could be the dripper material, but considering that MT drippers generally have a thinner wall than PT or glass tubes (GT), drippers material type rather determines the thickness of the tube wall.

RSW2023-20

Assessment of the effects of land use changes on surface runoff and soil erosion in a southern Alpine valley using a portable rainfall simulator device

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In mountain regions, soil landscapes are highly vulnerable to soil loss. Moreover, these environments are particularly affected by land use changes, which influence soil properties and related processes like surface runoff generation and soil erosion. These processes are in turn amplified by extreme climatic events and intensive geomorphological dynamics. The objective of this study is to quantitatively assess the effects of land use changes on surface runoff and soil erosion in a southern Alpine valley (Onsernone valley, Switzerland) characterized by a former intense land use followed by a progressive abandonment in the last decades. Surface runoff and related sediment transport has been analysed under controlled and reproducible conditions using a portable rainfall simulator device (PARS). The instrument is characterized by an aluminium frame, which rests on four adjustable legs. The frame supports a sprinkling plate, which consists of a Plexiglas cylinder being connected with 100 nozzles regularly arranged on a 90 × 90 cm^2 plate producing the raindrops. The sprinkling plate is driven by an electric motor and two inversion spindles moving horizontally in perpendicular directions and providing a uniformly irrigated area of 1 m^2. The amount of water per unit of time, which corresponds to the amount of rain per minute on an area of 1 m^2 can be adjusted up to 60 mm/h by a flow meter. In this study, we set the flow rate to 833 cm^3/min, which corresponds to 50 mm/h. For the study area this is equivalent to a precipitation event occurring with a return period of five years. The results show a statistically significant increase in surface runoff when the soil gets water repellent and reduces the surface infiltration capacity generating preferential flow paths, which prevent a homogeneous wetting of the soil. However, the documented high sensitivity of surface runoff to land use changes does not result in an equally high sensitivity to soil erosion processes. Instead, soils display a high aggregate stability leading to very low sediment transports except for abandoned agricultural terraces. Finally, the abandonment and progressive collapse of terrace walls locally increases slope angles and directly exposes the soil to atmospheric agents and surface runoff, which causes soil erosion rates beyond the customary natural level.

RSW2023-21

Spray nozzle simulators and drop properties: the role of meshes in acting on drop kinetic energy and size distribution

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Rainfall simulators’ design and operation might be rather demanding for achieving specific rainfall intensity distributions and drop characteristics. In particular, pressurized simulators produce drops that do not rely on gravity to reach terminal velocity, but are sprayed out under pressure; although these simulators yield a broad range of drop sizes, the drop size distribution do not meet often specific study requirements. We report results of laboratory experiments that aimed at investigating the suitability of combining spray nozzle simulators with meshes in order to change simulated rainfall characteristics (rainfall intensity and diameters and fall speed of drops).

As detailed in Carvalho *et al*. (2014, 2016), different types of spray nozzles were tested, such as single full-cone and multiple full-cone nozzles. The impact of the meshes on the simulated rain was studied by testing different materials (i.e. plastic and steel meshes), square apertures and wire thicknesses, and different vertical distances between the nozzle and the meshes underneath. The diameter and fall speed of the rain drops were measured using a Laser Precipitation Monitor (Thies Clima). The rainfall intensity range and coefficients of uniformity of the sprays and the drop size distribution, fall speed and kinetic energy were analysed. It was found that, while intercepting drop trajectories, meshes promote the formation of bigger drops and random their landing positions; thus, meshed were found capable of altering the drop size distribution and the spatial distribution of rainfall intensity. However, whereas in general the drops’ kinetic energy increased when meshes were used: (*i*) the shorter the distance between the mesh and the nozzle, the stronger was this effect; (*ii*) this increase differed according to the spray nozzle used.

References:

Carvalho, S.C.P., J.L.M.P. de Lima, M.I.P. de Lima, 2014. Using meshes to change the characteristics of simulated rainfall produced by spray nozzles. International Soil and Water Conservation Research (ISWCR), 3(3): 67-78.

Carvalho, S.C.P., J.L.M.P. de Lima, M.I.P. de Lima, 2016. Increasing the rainfall kinetic energy of spray nozzles by using meshes. Land Degradation and Development, 27: 1295–1302. doi: 10.1002/ldr.2349.

RSW2023-22

Using a portable rainfall simulator to understand sediment loss and runoff on an abandoned mine tailing in Alagoa, Portugal

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Abandoned mine soils and tailings usually have high concentrations of heavy metals that could increase the risk of ecosystems' pollution and endangering human health; moreover, usually these sites exhibit great vulnerability to water erosion.

This work reports field experiments that used a portable rainfall simulator to conduct an in situ exploratory evaluation of sediment loss and runoff in the abandoned mining area of Sanguinheiro, near Coimbra (Portugal), which was used in the past to explore lead and zinc metals. The field experiments were conducted in small plots (0.26×0.26 m^2) using a portable Kamphorst rainfall simulator. The characteristics of the experimental setting restricted the duration and intensity of the simulated rain. The equipment was used to simulate extreme short duration rain events of around 3-5 minutes, of intensities in the range of around 200–300 mm/h. The experiments were carried out in the main mine tailing, in the secondary mine tailing, and in a non-mine area (near the main mine tailing), which was considered the control reference area. Runoff hydrographs and sediment graphs were obtained in order to provide insight into the vulnerability of the mine soil to water erosion. The understanding of the dynamics of the overland flow processes and the sediment transport mechanisms in the study areas were preliminary essential steps to proceed with the investigation of the mechanisms of dispersion of heavy metals and contamination of downstream areas. Complementary laboratory experiments using a Full-jet nozzle spraying rainfall simulator and soil flumes were also conducted.

RSW2023-23

Studying the combined effect of wind and rain using rainfall simulators

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Although rainfall is assumed spatially uniform in conventional soil erosion and soil hydrology studies, moving storms have been shown to have substantial influence on runoff since the spatial and temporal characteristics of rainfall are altered by wind. The importance of storm movement, due to the combined effect of wind and rain, on surface flows has long been acknowledged, at scales ranging from headwater scales (e.g., plots) to large drainage basins. All the processes involved (e.g., rainfall, wind, runoff, soil erosion) typically exhibit extreme variability. In regions where intense rainfall events are frequent, these issues assume an increasing importance in a context of possible climate change scenarios.

The main objective of this work was to quantify the hydrologic response in terms of surface flows and soil loss caused by both non-moving and moving rainstorms. Results of a physically-based erosion model and laboratory rainfall simulations on soil flumes are presented. Controlled flume laboratory experiments were carried out using several soil flumes and a movable sprinkling-type rainfall simulator. To simulate moving rainstorms, the rainfall simulator was moved over the soil surface at different speeds. During runoff events overland flow and sediment transport were measured in order to determine hydrographs and sediment production over time. Granulometric curves, obtained through conventional hand sieving and optical spectrophotometer method (material below 0.250 mm), were constructed.

Both laboratory soil flumes and numerical model simulations showed that the direction of storm movement, especially in case of extreme rainfall events, significantly affected runoff and water erosion process. Downstream-moving storms caused significantly higher peak runoff and erosion than did upstream-moving storms. The hydrograph shapes were also different: for downstream-moving storms, runoff started later and the rising limb was steeper, whereas for upstream moving storms, runoff started earlier and the rising limb was less steep. The evolution of grain-size distributions of sediments generated during experimental simulations on a soil flume shows a clear dependence on the direction of storm movement.

RSW2023-24

Design and development of a novel automated 'runoff simulator' system

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Rainfall simulators, whether based within a laboratory or field setting, have been used extensively for a variety of hydrological, geomorphological and engineering-based research applications. Rainfall and runoff processes are often investigated together, with runoff regimes being a key component of the hydrological cycle. Rainfall simulators are well documented research apparatus. However, few published examples of an experimental setup capable of applying simulated and controlled artificially irrigated 'runoff' exist in the literature.

This paper presents the design, construction and evaluation of a novel experimental *runoff* simulator (as opposed to a *rainfall* simulator) setup capable of augmenting and upscaling inflow precipitation from natural rainfall events and applying additional 'top-up' volumes of water to account for runoff received from a wider catchment area and applying artificial storm events of controlled magnitude and timing. Runoff simulators were installed on eight above ground lysimeter bioretention cells (1.0 m × 2.0 m surface area, 1.2 m deep soil profile) based at the UKCRIC National Green Infrastructure Facility, Newcastle-upon-Tyne, UK. The runoff simulators have two primary functions. Firstly, the runoff simulators work in near real-time to upscale natural plot-scale precipitation data, recorded directly at each of the rain gauges fitted to the lysimeters, and incorporate a series of solenoid valve relays and turbine flow sensors to initiate, measure and isolate irrigation scheduling based on runoff received from an adjacent urban impervious surface or pavement. Secondly, the runoff simulators are used to apply controlled and uniform 'design storm' events of known intensities to simulate the response of the lysimeter systems to inflow conditions outside of the instrumented record. Data showing replicability and reproducibility of set inflow patterns are presented. Further, results from design storm events of varying magnitude (10-year, 30-year and 100-year storm magnitude) show the functionality of the runoff simulators and the response of the lysimeters to simulated inflows.

Rainfall and runoff processes should both be considered when undertaking hydrological experiments. The runoff simulator presented herein is adaptable to a variety of research applications and could be coupled with rainfall simulator piping to apply spatiotemporal design storms and automate the delivery of plot-scale irrigation to plot-scale experiments.

Technical Visits' Programme

Technical Visit 1

Monday, 22 May: 15:45-17:15

Meeting Point: Venue, 4th Floor, end of corridor of building E.

Experimental hydrology

A visit to the Laboratory of Hydraulics, Water Resources and Environment of the Department of Civil Engineering of the Faculty of Sciences and Technology of the University of Coimbra, in particular to its rainfall simulator installation.

SHORT DESCRIPTION:

The laboratory allows for pedagogical and research activities. It is equipped with a variety of installations and equipments and it is used by undergraduate and graduate students of civil and environmental engineering courses, as well as PhD students and researchers.

The laboratory facilities include rainfall simulators (drop former and full jet spraying nozzles). The spaying-nozzle rainfall simulator allows to simulate moving storms and the combined effect of rain and wind.

Most of the research activities carried out in the laboratory are embraced by research interests of MARE / ARNET, although other research centres are also involved.

MARE – Marine and Environmental Research Centre, is a multipolar RD&I Centre created in 2015, presently with seven poles, for research, technological development and innovation, with an integrative and holistic approach. It concentrates a wide diversity of expertise, skills, and capabilities, with a nationwide territorial implementation, developing its activities oriented to societal challenges, in close partnership with national and international research centres. Six of the seven MARE poles are located at higher education campi in mainland Portugal, respectively, University of Coimbra (MARE-UCoimbra), Polytechnic of Leiria (MARE-IPLeiria), University of Lisbon (MARE-ULisboa), NOVA University of Lisbon (MARE-NOVA), ISPA (MARE-ISPA), and University of Évora (MARE-UÉvora), plus one pole in the Madeira archipelago (MARE-Madeira).

MARE combines expertise allowing approaching scientifically and technologically all types of aquatic systems, from river basins to estuaries, coastal, and large marine ecosystems.

The thematic line Hydraulics, Hydrology and Sedimentary Environments, which is strongly linked to the activity developed in the Laboratory of Hydraulics, Water Resources and Environment of the University of Coimbra, encompasses two main areas of activity: environmental hydrology and hydraulics, and sedimentary geology and environment. It promotes interdisciplinary research to apply in the development of innovative tools, strategies and technologies to solve environmental problems in a sustainable way. The research activities involve the following areas: modelling of surface hydrological processes; non-linear processes in hydrology; urban hydrology and hydraulics; sedimentary hydrodynamics, sedimentary petrology, sedimentology, geomorphology, geoarchaeology and sedimentary basin analysis. The main goal of this line is to develop tools and methodologies that cut across several areas of water and environmental management, including sedimentary processes, improving the understanding and ability to manage natural and artificial environments in a sustainable way.

Views of the laboratory main hall and of the long wave/current flume and hydraulic channel/flume.

View of the nozzle spray rainfall simulator and soil flume. The installation includes attributes to simulate wind-driven rain.

View of the pedagogical laboratory.

Technical Visit 2

Tuesday, 23 May: 9:00-10:30

Meeting Point:
Rua Pedro Hispano, s/n, 3030-289 Coimbra, Portugal
Coordinates: 40.190167; -8.413305

Science and industry

A visit to the Itecons - Institute for Research and Technological Development in Construction, Energy, Environment and Sustainability, in Coimbra, including the opportunity to visit laboratories and assist to a rainfall simulator demonstration.

From the Workshop venue to Itecons (≈ 800 m, 10 min walk).

SHORT DESCRIPTION:

Itecons is a non-profit organization founded in 2006, which is part of the National Scientific and Technological System and develops pure and applied research. Itecons is classified as an institution of public utility that acts as a dynamic interface of knowledge between the scientific community and industry, providing applied research, testing, consultancy and training in the fields of construction, energy, environment and sustainability. It promotes innovation and the transfer of knowledge to companies, by developing research for different types of projects.

Itecons has at its disposal over 7500 m^2 of modern facilities and laboratories with highly qualified personnel (over 80 technicians and researchers, including approximately 30% of doctorates), with a vast experience in research services and consulting in the following areas: Materials and Sciences of Construction; Mechatronics, Electrotechnology, Chemistry, Energy and Environment, Hydraulics, Quality, Control and Automation, Industrial Management and Process Control.

This entity has a quality management system certified by APCER, complying with the EN ISO 9001 standard, and has over 300 IPAC (Portuguese Institute of Accreditation) accredited tests, in accordance to the EN ISO/IEC17025 standard. It provides an extensive list of testing services in Materials, Aggregates and Inert Materials, Mortars, Natural Stone, Soils, Binders and Bituminous Mixtures, Acoustics and Vibrations, Hygrothermics, Windows and Exterior Panel Materials, Equipment Testing, Chemistry, Energy and Environment. It is also a Notified Body (System 3) and a Technical Assessment Body under the CE Marking EU Regulation (EU) nr. 305/2011 of the European Parliament and of the Council, of 9 March 2011, for a wide range of construction products.

Itecons is qualified to perform R&TD, innovation, 4.0 industry, entrepreneurship and internationalization services.

Rainfall simulator and flume

The rainfall simulator and flume at Itecons' laboratories were initially designed for obtaining runoff coefficients for green roofs, following the FLL Green Roofing Guidelines - Guidelines for the Planning, Construction and Maintenance of Green Roofs.

The rainfall simulator consists of a set of seven downward-oriented full-cone nozzles supplied directly from the water supply system to generate a pre-set rainfall intensity of approximately 108 mm/h. The nozzles are fixed to the flume and are evenly distributed in a single line along the slope direction of the flume, at a distance of 60-80 cm above the flume surface, to generate a rainfall block as uniform as possible. The rainfall intensity can be finely regulated by continuously measuring the water inflow rate of the nozzles using an ultrasonic flowmeter and a manual control valve installed in the supply line.

The flume is 5 m long and 1 m wide, with adjustable longitudinal slope, which allows for different green roof constructive solutions and designs to be installed and to be tested. The installation of a mesh grid (sieve) of approximately 3 mm aperture at the downslope end of the testing table prevents the outflow of coarse material from the testing specimen. A reservoir placed on a digital scale installed at the flume-s outlet allows collecting and continuously measuring the water discharge that outflows from the testing table. All measuring systems are connected to a data logger and computer that allows for data recording and real time monitoring of rainfall and discharge.

Itecons' buildings.

View of rainfall simulator and flume.

Detailed view of rainfall simulator.

Technical Visit 3

Wednesday, 24 May: 9:45-15:30

Departure/arrival address:
Rua General Humberto Delgado 1, Casal da Misarela.
Coordinates: 40.20593, -8.36328.
Departure/arrival time: 9:45/13:30. Lunch: 13:30-15:30.

Insight into the fluvial environment of the River Mondego upstream of Coimbra

A kayak trip down a stretch of the River Mondego, upstream of Coimbra.

Map of kayak trip.

SHORT DESCRIPTION:

The River Mondego catchment has a dominant NE-SW orientation and an area of 6644 km^2; this catchment is the second largest in area of those that are located entirely in Portuguese territory. The river is 234 km long: the source is in the *Serra da Estrela* (mountain range), at an altitude of 1425 m a.s.l., and its mouth is near *Figueira da Foz*, on the Atlantic Ocean. The river undergoes a descent of 750 m within its initial 50 km, while the subsequent 80 km section showcases a gentle slope. The main geological formations are granites and schists of the Iberian Meseta, changing downstream to sandstones and marl and, closer to the mouth, to more recent sedimentary formations.

Descending 15 km down the River Mondego in a kayak will be a relaxing activity, combining physical activity and the opportunity to see the beautiful environment and the ecosystem characteristics of one section of the river. The selected section of the river is upstream of *Coimbra* and stretches from *Penacova* to the fluvial beach *Palheiros e Zorro* (left bank). In the first part the river runs through a deep, narrow valley, with a meandering course and enclosed by steep slopes that are covered mainly by pine and eucalyptus forests. The soils are derived from schists. Closer to *Coimbra* the river opens out to its lower course, running through a vast alluvial plain for the last 40 km of its course. The trip will end at the fluvial beach *Palheiros e Zorro.*

The kayak trip will be guided by professionals. Safety requirements are met. The kayaks are for two persons. Transportation from Coimbra to the departure and pick-up points could be provided.

At the end of the trip it will be possible to have lunch in a local restaurant (Restaurante Mariazinha), at Casal da Misarela, in front of the fluvial beach *Palheiros e Zorro*.

River Mondego.

Penacova.

Fluvial beach Palheiros e Zorro.

Coimbra and the Mondego River.

Coimbra and the University.

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