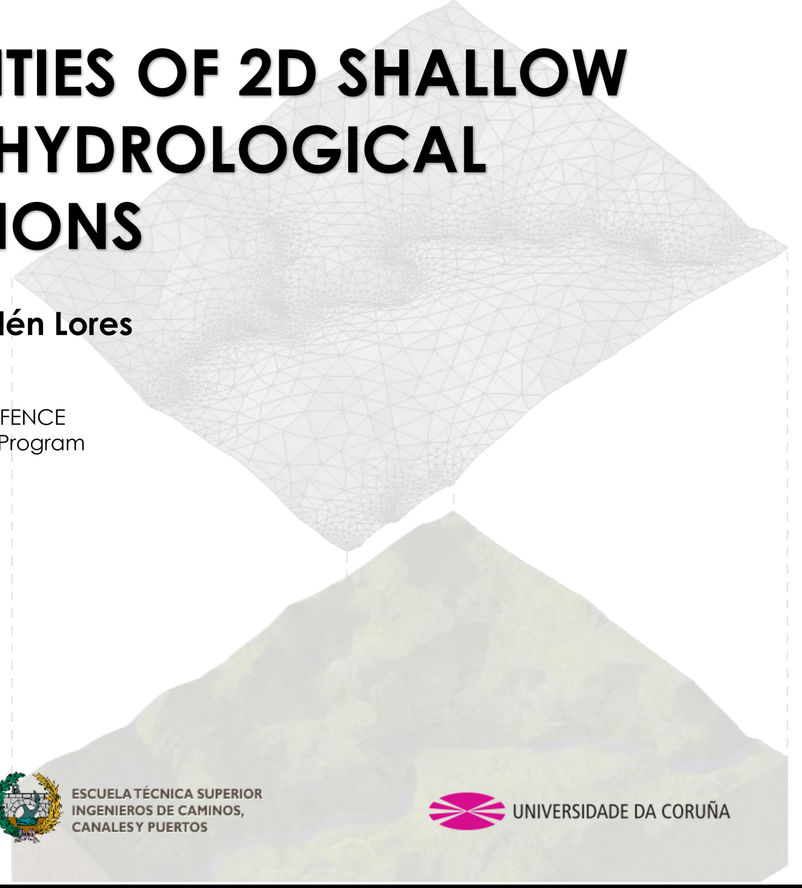
IMPROVING THE CAPABILITIES OF 2D SHALLOW WATER MODELS FOR HYDROLOGICAL APPLICATIONS

Gonzalo García-Alén Lores

DOCTORAL THESIS DEFENCE
Civil Engineering Ph.D. Program



Supervisors:
Luis Cea Gómez
Jerónimo Puertas Agudo

CITEEC Centro de Innovación Tecnolóxica en Edificación e Enxeñería Civil

Grupo de Ingeniería del Agua y del Medio Ambiente

ESCUELA TÉCNICA SUPERIOR INGENIEROS DE CAMINOS, CANALES Y PUERTOS

UNIVERSIDADE DA CORUÑA

THESIS FORMAT

COMPENDIUM OF ARTICLES

4 articles published in JCR indexed journals

INTERNATIONAL MENTION

Predoctoral stay of 1.5 months (2021):
Luxembourg Institute of Science and Technology (LIST), Luxembourg.

Predoctoral stay of 3 months (2022):
Institut de Recherche pour le Développement (IRD), Montpellier, France.

Renaud Hostache

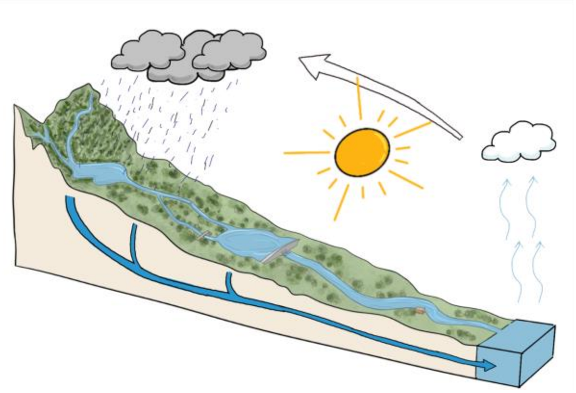
CONTENTS

CONTENTS

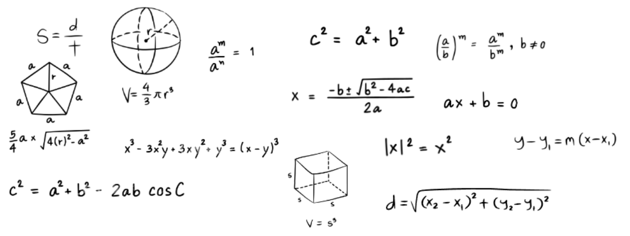
CONTENTS

INTRODUCTION

HYDROLOGICAL MODELS



Hydrological cycle of a river basin

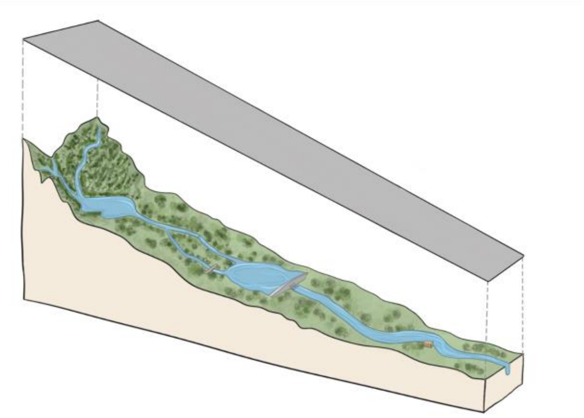


Numerical model

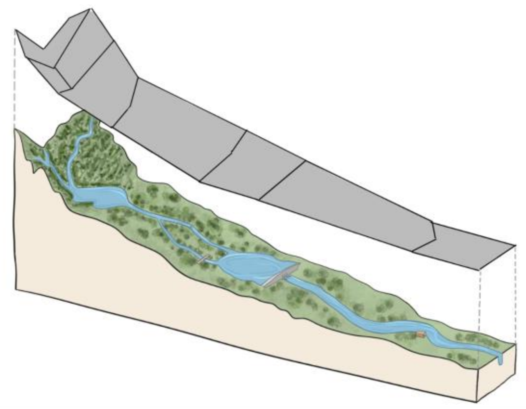
INTRODUCTION

HYDROLOGICAL MODELS

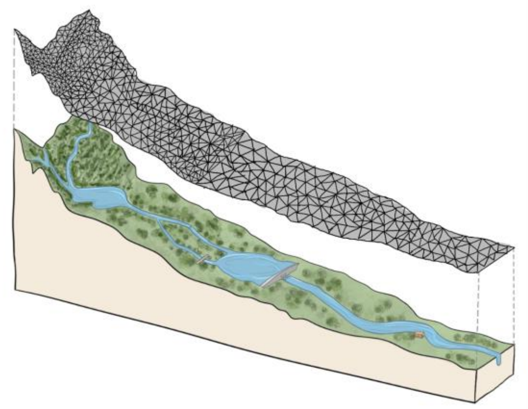
Lumped model



Semi-distributed model

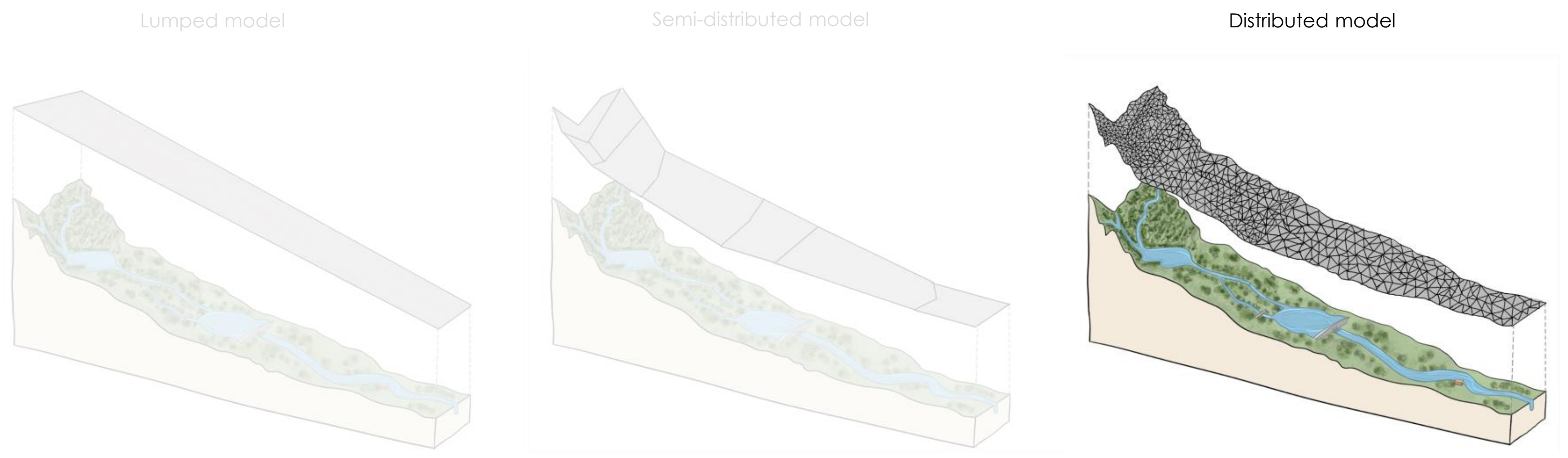


Distributed model



INTRODUCTION

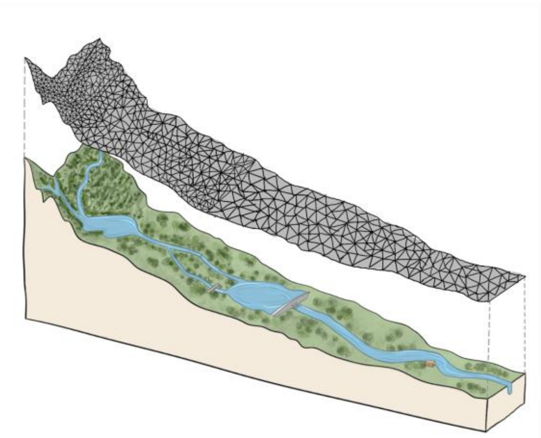
HYDROLOGICAL MODELS



INTRODUCTION

HYDROLOGICAL MODELS

Distributed model



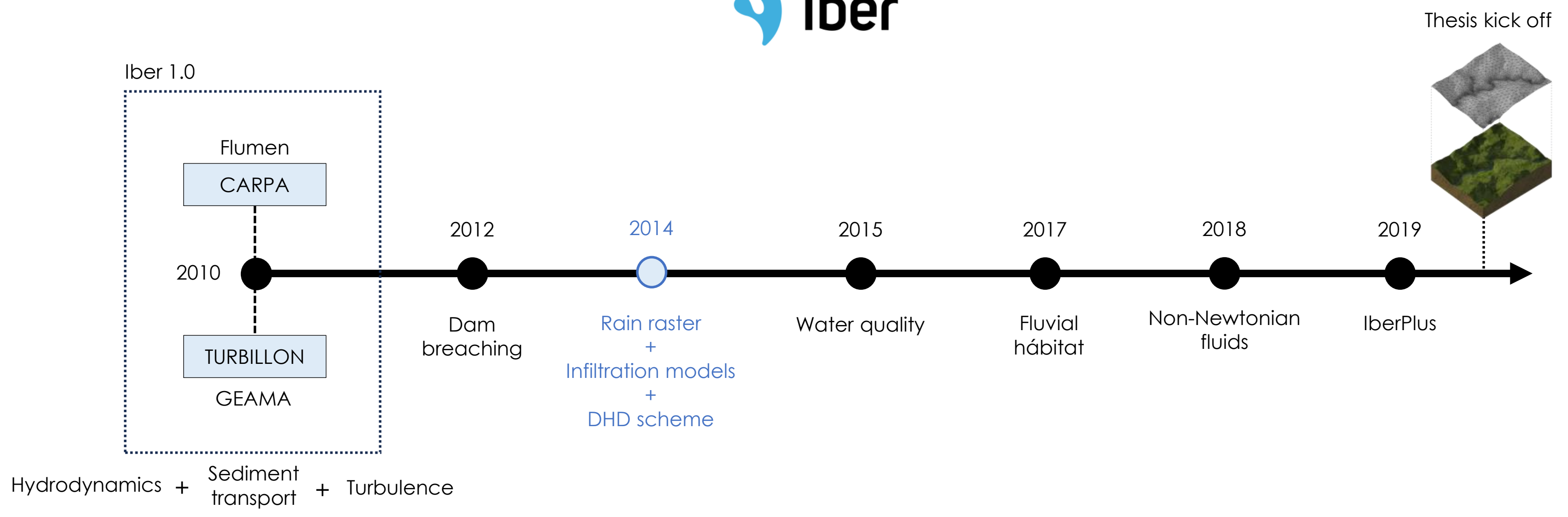
INTRODUCTION

HYDROLOGICAL MODELS

Distributed model

INTRODUCTION

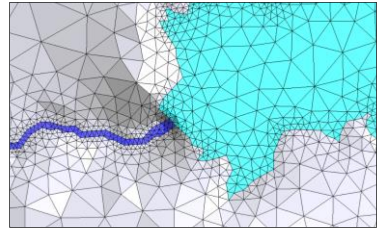
Iber



Collaboration between the Centre for Hydrographic Studies (CEDEX), GEAMA, Flumen and CIMNE. Supported by the Spanish Administration

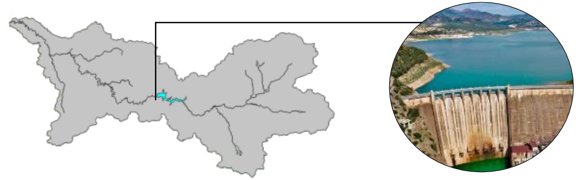
MOTIVATION

Scarcity of works that explicitly study the relationship between mesh sizes and DTM resolution, and their impact on the result.



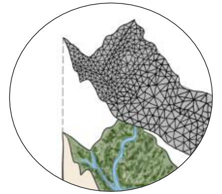
Scarcity of experimental data and numerical simplifications to include hydrodynamic computations at basin scale.

Models limited by not being able to include the presence of reservoirs and dams in the numerical modelling.



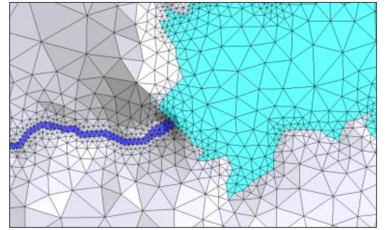
Need of reduction in uncertainty through the application of calibration techniques

3-7 parameters per element



MOTIVATION

Scarcity of works that explicitly study the relationship between mesh sizes and DTM resolution, and their impact on the result.



Scarcity of experimental data and numerical simplifications to include hydrodynamic computations at basin scale.

Models limited by not being able to include the presence of reservoirs and dams in the numerical modelling.

Need of reduction in uncertainty through the application of calibration techniques

3-7 parameters per element

MOTIVATION

Scarcity of works that explicitly study the relationship between mesh sizes and DTM resolution, and their impact on the result.

Scarcity of experimental data and numerical simplifications to include hydrodynamic computations at basin scale.

Models limited by not being able to include the presence of reservoirs and dams in the numerical modelling.

Need of reduction in uncertainty through the application of calibration techniques

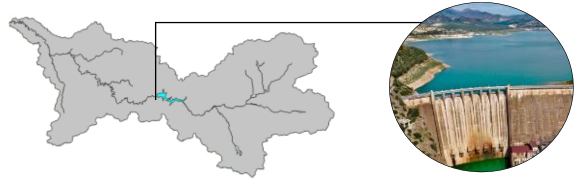
3-7 parameters per element

MOTIVATION

Scarcity of works that explicitly study the relationship between mesh sizes and DTM resolution, and their impact on the result.

Scarcity of experimental data and numerical simplifications to include hydrodynamic computations at basin scale.

Models limited by not being able to include the presence of reservoirs and dams in the numerical modelling.



Need of reduction in uncertainty through the application of calibration techniques

3-7 parameters per element

MOTIVATION

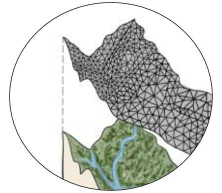
Scarcity of works that explicitly study the relationship between mesh sizes and DTM resolution, and their impact on the result.

Scarcity of experimental data and numerical simplifications to include hydrodynamic computations at basin scale.

Models limited by not being able to include the presence of reservoirs and dams in the numerical modelling.

Need of reduction in uncertainty through the application of calibration techniques

3-7 parameters per element



OBJECTIVES

MAIN OBJECTIVE

To contribute to the development of the hydrological module of the Iber model.

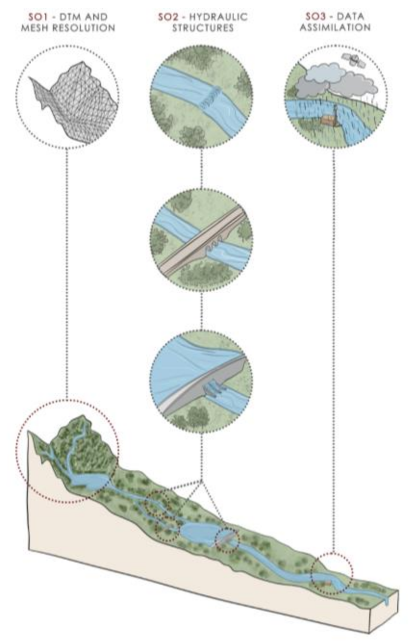
Iber

2024

To complete the capabilities of Iber for hydrological modelling at basin-scale

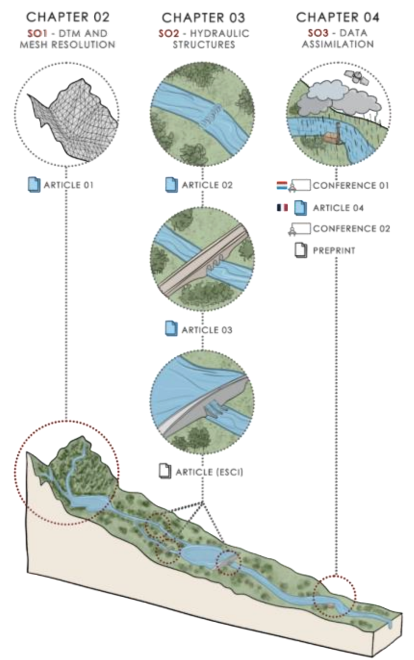
SPECIFIC OBJECTIVES

- **Specific Objective 1 (SO1)**: To evaluate the impact of Digital Terrain Model (DTM) resolution and mesh size on the result.
- **Specific Objective 2 (SO2)**: To evaluate the suitability of the Iber model in simulating anthropogenic modifications within natural catchments. To develop a dedicated reservoir module.
- **Specific Objective 3 (SO3)**: To explore the application new calibration techniques. To develop an automatic calibration tool to provide Iber modelers with flexible calibration options.

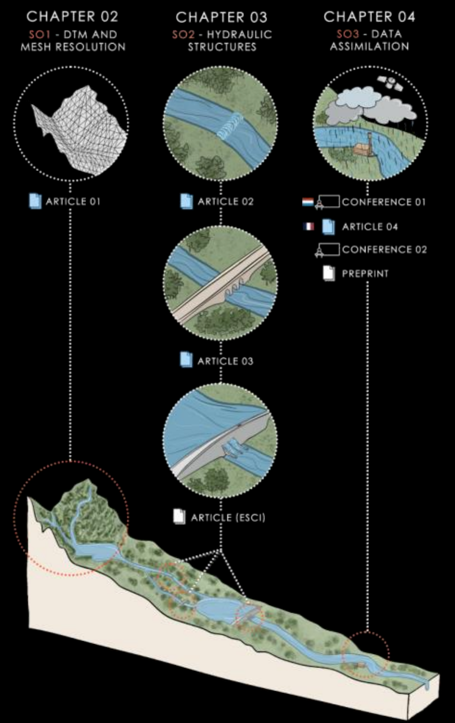


RESEARCH DEVELOPMENT

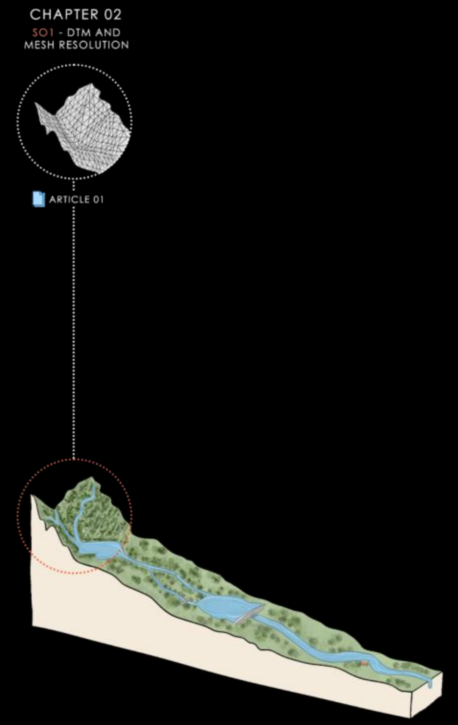
RESEARCH DEVELOPMENT



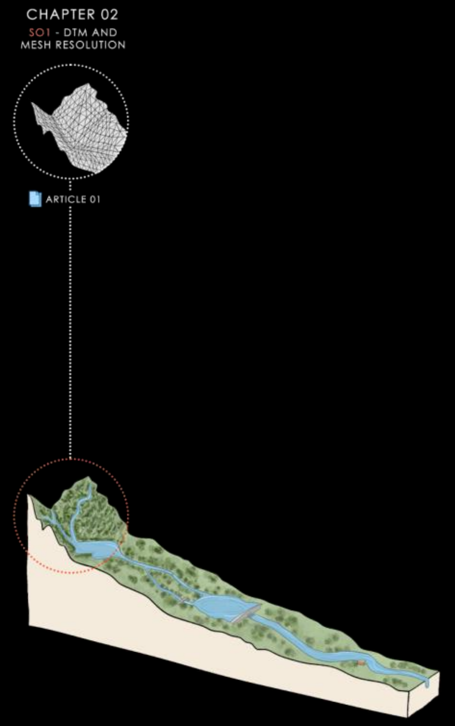
4. Research development



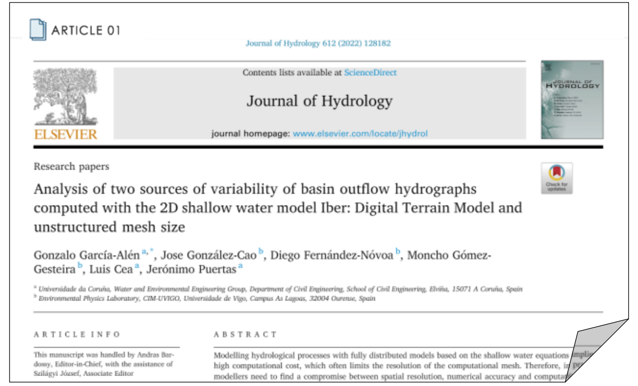
RESEARCH DEVELOPMENT



DTM AND MESH RESOLUTION



DTM AND MESH RESOLUTION



ARTICLE 01

Journal of Hydrology 612 (2022) 128182

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Analysis of two sources of variability of basin outflow hydrographs computed with the 2D shallow water model Iber: Digital Terrain Model and unstructured mesh size

Gonzalo García-Alén [a,*], Jose González-Cao [b], Diego Fernández-Nóvoa [b], Moncho Gómez-Gesteira [b], Luis Cea [a], Jerónimo Puertas [a]

[a] Universidade da Coruña, Water and Environmental Engineering Group, Department of Civil Engineering, School of Civil Engineering, Elviña, 15071 A Coruña, Spain
[b] Environmental Physics Laboratory, CIM-UVIGO, Universidade de Vigo, Campus As Lagoas, 32004 Ourense, Spain

ARTICLE INFO

This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Szilágyi József, Associate Editor

ABSTRACT

Modelling hydrological processes with fully distributed models based on the shallow water equations
high computational cost, which often limits the resolution of the computational mesh. Therefore, in
modellers need to find a compromise between spatial resolution, numerical accuracy and computat

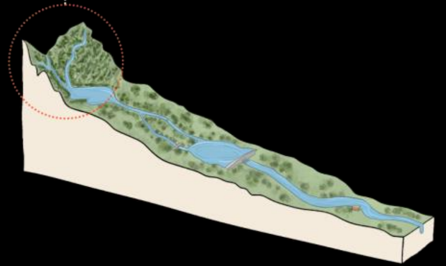
García-Alén, G., González-Cao, J., Fernández-Nóvoa, D., Gómez-Gesteira, M., Cea, L. & Puertas, J. (2022). Analysis of two sources of variability of basin outflow hydrographs computed with the 2D shallow water model Iber: Digital Terrain Model and unstructured mesh size. J. Hydrol. 612, 128182. https://doi.org/10.1016/j.jhydrol.2022.128182

In collaboration with:
Environmental Physics Laboratory
Universidade de Vigo

4. Research development

CHAPTER 02
S01 - DTM AND MESH RESOLUTION

ARTICLE 01

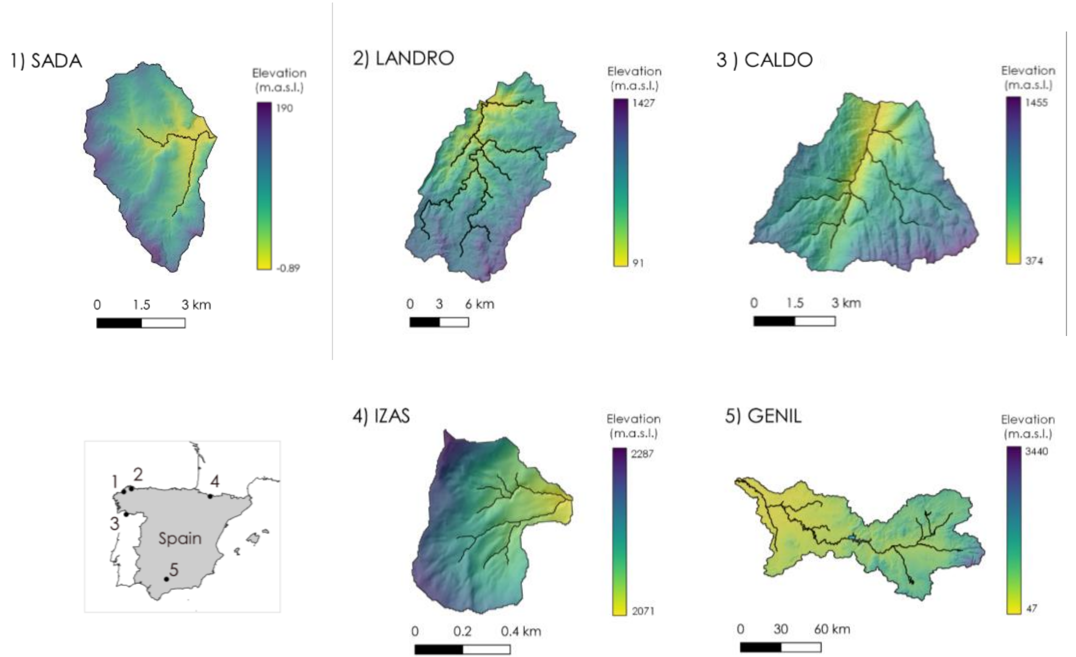


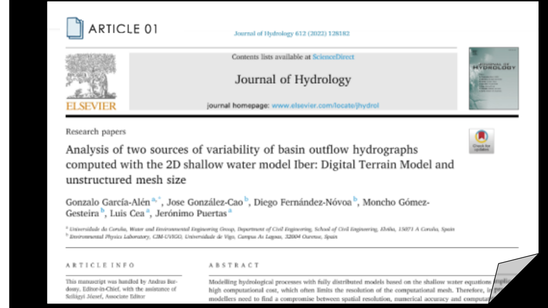
DTM AND MESH RESOLUTION

CASE STUDIES

Focus on diversity among the selected basins.

Watershed	Location	Area (km²)	Mean slope (°)	Altitude range (m.a.s.l.)	Average annual precip. (mm)	Average annual maximum daily precip. (mm)
Sada	North-western Spain	25	7	0 - 190	1300	66
Landro	North-western Spain	199	15	0 - 1033	1400	61.8
Caldo	North-western Spain	38	20	370 - 1200	1800	41
Izas	North-Eastern Spain	0.33	16	2060 - 2280	2000	36
Genil	Southern Spain	3750	7	47 - 1438	500	42.8




ARTICLE 01

Journal of Hydrology 612 (2022) 128182

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

ELSEVIER

Research papers

Analysis of two sources of variability of basin outflow hydrographs computed with the 2D shallow water model Iber: Digital Terrain Model and unstructured mesh size

Gonzalo García-Alén[a,*], Jose González-Cao[b], Diego Fernández-Nóvoa[b], Moncho Gómez-Gesteira[b], Luis Cea[a], Jerónimo Puertas[a]

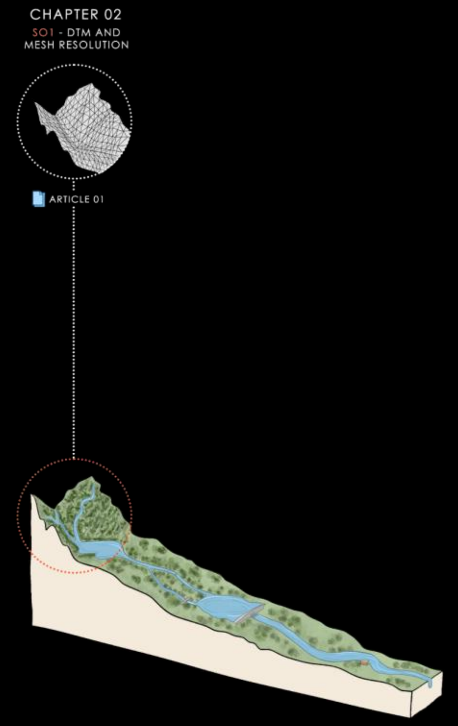
[a] Universidade da Coruña, Water and Environmental Engineering Group, Department of Civil Engineering, School of Civil Engineering, Elviña, 15071 A Coruña, Spain
[b] Environmental Physics Laboratory, CIM-UVIGO, Universidade de Vigo, Campus As Lagoas, 32004 Ourense, Spain

ARTICLE INFO

This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Szilágyi József, Associate Editor

ABSTRACT

Modelling hydrological processes with fully distributed models based on the shallow water equations
high computational cost, which often limits the resolution of the computational mesh. Therefore, in
modellers need to find a compromise between spatial resolution, numerical accuracy and computat



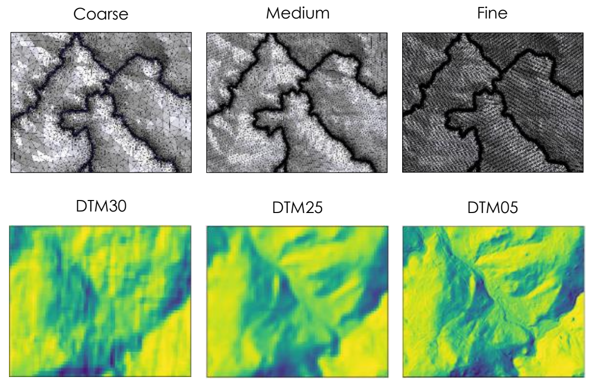
DTM AND MESH RESOLUTION

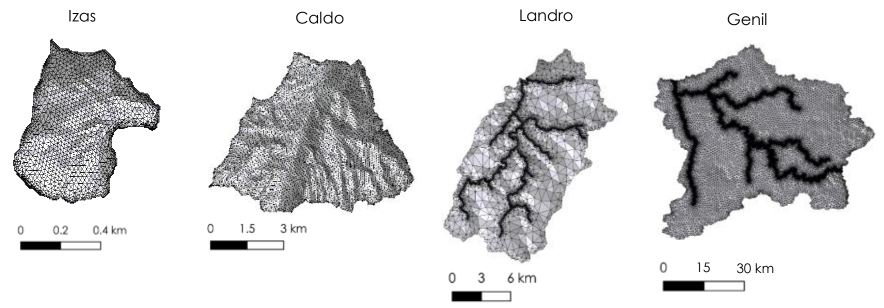
PURPOSE

Does the mesh size affect the outflow hydrograph of the catchment? And the DTM resolution?

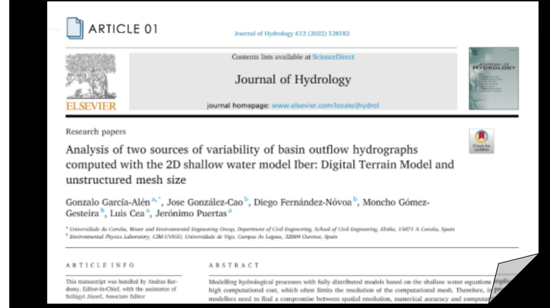
METHODOLOGY

- 7 rainfall events in 4 hydrological basins
- 9 model configurations were run for each event by combining 3 freely distributed DTMs with 3 different mesh sizes.





Watershed	Mesh size (m)	Number of elements (K)	Mesh Id.
Izas	10	7	Coarse
	2.5	116	Medium
	1	725	Fine
Caldo	100	9	Coarse
	25	127	Medium
	10	799	Fine
Landro	100	45	Coarse
	25	733	Medium
	10	4,587	Fine
Genil	250	119	Coarse
	62.5	1,933	Medium
	25	12,075	Fine


ARTICLE 01

Journal of Hydrology 612 (2022) 128182

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

ELSEVIER

Research papers

Analysis of two sources of variability of basin outflow hydrographs computed with the 2D shallow water model Iber: Digital Terrain Model and unstructured mesh size

Gonzalo García-Alén[a,*], Jose González-Cao[b], Diego Fernández-Nóvoa[b], Moncho Gómez-Gesteira[b], Luis Cea[a], Jerónimo Puertas[a]

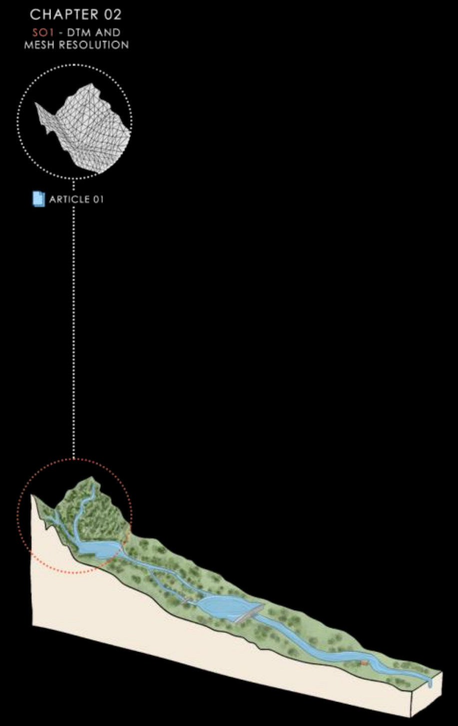
[a] Universidade da Coruña, Water and Environmental Engineering Group, Department of Civil Engineering, School of Civil Engineering, Elviña, 15071 A Coruña, Spain
[b] Environmental Physics Laboratory, CIM-UVIGO, Universidade de Vigo, Campus As Lagoas, 32004 Ourense, Spain

ARTICLE INFO

This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Szilágyi József, Associate Editor

ABSTRACT

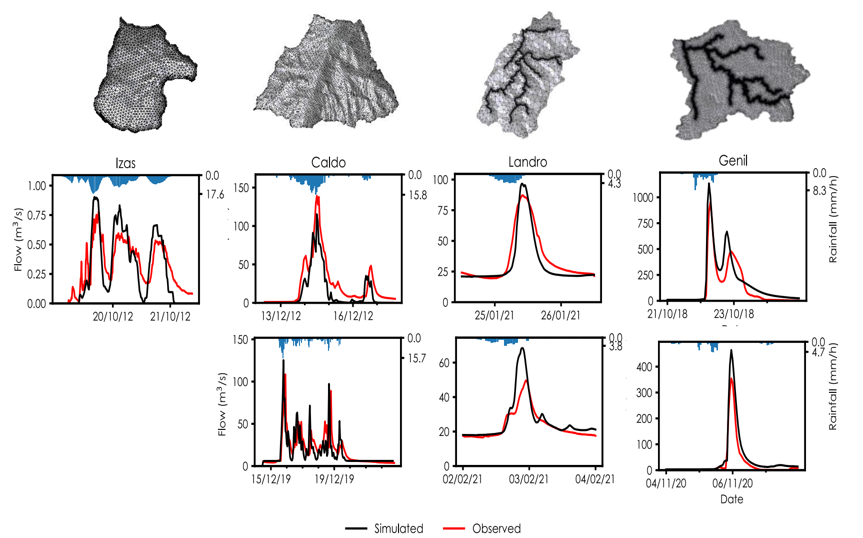
Modelling hydrological processes with fully distributed models based on the shallow water equations ... high computational cost, which often limits the resolution of the computational mesh. Therefore, in ... modellers need to find a compromise between spatial resolution, numerical accuracy and computat...

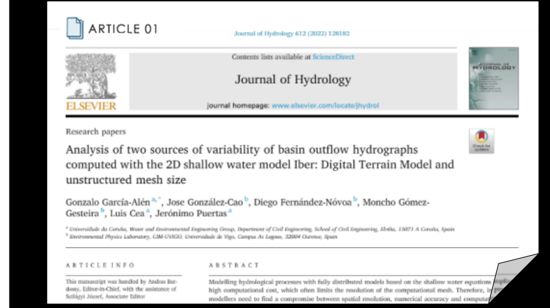


DTM AND MESH RESOLUTION

RESULTS

Result of DTM05 and fine mesh was taken as reference and compared with the observations for validation.




ARTICLE 01

Journal of Hydrology 612 (2022) 128182

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

ELSEVIER

Research papers

Analysis of two sources of variability of basin outflow hydrographs computed with the 2D shallow water model Iber: Digital Terrain Model and unstructured mesh size

Gonzalo García-Alén[a,*], Jose González-Cao[b], Diego Fernández-Nóvoa[b], Moncho Gómez-Gesteira[b], Luis Cea[a], Jerónimo Puertas[a]

[a] Universidade da Coruña, Water and Environmental Engineering Group, Department of Civil Engineering, School of Civil Engineering, Elviña, 15071 A Coruña, Spain
[b] Environmental Physics Laboratory, CIM-UVIGO, Universidade de Vigo, Campus As Lagoas, 32004 Ourense, Spain

ARTICLE INFO

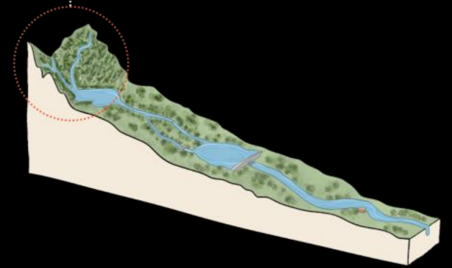
This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Szilágyi József, Associate Editor

ABSTRACT

Modelling hydrological processes with fully distributed models based on the shallow water equations ... high computational cost, which often limits the resolution of the computational mesh. Therefore, ... modellers need to find a compromise between spatial resolution, numerical accuracy and computat...

CHAPTER 02
SO1 - DTM AND MESH RESOLUTION

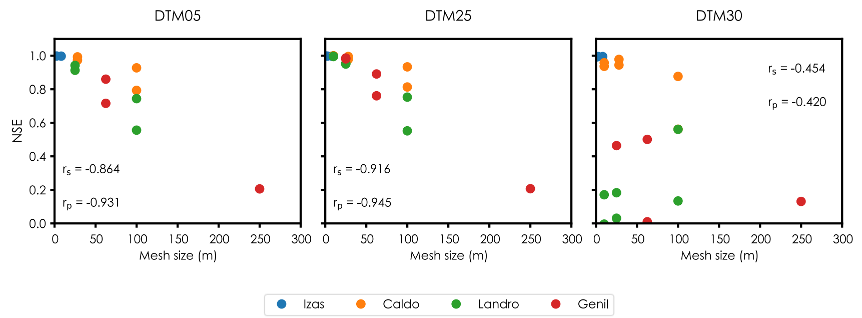
ARTICLE 01

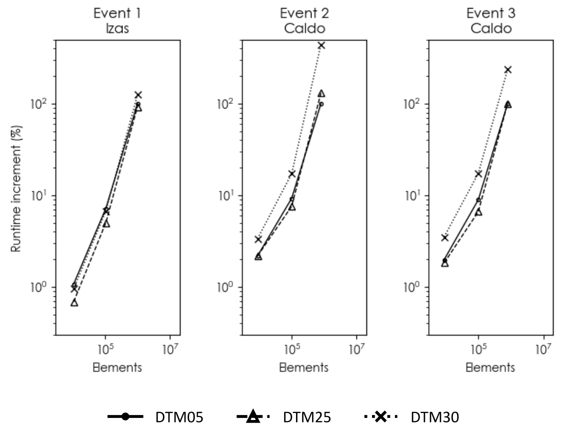


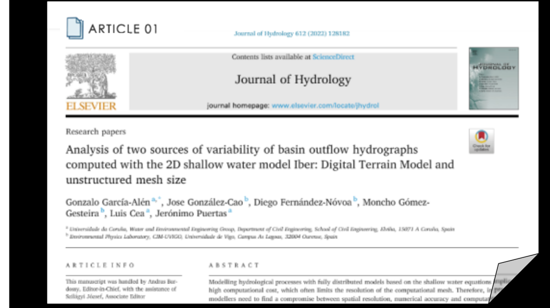
DTM AND MESH RESOLUTION

RESULTS

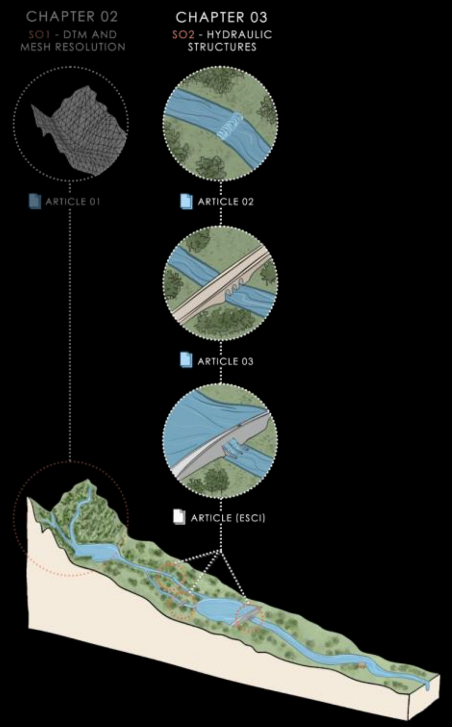
- Vertical accuracy is more relevant than the horizontal resolution of the DTM.
- For DTM05 and DTM25, we find good results from a mesh resolution threshold close to 25 m
- In comparison with the fine mesh, the use of the medium mesh results in a reduction of 90% on the calculation time.



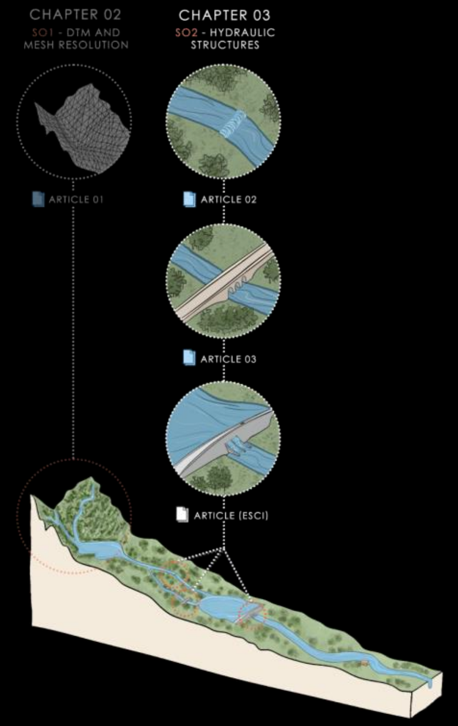




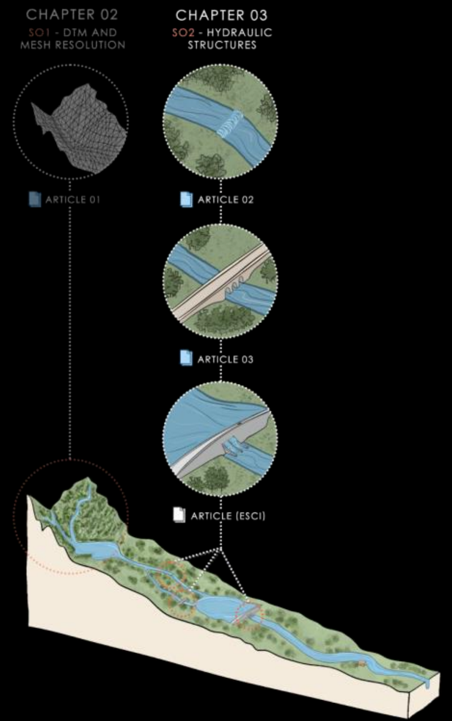
4. Research development



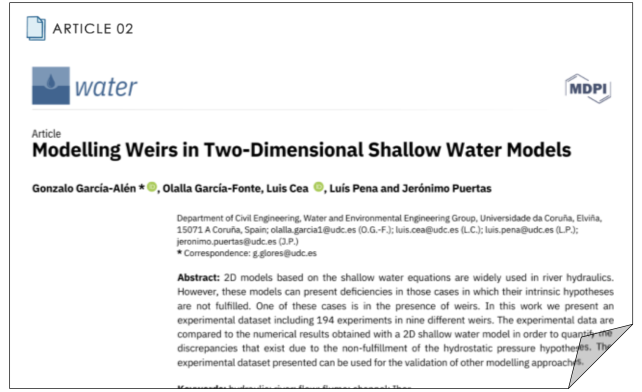
HYDRAULIC STRUCTURES



HYDRAULIC STRUCTURES



HYDRAULIC STRUCTURES: FLOW OVER WEIRS


ARTICLE 02

water MDPI

Article

Modelling Weirs in Two-Dimensional Shallow Water Models

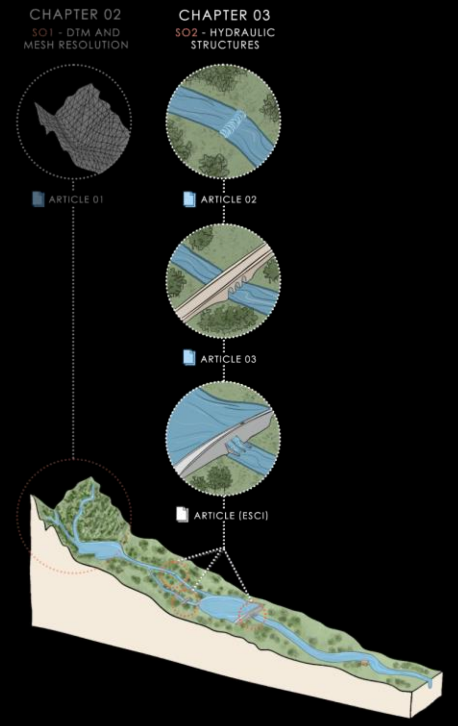
Gonzalo García-Alén *, Olalla García-Fonte, Luis Cea, Luís Pena and Jerónimo Puertas

Department of Civil Engineering, Water and Environmental Engineering Group, Universidade da Coruña, Elviña, 15071 A Coruña, Spain; olalla.garcia1@udc.es (O.G.-F.); luis.cea@udc.es (L.C.); luis.pena@udc.es (L.P.); jeronimo.puertas@udc.es (J.P.)
* Correspondence: g.glores@udc.es

Abstract: 2D models based on the shallow water equations are widely used in river hydraulics. However, these models can present deficiencies in those cases in which their intrinsic hypotheses are not fulfilled. One of these cases is in the presence of weirs. In this work we present an experimental dataset including 194 experiments in nine different weirs. The experimental data are compared to the numerical results obtained with a 2D shallow water model in order to quantify the discrepancies that exist due to the non-fulfillment of the hydrostatic pressure hypotheses. The experimental dataset presented can be used for the validation of other modelling approaches.

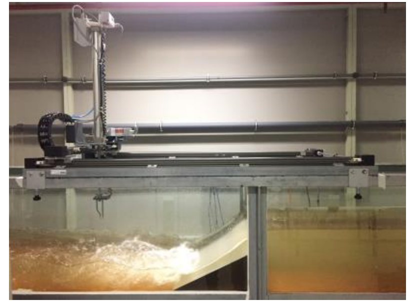
García-Alén, G., García-Fonte, O., Cea, L., Pena, L., Puertas, J., 2021. Modelling Weirs in Two-Dimensional Shallow Water Models. Water 13. https://doi.org/10.3390/w13162152

4. Research development

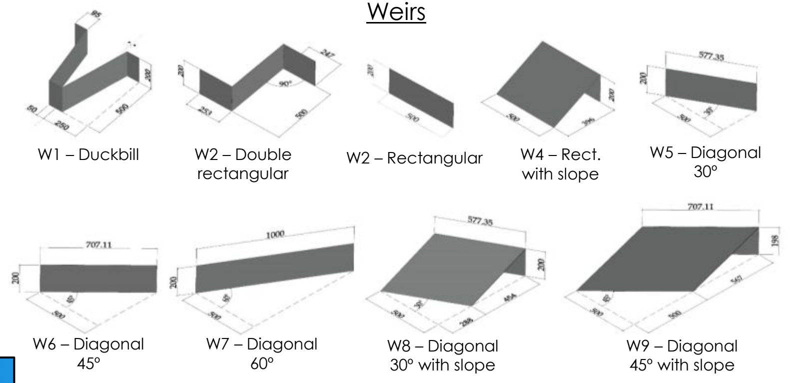


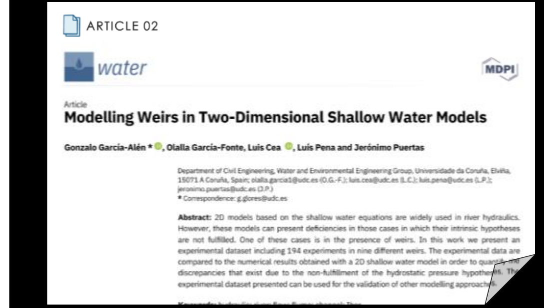
HYDRAULIC STRUCTURES: FLOW OVER WEIRS

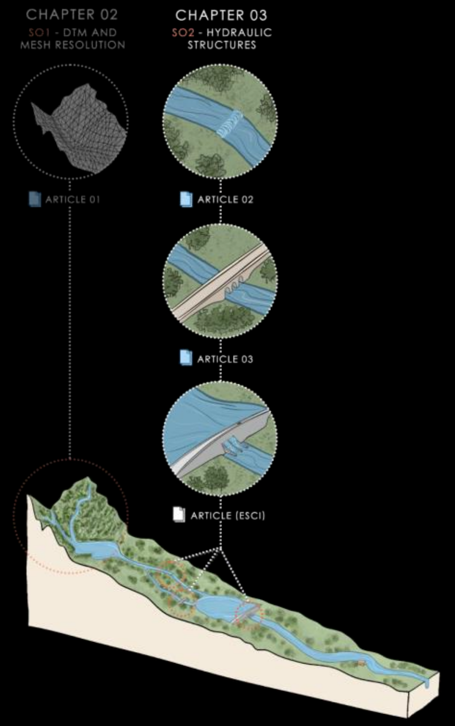
EXPERIMENTAL WORK



Weirs

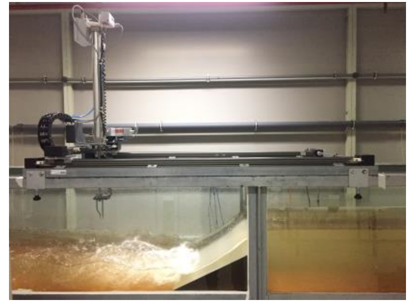


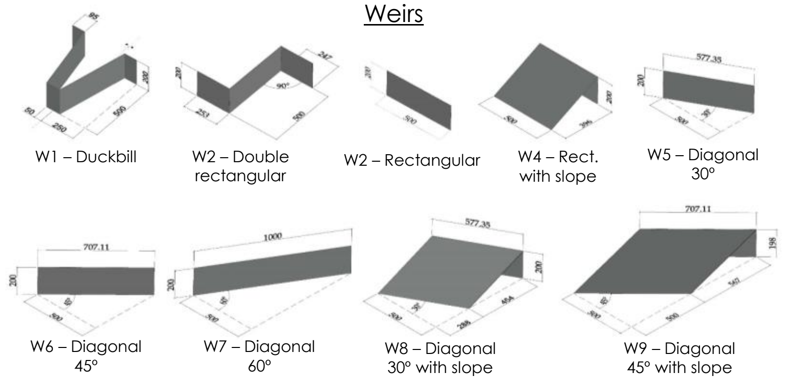


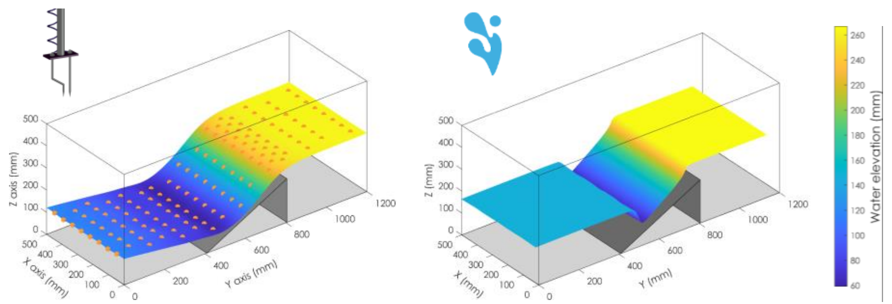


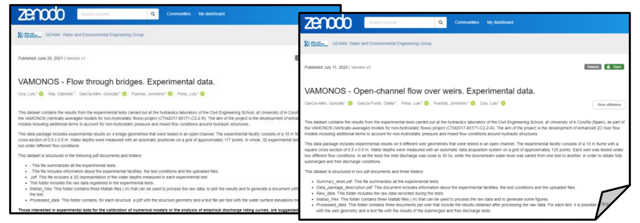
HYDRAULIC STRUCTURES: FLOW OVER WEIRS

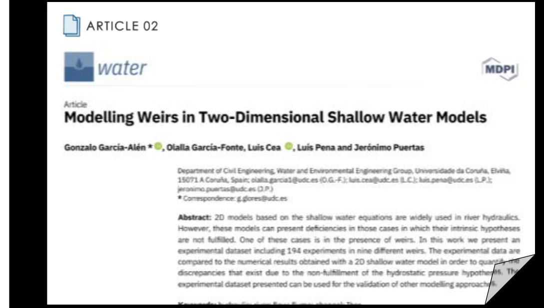
EXPERIMENTAL WORK










ARTICLE 02

water

MDPI

Article

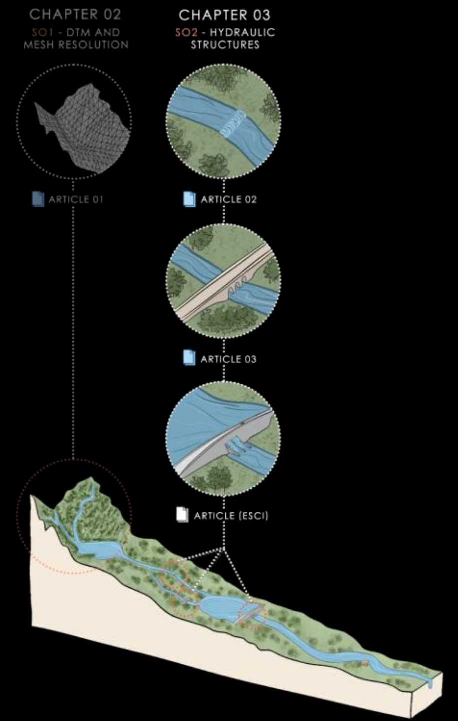
Modelling Weirs in Two-Dimensional Shallow Water Models

Gonzalo García-Alén *, Olalla García-Fonte, Luis Cea, Luís Pena and Jerónimo Puertas

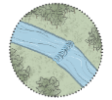
Department of Civil Engineering, Water and Environmental Engineering Group, Universidade da Coruña, Elviña, 15071 A Coruña, Spain; olalla.garcia1@udc.es (O.G.-F.); luis.cea@udc.es (L.C.); luis.pena@udc.es (L.P.); jeronimo.puertas@udc.es (J.P.)
* Correspondence: g.glores@udc.es

Abstract: 2D models based on the shallow water equations are widely used in river hydraulics. However, these models can present deficiencies in those cases in which their intrinsic hypotheses are not fulfilled. One of these cases is in the presence of weirs. In this work we present an experimental dataset including 194 experiments in nine different weirs. The experimental data are compared to the numerical results obtained with a 2D shallow water model in order to quantify the discrepancies that exist due to the non-fulfillment of the hydrostatic pressure hypotheses. The experimental dataset presented can be used for the validation of other modelling approaches.

4. **Research development**



HYDRAULIC STRUCTURES: FLOW OVER WEIRS

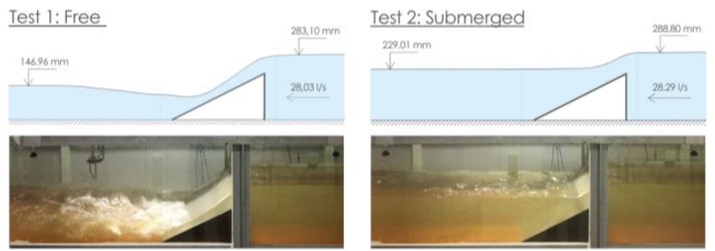


PURPOSE

What is the most accurate methodology for modelling flow over weirs?

METHODOLOGY

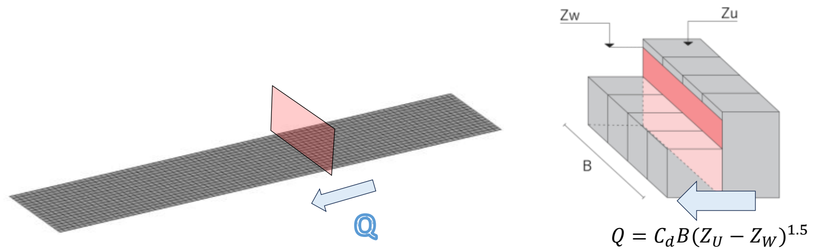
- Experimental campaign based on 2 flow conditions.



- Water depth was measured in a control point (CP) and with an automatic positioner.

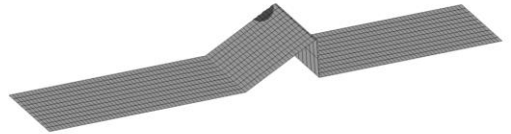
Experimental tests were modelled with the software Iber using two different approaches:

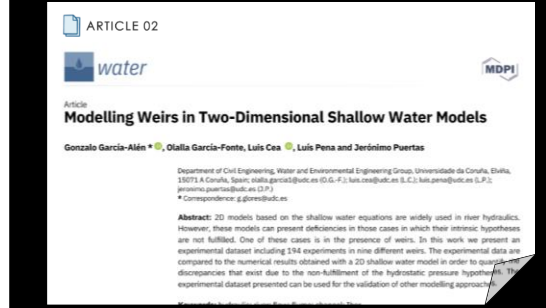
(1) Using a specific internal discharge equation (classic formulation).



$$Q = C_d B (Z_U - Z_W)^{1.5}$$

(2) Modelling the weirs as the topography of the flume.




ARTICLE 02

water MDPI

Article

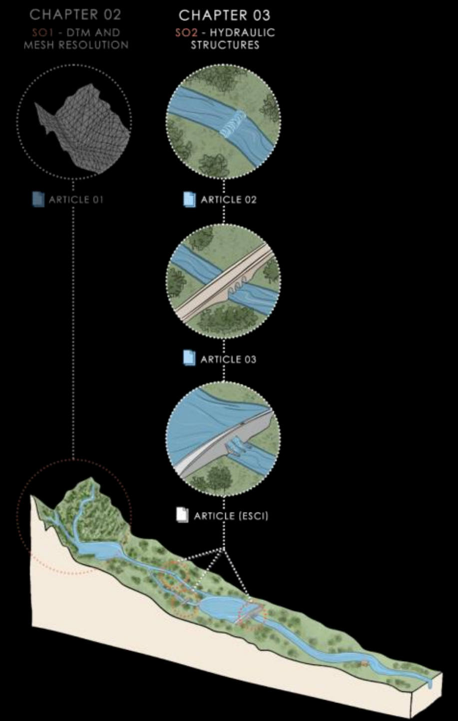
Modelling Weirs in Two-Dimensional Shallow Water Models

Gonzalo García-Alén *, Olalla García-Fonte, Luis Cea, Luis Pena and Jerónimo Puertas

Department of Civil Engineering, Water and Environmental Engineering Group, Universidade da Coruña, Elviña, 15071 A Coruña, Spain; olalla.garcia1@udc.es (O.G.-F.); luis.cea@udc.es (L.C.); luis.pena@udc.es (L.P.); jeronimo.puertas@udc.es (J.P.)
* Correspondence: g.glores@udc.es

Abstract: 2D models based on the shallow water equations are widely used in river hydraulics. However, these models can present deficiencies in those cases in which their intrinsic hypotheses are not fulfilled. One of these cases is in the presence of weirs. In this work we present an experimental dataset including 194 experiments in nine different weirs. The experimental data are compared to the numerical results obtained with a 2D shallow water model in order to quantify the discrepancies that exist due to the non-fulfillment of the hydrostatic pressure hypotheses. The experimental dataset presented can be used for the validation of other modelling approaches.

4. Research development



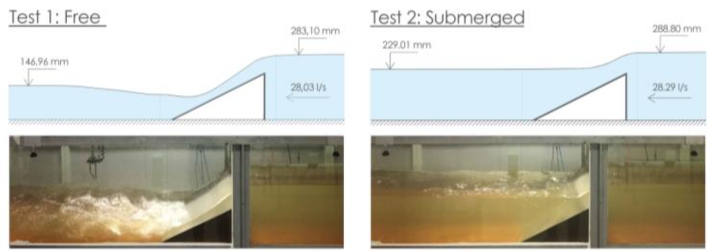
HYDRAULIC STRUCTURES: FLOW OVER WEIRS

PURPOSE

What is the most accurate methodology for modelling flow over weirs?

METHODOLOGY

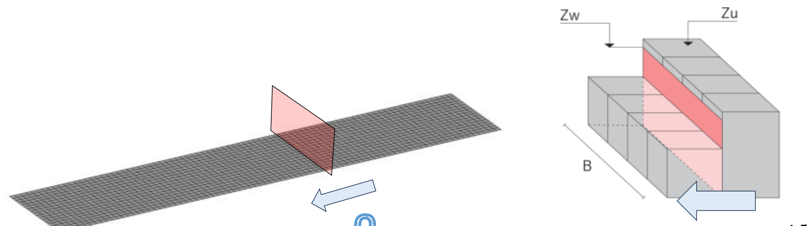
- Experimental campaign based on 2 flow conditions.



- Water depth was measured in a control point (CP) and with an automatic positioner.

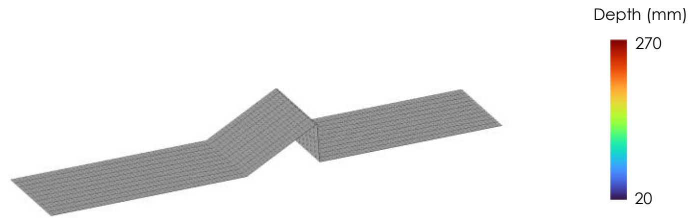
Experimental tests were modelled with the software Iber using two different approaches:

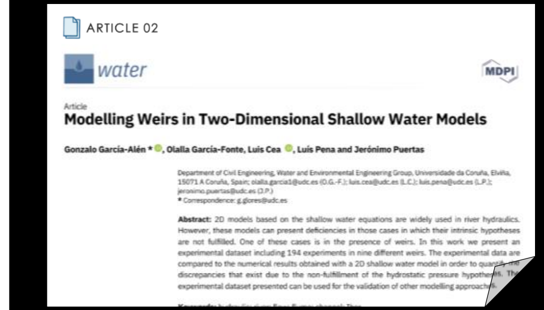
(1) Using a specific internal discharge equation (classic formulation).

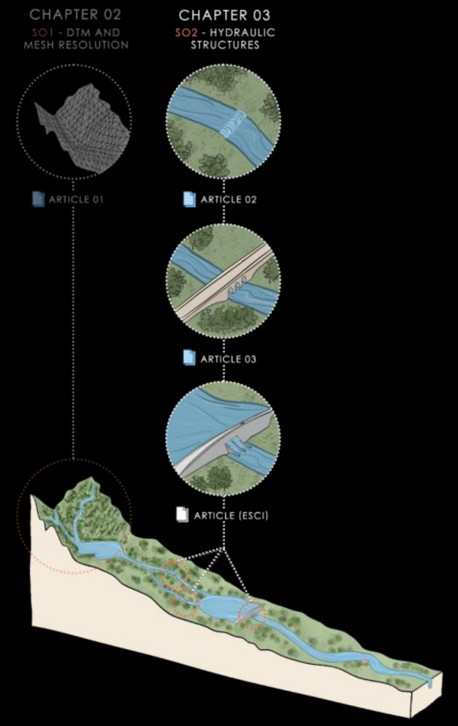


$$Q = C_d B (Z_U - Z_W)^{1.5}$$

(2) Modelling the weirs as the topography of the flume.

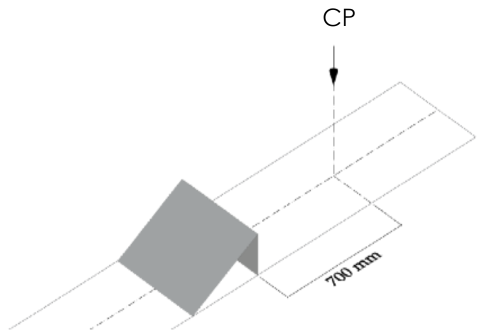


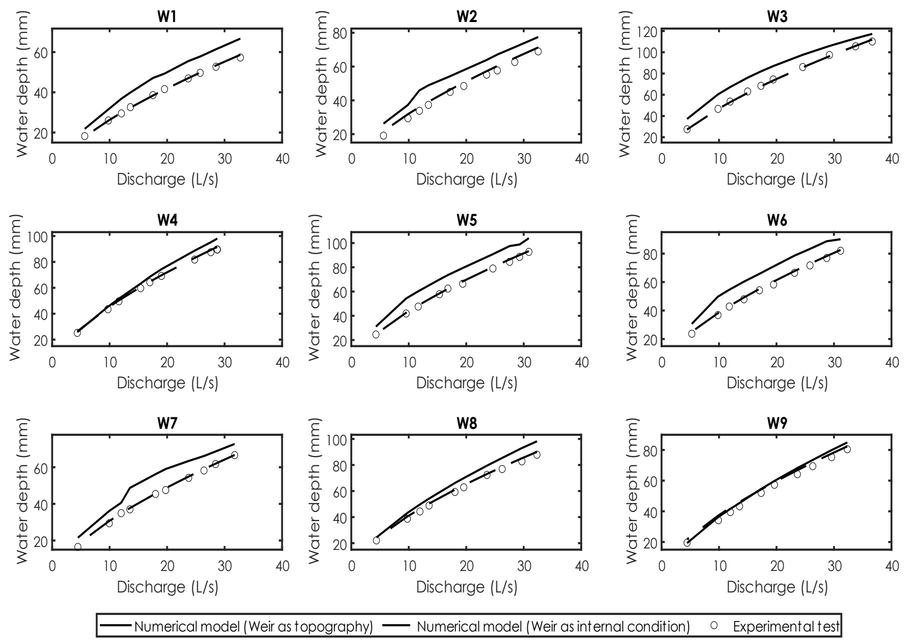


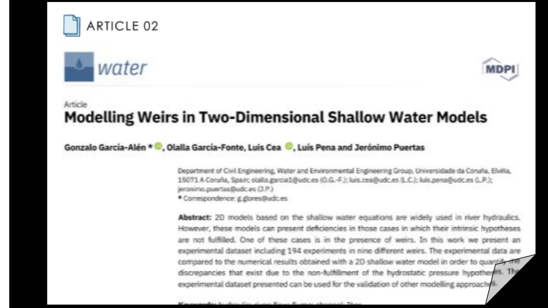


HYDRAULIC STRUCTURES: FLOW OVER WEIRS

RESULTS (CP POINT)






ARTICLE 02

water MDPI

Article

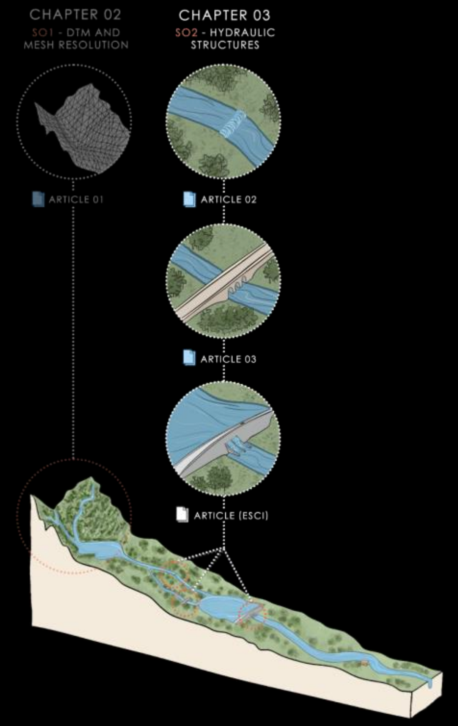
Modelling Weirs in Two-Dimensional Shallow Water Models

Gonzalo García-Alén *, Olalla García-Fonte, Luis Cea, Luís Pena and Jerónimo Puertas

Department of Civil Engineering, Water and Environmental Engineering Group, Universidade da Coruña, Elviña, 15071 A Coruña, Spain; olalla.garcia1@udc.es (O.G.-F.); luis.cea@udc.es (L.C.); luis.pena@udc.es (L.P.); jeronimo.puertas@udc.es (J.P.)
* Correspondence: g.glores@udc.es

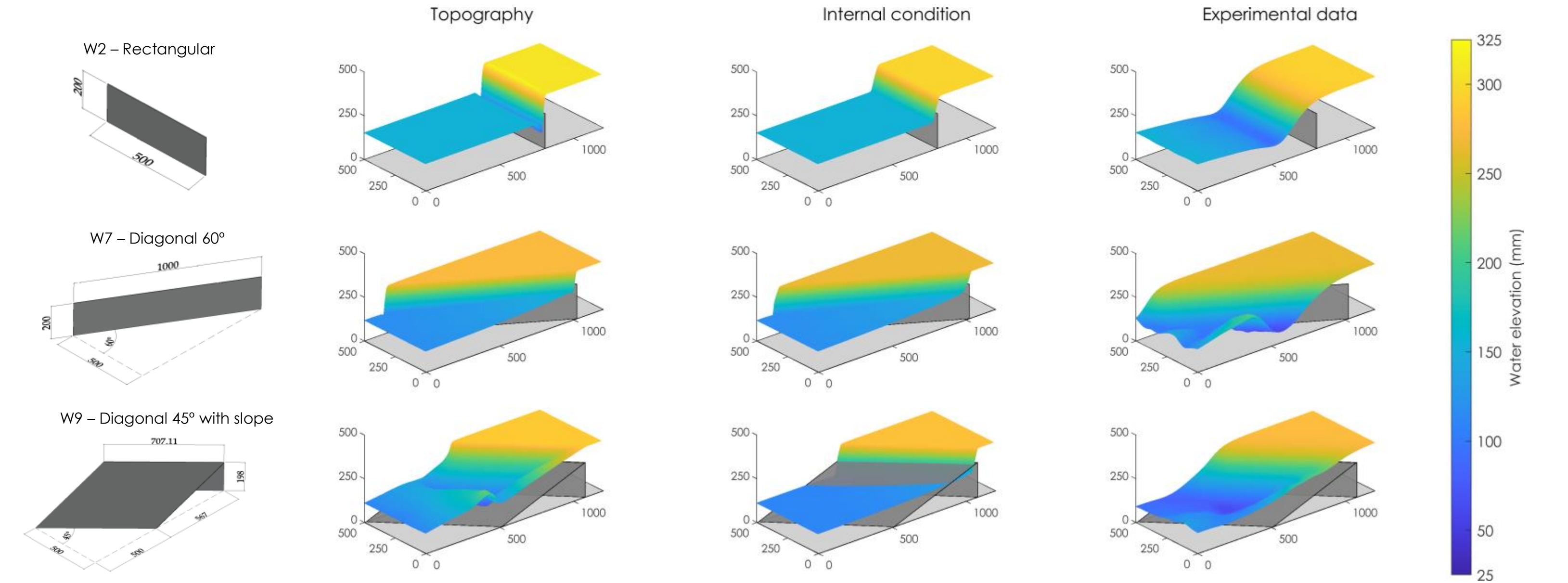
Abstract: 2D models based on the shallow water equations are widely used in river hydraulics. However, these models can present deficiencies in those cases in which their intrinsic hypotheses are not fulfilled. One of these cases is in the presence of weirs. In this work we present an experimental dataset including 194 experiments in nine different weirs. The experimental data are compared to the numerical results obtained with a 2D shallow water model in order to quantify the discrepancies that exist due to the non-fulfillment of the hydrostatic pressure hypotheses. The experimental dataset presented can be used for the validation of other modelling approaches.

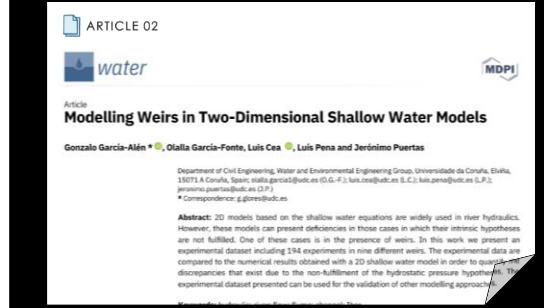
4. Research development



HYDRAULIC STRUCTURES: FLOW OVER WEIRS

RESULTS (AUTOMATIC POSITIONER)




ARTICLE 02

water

MDPI

Article

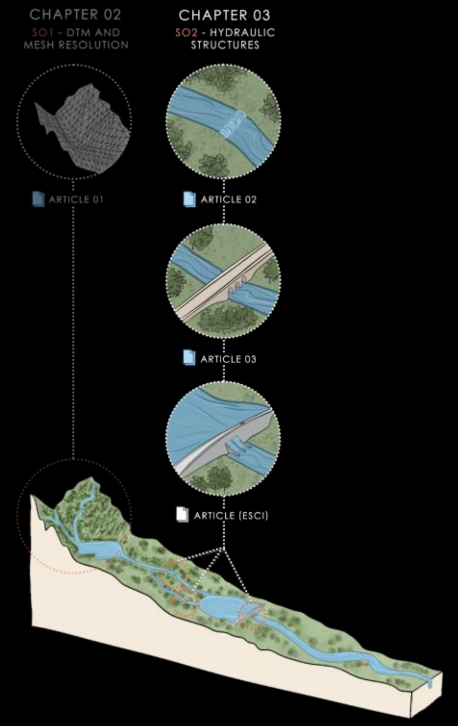
Modelling Weirs in Two-Dimensional Shallow Water Models

Gonzalo García-Alén *, Olalla García-Fonte, Luis Cea, Luís Pena and Jerónimo Puertas

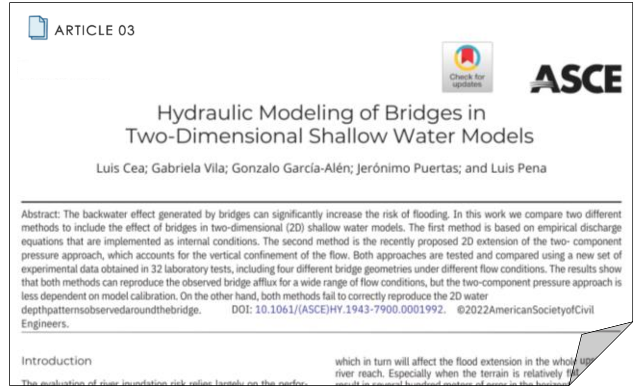
Department of Civil Engineering, Water and Environmental Engineering Group, Universidade da Coruña, Elviña, 15071 A Coruña, Spain; olalla.garcia1@udc.es (O.G.-F.); luis.cea@udc.es (L.C.); luis.pena@udc.es (L.P.); jeronimo.puertas@udc.es (J.P.)
* Correspondence: g.glores@udc.es

Abstract: 2D models based on the shallow water equations are widely used in river hydraulics. However, these models can present deficiencies in those cases in which their intrinsic hypotheses are not fulfilled. One of these cases is in the presence of weirs. In this work we present an experimental dataset including 194 experiments in nine different weirs. The experimental data are compared to the numerical results obtained with a 2D shallow water model in order to quantify the discrepancies that exist due to the non-fulfillment of the hydrostatic pressure hypotheses. The experimental dataset presented can be used for the validation of other modelling approaches.

4. Research development



HYDRAULIC STRUCTURES: FLOW THROUGH BRIDGES


ARTICLE 03

ASCE

Hydraulic Modeling of Bridges in Two-Dimensional Shallow Water Models

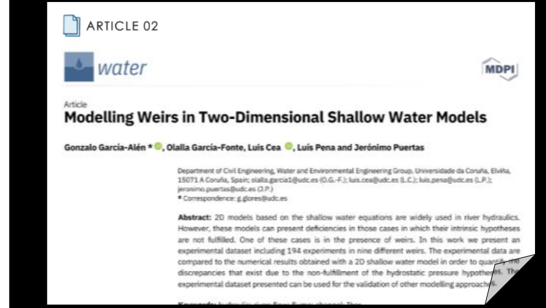
Luis Cea; Gabriela Vila; Gonzalo García-Alén; Jerónimo Puertas; and Luis Pena

Abstract: The backwater effect generated by bridges can significantly increase the risk of flooding. In this work we compare two different methods to include the effect of bridges in two-dimensional (2D) shallow water models. The first method is based on empirical discharge equations that are implemented as internal conditions. The second method is the recently proposed 2D extension of the two- component pressure approach, which accounts for the vertical confinement of the flow. Both approaches are tested and compared using a new set of experimental data obtained in 32 laboratory tests, including four different bridge geometries under different flow conditions. The results show that both methods can reproduce the observed bridge afflux for a wide range of flow conditions, but the two-component pressure approach is less dependent on model calibration. On the other hand, both methods fail to correctly reproduce the 2D water depthpatternsobservedaroundthebridge. DOI: 10.1061/(ASCE)HY.1943-7900.0001992. ©2022AmericanSocietyofCivil Engineers.

Introduction

which in turn will affect the flood extension in the whole river reach. Especially when the terrain is relatively

Cea, L., Vila, G., García-Alén, G., Puertas, J. & Pena, L. (2022). Hydraulic Modeling of Bridges in Two-Dimensional Shallow Water Models. Journal of Hydraulic Engineering. 148, 6022006. https://doi.org/10.1061/(ASCE)HY.1943-7900.0001992


ARTICLE 02

water

MDPI

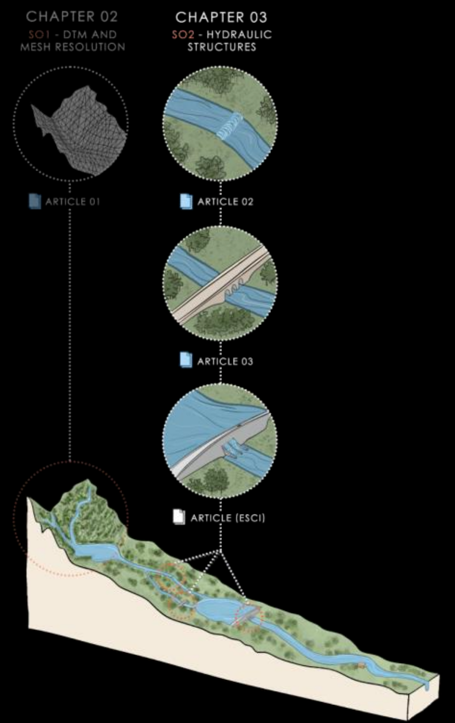
Article

Modelling Weirs in Two-Dimensional Shallow Water Models

Gonzalo García-Alén *, Olalla García-Fonte, Luis Cea, Luis Pena and Jerónimo Puertas

Department of Civil Engineering, Water and Environmental Engineering Group, Universidade da Coruña, Elviña, 15071 A Coruña, Spain; olalla.garcia1@udc.es (O.G.-F.); luis.cea@udc.es (L.C.); luis.pena@udc.es (L.P.); jeronimo.puertas@udc.es (J.P.)
* Correspondence: g.glores@udc.es

Abstract: 2D models based on the shallow water equations are widely used in river hydraulics. However, these models can present deficiencies in those cases in which their intrinsic hypotheses are not fulfilled. One of these cases is in the presence of weirs. In this work we present an experimental dataset including 194 experiments in nine different weirs. The experimental data are compared to the numerical results obtained with a 2D shallow water model in order to quantify the discrepancies that exist due to the non-fulfillment of the hydrostatic pressure hypotheses. The experimental dataset presented can be used for the validation of other modelling approaches.



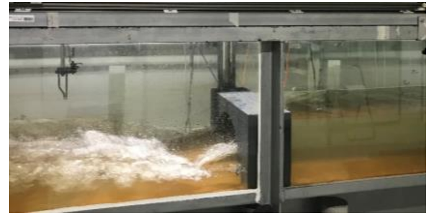
HYDRAULIC STRUCTURES: FLOW THROUGH BRIDGES

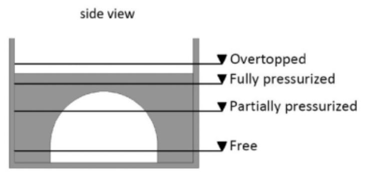
PURPOSE

What is the most accurate methodology for modelling flow through bridges?

METHODOLOGY

- Set of 32 experimental test conducted with four bridge geometries.
- Water depth was measured in a control point (CP) and with the automatic positioner.
- Four different test conditions: overtopped, fully pressurized, partially pressurized and free.



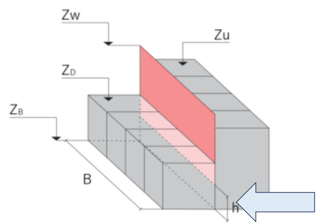


- All the experimental tests were reproduced in Iber using two different approaches to account for the deck:

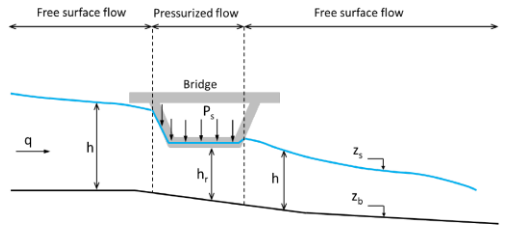
(1) the commonly used internal condition for bridges (**ICB**)

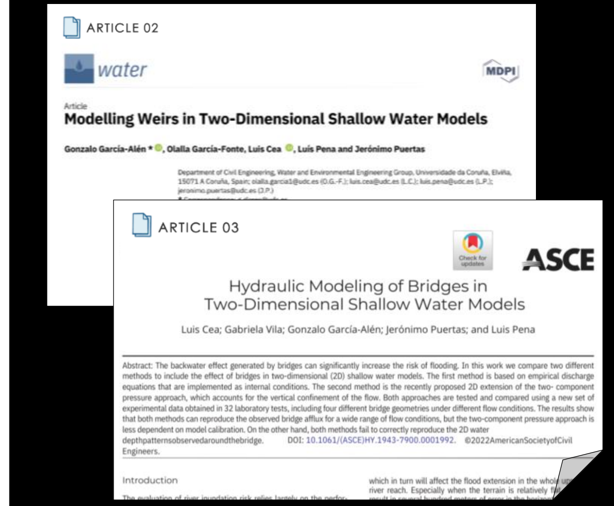
$$Q_{over} = C_d B (Z_U - Z_W)^{1.5}$$

$$Q_{under} = C_d B h \sqrt{2g(Z_U - Z_B)}$$



(2) the more recent extension of the two-component pressure approach (**TPA**) applied by Cea and López-Núñez (2021).




ARTICLE 02

water

MDPI

Article

Modelling Weirs in Two-Dimensional Shallow Water Models

Gonzalo García-Alén *, Olalla García-Fonte, Luis Cea, Luis Pena and Jerónimo Puertas

Department of Civil Engineering, Water and Environmental Engineering Group, Universidade da Coruña, Elviña, 15071 A Coruña, Spain; olalla.garcia1@udc.es (O.G.-F.); luis.cea@udc.es (L.C.); luis.pena@udc.es (L.P.); jeronimo.puertas@udc.es (J.P.)

ARTICLE 03

Check for updates

ASCE

Hydraulic Modeling of Bridges in Two-Dimensional Shallow Water Models

Luis Cea; Gabriela Vila; Gonzalo García-Alén; Jerónimo Puertas; and Luis Pena

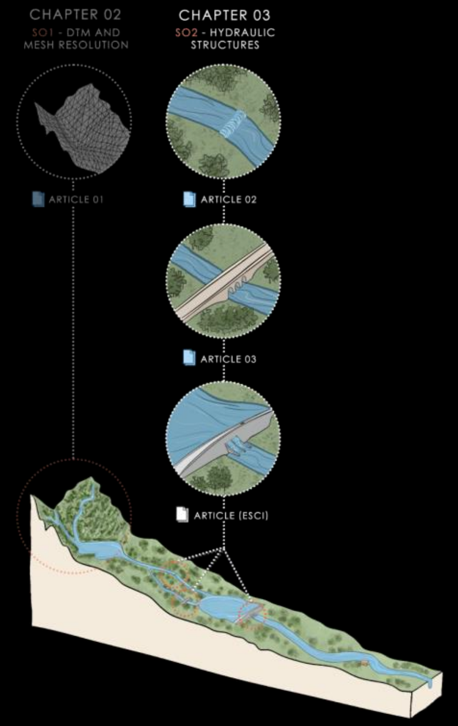
Abstract: The backwater effect generated by bridges can significantly increase the risk of flooding. In this work we compare two different methods to include the effect of bridges in two-dimensional (2D) shallow water models. The first method is based on empirical discharge equations that are implemented as internal conditions. The second method is the recently proposed 2D extension of the two- component pressure approach, which accounts for the vertical confinement of the flow. Both approaches are tested and compared using a new set of experimental data obtained in 32 laboratory tests, including four different bridge geometries under different flow conditions. The results show that both methods can reproduce the observed bridge afflux for a wide range of flow conditions, but the two-component pressure approach is less dependent on model calibration. On the other hand, both methods fail to correctly reproduce the 2D water depthpatternsobservedaroundthebridge. DOI: 10.1061/(ASCE)HY.1943-7900.0001992. ©2022AmericanSocietyofCivil Engineers.

Introduction

which in turn will affect the flood extension in the whole

river reach. Especially when the terrain is relatively

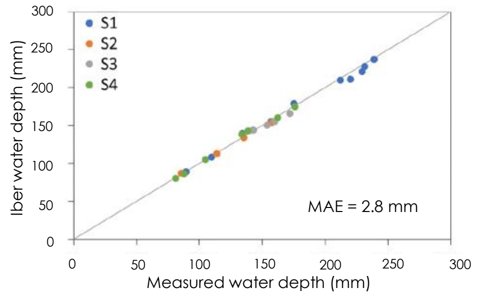
4. Research development

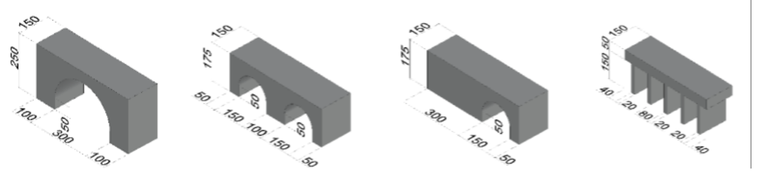


HYDRAULIC STRUCTURES: FLOW THROUGH BRIDGES

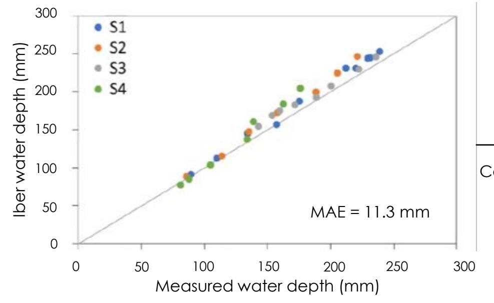
RESULTS (CP POINT)

TPA Approach



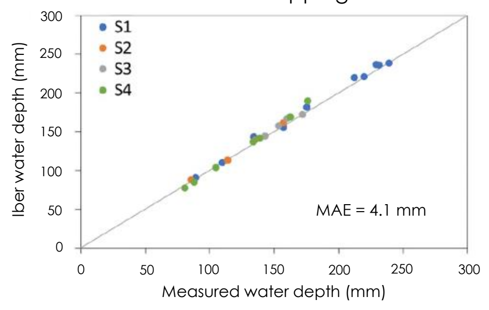


ICB Approach

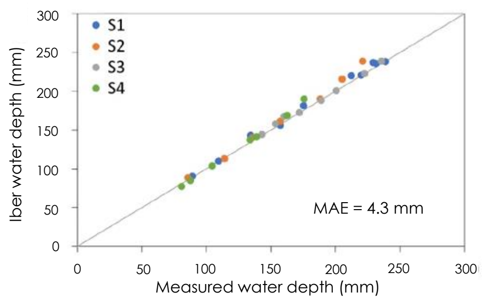


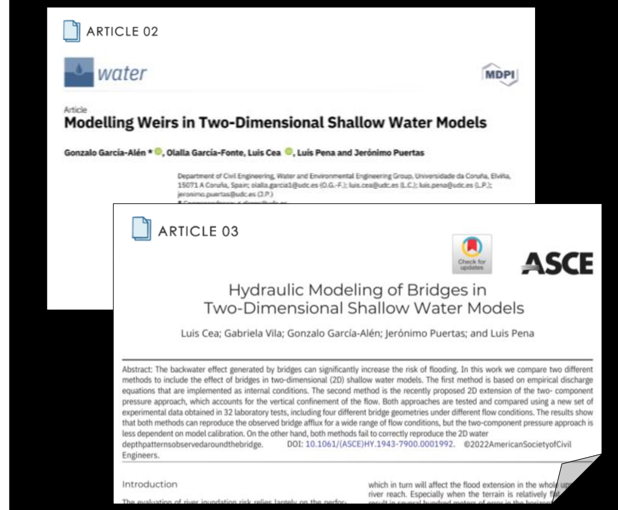
Calibration

No overtopping

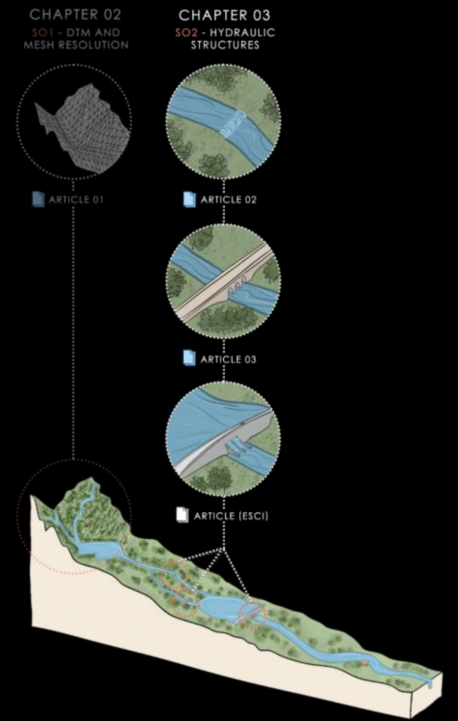


All tests



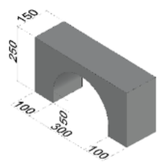


4. Research development

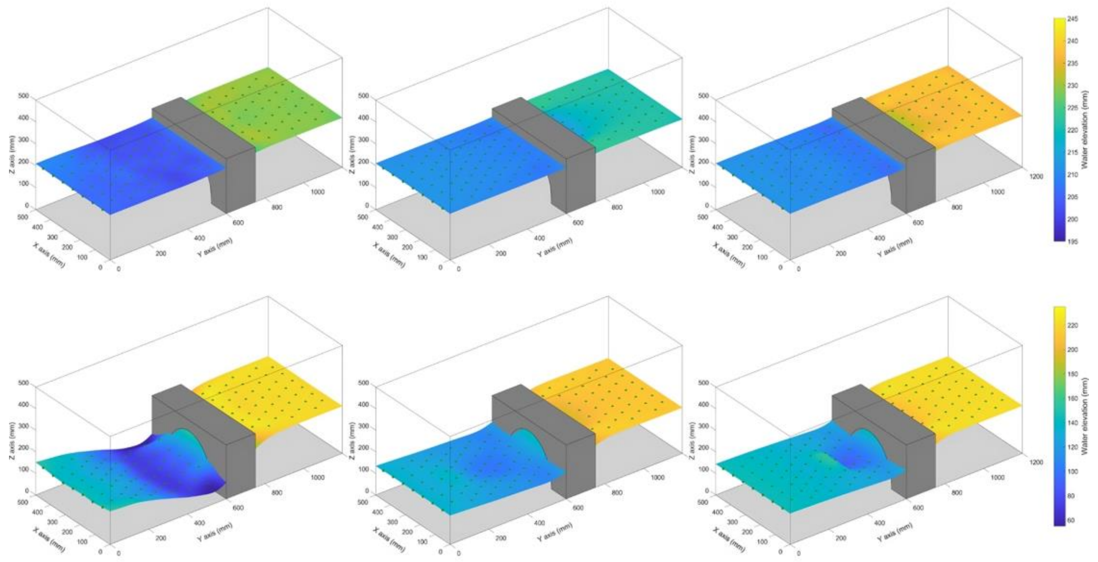


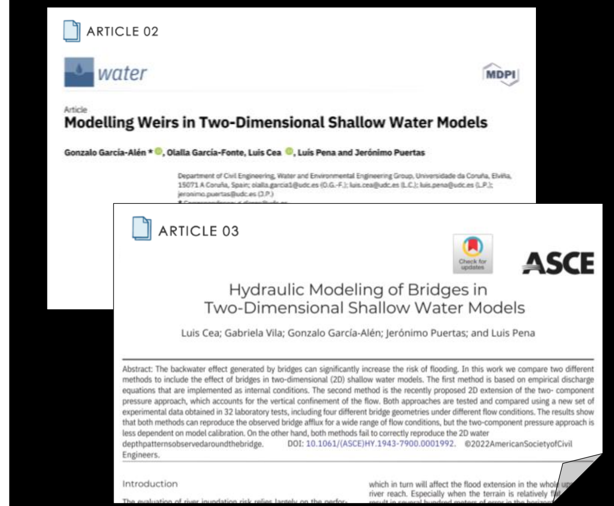
HYDRAULIC STRUCTURES: FLOW THROUGH BRIDGES

RESULTS (AUTOMATIC POSITIONER)



S1 – Simple arch bridge




ARTICLE 02

water

MDPI

Article

Modelling Weirs in Two-Dimensional Shallow Water Models

Gonzalo García-Alén *, Olalla García-Fonte, Luis Cea, Luis Pena and Jerónimo Puertas

Department of Civil Engineering, Water and Environmental Engineering Group, Universidade da Coruña, Elviña, 15071 A Coruña, Spain; olalla.garcia1@udc.es (O.G.-F.); luis.cea@udc.es (L.C.); luis.pena@udc.es (L.P.); jeronimo.puertas@udc.es (J.P.)

ARTICLE 03

Check for updates

ASCE

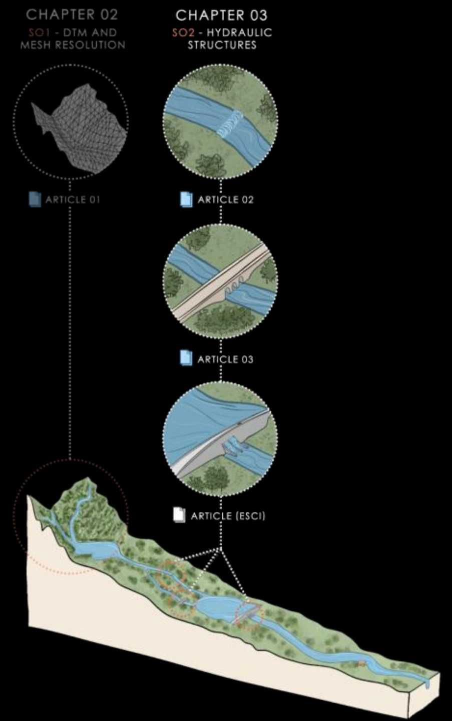
Hydraulic Modeling of Bridges in Two-Dimensional Shallow Water Models

Luis Cea; Gabriela Vila; Gonzalo García-Alén; Jerónimo Puertas; and Luis Pena

Abstract: The backwater effect generated by bridges can significantly increase the risk of flooding. In this work we compare two different methods to include the effect of bridges in two-dimensional (2D) shallow water models. The first method is based on empirical discharge equations that are implemented as internal conditions. The second method is the recently proposed 2D extension of the two- component pressure approach, which accounts for the vertical confinement of the flow. Both approaches are tested and compared using a new set of experimental data obtained in 32 laboratory tests, including four different bridge geometries under different flow conditions. The results show that both methods can reproduce the observed bridge afflux for a wide range of flow conditions, but the two-component pressure approach is less dependent on model calibration. On the other hand, both methods fail to correctly reproduce the 2D water depthpatternsobservedaroundthebridge. DOI: 10.1061/(ASCE)HY.1943-7900.0001992. ©2022AmericanSocietyofCivil Engineers.

Introduction

which in turn will affect the flood extension in the whole up river reach. Especially when the terrain is relatively fl



HYDRAULIC STRUCTURES: RESERVOIRS

ARTICLE (ESCI)

Ingeniería del Agua | 27.1 | 2023 — García-Alén *et al.* | Implementación de embalses en cálculos hidrológicos con Iber |..59

Implementación de embalses en cálculos hidrológicos con Iber

Implementation of reservoirs in hydrological calculations with Iber

Gonzalo García-Alén [a1*], Orlando García-Feal [a2,b], Luis Cea [a3] y Jerónimo Puertas [a4]

[a] Universidade da Coruña, Grupo de Ingeniería del Agua y del Medio Ambiente, Centro de Innovación Tecnolóxica en Edificación e Enxeñaría Civil (CITEEC), Elviña, 15071, A Coruña, España.

[b] Centro de Investigación Mariña, Universidade de Vigo, Environmental Physics Laboratory (CIM-EPhysLab), Campus Auga, Ourense, 32004, España.

E-mail: a1* g.glores@udc.es, a2,b orlando@uvigo.es, a3 luis.cea@udc.es, a4 jeronimo.puertas@udc.es.

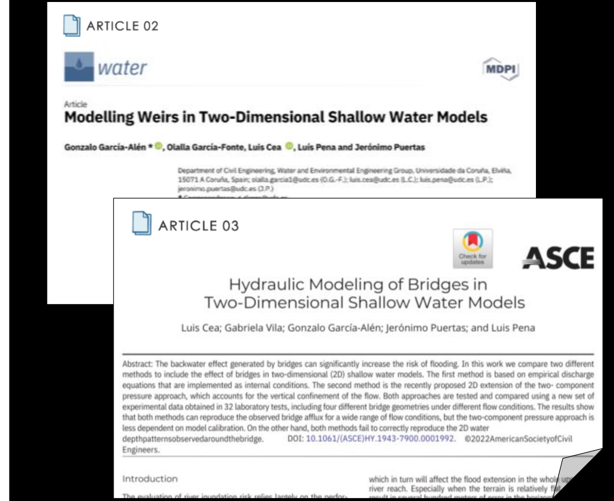
*Autor para correspondencia

Recibido: 11/11/2022 Aceptado: 18/01/2023 Publicado: 31/01/2023

Citar como: García-Alén, G., García-Feal, O., Cea, L., Puertas, J. 2023. Implementation of reservoirs in hydrological calculations with Iber. *Ingeniería del agua, 27*(1), 59-72. https://doi.org/10.4995/Ia.2023.18750

RESUMEN

García-Alén, G., García-Feal, O., Cea, L., Puertas, J., 2023. Implementación de embalses en cálculos hidrológicos con Iber. Ing. del Agua 27, 59–72. https://doi.org/10.4995/ia.2023.18750



ARTICLE 02

water — MDPI

Article

Modelling Weirs in Two-Dimensional Shallow Water Models

Gonzalo García-Alén *, Olalla García-Fonte, Luis Cea, Luís Pena and Jerónimo Puertas

ARTICLE 03

ASCE

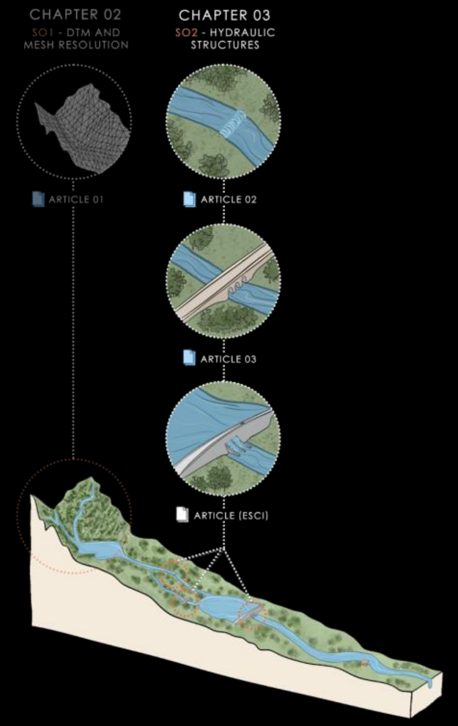
Hydraulic Modeling of Bridges in Two-Dimensional Shallow Water Models

Luis Cea; Gabriela Vila; Gonzalo García-Alén; Jerónimo Puertas; and Luis Pena

Abstract: The backwater effect generated by bridges can significantly increase the risk of flooding. In this work we compare two different methods to include the effect of bridges in two-dimensional (2D) shallow water models. The first method is based on empirical discharge equations that are implemented as internal conditions. The second method is the recently proposed 2D extension of the two- component pressure approach, which accounts for the vertical confinement of the flow. Both approaches are tested and compared using a new set of experimental data obtained in 32 laboratory tests, including four different bridge geometries under different flow conditions. The results show that both methods can reproduce the observed bridge afflux for a wide range of flow conditions, but the two-component pressure approach is less dependent on model calibration. On the other hand, both methods fail to correctly reproduce the 2D water depthpatternsobservedaroundthebridge. DOI: 10.1061/(ASCE)HY.1943-7900.0001992. ©2022AmericanSocietyofCivil Engineers.

Introduction

4. Research development



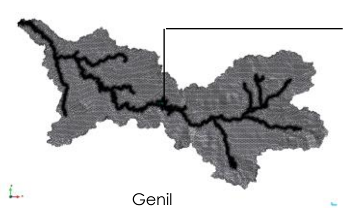
HYDRAULIC STRUCTURES: RESERVOIRS

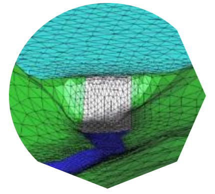
PURPOSE

Development of a reservoir module in Iber to include their routing effect in the numerical simulations at basin scale.

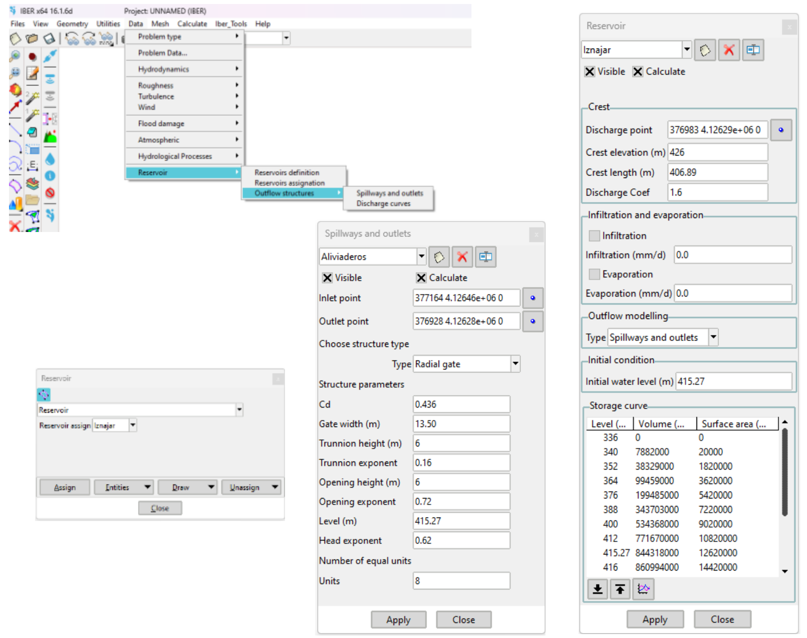
METHODOLOGY

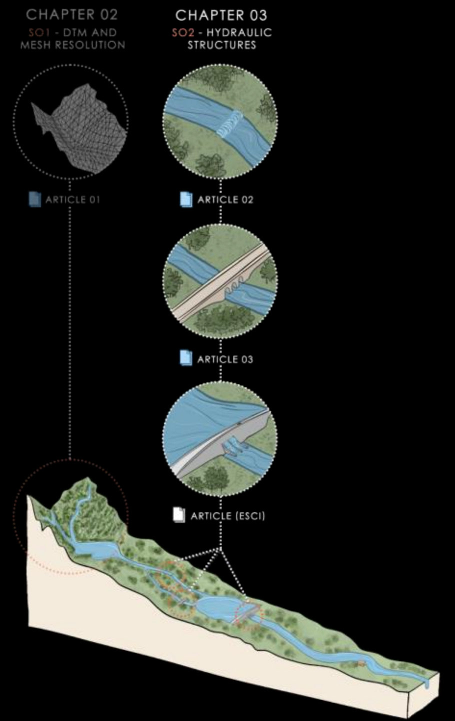
- Numerical implementation in the Iber model: reservoirs as virtual tanks and five different outflow structures.
- Development of a graphical user interface (GUI) integrated in the Iber preprocess and postprocess interface.
- Genil river basin and the Iznájar reservoir as study case





GUI INTEGRATED IN IBER

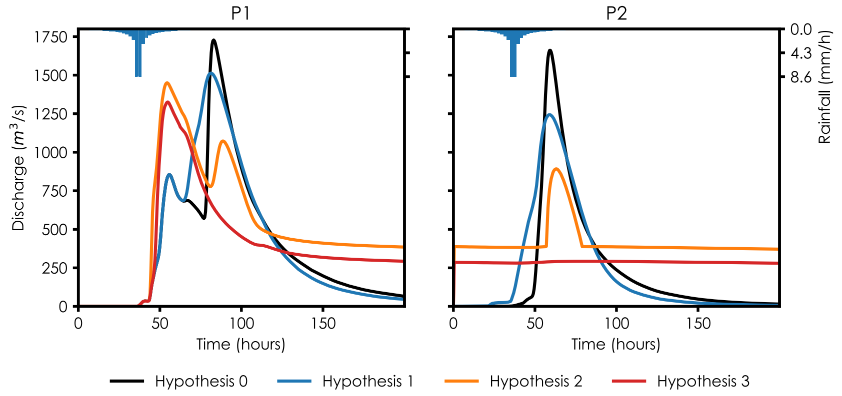




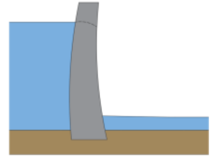
HYDRAULIC STRUCTURES: RESERVOIRS

RESULTS

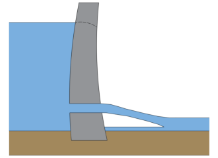
Hydrographs calculated at the watershed outlet point (P1) and at the outlet of the Iznájar reservoir (P2):



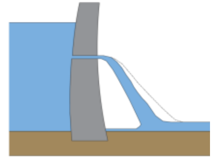
- Hypothesis 0: Model without reservoir.
- Hypothesis 1: Initial reservoir level equals spillway crest level.



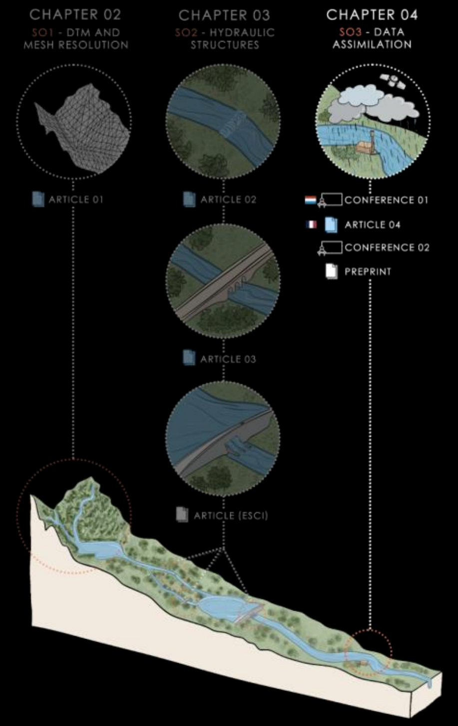
- Hypothesis 2: Initial reservoir level equals spillway crest level and three bottom outlets.



- Hypothesis 3: Initial reservoir level equals spillway crest level and discharge defined by a user-defined drainage curve.

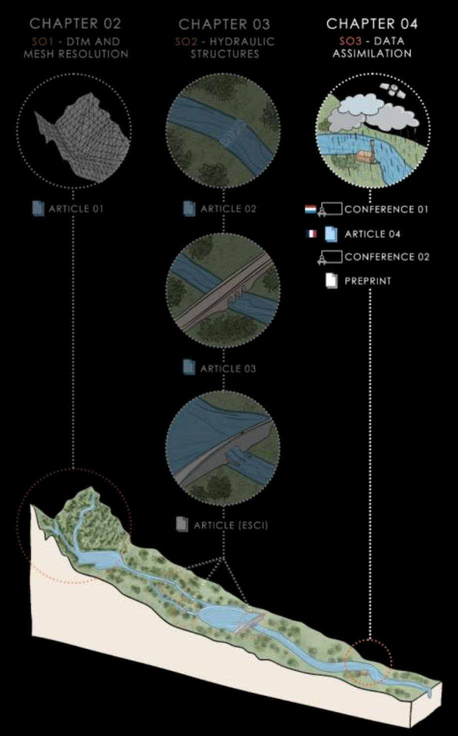


4. Research development



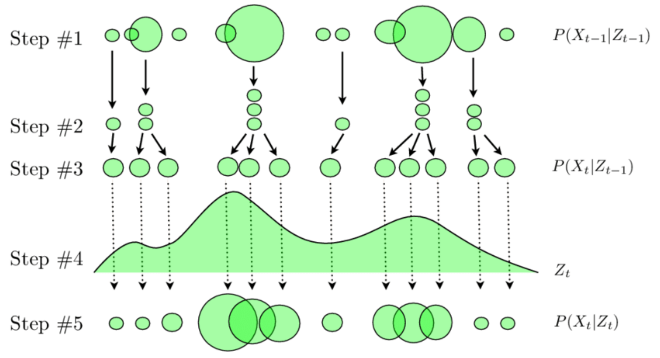
DATA ASSIMILATION

4. Research development



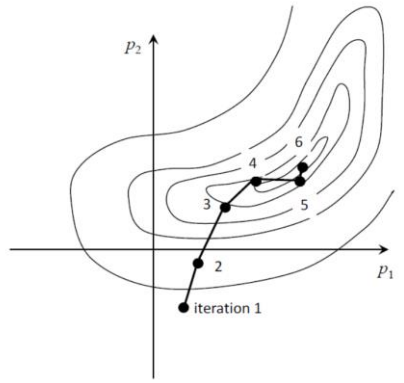
DATA ASSIMILATION

PARTICLE FILTER



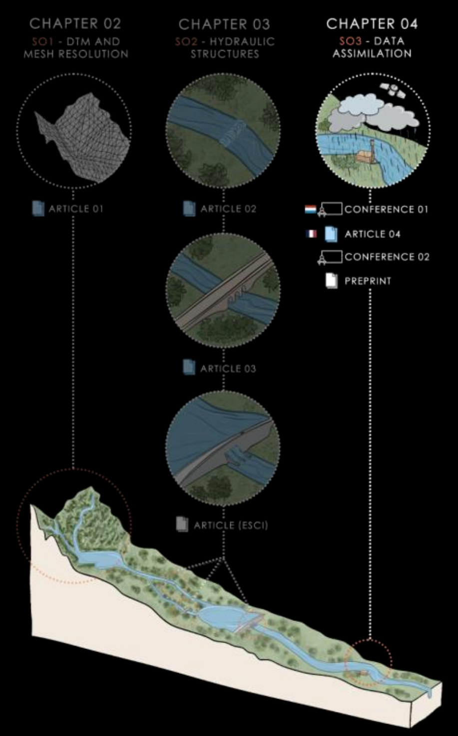
(Morais et al., 2014)

PARAMETER ESTIMATION MODEL (PEST)



$$\Phi = \sum (w_i r_i)^2$$

4. Research development



DATA ASSIMILATION: TEMPERED PARTICLE FILTER


CONFERENCE 01

Proceedings of the 39th IAHR World Congress
19-24 June
2022 Granada, Spain
1031

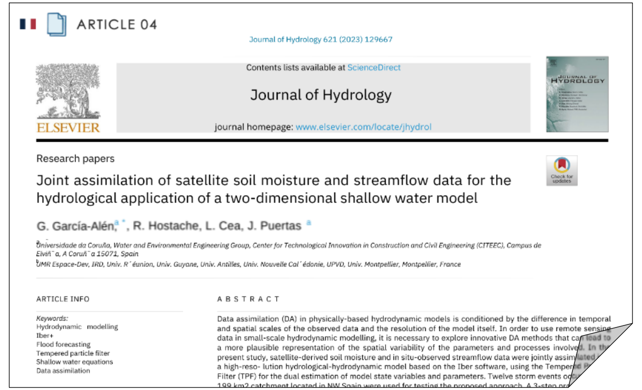
Assimilation of SMAP soil moisture data into a fully distributed hydrological model using a Tempered Particle Filter (TPF): the Landro basin in Spain as a test case

Gonzalo García-Alén [(1)], Renaud Hostache [(2)], Patrick Matgen [(3)], Luis Cea [(4)] and Jerónimo Puertas [(5)]

[(1,4,5)] University of A Coruña, Environmental and Water Engineering Group, Department of Civil Engineering, Elviña, 15071, A Coruña, Spain,
e-mail g.glores@udc.es, luis.cea@udc.es, jeronimo.puertas@udc.es
[(2)] UMR Espace-Dev, IRD, Univ. Réunion, Univ. Guyane, Univ. Antilles, Univ. Nouvelle Calédonie, UPVD, Univ. Montpellier, Montpellier, France,
e-mail renaud.hostache@ird.fr
[(2,3)] Department of Environmental Research and Innovation, Luxembourg Institute of Science and Technology, 5 Avenue des Hauts-Fourneaux, 4362 Esch-sur-Alzette, Luxembourg,
e-mail patrick.matgen@list.lu

Abstract

García-Alén, G., Hostache, R., Matgen, P., Cea, L. & Puertas, J. (2022). Assimilation of SMAP soil moisture data into a fully distributed hydrological model using a Tempered Particle Filter (TPF): the Landro basin in Spain as a test case, in: Ortega-Sánchez, M. (Ed.), 39th IAHR World Congress. Granda, Spain, pp. 3564–3573. https://doi.org/10.3850/IAHR-39WC2521711920221031


ARTICLE 04

Journal of Hydrology 621 (2023) 129667

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Joint assimilation of satellite soil moisture and streamflow data for the hydrological application of a two-dimensional shallow water model

G. García-Alén [a,*], R. Hostache, L. Cea, J. Puertas [a]

[a] Universidade da Coruña, Water and Environmental Engineering Group, Center for Technological Innovation in Construction and Civil Engineering (CITEEC), Campus de Elviña, A Coruña 15071, Spain
[b] UMR Espace-Dev, IRD, Univ. Réunion, Univ. Guyane, Univ. Antilles, Univ. Nouvelle Calédonie, UPVD, Univ. Montpellier, Montpellier, France

ARTICLE INFO

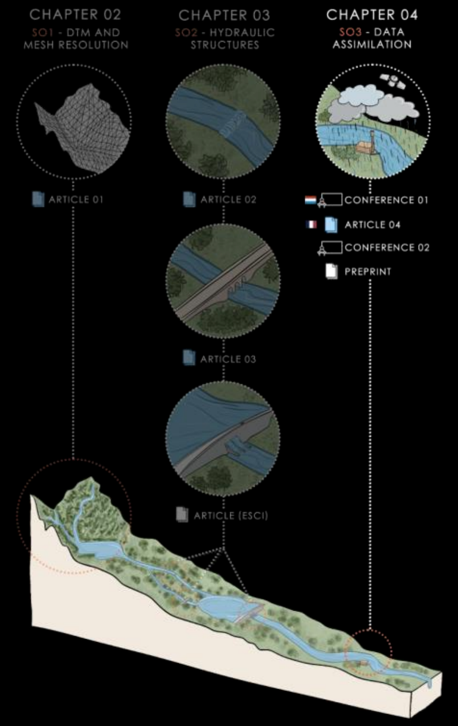
Keywords:
Hydrodynamic modelling
Iber+
Flood forecasting
Tempered particle filter
Shallow water equations
Data assimilation

ABSTRACT

Data assimilation (DA) in physically-based hydrodynamic models is conditioned by the difference in temporal and spatial scales of the observed data and the resolution of the model itself. In order to use remote sensing data in small-scale hydrodynamic modelling, it is necessary to explore innovative DA methods that ca[illegible] a more plausible representation of the spatial variability of the parameters and processes involve[illegible] present study, satellite-derived soil moisture and in situ-observed streamflow data were jointly assim[illegible] a high-reso- lution hydrological-hydrodynamic model based on the Iber software, using the Temper[illegible] Filter (TPF) for the dual estimation of model state variables and parameters. Twelve storm events oc[illegible] 199 km2 catchment located in NW Spain were used for testing the proposed approach. A 3-step pr[illegible]

García-Alén, G., Hostache, R., Cea, L. & Puertas, J. (2023). Joint assimilation of satellite soil moisture and streamflow data for the hydrological application of a two-dimensional shallow water model. Journal of Hydrology. 621, 129667. https://doi.org/10.1016/j.jhydrol.2023.129667

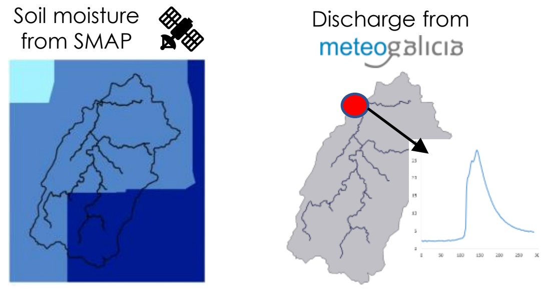
4. Research development



DATA ASSIMILATION: TEMPERED PARTICLE FILTER

PURPOSE

Development of a data assimilation technique based on the Tempered Particle Filter (TPF).



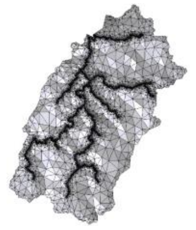
METHODOLOGY

- A total of 12 storm events.
- Joint assimilation of discharge and soil moisture data.
- Infiltration modelled with the Green & Ampt model.
- Sensitivity analysis of the parameters.
- TPF applied twice:

  (1) Using as first guess a set of random particles from their ranges of variation

  (2) Establishing the initial set of particles based on the hydrological antecedent conditions.

15K elements



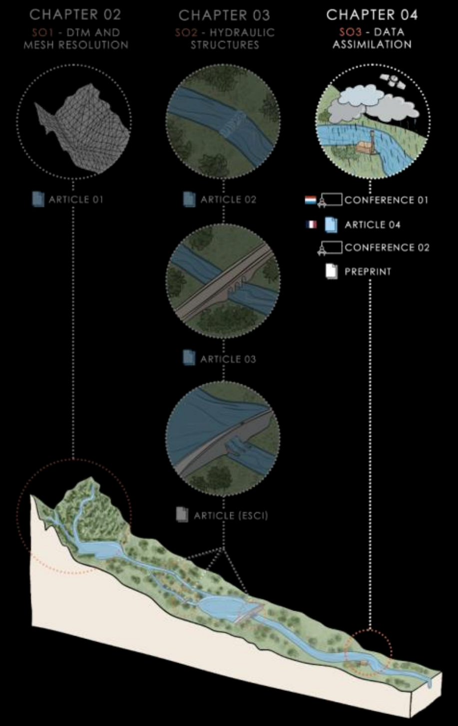
Landro

Parameter	Range of variation in DA
Manning multiplier (-)	0.5 – 5
k_s (mm/h)	0.3 – 10
ψ (mm)	55 – 355
$S_{r,0}$ (-)	0.2 – 1
I_a (mm)	0 – 30

Based on the SA results:

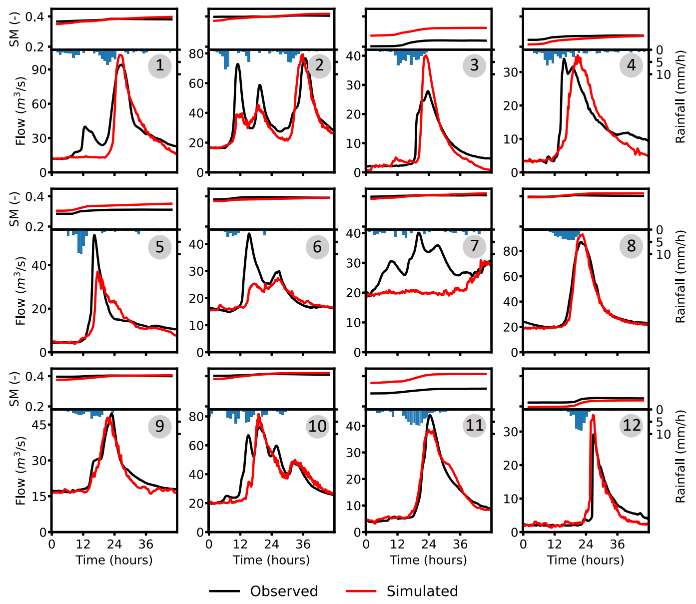
Parameter	Range of variation in DA
k_s (mm/h)	0.3 – 10
$S_{r,0}$ (-)	0.2 – 1
I_a (mm)	0 – 30

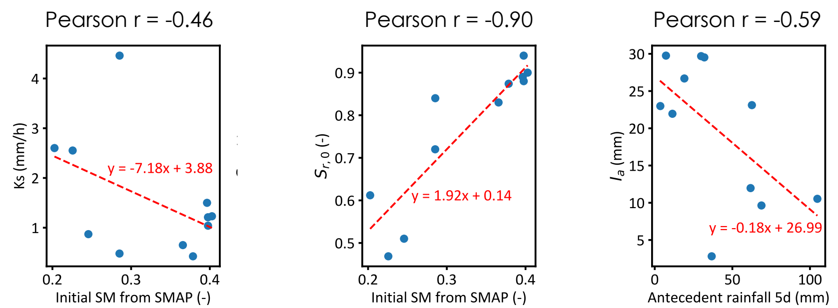
4. Research development



DATA ASSIMILATION: TEMPERED PARTICLE FILTER

RESULTS: (1) Frist application of TPF

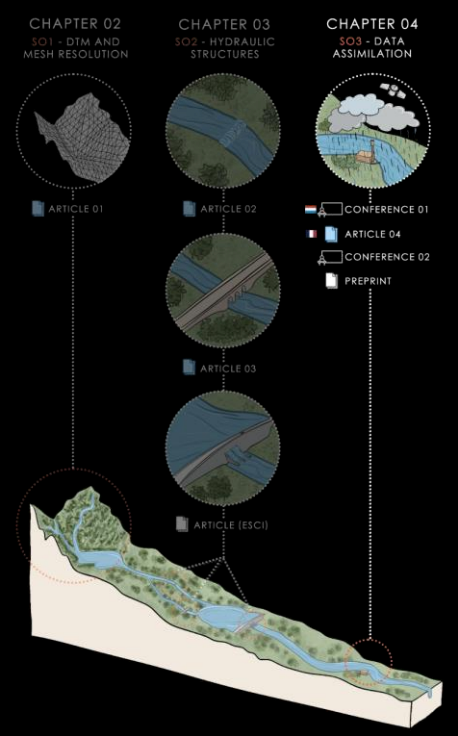




	k_s (mm/h)	$S_{r,0}$ (-)	I_a (mm)
Standard deviation	1.078	0.074	7.159

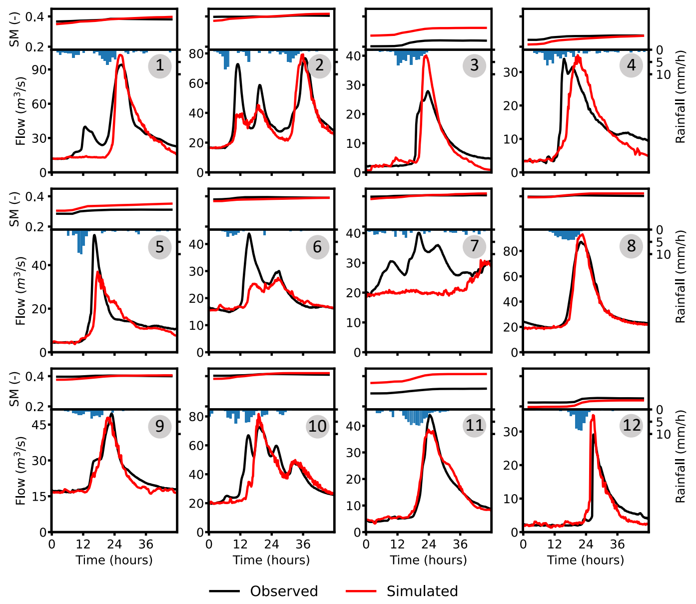
Linear regressions and standard deviations used to generate the first set of particles (first guess) to the assimilation (2nd application of TPF)

4. Research development

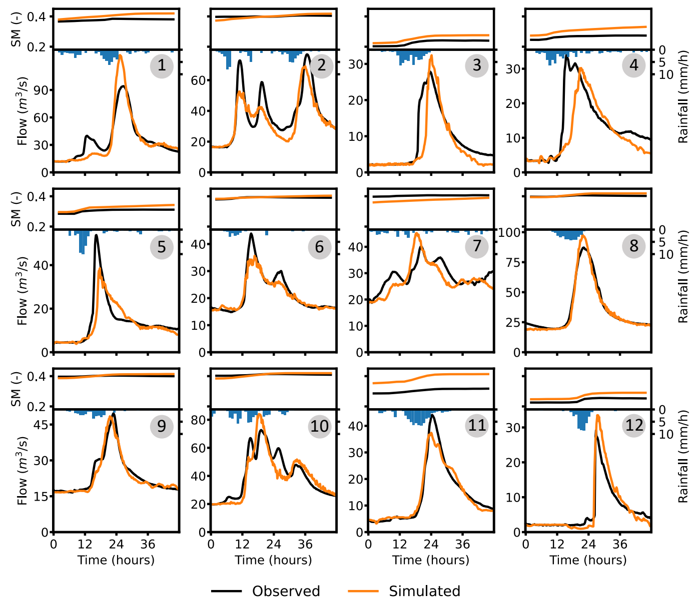


DATA ASSIMILATION: TEMPERED PARTICLE FILTER

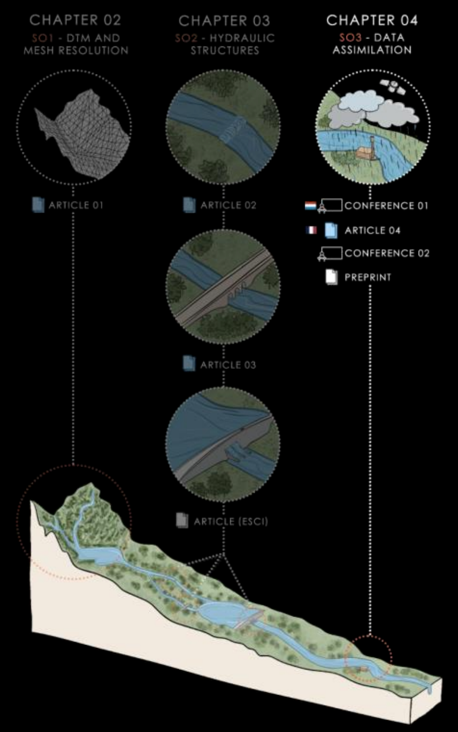
RESULTS: (1) Frist application of TPF



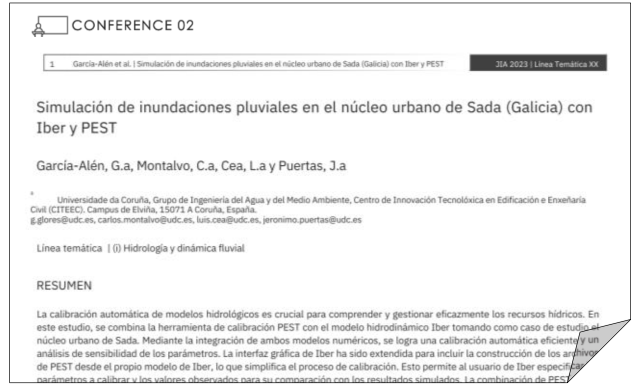
RESULTS: (2) Second application of TPF



4. Research development



DATA ASSIMILATION: PEST


CONFERENCE 02

1 García-Alén et al. | Simulación de inundaciones pluviales en el núcleo urbano de Sada (Galicia) con Iber y PEST — JIA 2023 | Línea Temática XX

Simulación de inundaciones pluviales en el núcleo urbano de Sada (Galicia) con Iber y PEST

García-Alén, G.a, Montalvo, C.a, Cea, L.a y Puertas, J.a

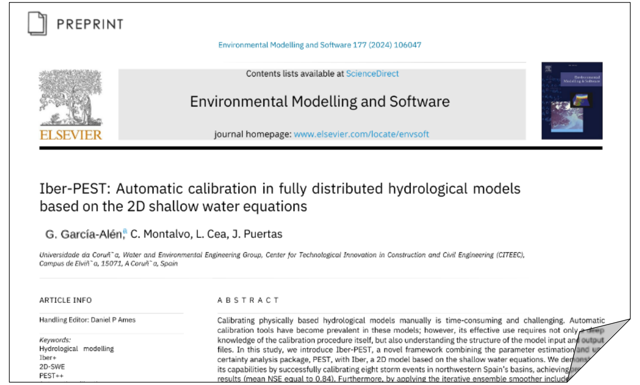
a Universidade da Coruña, Grupo de Ingeniería del Agua y del Medio Ambiente, Centro de Innovación Tecnolóxica en Edificación e Enxeñaría Civil (CITEEC). Campus de Elviña, 15071 A Coruña, España.
g.glores@udc.es, carlos.montalvo@udc.es, luis.cea@udc.es, jeronimo.puertas@udc.es

Línea temática | (i) Hidrología y dinámica fluvial

RESUMEN

La calibración automática de modelos hidrológicos es crucial para comprender y gestionar eficazmente los recursos hídricos. En este estudio, se combina la herramienta de calibración PEST con el modelo hidrodinámico Iber tomando como caso de estudio el núcleo urbano de Sada. Mediante la integración de ambos modelos numéricos, se logra una calibración automática eficiente y un análisis de sensibilidad de los parámetros. La interfaz gráfica de Iber ha sido extendida para incluir la construcción de los archivos de PEST desde el propio modelo de Iber, lo que simplifica el proceso de calibración. Esto permite al usuario de Iber especificar parámetros a calibrar y los valores observados para su comparación con los resultados simulados. La combinación de PEST

García-Alén, G., Montalvo, C., Cea, L., & Puertas, J. (2023). Simulación de inundaciones pluviales en el núcleo urbano de Sada (Galicia) con Iber y PEST, in: VII Jornadas Ingeniería Del Agua (JIA). Cartagena, Spain. 18-19 October 2023.


PREPRINT

Environmental Modelling and Software 177 (2024) 106047

Contents lists available at ScienceDirect

Environmental Modelling and Software

journal homepage: www.elsevier.com/locate/envsoft

ELSEVIER

Iber-PEST: Automatic calibration in fully distributed hydrological models based on the 2D shallow water equations

G. García-Alén,[a] C. Montalvo, L. Cea, J. Puertas

Universidade da Coruñ˜a, Water and Environmental Engineering Group, Center for Technological Innovation in Construction and Civil Engineering (CITEEC), Campus de Elviñ˜a, 15071, A Coruñ˜a, Spain

ARTICLE INFO

Handling Editor: Daniel P Ames

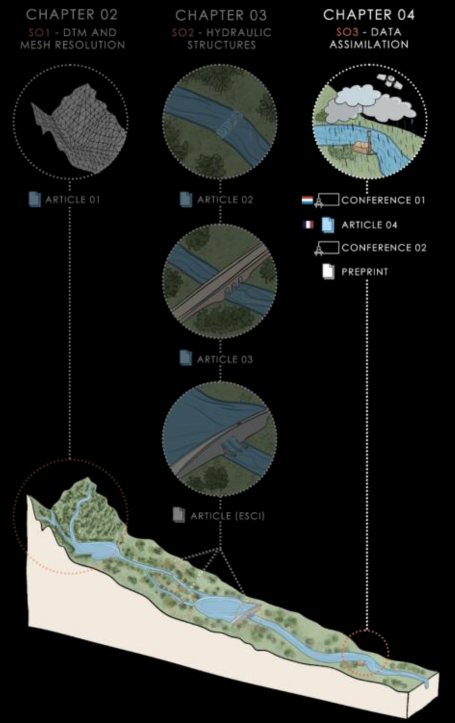
Keywords:
Hydrological modelling
Iber+
2D-SWE
PEST++

A B S T R A C T

Calibrating physically based hydrological models manually is time-consuming and challenging. Automatic calibration tools have become prevalent in these models; however, its effective use requires not only a deep knowledge of the calibration procedure itself, but also understanding the structure of the model input and output files. In this study, we introduce Iber-PEST, a novel framework combining the parameter estimation and uncertainty analysis package, PEST, with Iber, a 2D model based on the shallow water equations. We demonstrate its capabilities by successfully calibrating eight storm events in northwestern Spain's basins, achieving promising results (mean NSE equal to 0.84). Furthermore, by applying the iterative ensemble smoother include

García-Alén, G., Montalvo, C., Cea, L., & Puertas, J. (2024). Iber-Pest: Automatic Calibration in Fully Distributed Hydrological Models Based on the 2d Shallow Water Equations. Environmental Modelling & Software, 106047. https://doi.org/10.1016/j.envsoft.2024.106047

4. Research development



DATA ASSIMILATION: PEST

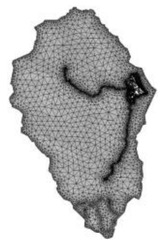
PURPOSE

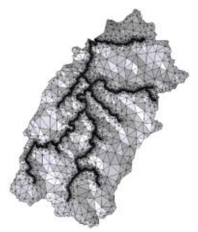
To develop an automatic calibration tool integrated in Iber: Iber-PEST

Iber + PEST

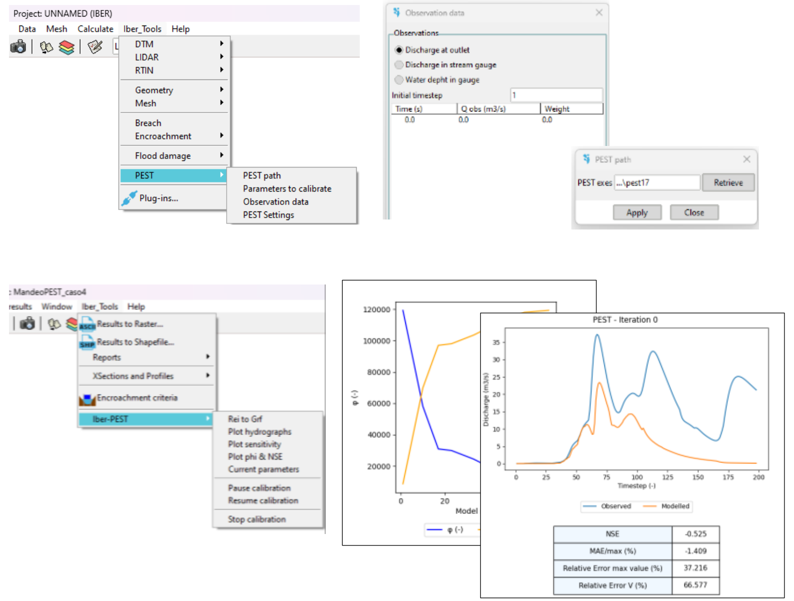
METHODOLOGY

- Development of a graphical user interface (GUI) integrated in the Iber preprocess and postprocess interface.
- Assimilation of water elevation in Sada and discharge in Landro.
- Calibration of four storm events in each basin.
- Infiltration modelled with the SCS-CN model (Sada) and the Green & Ampt model (Landro).
- Calibration of 4 parameters with PEST (basic capabilities) and PESTPP-IES.


Sada

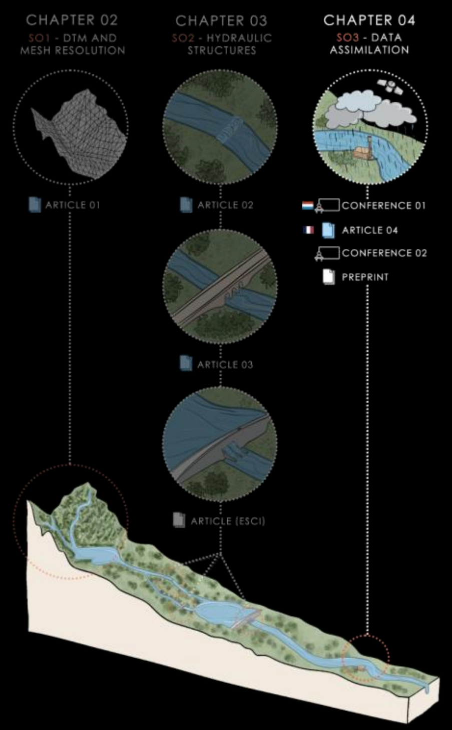

Landro

IBER-PEST FRAMEWORK



NSE	-0.525
MAE/max (%)	-1.409
Relative Error max value (%)	37.216
Relative Error V (%)	66.577

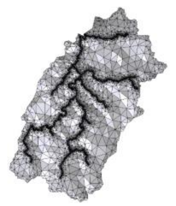
4. Research development



DATA ASSIMILATION: PEST

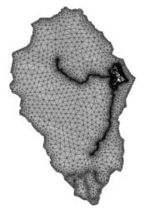
RESULTS: PEST

Landro

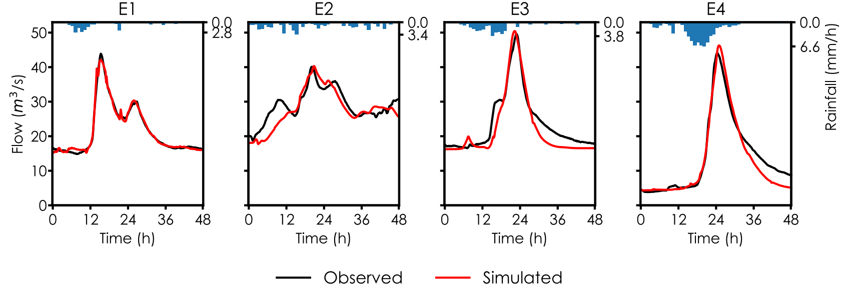


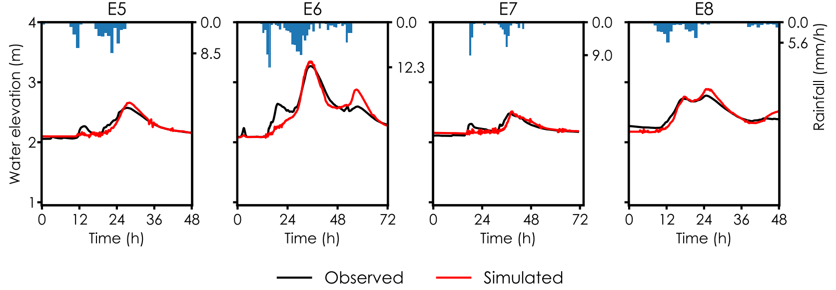
Event	NSE	Nº Iber runs
E1	0.99	221
E2	0.61	297
E3	0.89	267
E4	0.95	177

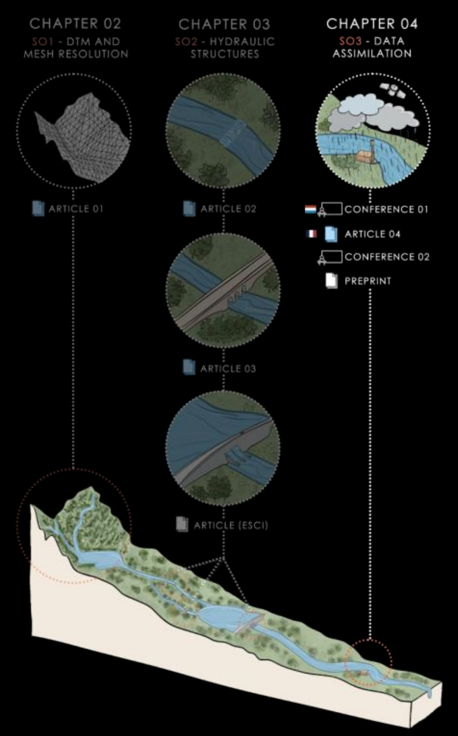
Sada



Event	NSE	Nº Iber runs
E5	0.88	297
E6	0.83	172
E7	0.74	178
E8	0.865	169



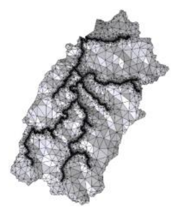




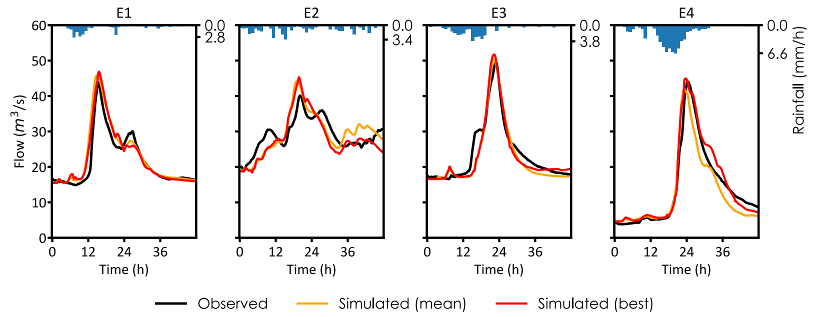
DATA ASSIMILATION: PEST

RESULTS: PESTPP-IES

Reduction of 36.7%, 54.4%, 47.6% and 20.9% in the number of simulations required to calibrate the event E1, E2, E3 and E4, respectively.



Event	NSE	Nº simulations
E1	0.88	140 (2 iterations)
E2	0.43	
E3	0.91	
E4	0.96	

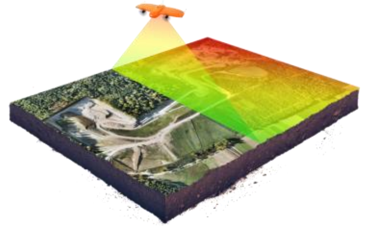


CONCLUSIONS

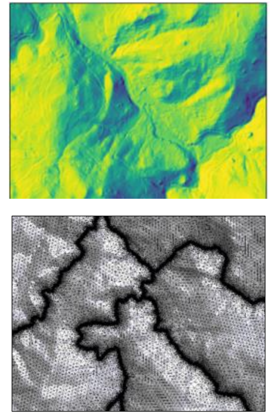
CONCLUSIONS

DTM AND MESH RESOLUTION ANALYSIS

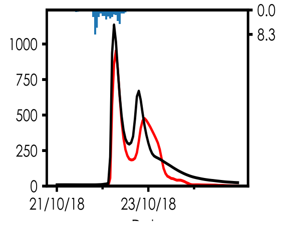
The vertical accuracy of the DTM has a greater effect on the outflow hydrograph of the model than the horizontal resolution.



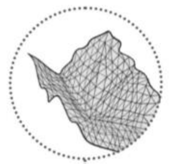
Threshold of 25 m



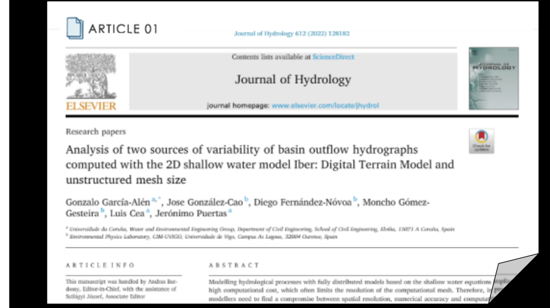
Further analysis with finer meshes and higher resolution DTMs



SO1 - DTM AND MESH RESOLUTION



ARTICLE 01


ARTICLE 01

Journal of Hydrology 612 (2022) 128182

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Analysis of two sources of variability of basin outflow hydrographs computed with the 2D shallow water model Iber: Digital Terrain Model and unstructured mesh size

Gonzalo García-Alén [a,*], Jose González-Cao [b], Diego Fernández-Nóvoa [b], Moncho Gómez-Gesteira [b], Luis Cea [a], Jerónimo Puertas [a]

[a] Universidade da Coruña, Water and Environmental Engineering Group, Department of Civil Engineering, School of Civil Engineering, Elviña, 15071 A Coruña, Spain
[b] Environmental Physics Laboratory, CIM-UVIGO, Universidade de Vigo, Campus As Lagoas, 32004 Ourense, Spain

ARTICLE INFO

This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Szilágyi József, Associate Editor

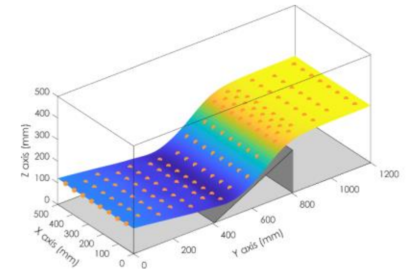
ABSTRACT

Modelling hydrological processes with fully distributed models based on the shallow water equations
high computational cost, which often limits the resolution of the computational mesh. Therefore, in
modellers need to find a compromise between spatial resolution, numerical accuracy and computat

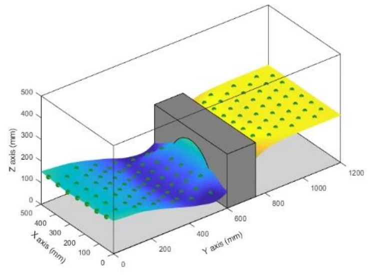
CONCLUSIONS

HYDRAULIC STRUCTURES

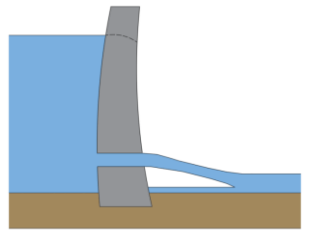
Weirs: classical formulations led to better results than the modelling as the flume topography.

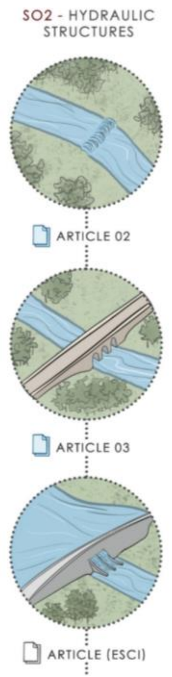


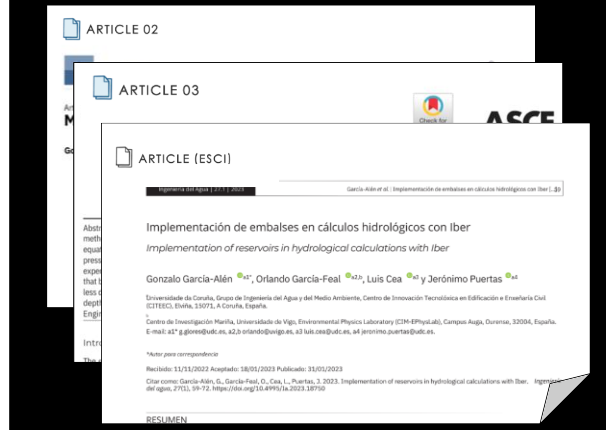
Bridges: when no calibration data is available, TPA method is more accurate than the ICB approach.



Reservoirs: Iber can now incorporate the routing effect of reservoirs in basin-scale hydrological models.



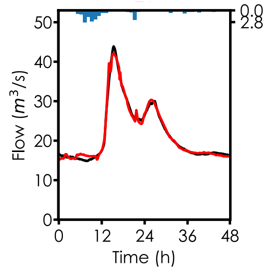




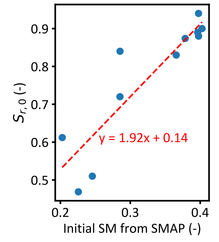
CONCLUSIONS

DATA ASSIMILATION

Successful application of 2 calibration techniques to reduce model uncertainty.

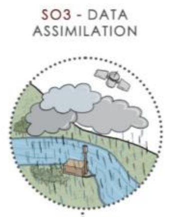


Hydrological parameters can be related with the antecedent conditions of the basin

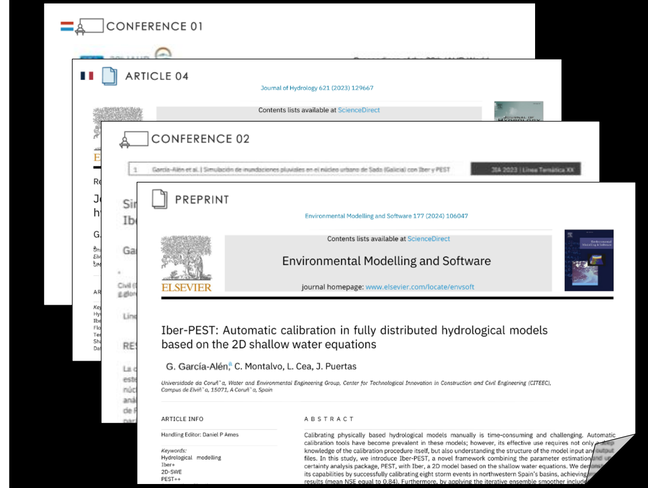


Iber now incorporates a dedicated tool to facilitate the calibration of basin-scale hydrological models.

Iber + PEST

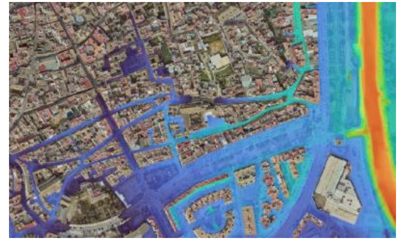


CONFERENCE 01
ARTICLE 04
CONFERENCE 02
PREPRINT

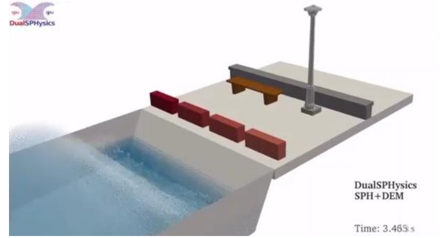


FUTURE RESEARCH

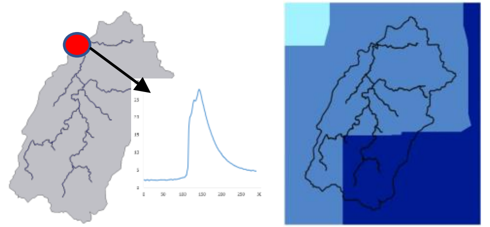
Analysis of the influence of the DTM and mesh size in depth and velocity maps



Coupling of Iber with a 3D non-hydrostatic free surface model (DualSPHysics, for example)



Explore new data assimilation techniques to reduce the computational cost of model calibration.



Thank you for your attention

IMPROVING THE CAPABILITIES OF 2D SHALLOW WATER MODELS FOR HYDROLOGICAL APPLICATIONS

Gonzalo García-Alén Lores

DOCTORAL THESIS DEFENCE
Civil Engineering Ph.D. Program

Supervisors:
Luis Cea Gómez
Jerónimo Puertas Agudo

IMPROVING THE CAPABILITIES OF 2D SHALLOW WATER MODELS FOR HYDROLOGICAL APPLICATIONS

Gonzalo García-Alén Lores

DOCTORAL THESIS DEFENCE
Civil Engineering Ph.D. Program

Supervisors:
Luis Cea Gómez
Jerónimo Puertas Agudo

CITEEC Centro de Innovación Tecnolóxica en Edificación e Enxeñería Civil
Grupo de Ingeniería del Agua y del Medio Ambiente
ESCUELA TÉCNICA SUPERIOR INGENIEROS DE CAMINOS, CANALES Y PUERTOS
UNIVERSIDADE DA CORUÑA