The role of physical models and field monitoring in Environmental and Maritime Hydraulics

Michele Mossa

POLITECNICO DI BARI
DICATECh - Dpt. of Civil, Environmental, Building Engineering and Chemistry
Professor of Hydraulics
Chief Scientist of the LIC (Coastal Engineering Laboratory)
michele.mossa@poliba.it
www.michelemossa.it
www.iahrmedialibrary.net
Typical environmental problems where knowledge of the land, monitoring and physical modeling are of great help

- Coastal erosion and sand transport
- Diffusion of pollution
- Oil spilling
- Support to administrations for the design, construction and maintenance of hydraulic engineering works
- Many others…
Typical scientific approach to the problem

- Field Measurement and Monitoring
- Physical models
- Numerical models
- Hybrid models
Coastal Engineering Laboratory funded by Programma Operativo Plurifondo Puglia
D.R. 29/10/90 n. 6155, cofinanced with structural funds CEE-REG.
CEE n. 20522/68 e 4253/88, Sottoprogramma 6, Misura 6.3
Width=50 m; length=100 m; depth=1.2 m.

3D wavemaker:

- Number of modules = 6
- Number of paddles = 8
- Paddle width = 60 cm
- Max wave front length = 28.8 m
- Hmax=30 cm
OFF-SHORE PHYSICAL MODEL BASIN

Width=50 m; length=30 m; depth=3 m


TSUNAMI WAVES GENERATED BY LANDSLIDES IN WATER: MECHANICS OF WAVE GENERATION AND PROPAGATION, DEVELOPMENT OF FORECASTING TOOLS AND REAL-TIME WARNING SYSTEMS BASED ON TIDAL MEASUREMENTS. The photo shows a tsunami scenario generated by landslide at Sciarra del Fuoco (Stromboli island). The physical model was constructed at the LIC of the Technical University of Bari.
TWO WAVE CHANNELS

Experimental research of different regular and irregular waves breaking and the coherent structures due to the wave breaking using LDA and PIV, in cooperation with the Polytechnic University of Marche and the network Hydralab+.

The investigation refers particularly to the surf zone, with the aim to develop two themes: the study of velocity and Reynolds and wave shear stresses distributions greatly influence many coastal processes, such as undertow currents, sediment transport and action on maritime structures.

Awarded with a fellowship Gii Placement in Water Engineering. Call of 23rd October 2015

Some references:
Other images of the LIC
Channel with a very large aspect ratio (width 4 m) used for the study of the jet diffusion, in cooperation with prof. Peter Davies (University of Dundee, UK).

A part of the very large channel of the LIC is the buoyant jet thermal-hydraulic system. The discharged heated water generating the turbulent buoyant jet is pumped into the channel through a round steel tube mounted at the bottom of the channel in the central longitudinal section.
WHY IS MONITORING IMPORTANT?

1. **Systematic collection of data of interest** (hydrodynamic and physical parameters) to be made available to stakeholders with database analysis, processing and storage

   - Support local government in its coastal planning and management activities
   - Allow intervention in an emergency (i.e., accidental oil spilling)
   - Check currents and waves role in coastline erosion and their impact on recreational activities
   - Diffusion and dispersions of polluting tracers is strictly connected to currents and waves propagation

2. **Establish a reliable set of 'good' measurements** to be used for calibration and validation of numeric models.
MONITORING
Measurement stations installed and operated in the Gulf of Taranto by the Research Group of the LIC

The area in question is in southern Italy and is composed by two basins, an inner one named Mar Piccolo and an external one named Mar Grande.

This study area is highly vulnerable, because exposed to a strong anthropic pressure, to urban and industrial discharges as well as to an intense naval traffic. For all these reasons, at present, it is enclosed in the so-called SIN (site of national interest) list and is under the control of the Special Commissioner appointed by the Italian Government to evaluate and dispose urgent measures of remediation and environmental requalification of Taranto city.
System in the Mar Grande Taranto (Italy) for the monitoring of sea currents (ADCP) and waves. Also a meteo station, a CTD, a combined fluorometers, turbidity meters and a C3 Submersible Fluorometer for CDOM, Crude Oil and Refined Fuels have been installed.

The real time data area available from this web site:
http://www.michelemossa.it/stazionemeteo.php
RITMARE is the Italian leading national marine research project for the period 2012-2016 (overall project budget amounts to 250 million euros, co-funded by public and private resources). In this frame, we installed a system in the Navigable Channel of the Mar Piccolo of Taranto (Italy) for the monitoring of sea currents and waves.

The real time data are available from this web site: http://www.michelemossa.it/stazionemeteo2.php
Ultrasonic tide gauge in Navigable Channel of Mar Piccolo (Taranto)

- Installed on August 2015
- Acquisition frequency: 5Hz

Spectral analysis of the sea currents and the tide in the Navigable Channel

Some references:

De Serio Francesca, Mossa Michele (2016). Assessment of hydrodynamics, biochemical parameters and eddy diffusivity in a semi-enclosed Ionian basin. DEEP-SEA RESEARCH. PART 2, TOPICAL STUDIES IN OCEANOGRAPHY, ISSN: 0967-0645.


FIELD MEASUREMENTS OF THE SEA CURRENT WITH A VM-ADCP
(VEssel-MOUNTED ACOUSTIC DOPPLER PROFILER)
for the comparison between the field measurements and the numerical codes

Sea current measurements: **VM-ADCP** with GPS receiver (the accuracy of the GPS velocity should be 0.05 m/s or better (DGPS))
Gyro: with serial output and accuracy better than 1°. It is also possible to use combined gyro and GPS system
Computer: The survey computer needs at least 3 serial ports and it is advisable to use an intelligent multi-port card.

Simultaneous measurements of water temperature and salinity with a CTD
Two case studies:

1) Jets with waves
2) Jets in vegetated flows
CASE STUDY 1
JETS IN WAVE ENVIRONMENT

- The sea has always been the final destination for water-borne waste products coming from the land.

- While there are several studies in literature on jets and their interaction with currents, few deal with jet-wave interaction.
Experiments were carried out in a wave channel at the hydraulics laboratory of the Polytechnic University of Bari. The channel is about 45 m long and 1 m wide, with a depth of 1.2 m.

We used resistance probes for wave profile measurements.

The velocities were measured with a LDA system.
COMPARISON BETWEEN JETS IN STAGNANT WATER AND WITH WAVES

Jet without waves

Jet with waves
Variation of the cross length scale \( b \) (jet enlargement) as a function of the distance from the jet nozzle

For further details see:
Vegetation is not just a static element of marine and fluvial ecosystems, unchanging with changing conditions, but it interacts with different processes at different scales, e.g. blade scale, patch scale or canopy scale.

CASE STUDY 2
JETS IN VEGETATED FLOWS

Pollination/Pesticide spray
Vegetation is not just a static element of marine and fluvial ecosystems, unchanging with changing conditions, but it interacts with different processes at different scales, e.g. blade scale, patch scale or canopy scale.

Important parameters:
1) Stem diameter $d$
2) Jet cross section length $b$
3) Distance between two neighboring stems $s$
Examples of jets with vegetation as a function of $d/s$ and $b/d$ and $b/s$

- **Case with $b/s\geq 10$**
  - Case $d/s=O(10^{-1}-1)$, $b/d=O(10-10^2)$, $b/s=O(10-10^2)$: Widespread effects on both the ambient current and the jet. Example of flows: jets in rivers and sea with vegetated bottom current.
  - Case $d/s=O(1-10)$, $b/d=O(10^{-2}-10^{-1})$, $b/s=O(10^{-2}-10^2)$: Big effects on both the jet and the ambient current. Example of flows: High-flow-blockage canopy; diffusion of contaminants in porous groundwater; injections of jets in groundwater; interior flows associated with porous obstruction. In this case, the jet will tend to diverge significantly in the canopy.

- **Case with $b/s<10$**
  - Case $d/s=O(1)$, $b/d=O(1)$, $b/s=O(1)$: effects mainly on the ambient current and local effects on the jet boundary at the same scale of $b$. Example of flows: peculiar situation of the cases described below.
  - Case of $d/s=O(10^{-2}-10^{-1})$, $b/d=O(1-10)$, $b/s=O(10^{-2}-10^{-1})$: Effects almost absent on the jet and locally present on the ambient current. Example of flows: release of water of boats between oyster farms.
  - Case $d/s=O(10^{-2}-10^{-1})$, $b/d=O(10-10^2)$, $b/s=O(1)$: Local effects on the jet boundary at a scale with an order of magnitude less than $b$. Effects locally present on the ambient current. Example of flows: peculiar situation of the previous case; river in a flood plain with an array of trees.
  - Case $d/s=O(10-10^2)$, $b/d=O(10^{-2}-10^{-1})$, $b/s=O(1)$: Very strong effects on the ambient current and locally at the jet boundary. Example of flows: narrow jets in groundwater; release of a dye trace in groundwater.
  - Case $d/s=O(1)$, $b/d=O(10^{-1})$, $b/s=O(10^{-1})$: Very strong effects on the ambient current and locally at the jet boundary. Example of flows: narrow jets in groundwater; release of a dye trace in groundwater.
Transport of tracers and turbulent kinetic energy

\[
\frac{\partial \overline{c}}{\partial t} + \frac{\partial \overline{u_i c}}{\partial x_i} = K_{ii} \frac{\partial^2 \overline{c}}{\partial x_i^2}
\]

\[
\frac{\partial k}{\partial t} + \frac{\partial \overline{u_i k}}{\partial x_i} = D_k \frac{\partial^2 k}{\partial x_i^2}
\]

where \( c \) = tracer concentration and \( k = \frac{1}{2} \overline{u_i 'u_i '} \) is the time-averaged turbulent kinetic energy.

The analogy between the two equations enables us to conclude that the dispersion coefficients is

\[
K_{ii} = \alpha \sqrt{k} l_i
\]

The scale factor \( \alpha \) could be different for horizontal and vertical diffusion, even if generally it is of \( O(1) \).

In the present study, the integral length scale \( l_i \) is evaluated by multiplying the integral time scale \( T_u \) by the local time-averaged velocity, where \( T_u \) is estimated by the autocorrelation function of the turbulent velocity fluctuations.
Experimental apparatus

A square array of rigid circular steel cylinders was used to simulate vegetation stems. The stem diameter, \( d \), was equal to 0.003 m.

Stems were spaced longitudinally and transversally with the same distance \( s \) 0.05 m, so that the stem density, \( n \), was 400 stems/m\(^2\), and the projected plant area per unit volume, was \( a=nd=\frac{dH}{s^2H}=\frac{d}{s^2}=1.2 \text{ m}^{-1} \).

Main parameters of the analyzed runs

<table>
<thead>
<tr>
<th>Flow type</th>
<th>Runs</th>
<th>( H ) [cm]</th>
<th>( U_e ) [ms(^{-1})]</th>
<th>( U_0 ) [ms(^{-1})]</th>
<th>( R ) [-]</th>
<th>Re</th>
<th>Re0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet in an unobstructed flow</td>
<td>U1</td>
<td>37</td>
<td>0.16</td>
<td>5.90</td>
<td>37.36</td>
<td>16036</td>
<td>13845</td>
</tr>
<tr>
<td></td>
<td>U2</td>
<td>30</td>
<td>0.19</td>
<td>5.90</td>
<td>30.29</td>
<td>20383</td>
<td>15437</td>
</tr>
<tr>
<td></td>
<td>U3</td>
<td>37</td>
<td>0.16</td>
<td>3.93</td>
<td>24.91</td>
<td>18802</td>
<td>10822</td>
</tr>
<tr>
<td></td>
<td>U4</td>
<td>30</td>
<td>0.19</td>
<td>3.93</td>
<td>20.20</td>
<td>20733</td>
<td>10468</td>
</tr>
<tr>
<td>Jet in an obstructed flow</td>
<td>O1</td>
<td>37</td>
<td>0.16</td>
<td>5.90</td>
<td>37.36</td>
<td>23054</td>
<td>19904</td>
</tr>
<tr>
<td></td>
<td>O2</td>
<td>30</td>
<td>0.19</td>
<td>5.90</td>
<td>30.29</td>
<td>26282</td>
<td>19904</td>
</tr>
<tr>
<td></td>
<td>O3</td>
<td>37</td>
<td>0.16</td>
<td>3.93</td>
<td>24.91</td>
<td>24591</td>
<td>14154</td>
</tr>
<tr>
<td></td>
<td>O4</td>
<td>30</td>
<td>0.19</td>
<td>3.93</td>
<td>20.20</td>
<td>26282</td>
<td>13270</td>
</tr>
</tbody>
</table>
Longitudinal profiles of the dimensionless time-averaged streamwise $u$ velocity components without and with vegetation.
Longitudinal profiles of the dimensionless time-averaged vertical $w$ velocity components without and with vegetation

c) $\overline{w}/U_e$ of run U4

d) $\overline{w}/U_e$ of run O4
Effects of vegetation on the diffusion

Values of $K_{xx}$ (longitudinal diffusion) and $K_{yy}$ (transversal diffusion) of tests U4 (without vegetation) and O4 (with vegetation) with the line of the averaged-values
Values of $U_k$ (longitudinal advection) of tests U4 (without vegetation) and O4 (with vegetation) of the longitudinal sections with the time-averaged values

Values of $V_k$ (transversal advection) of tests (without vegetation) and O4 (with vegetation) of the transversal section at $x/D=26.67$ with the time-averaged values
Turbulent jets flowing in currents have been widely examined because of their relevance to many environmental conditions. This study examines a pure turbulent jet issued into an obstructed flow (i.e. vegetated flow), simulated with a regular array of cylinders. The main conclusions can be summarized as follows:

1) Differently from the case of jets in unobstructed flows, in the presence of a cylinder array, **the streamwise turbulent diffusion is reduced**, while the transverse diffusion is enhanced. Importantly, in the obstructed condition, the streamwise and transverse turbulent diffusion coefficients are of the same order of magnitude.

2) The presence of the **vegetation reduces both the diffusion and advection processes of the jet in the longitudinal direction**. In contrast, the **lateral dispersion does not experience the same reduction**, because of the transversal deviation of the streamwise flow around individual cylinders.

For further details, see:

Mossa, M. and De Serio, F. Rethinking the process of detrainment: jets in obstructed natural flows. Sci. Rep. 6, 39103; doi: 10.1038/srep39103 (2016)
https://www.nature.com/articles/srep39103

https://www.nature.com/articles/s41598-017-05881-1
Other channels of the LIC for the same study

Some references:


Mossa, M. & De Serio, F. Rethinking the process of detrainment: jets in obstructed natural flows, Scientific Reports, 6, Article number: 39103, doi:10.1038/srep39103, 2016.


Journal’s Aims and Scope:

*Water* (ISSN 2073-4441) is an open access journal on water science and technology, including the ecology and management of water resources, the scope encompasses:

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- Hydrology & hydraulics
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- Water quality
- Water & wastewater treatment
- Urban water management
- Water footprint assessment
- Water-food
- Water-energy
- Water-human development
- Water-ecosystems

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The Netherlands

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**Article**

**SPH Modelling of Hydraulic Jump Oscillations at an Abrupt Drop**

Diana De Padova 1,*, Michele Mosa 1 and Stefano Sibilla 2

1 Department of Civil, Environmental, Land, Building Engineering and Chemistry (DECATLU), Polytechnic University of Turin, 20122 Turin, Italy; michele.mosa@polito.it
2 Department of Civil Engineering and Architecture, University of Pavia, via Bossi 5, 27100 Pavia, Italy; stefano.sibilla@unipv.it

* Correspondence: diana.depadova@polito.it

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**Abstract**:

This paper shows the results of the numerical modelling of the transition from supercritical to subcritical flow at an abrupt drop, which can be characterized by the occurrence of oscillatory flow conditions between two different jump types. Weakly-Compressible Smoothed Particle Hydrodynamics (WCSPH) model was employed and built an algebraic missing length model and a two-equation model were used to represent turbulent stresses. The purpose of this paper is to obtain, through the WCSPH model, a deeper understanding of the physical features of a jump, which is, in general, difficult to be reproduced numerically, owing to its unstable character. In particular, the experience already gained in SPH simulations of wavy-velocity-dominated flows allows one to assess the fluctuations of hydrodynamic characteristics of the flow field, e.g., free surface profile downstream of the jump, velocity, pressure and vorticity. Numerical results showed satisfactory agreement with measurements and of the peculiar features of the flow were qualitatively and quantitatively reproduced.

**Keywords**: Hydraulic jump; Smoothed particle hydrodynamics models; oscillating characteristics
Thank you for your attention
CONCLUSIONS

• This presentation has the main aim of exposing the importance of Hydraulic research (with physical and numerical models and with monitoring) in the branch of the environment.

• The importance of physical models and monitoring systems have been highlighted.

• A deeper knowledge of complex environmental flows should be pursued both for research and technical interests.

• Two case studies have been analyzed, i.e. jets in wave environment and jets in vegetated flows.

• The results highlight that the diffusion and advection processes of the same jet issued in a wave environment or in a vegetated flows are different from those of the same jet issued in still water.

• On this point, the recommendation to explore this research field is very strong, considering that now connections to physics, geology, geomorphology, erosion science, ecology, biology, plant physiology, etc. are to be considered obvious.

• We should instead work with the sole fascinating purpose of protecting this small spacecraft which is our planet Earth.
THEORETICAL BACKGROUND

The $u_i (i=1,2,3)$ velocity components can be expressed as follows

$$u_i(x_i,t) = \langle u_i \rangle(x_i,t) + u'_i(x_i,t) = U_i(x_i) + \tilde{u}_i(x_i,t) + u'_i(x_i,t)$$

The ensemble average of the motion equations for turbulent non-buoyant jet flow under wave action are

$$\frac{\partial \langle u_i \rangle}{\partial t} + \frac{\partial \langle u_i \rangle \langle u_j \rangle}{\partial x_j} = \frac{1}{\rho} \frac{\partial}{\partial x_j} \left( -\langle p \rangle \delta_{ij} + \mu \left( \frac{\partial \langle u_i \rangle}{\partial x_j} + \frac{\partial \langle u_j \rangle}{\partial x_i} \right) - \rho \langle u'_i u'_j \rangle \right)$$

The motion of the incompressible fluid is periodic, so the average over the period $T$

$$\frac{\partial}{\partial x_j} \left( U_i U_j + \tilde{u}_i \tilde{u}_j + u'_i u'_j \right) = \frac{1}{\rho} \left( -\frac{\partial P}{\partial x_j} \delta_{ij} + \mu \frac{\partial^2 U_i}{\partial x_j \partial x_j} \right)$$
## MAIN QUANTITIES OF THE RUNS

<table>
<thead>
<tr>
<th>Quantities</th>
<th>Configuration 1</th>
<th>Configuration 2</th>
<th>Configuration 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H$ [cm]</td>
<td>4.20</td>
<td>4.40</td>
<td>4.13</td>
</tr>
<tr>
<td>$L$ [m]</td>
<td>5.10</td>
<td>3.05</td>
<td>1.56</td>
</tr>
<tr>
<td>$T$ [s]</td>
<td>2.00</td>
<td>1.43</td>
<td>1.00</td>
</tr>
<tr>
<td>$H/L$</td>
<td>0.0082</td>
<td>0.014</td>
<td>0.027</td>
</tr>
<tr>
<td>$h/L$</td>
<td>0.157</td>
<td>0.262</td>
<td>0.513</td>
</tr>
<tr>
<td>$M$ [m$^4$/s$^2$]</td>
<td>1.43E-4</td>
<td>1.43E-4</td>
<td>1.43E-4</td>
</tr>
<tr>
<td>$L_Q$ [mm]</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>$\tilde{v}_{\text{max}}$ [m/s]</td>
<td>0.0530</td>
<td>0.0375</td>
<td>0.0103</td>
</tr>
<tr>
<td>$X_M$ [m]</td>
<td>0.23</td>
<td>0.32</td>
<td>1.16</td>
</tr>
<tr>
<td>$X_M/L_Q$</td>
<td>1.21E+02</td>
<td>1.68E+02</td>
<td>6.11E+02</td>
</tr>
</tbody>
</table>

$H = \text{wave height}$  
$L = \text{wave length}$  
$T = \text{period}$  
$M = \text{momentum flux}$  
$L_Q = \text{discharge geometric scale}$  
$\tilde{v}_{\text{max}} = \text{maximum horizontal wave-induced velocity at the tank bottom}$  
$X_M = M^{1/2}/\tilde{v}_{\text{max}} = \text{the length scale of jet penetration before jet is strongly affected by the wave}$
Transport of tracers and turbulent kinetic energy

The time-averaged, turbulent transport of a solute concentration is described by the following equation

\[
\frac{\partial \overline{c}}{\partial t} + \frac{\partial u_i \overline{c}}{\partial x_i} = K_{ii} \frac{\partial^2 \overline{c}}{\partial x_i^2}
\]

where the overbar indicates the time-average operator and the prime symbol denotes the turbulent fluctuations, \( c(x) \) is the solute concentration, \( v(x) = (u,v,w) = (v_1,v_2,v_3) \) is the fluid velocity, \( x = (x,y,z) = (x_1,x_2,x_3) \), with \( x=x_1 \), \( y=x_2 \) and \( z=x_3 \) the longitudinal, transversal and vertical axes, respectively, and \( K_{ii} \) are the coefficients for dispersion. For further details see Tanino, Y. & Nepf, H.M. Lateral dispersion in random cylinder arrays at high Reynolds number. Journal of Fluid Mechanics, 600, 339-371, 2008.

In the analysis of the flow-dispersion interaction, the turbulent kinetic energy is important in determining the turbulent dispersion coefficient and thus the mass transport. For high Reynolds numbers, assuming that the production term is of order of the dissipation term, the equation of the turbulent kinetic energy is

\[
\frac{\partial \overline{k}}{\partial t} + \frac{\partial u_i \overline{k}}{\partial x_i} = D_k \frac{\partial^2 \overline{k}}{\partial x_i^2}
\]

where \( k = \frac{1}{2} \overline{u_i' u_i'} \) is the time-averaged turbulent kinetic energy and \( D_k \) is the turbulent diffusion coefficient, which can be expressed as the product of a length scale and a velocity scale. A physical meaningful velocity scale

\[
D_k = l \sqrt{k}
\]
Velocity and vorticity (positive with dashed line and negative with continuous lines) in some transversal section of the jet