Hydrology, Applied Hydrodynamics and Hydraulic Constructions

Improving the Design of Hydraulic Structures

A Unified 1D Simulation Tool for Highly Transient Water Flow

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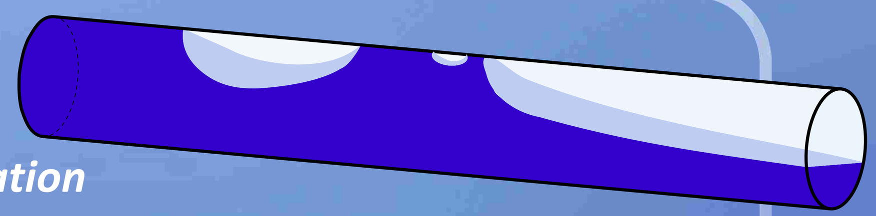
Pipe flow general context

It is distinguished three potential kinds of flow in pipes :

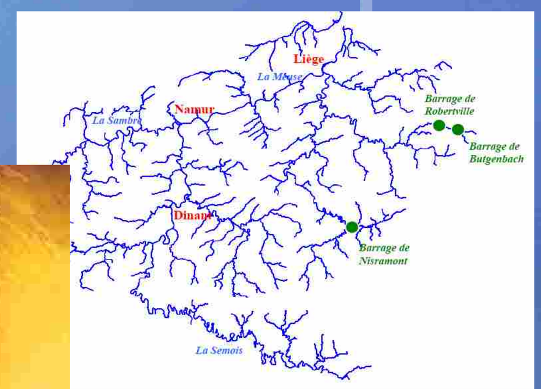
- *Free surface : sub/super-critical flows*
- *Pressurized : high celerity pressure wave propagation*
- *Mixed : simultaneous occurrence of a free-surface and a pressurized flow.*

Each one is traditionally simulated with a specific software !

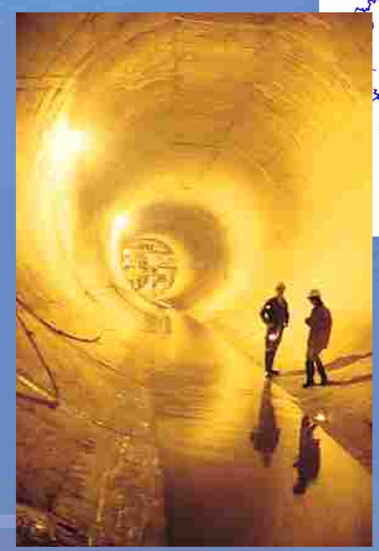


The temporal/spatial scales range of involved phenomena is wide :

- *from (quasi-)stationary flow in large network*
- *to highly transient flow as water-hammer*



Wallonie river network
Source : HACH- P. Archambeau



Chicago TARP system
Source : A. S. Leon

Interaction between the water and the air may appear :

Aeration in a hydraulic jump.
Source : HACH

The HACH research unit has been developing for over ten years two types of complementary activities, leading to an expertise in physical modelling of various hydraulic structures as well as in numerical simulation relying on the self-developed modeling system WOLF

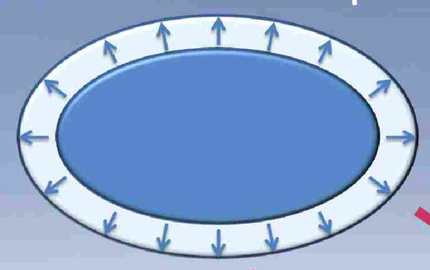
Theoretical development

1. The classical Preismann hypothesis sets out that a pressurized flow can be equally simulated through the free surface flow set of equations by adding a narrow slot at the top of the pipe.

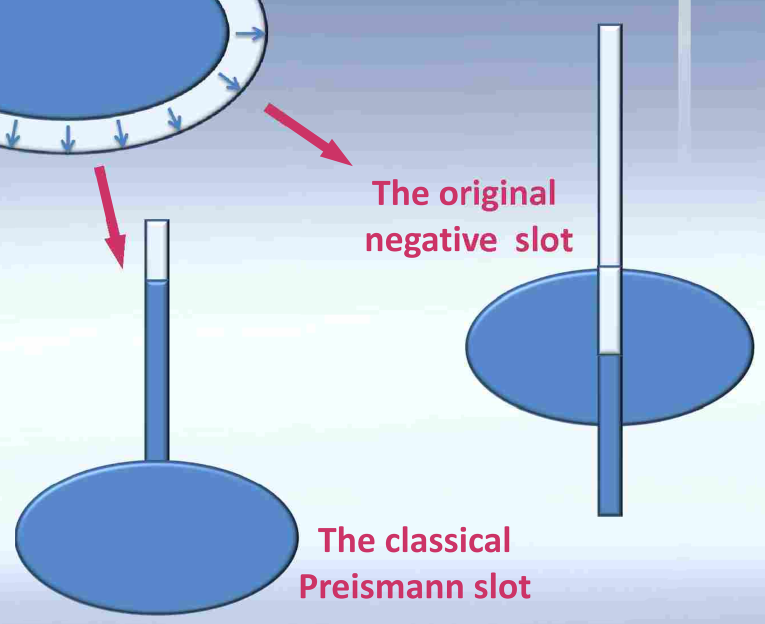
2. An original negativ slot is proposed to take into account sub-atmospheric flow.

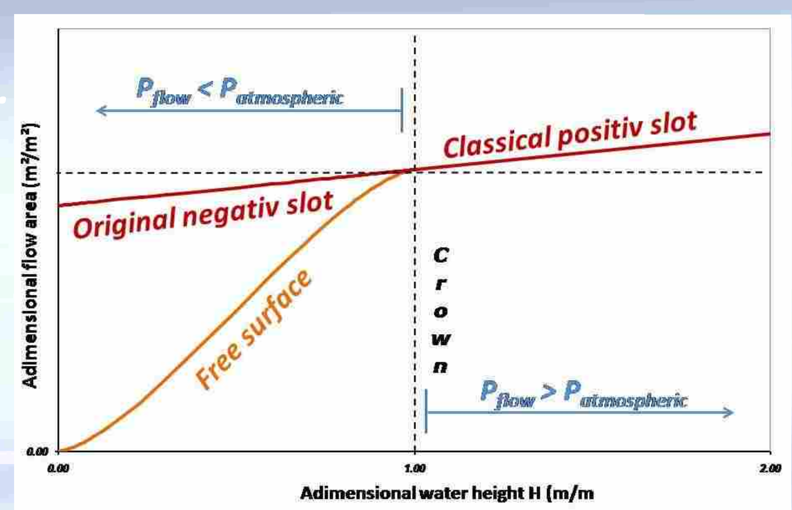
3. All the relevant geometrical information is implemented through the relation between

- *the flow area,*
- *the water height.*



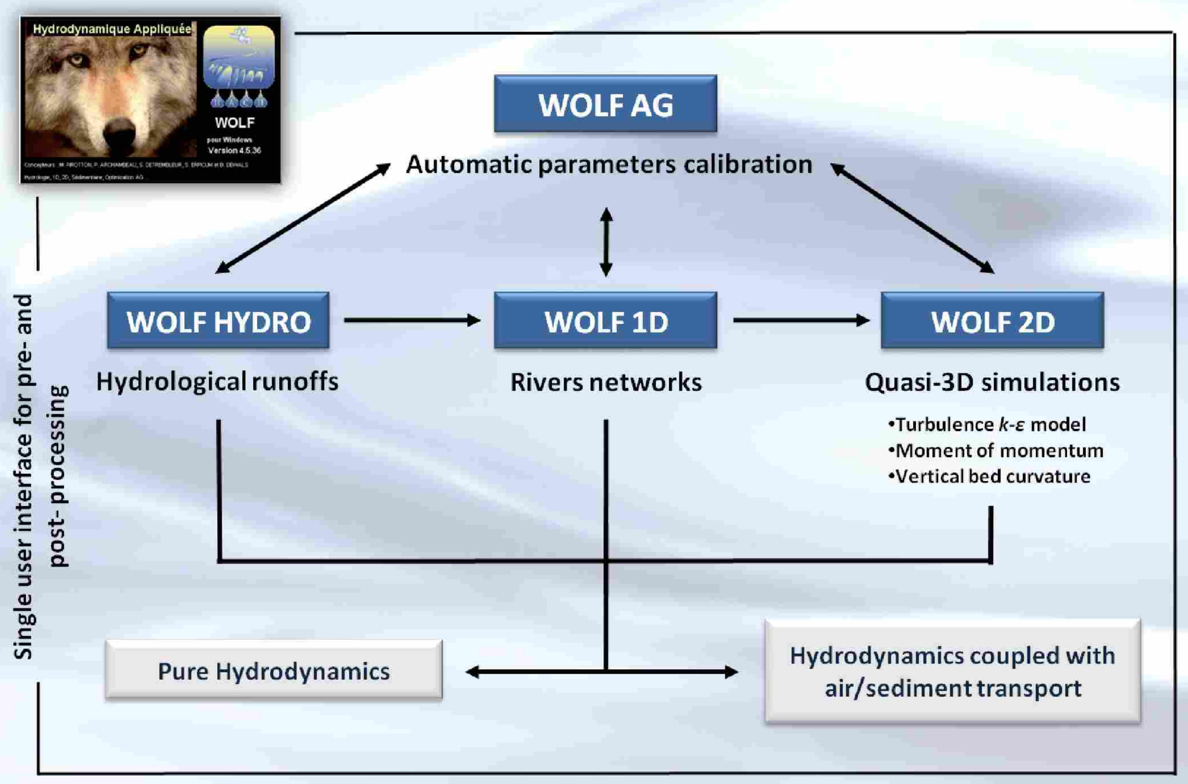
Pipe dilatation/contraction under a variation of the flow pressure





Numerical environment for practical development

Implementation within the 1D module of the WOLF modelling system :



WOLF 1D

Navier-Stokes equations integrated on the flow area :

$$\frac{\partial \Omega}{\partial t} + \frac{\partial Q}{\partial x} = -q_L$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{\Omega}\right) + g\Omega\frac{\partial Z}{\partial x} = -J$$

Upwind Finite Volume Discretization

- *Convective term : upstream*
- *Pressure term : downstream*

Ω = flow area
Q = flow discharge
q_L = lateral discharge
Z = free surface elevation
J = friction slope

The project in a few words

Civil engineers face every days the challenge to improve the design of hydraulic structures for reasons of security, economical rentability and environmental preservation. In this **context**, they ought to rely on accurate simulation tools. In particular, difficulties arise when the dynamics of air/water interactions within the flow and the impact of the presence of entrapped air on the structure need to be accurately predicated.

The **ambition** of this project consists of creating an original algorithm to simulate a large spectrum of practical applications in a unified numerical framework. In this process, special attention will be given to the two-phase flow behaviour ! The existing finite volume modelling system WOLF, which is originaly dedicated to free surface flow simulation, is used as a validated background of all the new development.

The **planification** of the modelling system improvement includes 4 steps:

1. Adapting the WOLF 1D module to pressurized flow.
2. Extending the resulting algorithm to take into account the air/water interaction with a two-phase formalism.
3. Integrating the air/water interaction within the quasi-2D module of WOLF as well.
4. Assessing the WOLF 3D module for two-phase flow purpose (currently in development by the HACH research team).

This poster highlights the rigorous **scientific approach** used to tackle the first step of the project : simulate free-surface flow and pressurized flow in a unified framework. It is shown how the theoretical development of a single set of equations based on the classical Preismann slot and on an original negative slot had been implemented in the WOLF 1D module using a well established finite volume scheme. Finally, the validation of the new simulation tool performed on a published benchmark show its ability to simulate sub-atmospheric pressure.

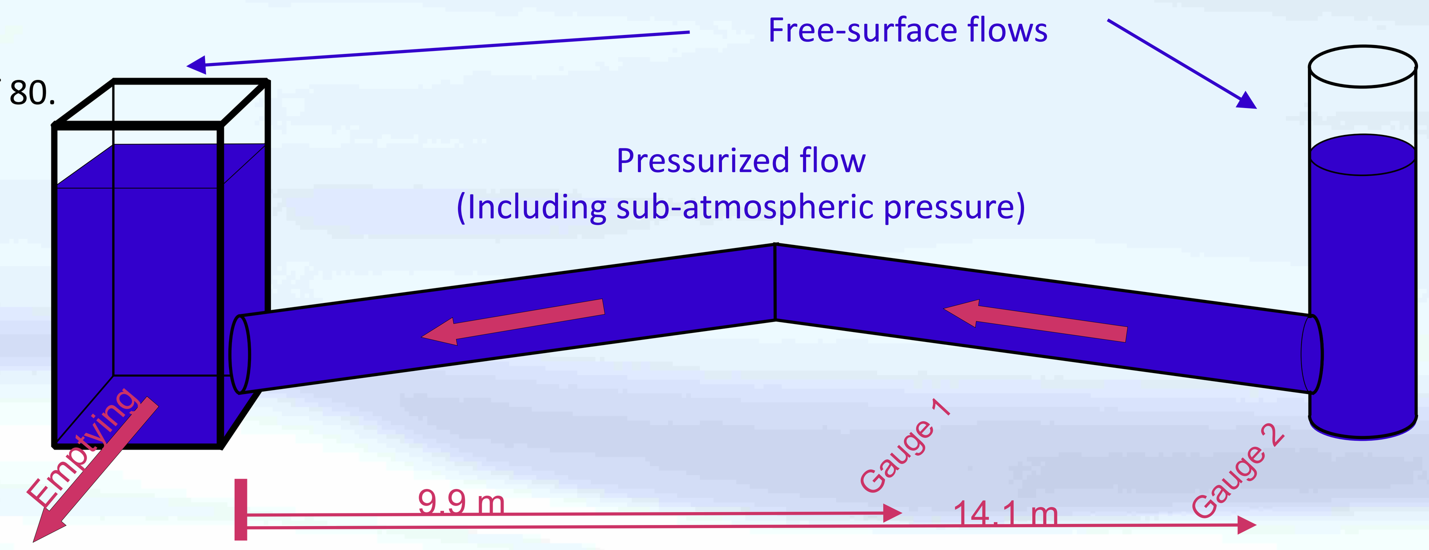
Model assessment on published benchmark

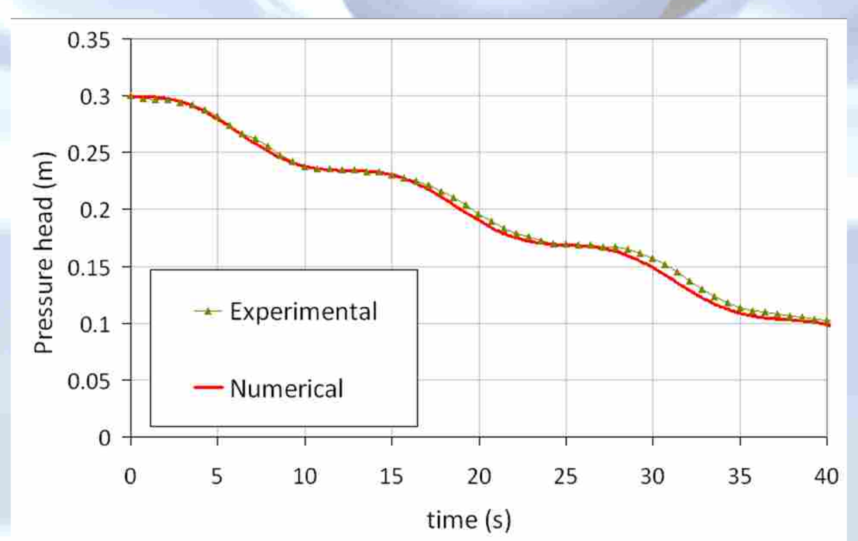
Experimental apparatus (Vasconcelos - 2005) :

1. 2 storage towers connected by a pipe.
2. The pipe has a length of 14.1 m, a diameter of 9.4 cm and a Manning-Strickler coefficient of 80.
3. The pipe reaches its top 15 cm above the basic level.

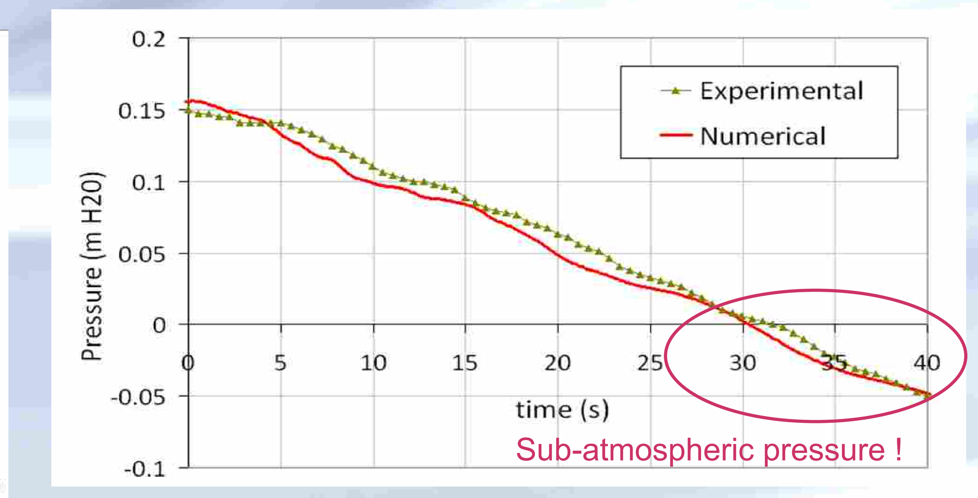
Experimental procedure :

- the initial level of water is 30 cm,
- a controlled valve is opened at the bottom of the cubical storage tower resulting in the emptying of the pipe at a rate of 0.45 l/s
- the combination of the water level decrease and the fluid velocity increase creates a sub-atmospheric pressure at the top of the pipe.
- the temporal evolution of the pressure head is measured by the gauge 1 and 2
- the temporal evolution of the velocity is followed at the gauge 1.

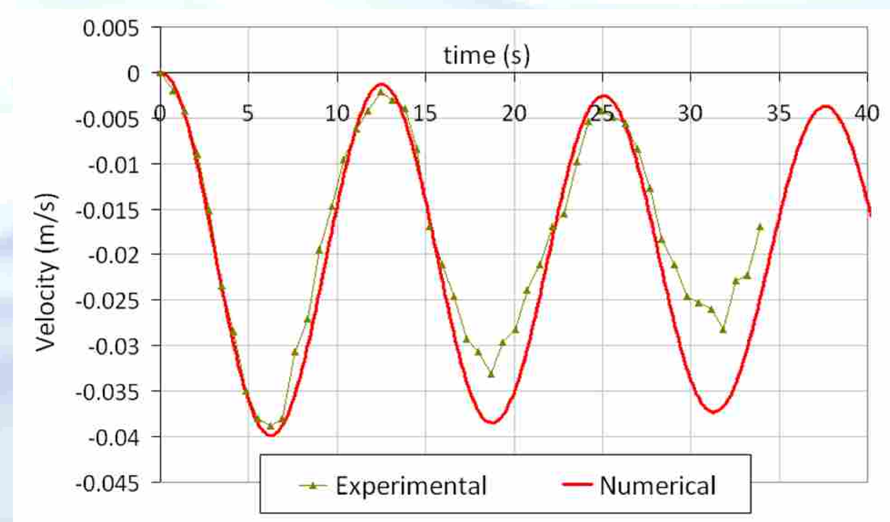




Gauge 2 : pressure head



Gauge 1 : Pressure head



Gauge 1 : Velocity

ArGEnCo

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