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The use of Iber as learning tool for two-dimensional channel flow analysis

Michel Huber Cueva Portal [a], Julio Eduardo Cañón Barriga [b] & Luis Cea [c]

[a] Facultad de Ingeniería Hidráulica, Universidad Nacional de Cajamarca, Cajamarca, Perú.
[b] Facultad de Ingeniería, Universidad de Antioquia, Medellín, Colombia.
[c] ETS de Ingenieros de Caminos, Canales y Puertos, Universidade da Coruña, La Coruña, España.
mhcuevap12@gmail.com julio.canon@udea.edu.co luis.cea@udc.es

Abstract— Visual examples and interactive graphs of controlled experiments allow the student to solve problems, demonstrate, measure, and do other practical and theoretical activities. Iber is a two-dimensional numerical model for simulating surface flow that combines modules of hydrodynamics, turbulence, sediment transport, and water quality, using the finite volume method to solve the corresponding equations. Its friendly interface for pre and post processing allows creating videos with results and displaying variables in 3D, making it a robust, free, relatively easy to use, practical and effective didactic teaching tool for hydraulic and hydrodynamic modeling. In this paper, we present some numerical examples of free surface flow simulation as complements to the experimental teaching practices that are difficult in many institutions due to lack of financial and human resources, or due to excessive assembly and operation time. The results show considerable time saved compared to the laborious and inevitable iterative calculations of the numerous equations involved; the versatility to enter, correct and visualize data is a great advantage to tabulate and present results during simulations of "real life" practices. The simulation times are also very reasonable and are associated with the type of problem, calculation method, numeric scheme, and obtained results, aspects that can be easily modified during class sessions.

Keywords— teaching tool, hydraulic numerical modeling, digital labs.

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Uso de Iber como herramienta de aprendizaje y análisis de flujos bidimensionales en canales

Resumen— Iber es un modelo numérico bidimensional para la simulación del flujo superficial que combina módulos de hidrodinámica, turbulencia, transporte de sedimentos y calidad de aguas, utilizando el método de volúmenes finitos para solucionar las ecuaciones correspondientes. Su interfaz amigable para el pre y pos procesamiento permite crear videos con resultados y visualizar variables en 3D, convirtiéndose en una herramienta docente didáctica, robusta, gratuita, relativamente fácil de usar, práctica y eficaz para modelaciones hidráulicas e hidrodinámicas. En este trabajo presentamos algunos ejemplos numéricos de simulación de flujo en lámina libre como complementos a las prácticas de docencia experimental que se dificultan en muchas instituciones por falta de recursos económicos y humanos, o por el excesivo tiempo de montaje y operación. Los resultados muestran el ahorro de un tiempo considerable frente a los laboriosos e inevitables cálculos iterativos de las numerosas ecuaciones; la versatilidad para introducir, corregir y visualizar datos es un gran avance al momento de tabular y presentar los resultados como si se tratara de una práctica real. Los tiempos de simulación también son muy razonables y están asociados al tipo de problema, método de cálculo, esquema numérico, resultados a obtener, aspectos que pueden modificarse fácilmente durante las sesiones de clase.

Palabras Clave— herramienta docente, modelización numérica hidráulica, laboratorios digitales.

1 Introduction

Iber is a two-dimensional numeric-modeling program that combines hydrodynamics, turbulence, sediment transport and waters quality modules to simulate overland flow, using the finite volume method to solve the 2D Saint Venant equations [1]. The program was initially developed for consultancy and applied research studies from which numerous scientific publications have already emerged. However, due to its versatility, user-friendliness and free distribution, it has become a reasonable alternative for the academic field in teaching topics related to free surface flow hydraulics.

The Godunov-type numerical schemes implemented on the program [2], [3] allow, for example, to capture hydraulic regime change phenomena, like hydraulic jumps, among others, without stability problems and also to capture cross-waves easily, thus obviating one of the big 1D models limitations, that consider the water film to be completely horizontal and transversal to the flow direction [4]. Iber's model has been experimentally validated and utilized in several field and lab studies (see [1], [5], [6], [7][7]), being therefore a reliable tool for 2D free film flow calculations. Besides, a parallelized version has been recently developed, compatible with NVIDIA graphics cards, enabling accelerations up to two magnitude orders in computation time [8].

The aim of this paper is to explore Iber program's capacities to work as a didactic support tool in a course on channel hydraulics, as a complement to experimental teaching practices. For that purpose, we present seven examples of flow situations that are explained in a conventional course of fluvial and open channel hydraulics and that, with the use of this tool, can be enhanced within the classroom.

2 Comparison between Iber and HEC-RAS 2D

In this section, we present a brief comparison between the characteristics of Iber and those of the HEC-RAS 2D program, one of the most used in the teaching of channel and river hydraulics in Latin America. HEC-RAS is usually used at the end of the course to develop an integrated term project in which students put into practice the concepts seen during the course (permanent and non-permanent, gradually varied flows with scour and hydrographic transit calculations). On the one hand, learning to use HEC-RAS comes relatively fast, but with many restrictions in establishing sections with changes in direction, with 2D components that are not very intuitive and with limited graphic components to present the outputs. On the other hand, Iber allows the relatively simple definition of structure geometries and channel sections in one and two dimensions, introducing the student to the use of CFD tools in a pleasant and very intuitive way (if compared, for example, with other programs such as Open-FOAM, which require more learning time and programming knowledge). Some studies have focused on comparing the strengths and weaknesses of these two programs [9], [10]. In table 1 we abridge some of the relevant features of these two models.

Table 1
Iber and HEC-RAS 2D model comparison

Features	Iber	HEC-RAS 2D
Language	English and Spanish	English
License	Free	Free
Operating system	Windows	Windows
System of units	Metric	Metric and English
Equations	Saint	Venant/ 2D diffusive wave
Modules	Hydrodynamics, turbulence, sediment transport, water quality and hydrology	Hydrodynamics, sediments transport, water quality, scour and hydrology
Format and data management	Shapefile, csv, dxf, iges, kml, orthophotos, dem	Shapefile, csv, dem, orthophotos
Boundary conditions	Hydrograph, rating curve, water level, landfill, source, sink	Normal depth hydrograph, rating curve, precipitation, floodgates control
Internal conditions	Bridge, landfill, floodgate, sewers, culvert	Bridge, side and front landfill, floodgate, culvert
Computational meshing methodology	Structured and non-structured triangles and rectangles	Delaunay triangulation and Voronoi diagram
Results	Draught, specific discharge, speed rate, water level, Froude, tension, critical diameter	Draught, specific discharge, speed rate, water level, Froude, scour
Display of results	Cuts/sections, vectors, color maps, graphics, export results to GIS, time probes.	Cuts/sections, vectors, color maps, graphics, export results to GIS,

3 Examples for classroom adaptation

We present some flow examples that are part of a conventional channel course and can be adequately supported by Iber simulations carried out during the class. The first is a primarily unidirectional modeling case, regarding section changes in transitions (Parshall flume). The second example is a flow in a straight composite channel with variable roughness and flow regimes, with visible cross-flow effects on both the Froude number and velocity vectors. The third is the combined use of several structures (dams, culverts) with pressure flow and open-flow, where the two-dimensional effects are more visible. The fourth is a dam break case, in which the mesh changes as the break takes place. The fifth is the flow in the steep curve of a channel that exhibits the margin protection effects. The sixth is a branched flow in anastomosed channels of gentle slope and the seventh is a lateral flow derivation through two longitudinal channels.

3.1 Example 1: transitions in unidirectional flow

One of the first concepts studied in channels is that of the effect of section changes on a one-way flow. The counter-intuitive drop of the flow profile in a subcritical regime is usually explained by the concept of the specific energy curve, from which it is also taught why flow meters must pass through critical condition to ensure a one-to-one relation of flow rate and head. The Parshall flume serves as a good example to follow these concepts, since it presents bottom and cross section changes at the same time at a relatively short distance. In Fig. 1 we show the simulation of the flume with flow depths and Froude numbers, where the simulated flow closely resembles what is observed in the laboratory.

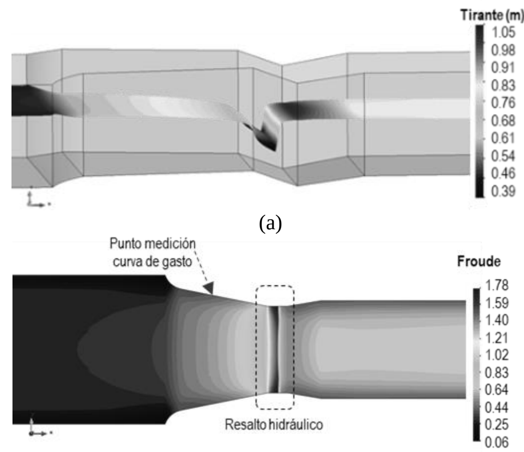


Figure 1. (a) Hydraulic profile y (b) Froude number in transitions.

Although the flow is primarily unidirectional, the simulation allows us to observe certain cross-sectional components of velocity that illustrate waves and differences in depth in the cross-section that are not usually discussed in theory. We can also follow the changes in flow depth over time for different flows along the profile (Fig. 2) and at any given point along the calculated nodes (Fig. 3).

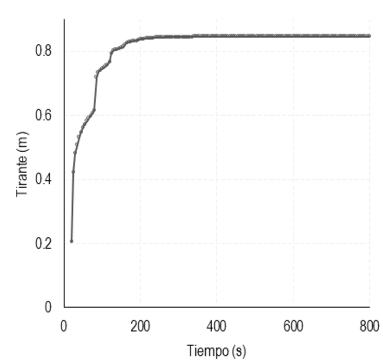


Figure 2. Temporary brace evolution.
Source: The authors.

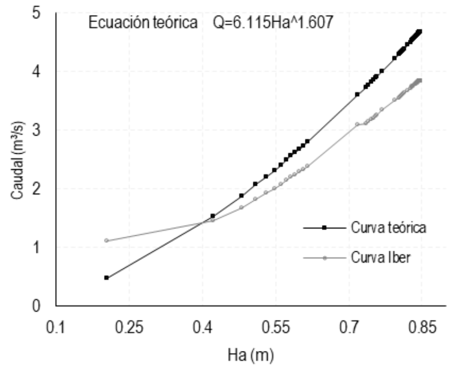


Figure 3. Flow curve (relation specific flow rate – brace).

Particularly, the comparison between the flow rate and the flow depth at the point where the level in the flume is normally measured, allows the student to calculate the corresponding equation ($Q=AH^B$), in a way similar to that followed in a real laboratory practice. Table 2 summarizes the features of the run model for this example.

Table 2
Features of the plant/profile transition model

Flow rate	Q = 3.85 m^3/s
Roughness coefficient	0.014
Structured mesh	0.10 m x 0.80 m
Element quantity	10 800
Simulation time	750 s
Simulation duration	10 min 13 s
Geometry construction	5 min

3.2 Example 2: hydraulic resistance due to roughness and relief in a composite section channel

In classes, we usually work with examples of prismatic sections with single roughness coefficients in the study of the gradually varied flow along a channel. In this example, we combine Manning's n-factor values with meso-forms generated in the Iber program's mesh to produce typical roughness of river stream sections. Fig. 4 shows variations of the stream level under varying conditions of roughness, and Fig. 5 shows one of the transversal profiles with flow levels over the overflowed area of the channel, which also allows seeing differences in lateral regime with the Froude number. Finally, Fig. 6 shows the variation of the flow rate as a function of changes in the Manning's roughness factor for a sensitivity analysis. The model provides graphs such as time probes, longitudinal and transversal profiles that are often very useful in the analysis.

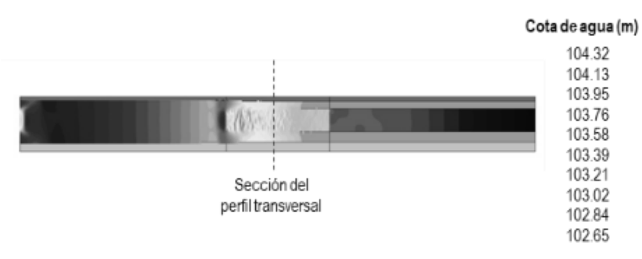


Figure 4. Channel plant with meso-forms.

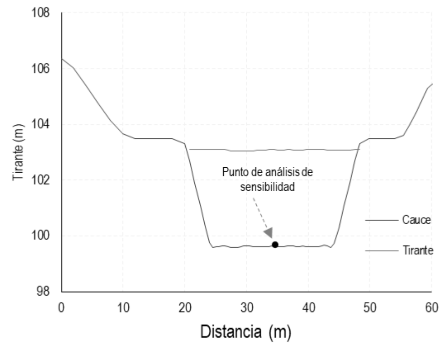


Figure 5. Transversal profile of the channel with meso-forms.

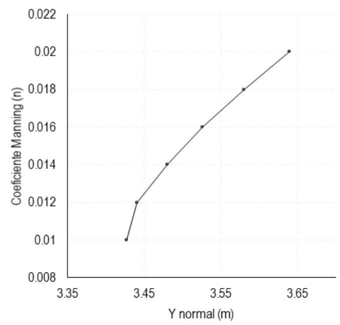


Figure 6. Variation of depth with Manning's n.

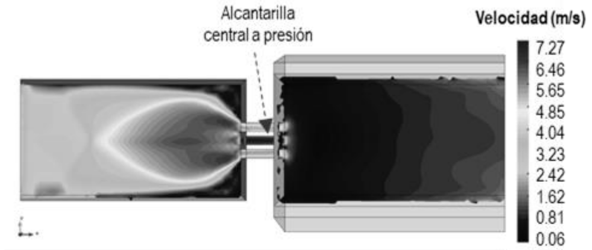
Table 3 summarizes the features of the run model for this example

Table 3
Roughness model features

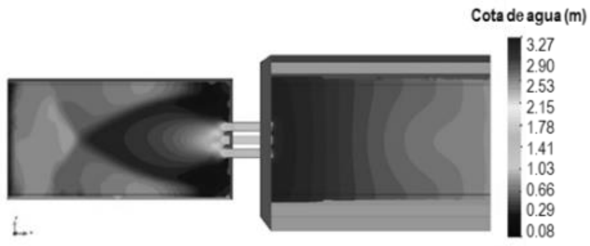
Input hydrograph	Q = 150 m^3/s
Roughness	0.010 – 0.020 each 0.002
Structured mesh	0.50 m x 1.00 m
Number of elements	30 000
Simulation time	1500 s
Simulation duration	16 min 2 s
Geometry construction	15 min

3.3 Example 3: combined pressure flow and free surface drainage structures

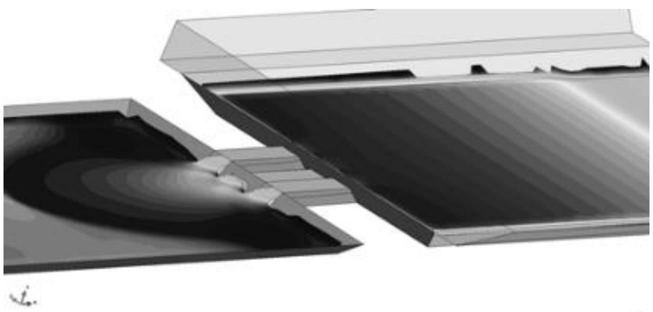
The introduction of hydraulic structures and unsteady flows in a regular course of channel hydraulics includes culverts and dams that resemble road drainage situations. In this example, we built a mesh with a transverse dam and the passage of three culverts for flow release. The central culvert works under pressure while the other two work on free surface. Fig. 7 shows the two-dimensional velocity distributions and level differences in the backwater and the flow output in the contraction and expansion of the culverts, as well as their interaction.



(a)



(b)



(c)

Figure 7. Flow through a battery of culverts in a transversal dam: (a) Plant velocities; (b) Water levels in plant; (c) Water levels Isometric.

This simulation represents a pedagogical advantage, since lateral variations and flow interactions in regular class examples of a single culvert for steady flow condition are difficult to observe or calculate, especially for gradually varied profiles. Table 4 summarizes the features of the run model for this example.

Table 4
Culverts model features

Input level	Z= 2.5 m
Roughness	0.018
Non-structured mesh	0.25 m x 2.00 m
Number of elements	11350
Simulation time	750 s
Simulation duration	35 min 15 s
Geometry construction	45 min

3.4 Example 4: dam break and flooding

In a channel course, the fast varying non-permanent flow (e. g, positive and negative surges) is usually exemplified with rapidly operating gates or the sudden bursting of a vertical dam, for which there are simple and well-defined equations. In this example, the meshing of an overflowing dike allows to follow the process of the dam's bursting over time (Fig. 8). The mesh also deforms as the overflow occurs in a similar way to embankment and dikes failures, so students have a clear perspective on what to expect in this type of event. You can also follow the hydrograph of the overflow in different sections along the channel, which gives an idea of the transit of positive and negative surges.

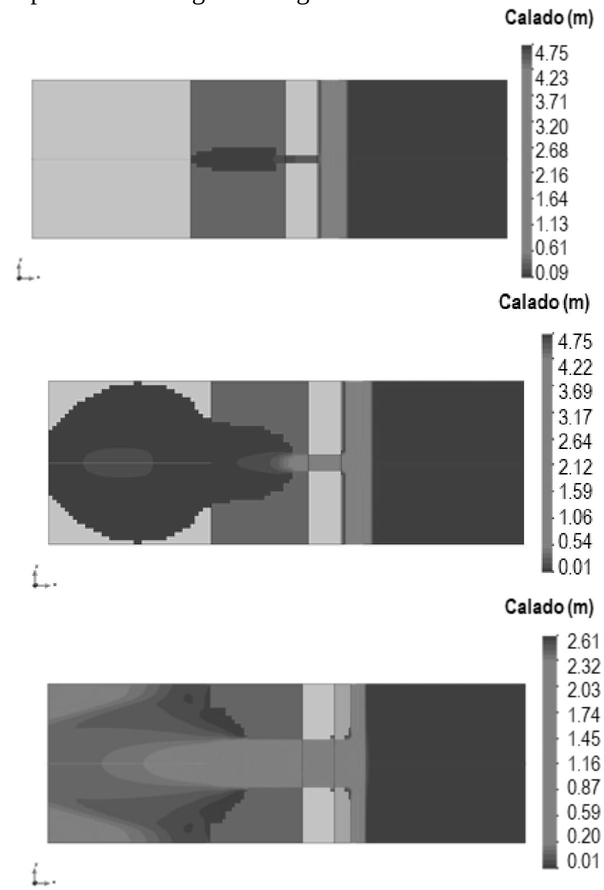


Figure 8. Dam breaking evolution.

Table 5 summarizes the features of the run model for this example.

Table 5
Main features of the dam break model

Water level	4.75 m
Roughness	0.035
Structured mesh	0.25 m x 0.25 m
Number of elements	5640
Simulation time	750 s
Simulation duration	5 min 305 s
Geometry construction	5 min

3.5 Example 5: design of protection for transversal and longitudinal structures

Generally, rivers and channels have major curvatures that modify velocity profiles in the transversal section as they influence sediment transport and erosion rates. In meandering rivers, for example, erosion occurs on the outer margin and sediment deposition on the inner margin due to the asymmetric distribution of longitudinal velocities (maxima on the outer margin, matching the greatest depths of the section).

Furthermore, when it comes to rectangular, fixed bed channels, the maximum velocities occur in the area near the inner margin of the curve and are displaced towards the outer margin at the end of the curve, when the water surface rise (produced by centrifugal forces) becomes insignificant. These curves usually require erosion protection works with longitudinal structures on the margins. Figure 9 illustrates changes in surface velocities in the curve sector of a vertical stiff-walled channel.

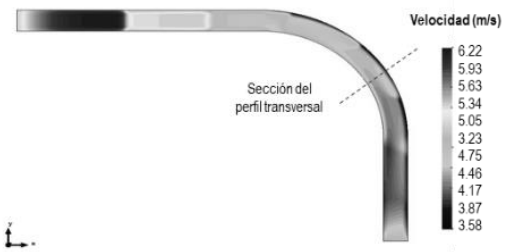


Figure 9. Curved channel in plant.

Fig. 10 shows the variation of the longitudinal flow profile in the section. It should be noted that Iber, being a 2D model, cannot show the secondary flows that form in the channel's transversal section, meaning that it integrates just vertical values. Table 6 summarizes the features of the run model for this example.

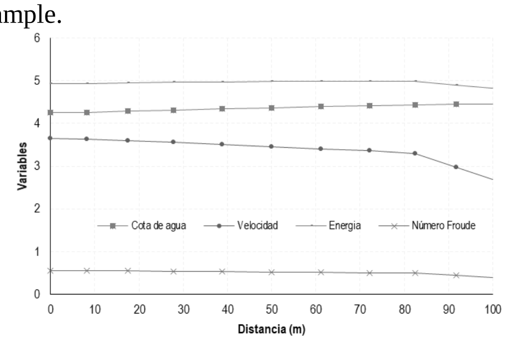


Figure 10. Profiles of depth, velocity, energy and Fr.
Source: The authors.

Table 6
Curved channel model features

Input flow rate	Q = 5000 m^3/s
Roughness	0.025
Structured mesh	5.0 m x 5.0 m
Number of elements	2500
Simulation time	1500 s
Simulation duration	2 min 6 s
Geometry construction	15 min

Source: The authors

3.6 Example 6: hydraulics in braided rivers

One of the purposes of channel courses is to teach how flows distribute in branches and flow networks, similar to those of braided and anastomosed channels in rivers. Anastomosed rivers have high sinuosity and several channels with very low slopes that allow continuous and rapid vertical sedimentation. In this example, the mesh represents several flow arms around lightly elevated bars above the main channels with gentle bed slopes. The definition of initial conditions of flows in the two right arms allows the simulation in time of the bifurcated flows and the establishment of energy and depths. The walls of the outlet channels and outer edges correspond to fixed vertical walls, while internally the flow is free to overflow on the internal bars. Fig. 11 shows the distribution of velocity vectors in the sections. The throttle speed of the lower right arm stands out as it increases until reaching supercritical flow and even forming hydraulic jumps, due to the damming caused by the upper right arm's flow.

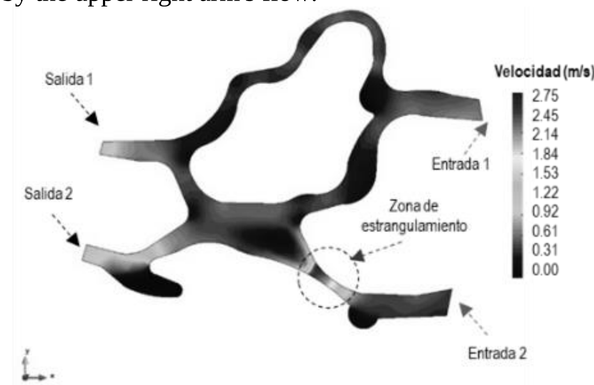


Figure 11. Flow velocity rates in fixed-walled braided channels.

Fig. 12 shows a simulated picture of the depths after the discharge overflows the bars.

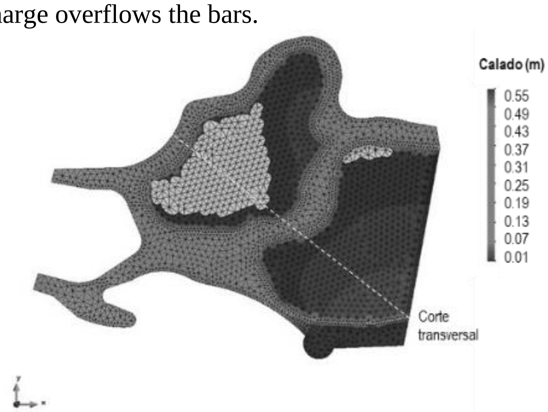


Figure 12. Meshing and brace levels with overflow on the bars towards the end of the simulation.

Fig. 13 shows the cross section through the two main bars, with the effect of the overflow and the flow depths in the main channels. Table 7 summarizes the features of the run model for this example.

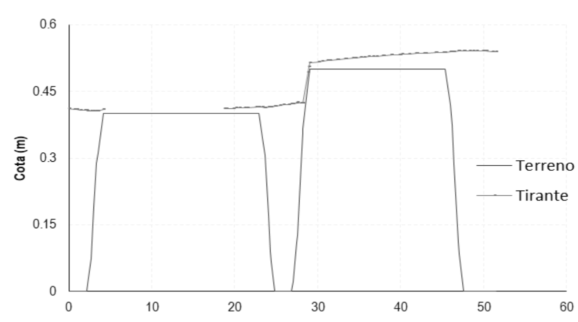


Fig 13. Transversal cut over braided sections.
Source: The authors

Table 7
The features of the run model for transversal cut over braided sections.

ut water flow	$Q_{(especìfico)}$ = 1 m^3/s, v = 2 m/s
Roughness	0.025
Structured mesh	5.0 m x 5.0 m
Number of elements	2500
Simulation time	1500 s
Simulation duration	2 min 6 s
Geometry construction	15 min

Source: The authors

3.7 Example 7: lateral flows in curved and straight sections

Many by-pass flow structures in treatment plants and urban drainage consist of lateral dumps that extract some of the main channel flow. In this example, we show the flow diversion from a curved channel to a straight channel and from the straight channel to a smaller channel at an angle of 40 degrees (Fig 14).

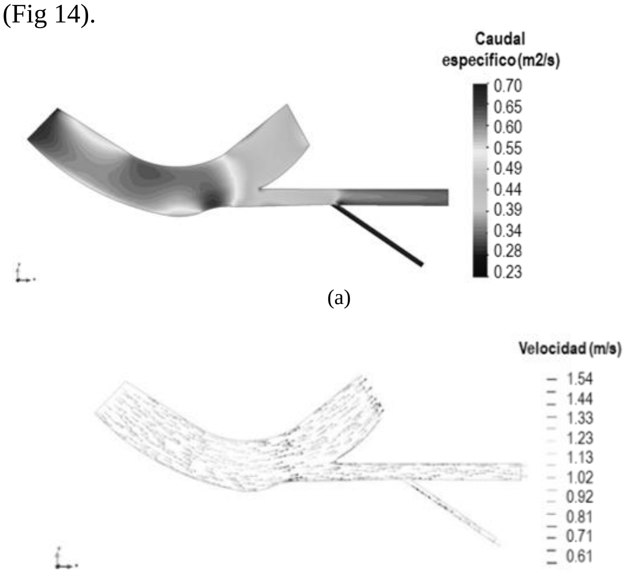


Figure 14. Lateral flow diversions: a) specific flow rates, b) velocity field.
Source: The authors.

Fig. 14a shows the discharge circulating through the three channels. We highlight the changes in flow rates after passing the discharge points. The velocity field shown in Fig. 14b indicates that the assumption of unidirectional flow can be valid in this type of flow derivatives. Table 8 summarizes the features of the run model for this example.

Table 8
Side derivations model features

Input flow rate	$Q_{(especìfico)}$ = 2 m^3/s
Roughness	0.025
Structured mesh	1.0 m x 5.0 m
Number of elements	2500
Simulation time	1500 s
Simulation time	2 min 6 s
Geometry construction	15 min

Source: The authors.

4 Pedagogical benefits of using Iber in the classroom

The examples presented in this article highlight some pedagogical benefits of using a program like Iber in a channel hydraulics course:

- The clear display of flow phenomena with two-dimensional regime changes in simple settings that are ideal for explanations.
- The development of combined meshes of hydraulic structures of a certain degree of complexity to resemble real flow conditions in engineering.
- The development of term projects for the design of capture, storage, sedimentation, treatment and drainage structures, among others.
- The intuitive and relatively easy approach to computational fluid mechanics and 2D modeling.
- The convenience for the verification and quantification of hydraulic phenomena in rivers explained in class in a qualitative way, as they are difficult to calculate analytically without the aid of a calculation programs. This allows students to assimilate these phenomena in a better way and to acquire a greater intuition regarding water movement in natural channels.

In addition, students have the possibility to build complex designs that will bring them closer to a professional practice and consultancy. This is particularly helpful in the calculation of discontinuous flows (i.e., hydraulic jumps, wave fronts); the evaluation of flooding zones in sections with the presence of structures such as bridges; and in the design of protections for transversal and longitudinal structures to the riverbed, among others.

Many institutions, due to the lack of economic and human resources, or due to excessive assembly and operation time, find experimental teaching practices difficult. This tool shows some numerical examples of free surface flow simulation that complements a “white-board” traditional class.

Unlike the HEC-RAS program which, from a pedagogical point of view, is only suitable for end of term work (i.e., scour and transit conditions of hydrographs included), Iber offers the possibility to continuously introduce examples in class, by means of fine resolution graphics and quickly executed simulations, once the corresponding example has been run. While it is true that Iber cannot display many other relevant conditions (such as secondary flows, horseshoe vortices and turbidity flows) due to its 2D nature, many topics may benefit from the use of these simulations in class.

Furthermore, even though they have not been dealt with in this article, Iber includes some other modules that can also be used in the teaching of courses related to water quality in a natural environment [11], [12] and hydrological calculations at watershed level [5], [13].

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M. H. Cueva Portal recibió el grado académico de Ingeniero Hidráulico en la Universidad Nacional de Cajamarca en 2017, actualmente es estudiante de la maestría de Ingeniería Hidráulica en la Universidad Nacional de Ingeniería.

J. E. Cañón Barriga recibió los títulos de Ingeniero Civil (Grado de Honor) en 1996 y MSc. en Recursos Hídricos en 2002 de la Universidad Nacional de Colombia-sede Bogotá, y Ph.D. en Hidrología de la Universidad de Arizona en 2009. Desde 2003 es profesor de la Universidad de Antioquia, universidad en la que asesora investigaciones de maestría y doctorado en diversos ámbitos de la ingeniería ambiental y en la que imparte cursos de pregrado y posgrado, entre ellos Mecánica de Fluidos, Hidráulica de Canales, Metodología de la investigación y Análisis de series de tiempo. Más información en la página web: https://sites.google.com/site/jecanon/.
ORCID: 0000-0001-8041-2774

L. Cea obtuvo el título de Ingeniero de Caminos Canales y Puertos en la Universidade da Coruña en enero de 2001, y el título de Doctor en Ingeniería Civil en 2005. Desde 2012 es Profesor Titular del área de Ingeniería Hidráulica en la Universidade da Coruña, impartiendo clases de evaluación y gestión del riesgo de inundación, modelización numérica de flujos en lámina libre y obras hidráulicas. Es uno de los principales desarrolladores del modelo Iber (www.iberaula.com) y uno de los coordinadores del programa de cursos online de Iber (www.ibercursos.com).
ORCID: 0000-0002-3920-0478