University of Naples-Italy FEDERICO II

Department of Civil, Architectural and Environmental Engineering

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On evaluating flow resistance of rigid vegetation using classic hydraulic roughness at high submergence levels: an experimental work

Vittorio Pasquino, Paola Gualtieri, Guelfo Pulci Doria

Introduction

Important role of river rehabilitation in global environmental policies

Water Framework Directive (Directive 2000/60/EC) commits European Union member states to achieve good qualitative and quantitative status of all water bodies by 2015

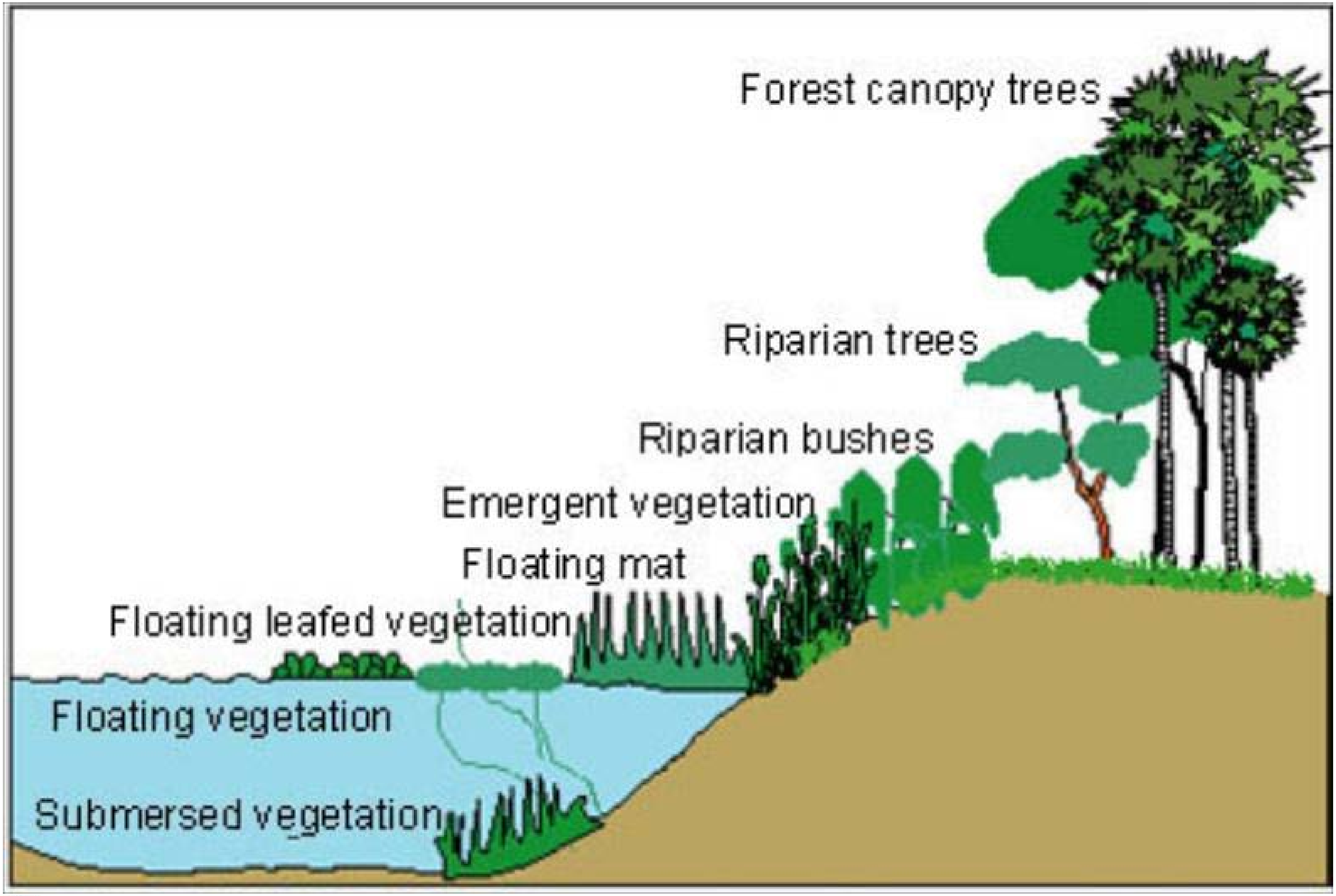
Preserving vegetation gives ecosystems benefits and improves water quality

Hydraulic research needs to deepen vegetation-flow interactions

Introduction

Sarno River is a stream that passes through Pompei to the south of the Italian city of Naples. It flows about 24 kilometres from the base of Mt. Sarno to the Bay of Naples. It is considered the most polluted river in Europe

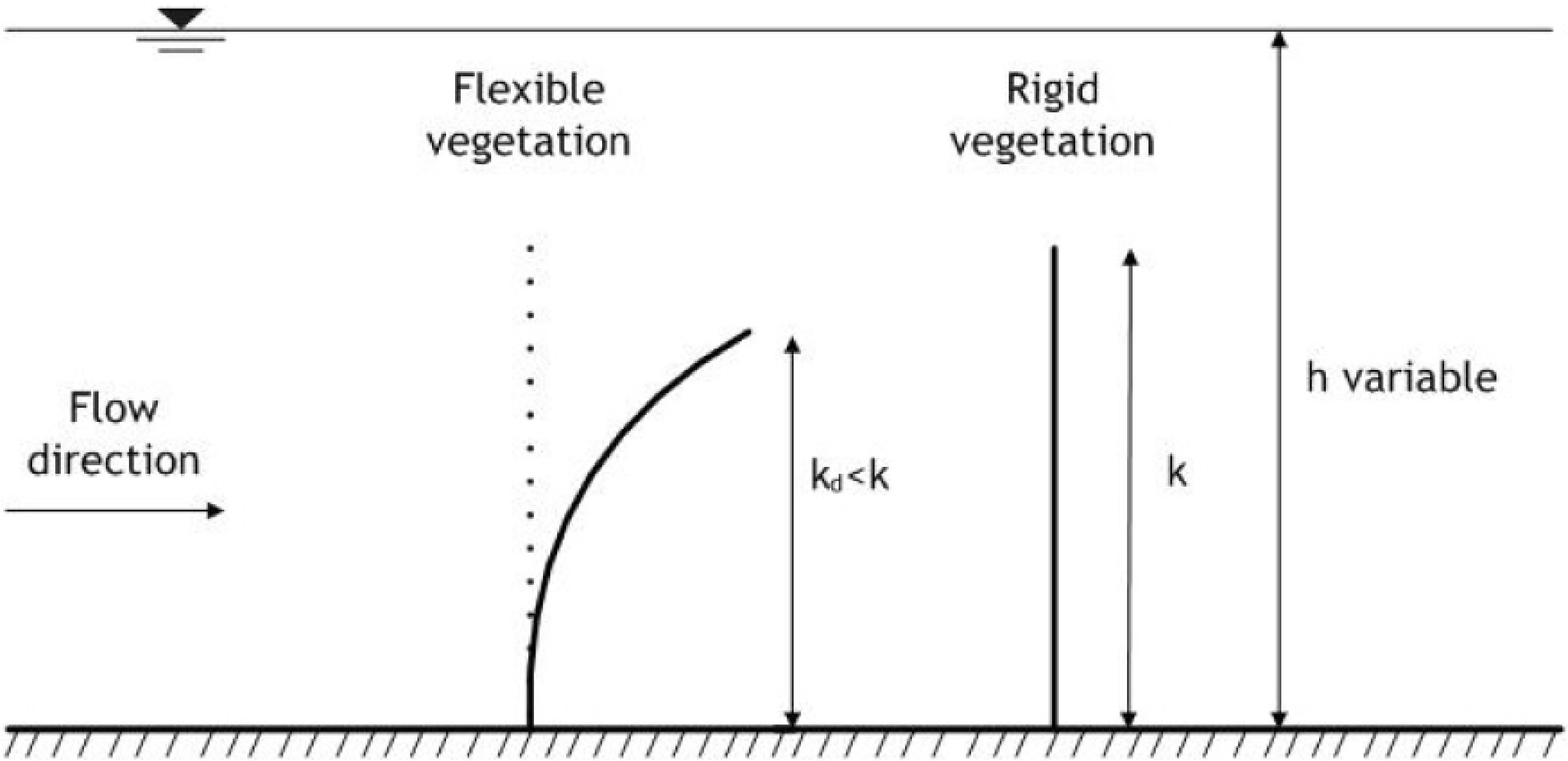
Introduction



Vegetation Models

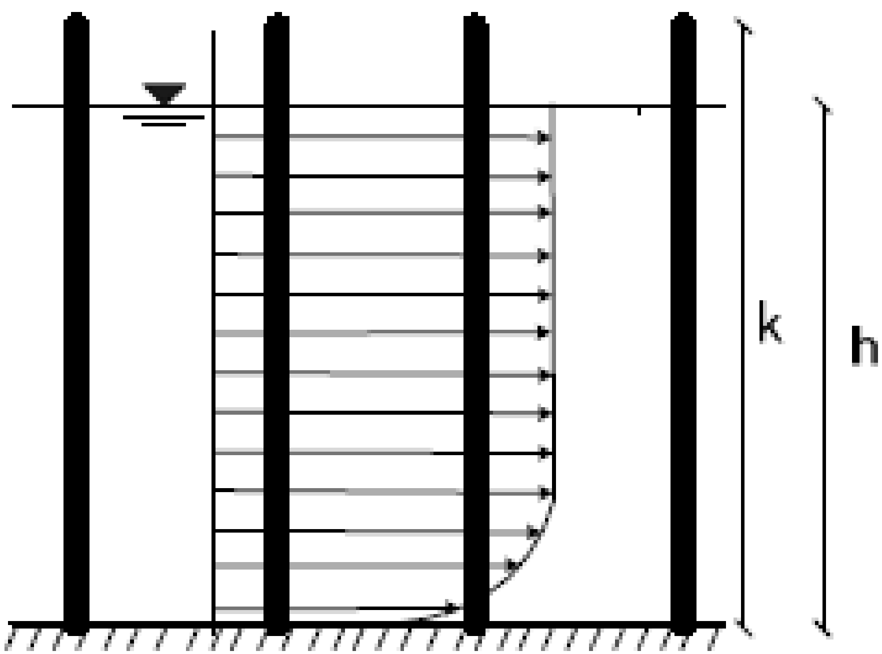
Literature studies vegetation of two different types

Rigid Vegetation
Flexible Vegetation

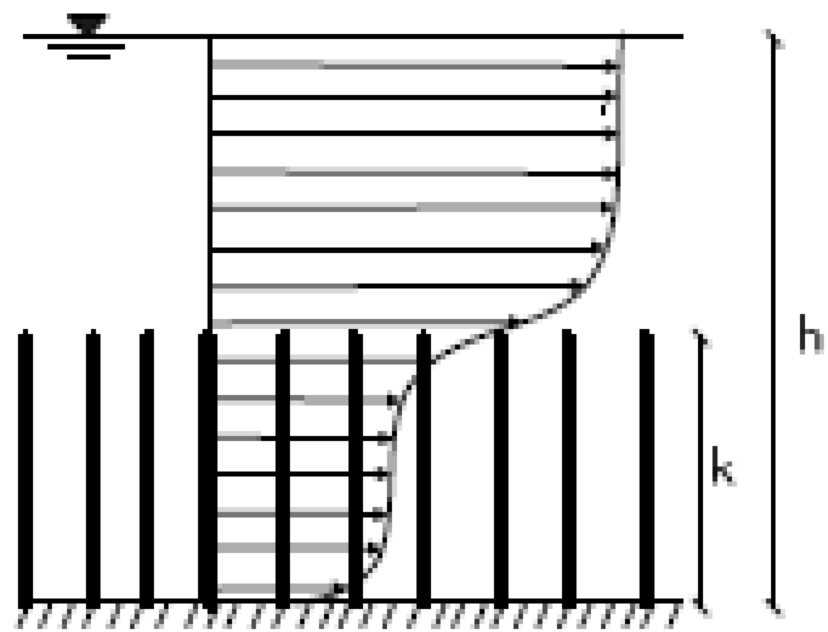


Vegetation Models

Literature studies vegetation in two different hydraulic conditions



Emergent



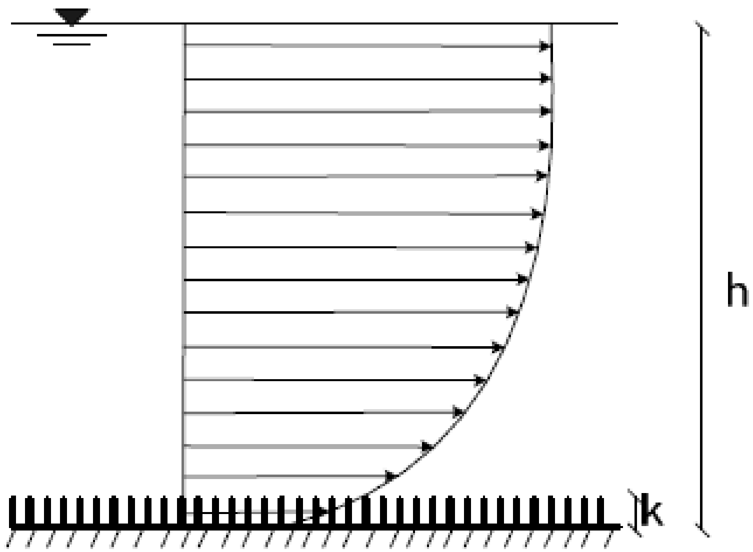
Submerged

Vegetation Resistance

Vegetation resistance is largely evaluated using Drag Force Equation

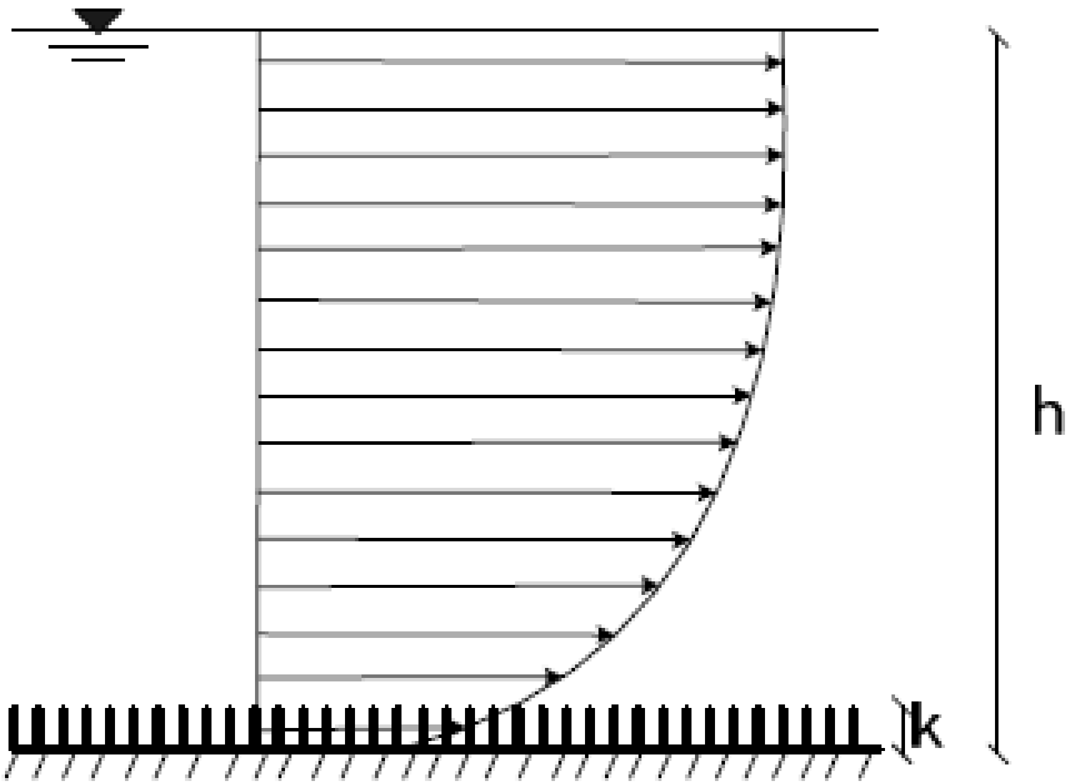
In case of low submergence classic roughness formulas cannot be used as by definition; classic formulas are used in order to find a relation between Cd and classic roughness

Nevertheless recent literature has considered the possibility of using classic roughness coefficients for open channel flows in case of high submergence, i.e. h/k>5



Vegetation Resistance

Our study concerns fully submerged rigid vegetation in case of high submergence i.e. $h/k>5$



Vegetation is modeled as cylinders without side branches and foliage

Vegetation Resistance

Nepf and Vivoni (2000) classified vegetated flows into three types, depending on the submergenceh/k. If $h/k > 5$, then terrestrial canopy flow occurs, which is analogous to flow over a rough boundary layer

Lopez and Garcia (2001) showed that vegetation resistance evaluated with Manning coefficient n exhibits an almost constant value up to a specific threshold of non dimensional vegetation density $\lambda=mDk$

Augustijn et al. (2008) found that for submergence $h/k>5$ Manning and Chezy coefficients were generally not accurate and on average the Keulegan equation yielded the best fit with the experimental data

Cheng(2011) proposed a roughness height for quantifying effect of submerged vegetation on flow resistance in the surface layer

Huthoff (2007,2012, 2013) assumed for the flow a two-layer model, considered the surface layer flowing on a bed created by the vegetation layer and evaluated the flow resistance in the surface layer using Manning coefficient n

Nepf (2012) for wide channels pointed out a link among Manning coefficient n and the submergence h/k

Research Goals

Recent studies have criticized the use of the dimensional Manning's *n* coefficient (Ferguson 2010, Mrokowska et. al 2014)

Other studies and have instead proposed the use of the dimensionless Darcy–Weisbach friction factor *f* (Järvelä 2002, Fathi-Moghadam 2007, 2012)

If it is possible to use classic roughness coefficient (Nikuradse, Strickler) for high submergences levels (i.e h/k>5), which one could be considered as more reliable to evaluate flow resistance and why?

Classic Hydraulic Formulas

Yen(2002) by matching Darcy-Weisbach formula with Colebrook-White equation and neglecting viscosity effects and Reynolds number obtained:

$$V = -K_1\sqrt{8g}\log\left(\frac{k_N}{K_2 R}\right)\sqrt{RS}$$

Huthoff (2007) following Chow (1959, 1988) and Gioia and Bombardelli analysis (2002) obtained:

$$V = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{\phi_s k_s^{\frac{1}{6}}}$$

k_N is Nikuradse roughness coefficient and k_S is Strickler roughness coefficient. They have same dimension [L] and then it is possible to compare them

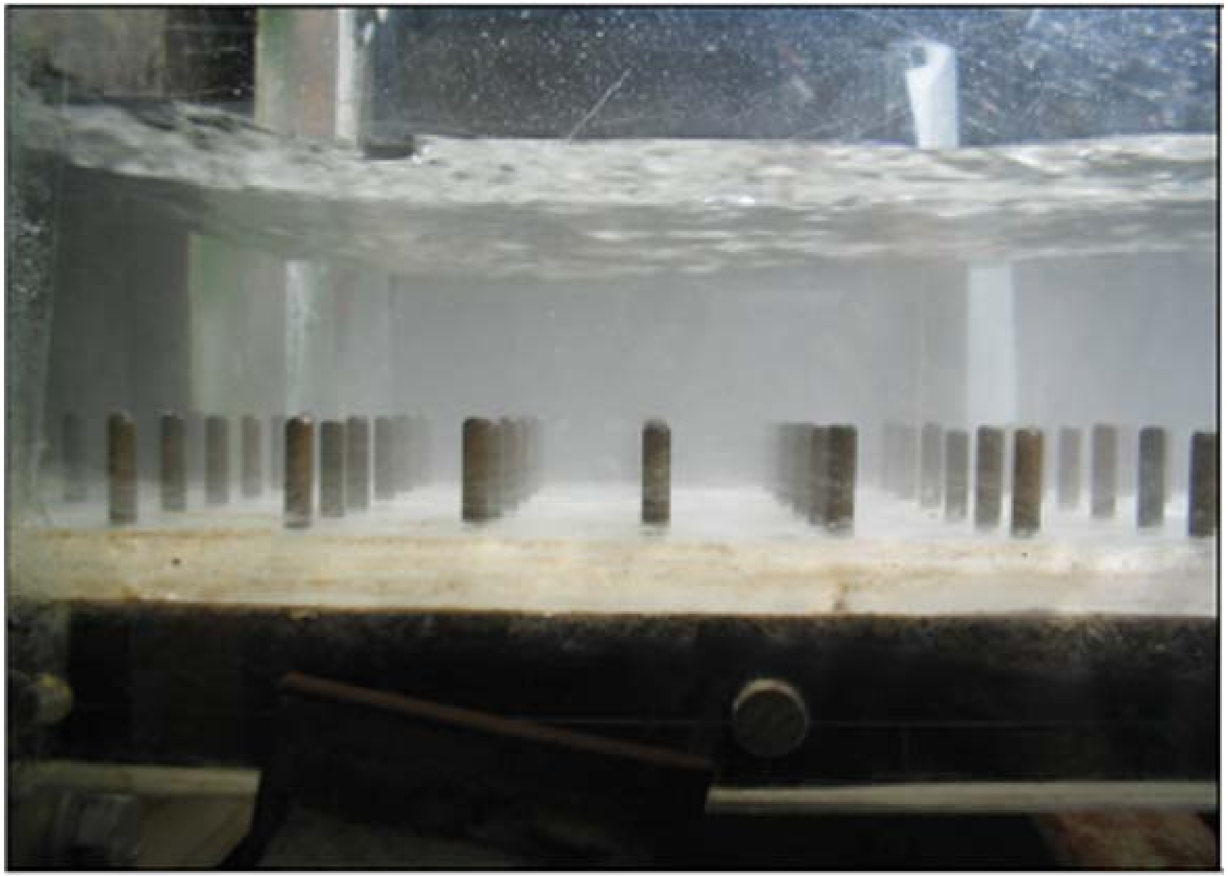
Experimental measurements

In order to compare k_N and k_S, experimental measurements were carried out in the laboratory of the Department of Civil, Architectural and Environmental Engineering

The channel, with a variable slope, was 8 m long and had a cross section of 0.40 × 0.40 m^2

Experimental measurements

Vegetation was modeled as rigid cylinders of height k = 1.5cm and diameter D = 0.4cm, set in two arrangements (aligned and staggered) each one with three non-dimensional densities λ (i.e. 0.024, 0.048 and 0.096)



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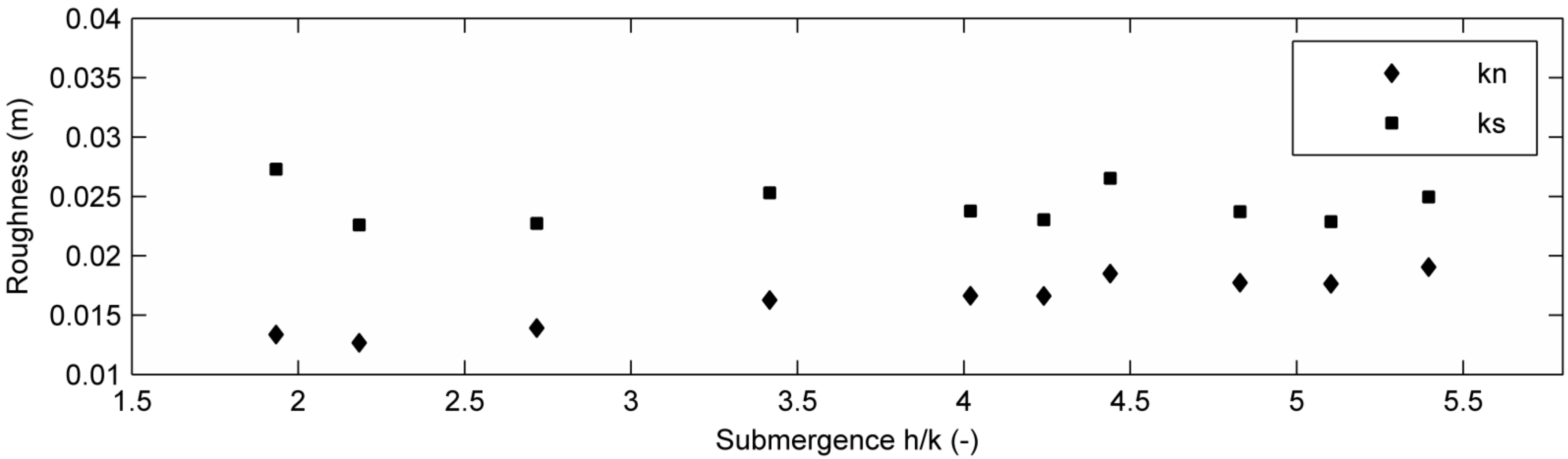
Experimental measurements

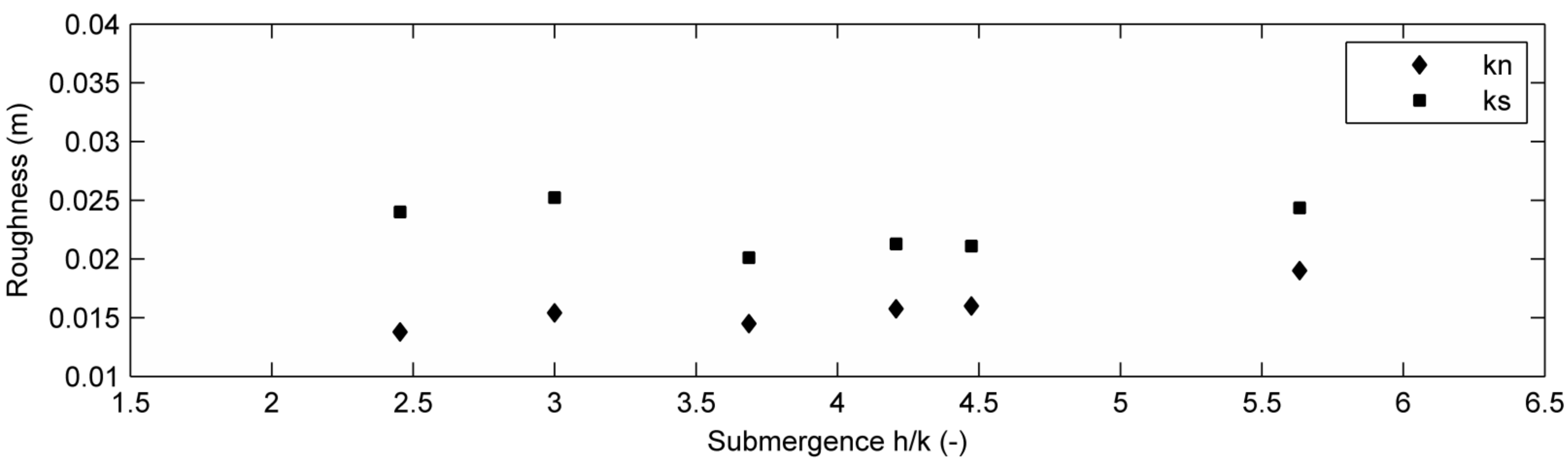
k_N and k_S were evaluated for 10 different hydraulic conditions and 3 different non-dimensional vegetation density

For each vegetation density a number of flow depths varying from 5 to 10 was considered. Maximum submergence *h/k* ranged from 5.55 to 8.78

Run	Arr.	k(m)	D(m)	m(m^{-2})	λ(-)	flow depths	$(h/k)_{max}$
1	Al.	0.015	0.004	1600	0.096	9	8.78
2	Al.	0.015	0.004	1600	0.096	6	6.50
3	St.	0.015	0.004	800	0.048	10	5.72
4	Al.	0.015	0.004	800	0.048	7	8.27
5	St.	0.015	0.004	800	0.048	7	5.31
6	St.	0.015	0.004	800	0.048	9	6.88
7	Al.	0.015	0.004	400	0.024	10	5.40
8	St.	0.015	0.004	400	0.024	6	5.63
9	Al.	0.015	0.004	400	0.024	7	6.79
10	St.	0.015	0.004	400	0.024	5	5.55

Experimental Results





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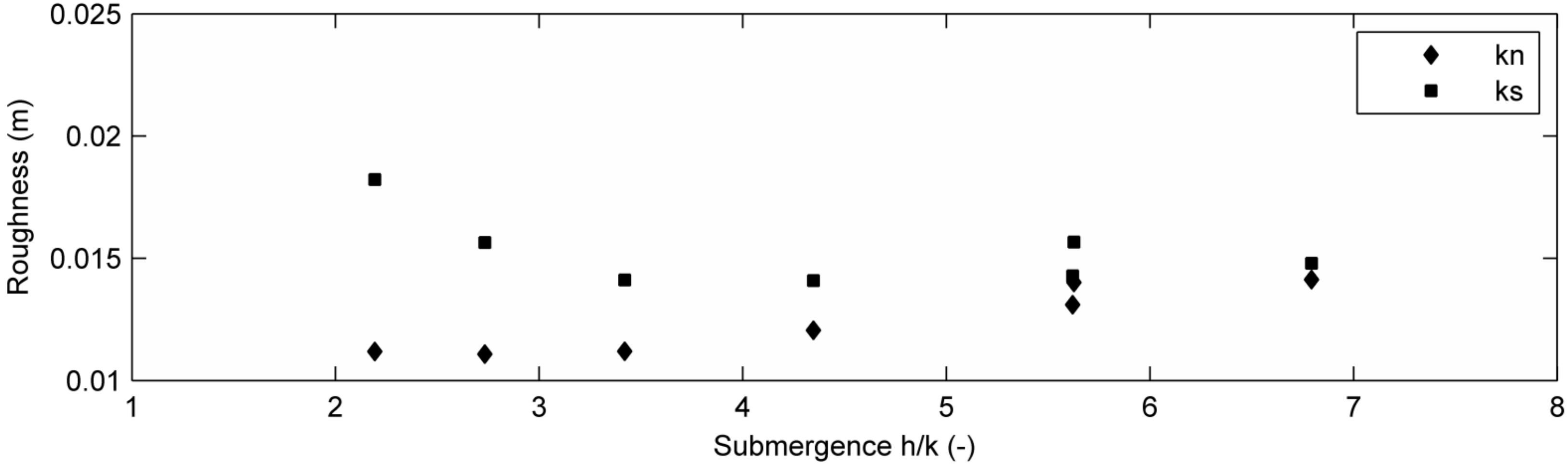

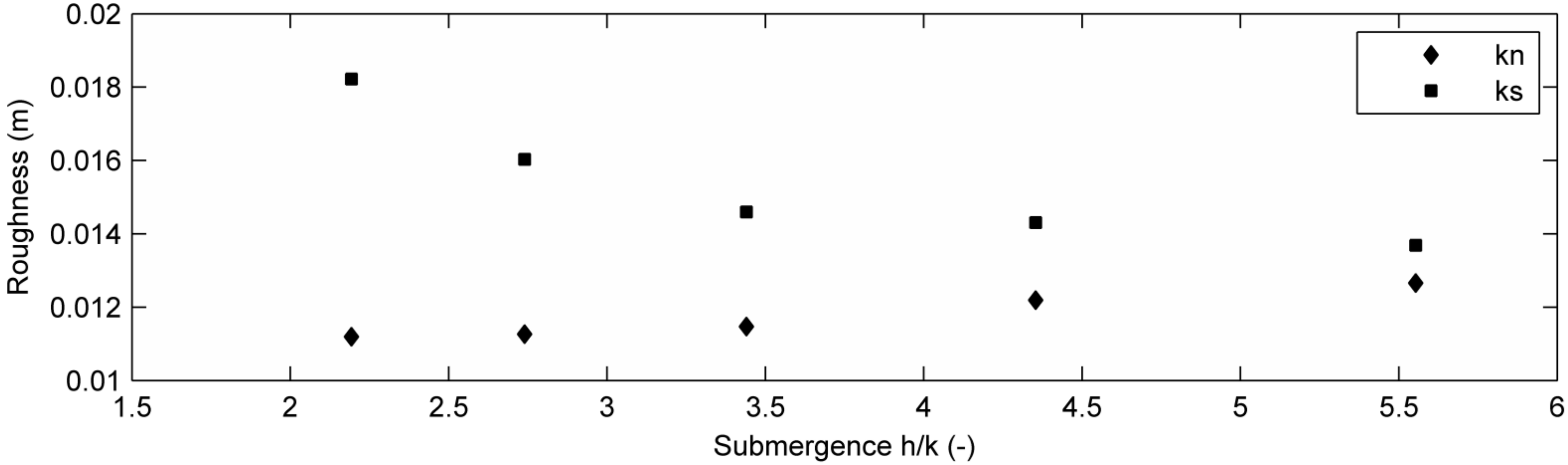

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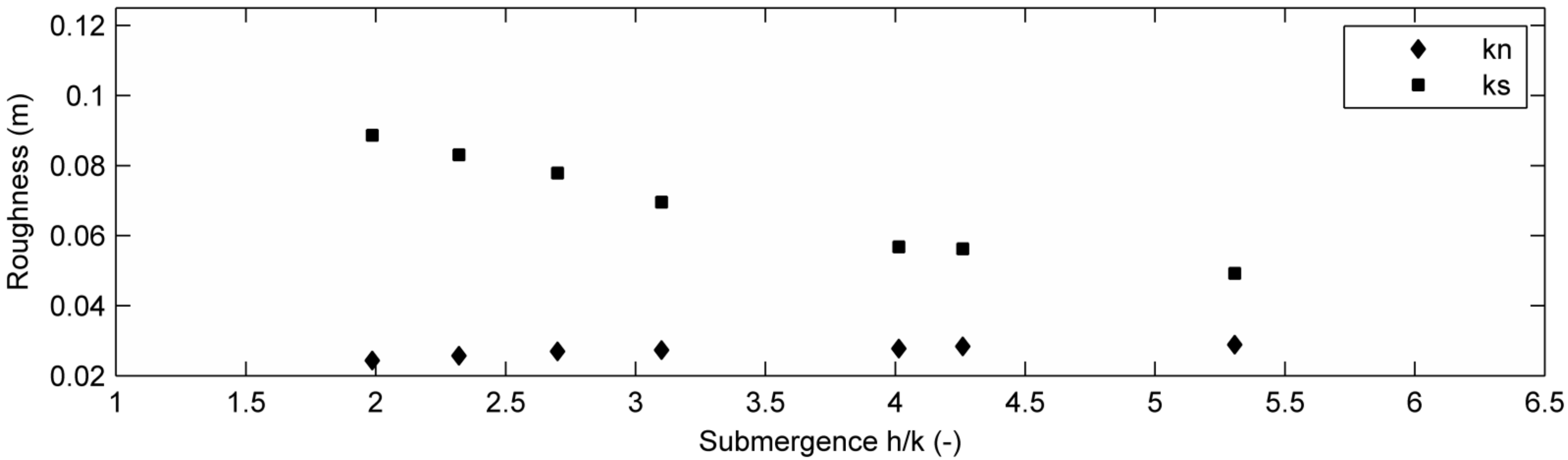

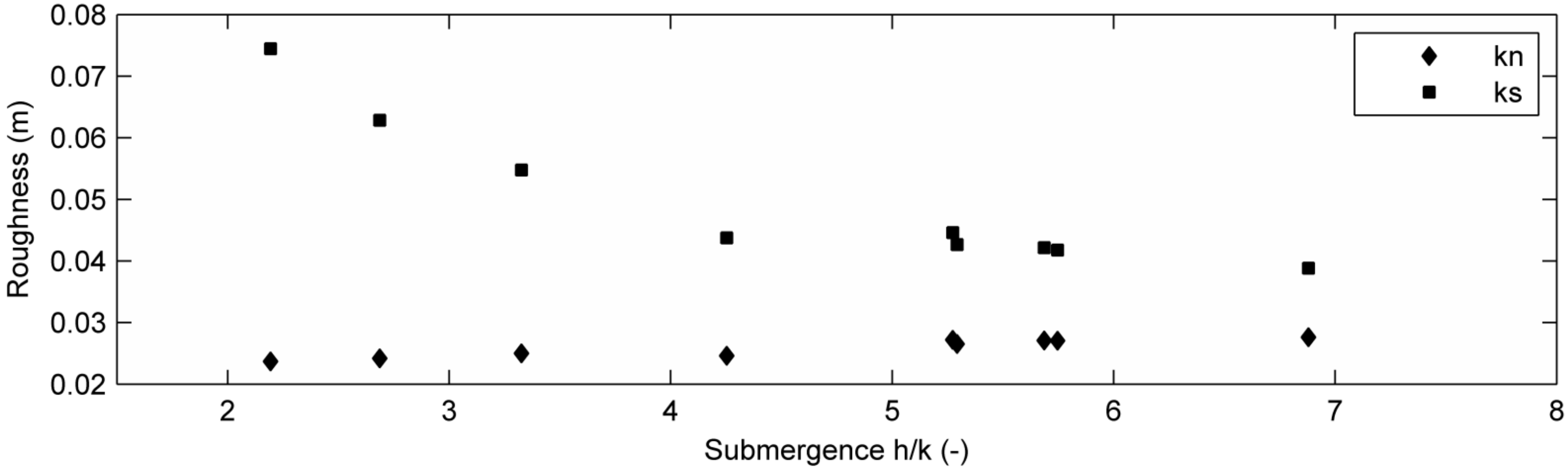

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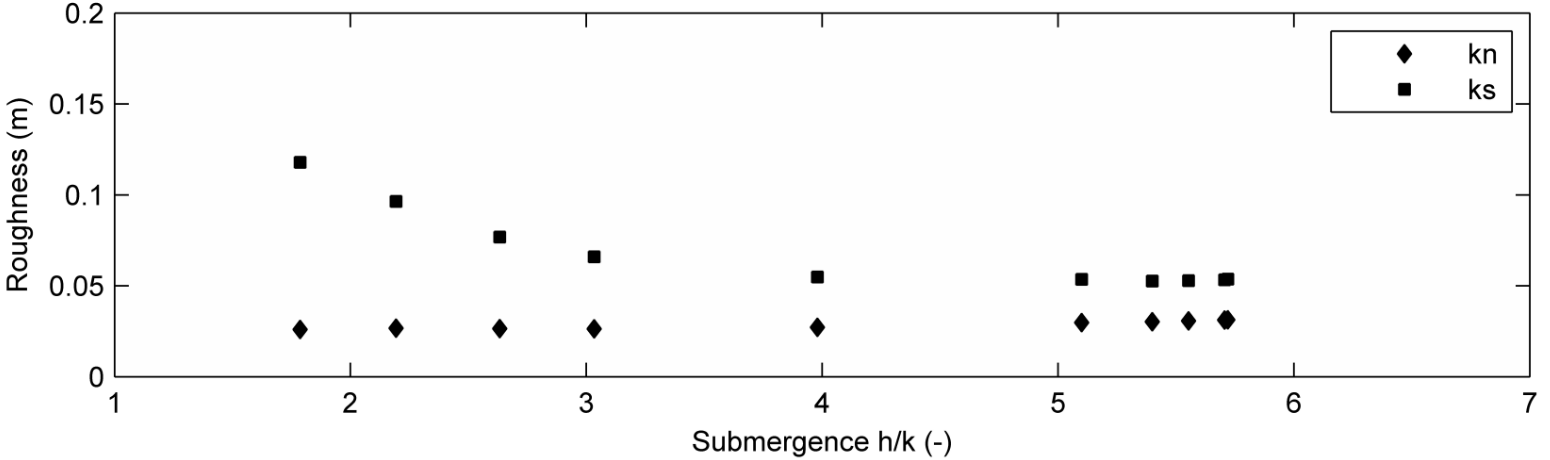

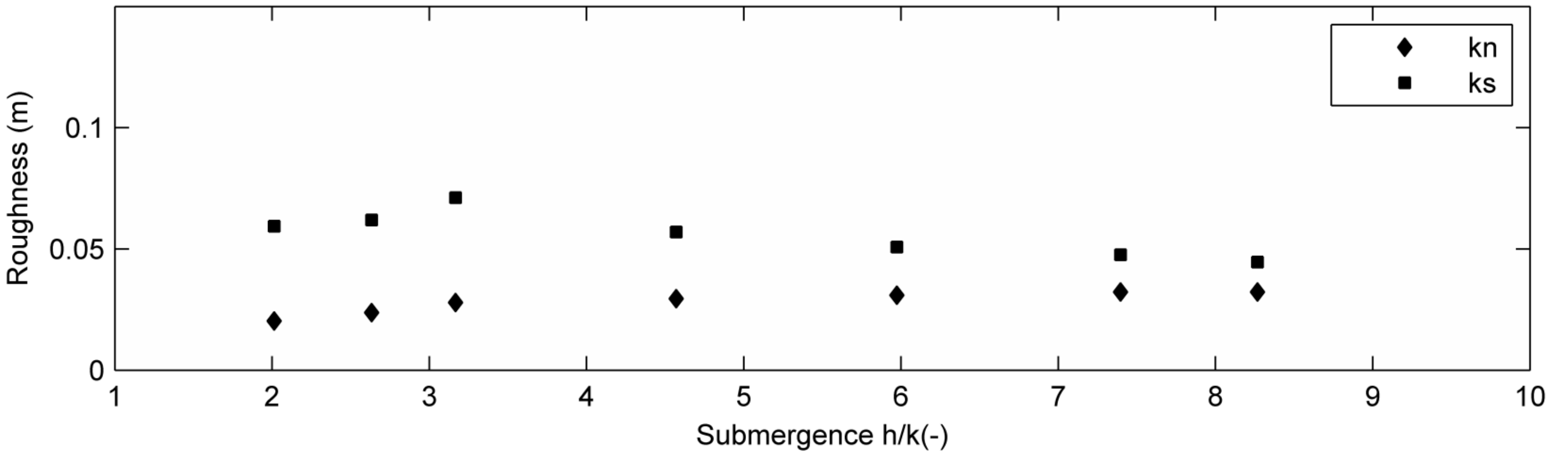

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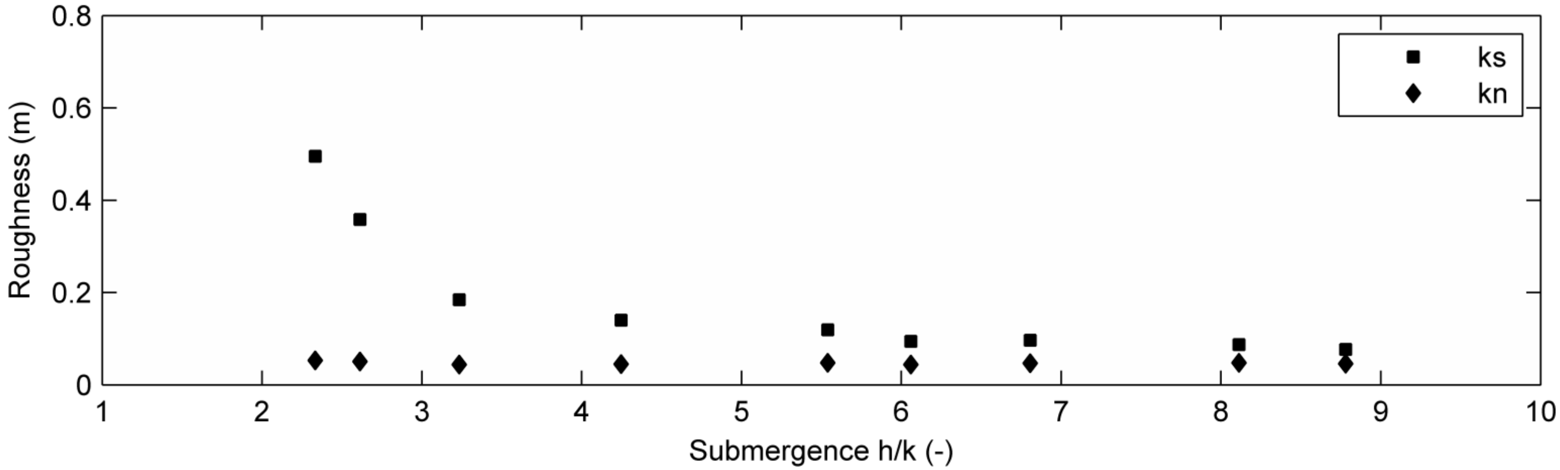

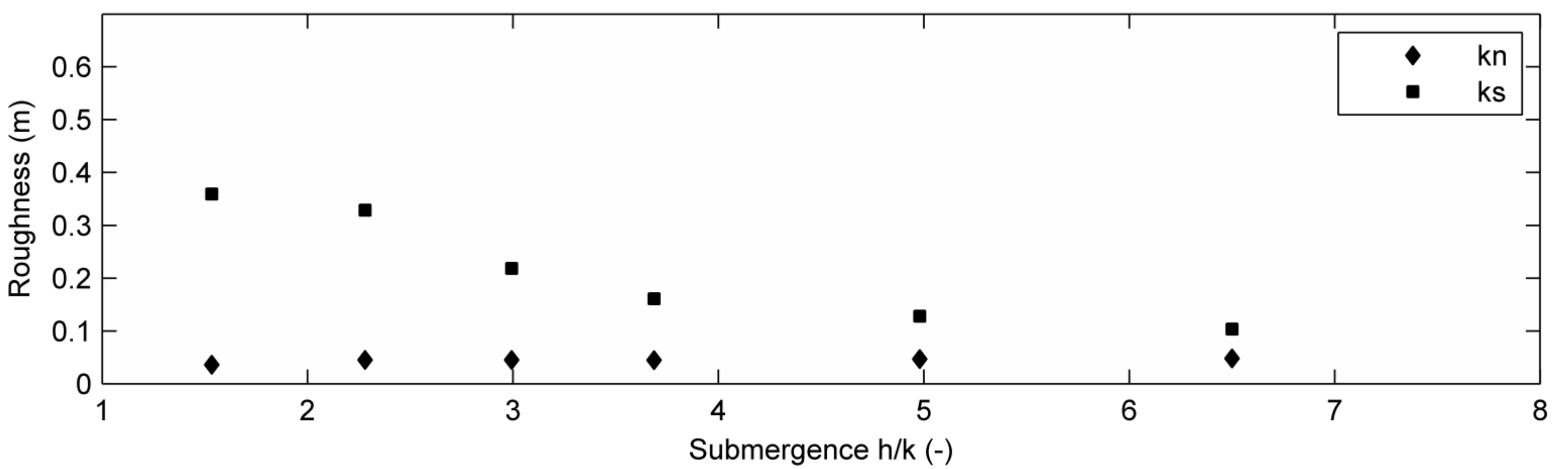

Experimental results and conclusions

For 10 different hydraulic conditions and 3 different non-dimensional vegetation density 76 values of k_N and k_S have been obtained and represented vs h/k

From the graphs it is possible to observe that:

- increasing the submergence, k_N and k_S converges to a constant value
- while k_S converges to a constant value for h/k>5, k_N converges to a constant value for h/k slightly lower than 5
- k_N shows a more horizontal trend than k_S

From experimental results it is possible to observe that k_N seems to be more reliable than k_S
This result can be considered interesting because k_S is largely used in hydrodynamic models for vegetated rivers and floodplains

Future research

Future goals of the research are :

- to analytically state which could be the best roughness coefficient (k_N and k_S) to evaluate vegetation resistance in case of high submergence
- to develop an hydraulic model to evaluate flow resistance directly linked with non dimensional vegetation density λ and vegetation height k

THANK YOU FOR YOUR ATTENTION!

Figures 4-5-6-7 by courtesy of *NTEAP 2007,* A. Galema (2009), campaniasulweb.it