7th International Symposium for Wetland Pollutant Dynamics and Control (WETPOL)

REMOVAL PERFORMANCE AND CLOGGING INVESTIGATION OF AN HYBRID TREATMENT WETLAND IN MEDITERRANEAN AREA

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Objectives

Evaluate the reliability of a **hybrid-TW system** (which includes three beds in series - one horizontal, HF and two vertical beds, V1 and V2) used as secondary wastewater treatment system of a retail store (IKEA) in South Italy, in term of:

- **removal efficiency** (based on physical-chemical and bacteriological concentration of the wastewater with respect to Italian Regulation for wastewater discharge into water bodies (LD 152/06) and agricultural reuse (MD 185/03);
- **potential clogging risk** by:
  - hydraulic conductivity measurements *in situ* (K_s)
  - flow paths visualization by means of tracer tests
  - 2-D electrical resistivity tomography (ERT) imaging

Area location: IKEA store

- Restaurant, bar, toilets
- ~ 300 employees
- ~ 6.000 visitors per day
- ~ over 16.000 visitors on Sunday/ holydays (23.000 visitors on Dec 8th 2016)
- ~ 800 meals served per day (up to 2.000 per day)

Onsite wastewater treatment plant

Wastewater ***toilets restaurant Bar*** → Grease&Oil-water separation → Coarse Screen + Equalization tank → Sequential Batch Reactor (SBR) → **river disposal**

- *2 cycles per day (2013-2014)*
- *3 cycles per day (2015- April 2017)*
- *4 cycles per day (since April 2017)*

SBR Design Parameters	Unit	Values
Maximum daily flow (Qi)	**m^3/day**	**30**
Mean flow (24 hours)	m^3/day	1,3
TSS	mg/L	350
COD	**mg/L**	**500**
BOD	**mg/L**	**300**
Total Nitrogen	**mg/L**	**135**
Total Phosphorus (P)	mg/L	15

High fluctuations of hydraulic load

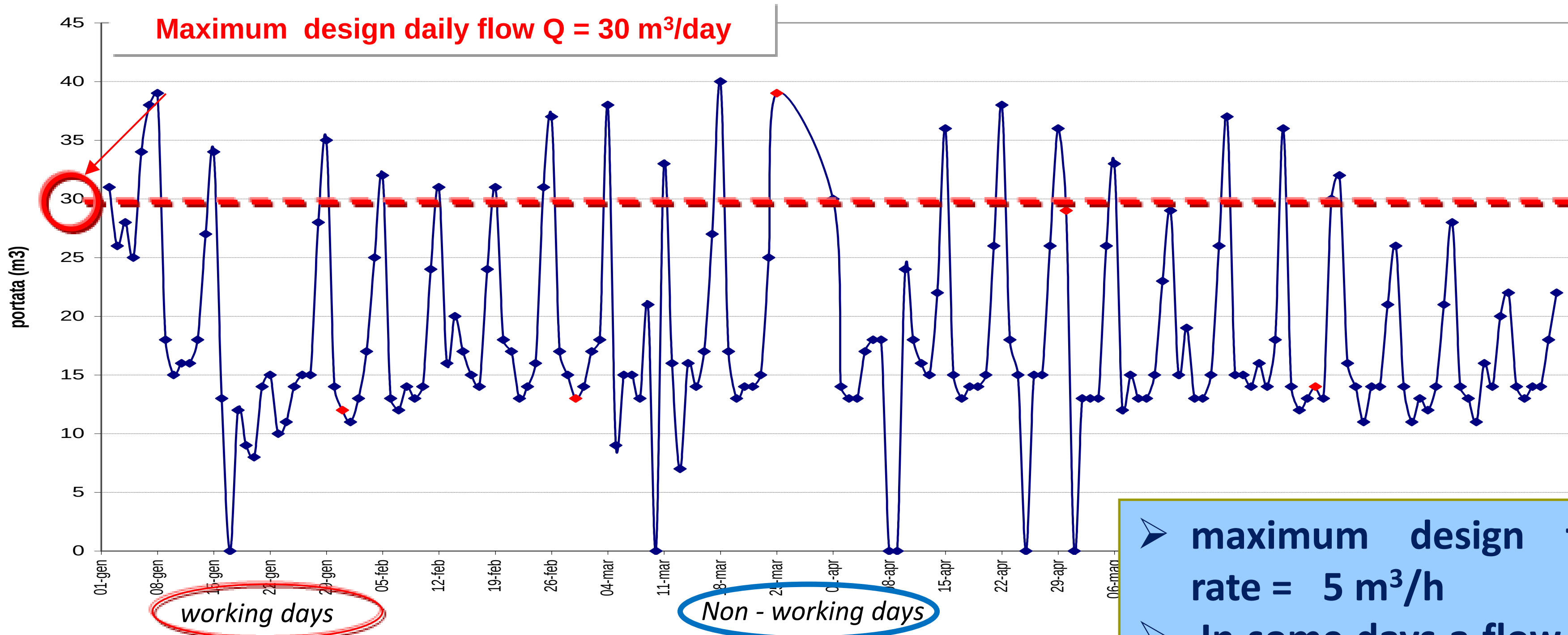
High fluctuations in pollutant load

↓

considerable differences with the SBR design parameters

Wastewater volume

The daily wastewater volume from toilets, showers, kitchen sinks, ecc. has been measured by two flow meters.



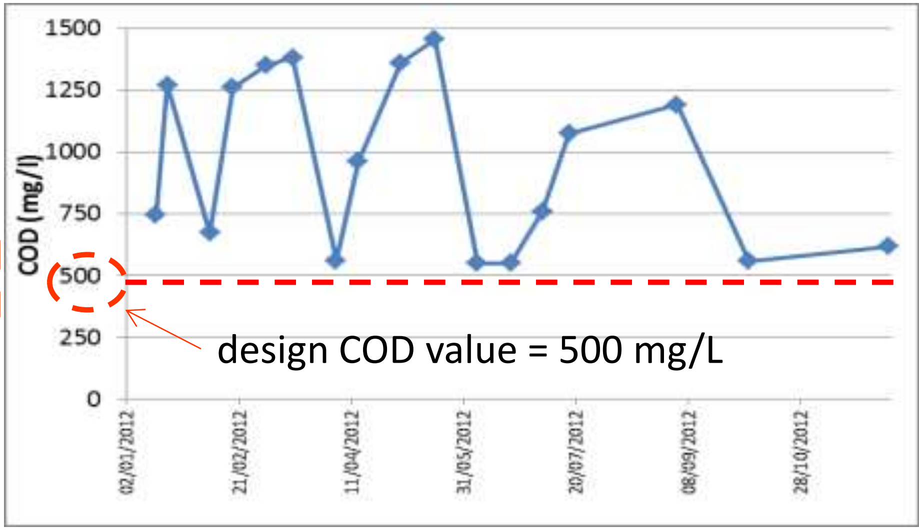
Min value	m³/day	7
Max value	m³/day	27
Range	m³/day	20
Mean value	m³/day	14,73

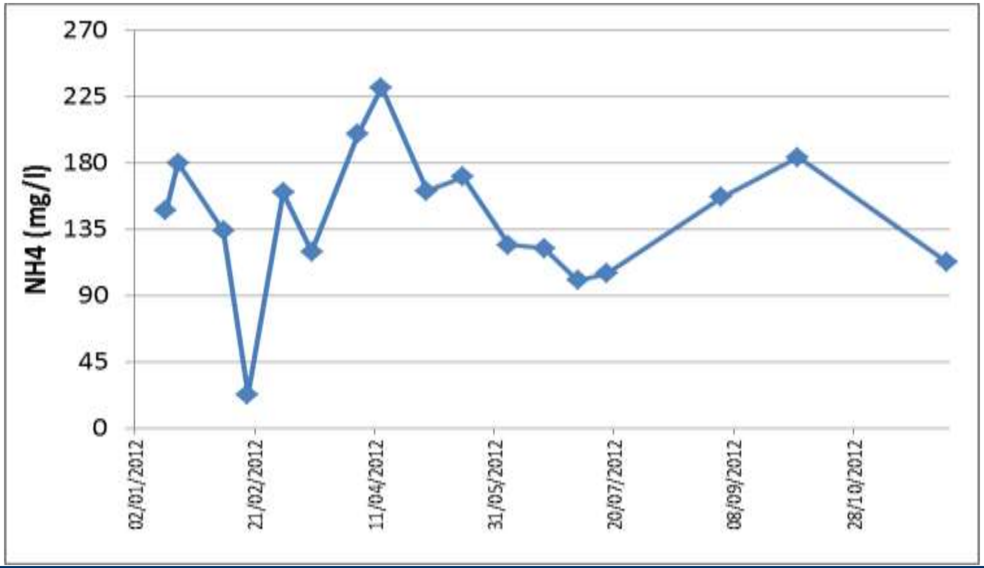
Min value	m³/day	15
Max value	m³/day	40
Range	m³/day	25
Mean value	m³/day	27,85

- **maximum design flow rate = 5 m³/h**
- **In some days a flow rate of 10-12 m³/h has been recorded**

Rough wastewater characteristics

Parameters	Units	Min	Max	Mean
SST	mg/L	68	200	140
BOD_5	mg/L	295	980	532
COD	mg/L	600	1450	940
Total phosphorus	mg/L	12	23	17
Ammonium (NH_4)	mg/L	20	231	114





Design concentration of Total Nitrogen was 135 mg/L

Layout of Hybrid CW plant (implemented in June 2014)

m^3/day

Wetland characteristics: HF

Constructed wetland	Area (m^2)	W (m)	L (m)	Q (m^3/day)	Gravel			macrophytes	
					Type	size (mm)	depth (m)	species	Density (rhizomes /m^2)
HF (I stage)	400	12	34	45-50	*Volcanic gravel*	8-15	0.6	*Phragmites australis*	4

Wetland characteristics: VF

Constructed wetlands	Area m^2	Flow rate (m^3)	HLR (m^3/m^2/day)	Gravel			macrophytes	
				Type	size (mm)	depth (cm)	species	Density (rhizomes /m^2)
VF1 (II stage)	530	≈ 8÷10 m^3 6 times per day (every 4 hours)	≈ 0.09	*Volcanic Sand*	~ 5-15	~ 45	*Cyperus Papyrus* *Canna Indica L.*	2.5
VF2 (III stage)				*Volcanic Gravel*	25-40	30	*Typha latifolia* *Iris pseudacorus*	





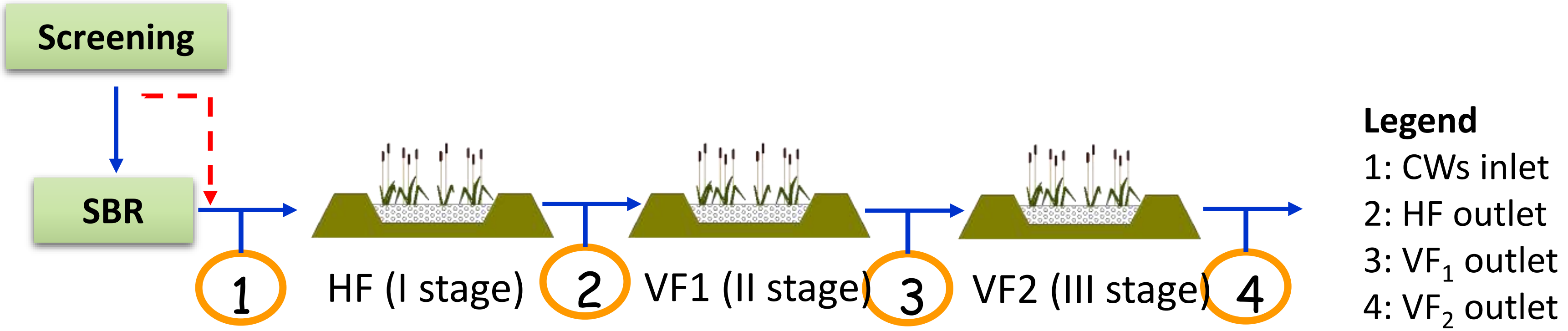


Methodology

REMOVAL PERFORMANCE AND CLOGGING INVESTIGATION OF AN HYBRID TREATMENT WETLAND IN MEDITERRANEAN AREA

Removal efficiency

- **Wastewater sampling period:**
  - from January 2015 -May 2017 at 30-day intervals
- **Wastewater sampling points:**

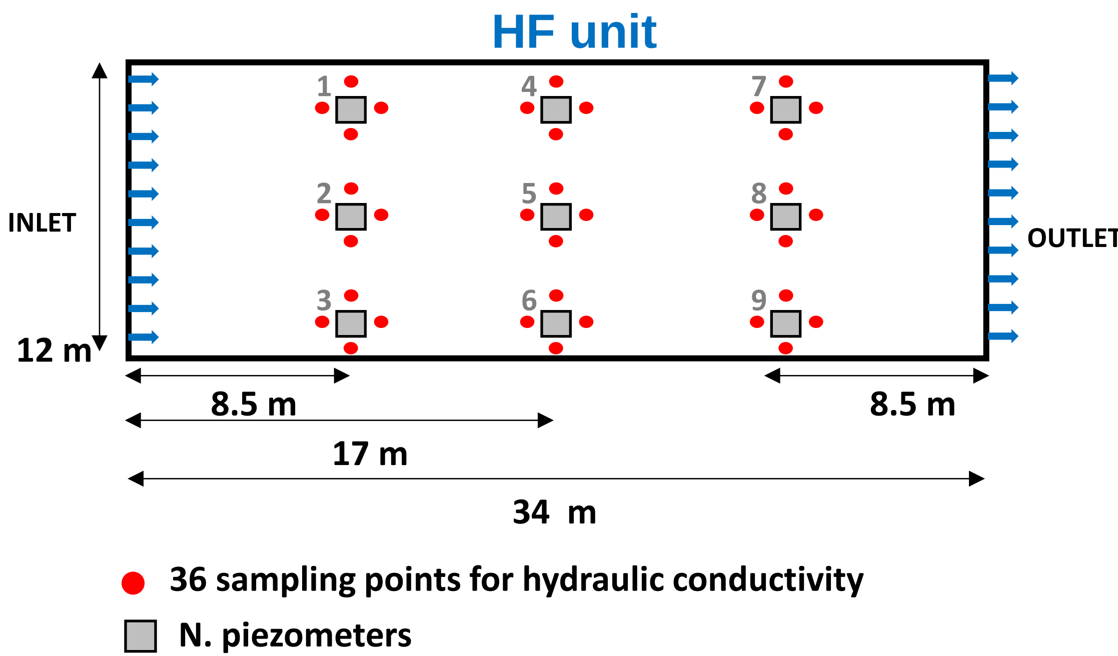


- **Wastewater analysis:**
  - physicochemical parameters (mg/L): TSS, BOD_5, COD, NH_4, Ptot
  - microbiological parameter (Ulog): *E. Coli, Salmonella*

Clogging investigation: HF unit - K_s measurements

- **hydraulic conductivity at saturation (K_s) *in situ***
- flow paths visualization by means of tracer tests
- 2-D electrical resistivity tomography (ERT) imaging

- **Measurements:**
  - *hydraulic conductivity* (m d^{-1}) was measured using the falling-head test method (NAVFAC, 1986, Pedescoll et al., 2009)
  - 36 measurement points
- **Monitoring campaigns**:
  - 2016 – 2017
  - one survey per year



•NAVFAC, 1986. Soil Mechanics. Design Manual 7.01. Naval Facilities Engineering Command. Alexandria, Virginia, USA, 389 pp.
•A. Pedescoll, E. Uggetti , E. Llorens, F. Granés, D. García , J. García. (2009). Practical method based on saturated hydraulic conductivity used to assess clogging in subsurface flow constructed wetlands

Clogging investigation: HF unit - K_s measurements

- **hydraulic conductivity at saturation (K_s) measurements *in situ***
- flow paths visualization by means of tracer tests
- 2-D electrical resistivity tomography (ERT) imaging

■ **In each point:** a steel tube, was inserted into the wetted material and was filled with water in a pulse mode using a bucket.

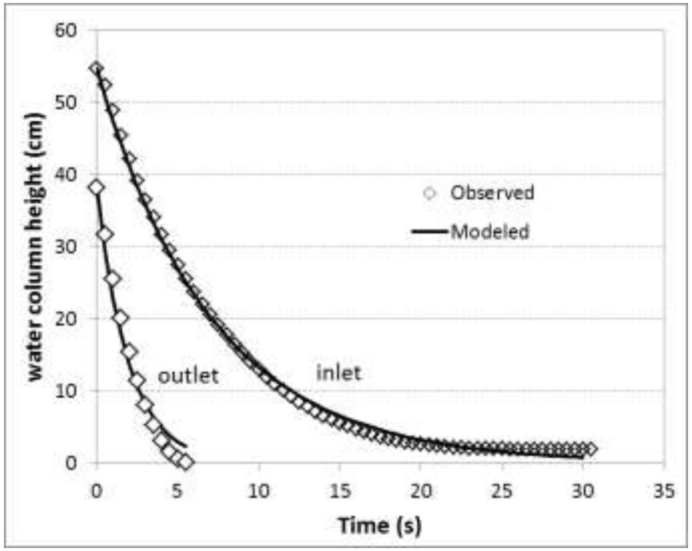
a pressure probe, connected to laptop, measured and record automatically pressure variatio proportional to the water colur height

a small hole was dug in the granular medium until the water level was reached

Clogging investigation: HF unit - K_s measurements

- **hydraulic conductivity at saturation (K_s) measurements *in situ***
- flow paths visualization by means of tracer tests
- 2-D electrical resistivity tomography (ERT) imaging

- Combining the observed measurements and the geometric characteristics of the tube, **Saturated hydraulic conductivity** (K_s) was determined according to Lefranc's formula:



$$K_S = \frac{d^2 \ln(2L/d)}{8Lt} \ln\frac{h_1}{h_2}$$

Diameter of permeameter

Water height at time zero

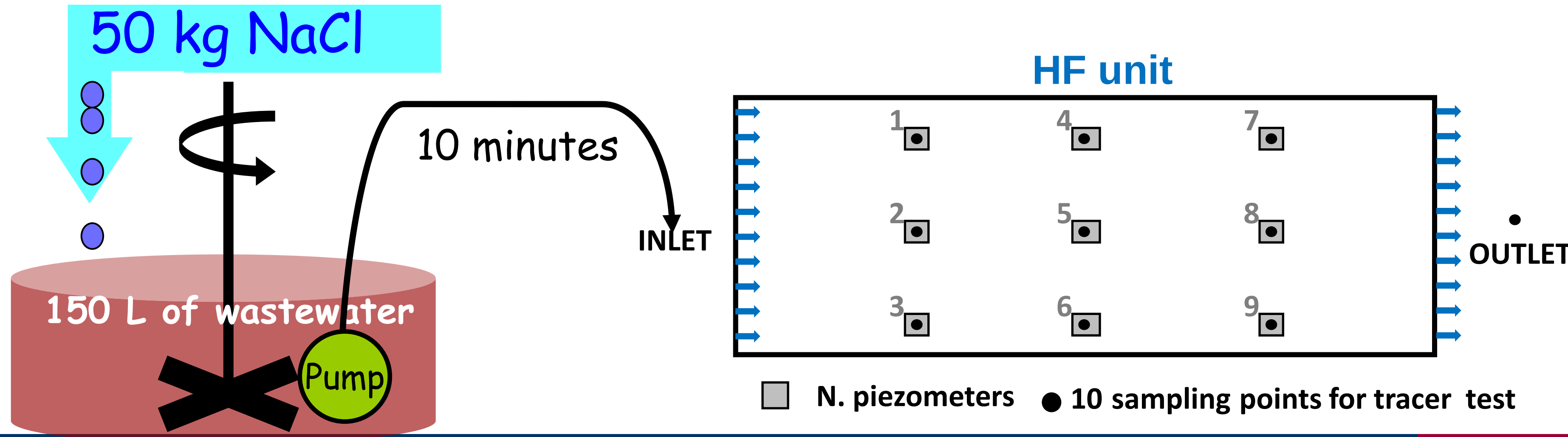
length of the submerged part of the tube (perforated zone)

Water height at time t

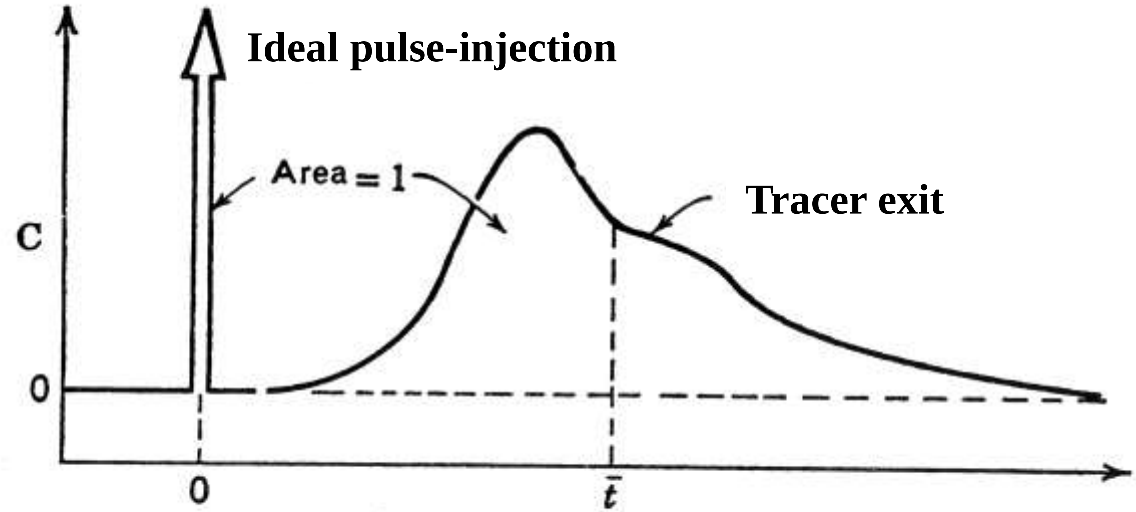
Clogging investigation: HF unit - tracer tests

- hydraulic conductivity at saturation (Ks) measurements *in situ*
- **flow paths visualization by means of tracer tests**
- 2-D electrical resistivity tomography (ERT) imaging

- **Tracer:** 50 kg sodium chloride (NaCl) dissolved in 150 L
- **Measurements:**
  - *electrical conductivity* ($S \cdot m^{-1}$) was measured and recorded automatically by a probe with a data logger (Delta OHM-HD 2106.2) at the wetland outlet and in the piezometers
  - 10 measurement point
- **Monitoring campaigns**: 2016 – 2017 one tracer test per year



Residence Time Distribution (Levenspiel, 1972)



$$f(t) = \frac{C(t)}{\int_0^\infty C(t)dt}$$

$$\tau = \int_0^\infty t \cdot f(t)dt = \frac{\int_0^\infty t \cdot C(t)dt}{\int_0^\infty C(t)dt}$$

$$\sigma^2 = \int_0^\infty (t-\tau)^2 \cdot f(t)dt = \frac{\int_0^\infty (t-\tau)^2 \cdot C(t)dt}{\int_0^\infty C(t)dt}$$

$$\sigma_\theta^2 = \frac{\sigma^2}{\tau^2}$$

Actual residence times (first absolute moment)

variance (second absolute moment)

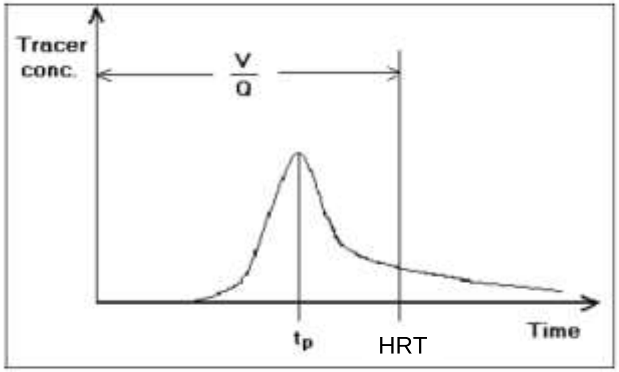
dimensionless variance

Dispersion Number (D) and hydraulic efficiency

- The equation for D (Dispersion Number) estimation, by trial and error, was:

dimensionless variance ← $$\sigma_\theta^2 = 2D - 2D^2\left[1 - \exp\left(-\frac{1}{D}\right)\right]$$ → Dispersion number

- The hydraulic efficiency of wetlands (λ) was determined according to Persson et al. (1999)

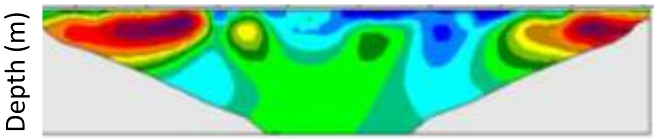


$$\lambda = \frac{t_p}{HRT}$$ → peak residence time

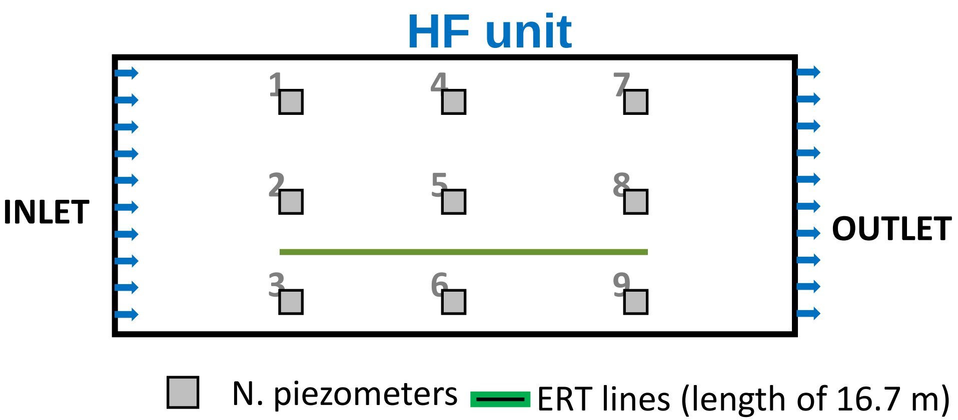
Clogging investigation: HF unit - ERT surveys

- hydraulic conductivity at saturation (Ks) measurements *in situ*
- flow paths visualization by means of tracer tests
- **2-D electrical resistivity tomography (ERT) imaging**

- **Measurements:**
  - 168 superficial electrodes, spacing 10 cm, 2 m far from the inlet for a total length of 16.7 m
  - *electrical resistances* values (ohm, Ω) were measured by a resistivity meter (dipole-dipole scheme) through electrical resistivity tomography technique (ERT, Binley and Kemna, 2005) and inverted to calculate the *electrical resistivity distribution* (Ω m)
- **Monitoring campaigns**:
  - 2017
  - two surveys (ERT1 and ERT2)



electrical resistivity distribution (Ω m)



•Binley, A.M., and Kemna, A., (2005). DC resistivity and induced polarization methods. In: Rubin Y, Hubbard SS (eds) Hydrogeophysics. Water Sci. Technol. Library, Ser. 50. Springer, New York, pp 129–156

Clogging investigation: HF unit

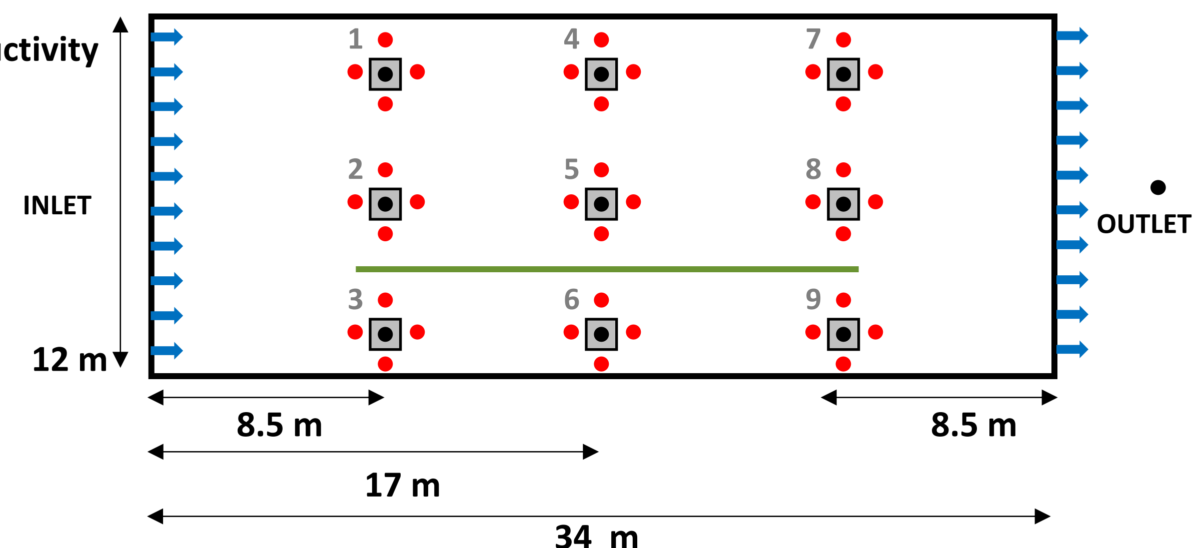
- hydraulic conductivity at saturation (K_s) measurements *in situ*
- flow paths visualization by means of tracer tests
- 2-D electrical resistivity tomography (ERT) imaging

Setup of the HF unit with the indication of the measurements points

Legend

- 36 sampling points for hydraulic conductivity
- 10 sampling points for tracer test
- ERT lines (length of 16.7 m)
- N. piezometers

HF unit



Results

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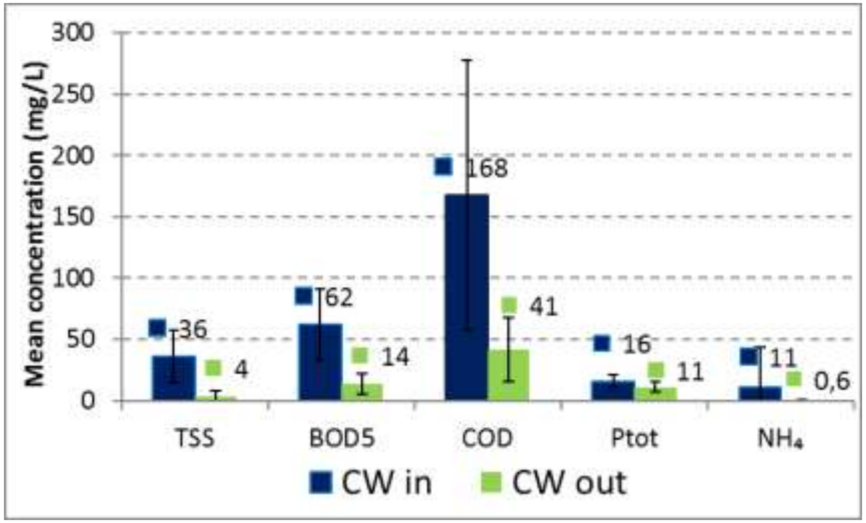
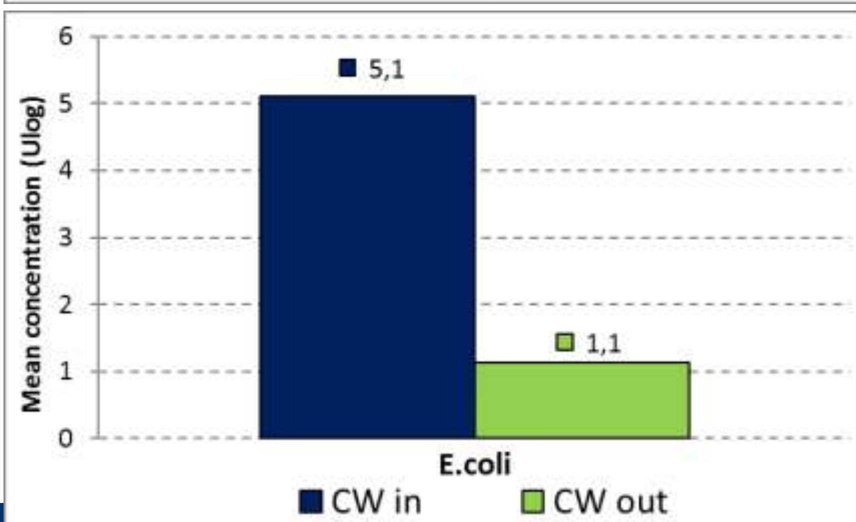
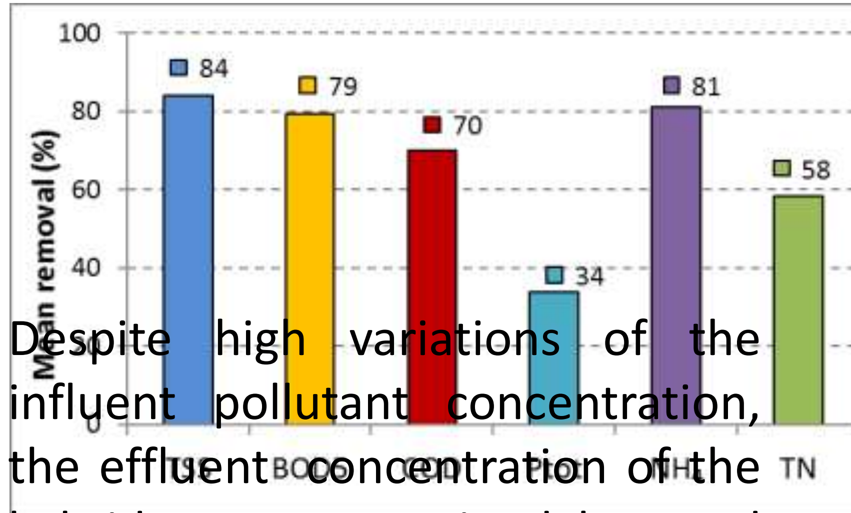
hybrid CW performance

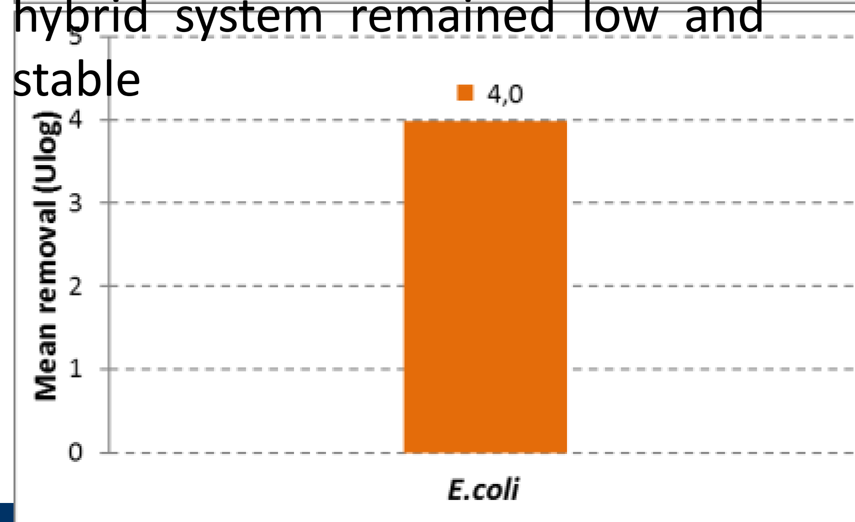
Mean concentrations





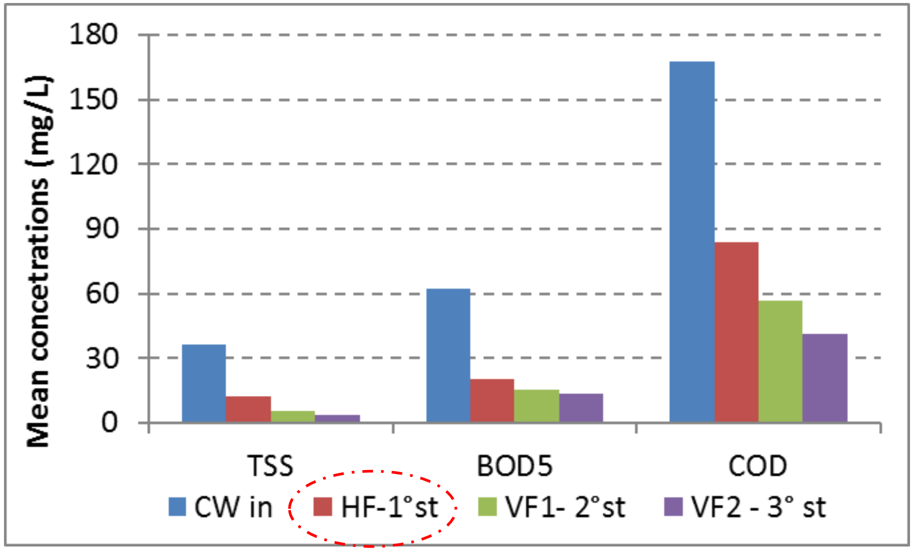
Mean removals

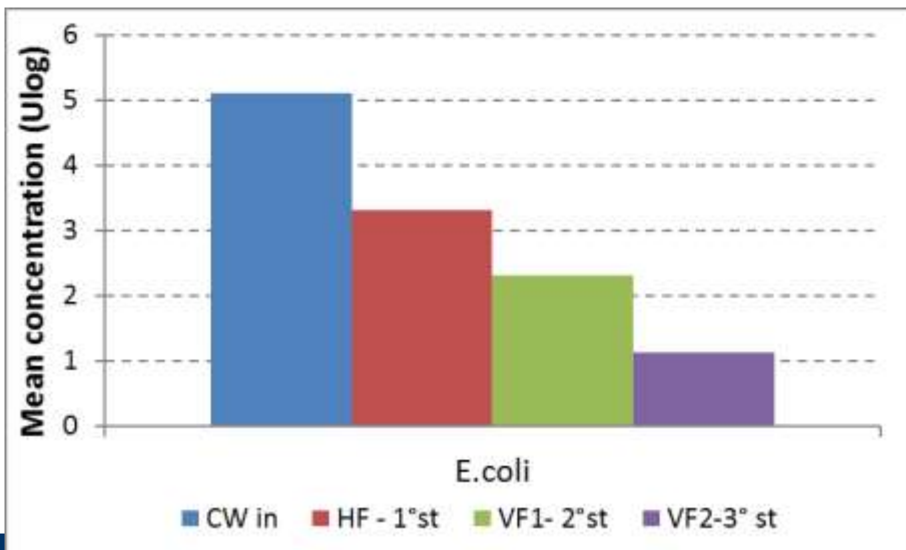


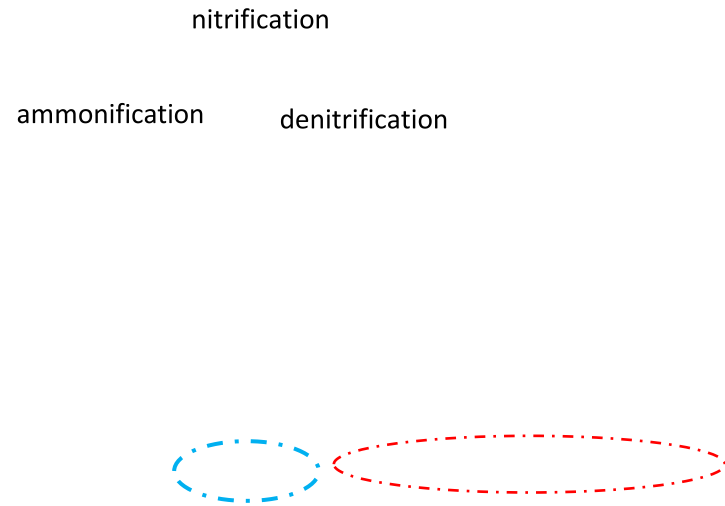


- Despite high variations of the influent pollutant concentration, the effluent concentration of the hybrid system remained low and stable

hybrid CW performance







- the main part of BOD_5, COD and TSS removal occurs in the 1st stage (HF)
- ammonification of N-org and the denitrification of the nitrates occurs effectively throughout the HF bed.
- the freshly formed ammonia is then almost completely oxidised by the two VF beds→ high concentration of NO3 in the final effluent
- a progressive reduction in the concentrations of *E. coli*: 1.8 Ulog decrease between the inlet and the HF outlet, and a further 1.0 Ulog and 1.2 decrease after VF1 and VF2 treatment

Italian WW law limits for discharge and reuse

Parameters	WW Italian limits to discharge in surface water body	WW Italian limits for agriculture reuse	Hybrid CW out	
			% samples under **discharge** limits	% samples under **reuse** limits
TSS	80 mg/L	10 mg/L	100	93
BOD_5	40 mg/L	20 mg/L	100	82
COD	160 mg/L	100 mg/L	100	100
NH4	15 mg/L	-	100	-
NO3	20 mg/L	-	41	-
NO2	0,6 mg/L	-	100	-
TN	-	35	-	100
TP	10 mg/L	10 mg/L	100	100
E. coli	5000 UFC/100 mL (1)	50 UFC/100 mL (2)	100	50
		200 UFC/100 mL (3)		75

(1) Recommended value for P.E > 2000;

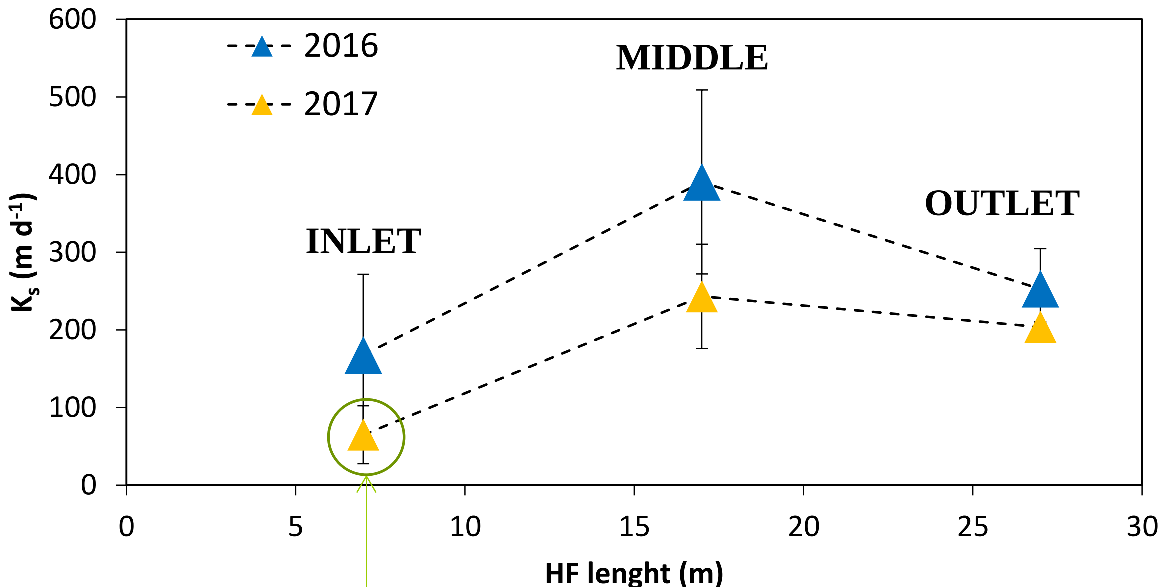
(2) Maximum value to be detected in 80% samples

(3) maximum limit;

In May 2017, after an hydraulic setup of feeding operation the limits for irrigation reuse were achieved on 100% of samples (DATA NOT SHOWN)

Clogging investigation: HF unit - K_s measurements

Average saturated **hydraulic conductivity** values along the length of HF wetland in 2016 and 2017



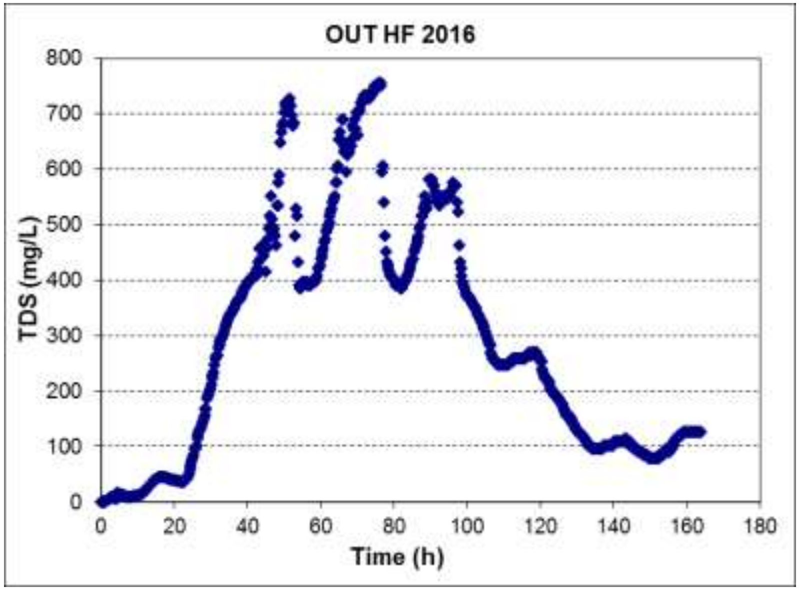
- **Similar trend** to both surveys, K_s values tend to increase from the inlet to the central part of the bed (e.g. about half of the unit length) and to decrease a little bit at the HF outlet;
- In 2017, a general sharp decrease in K_s was observed respect to 2016.

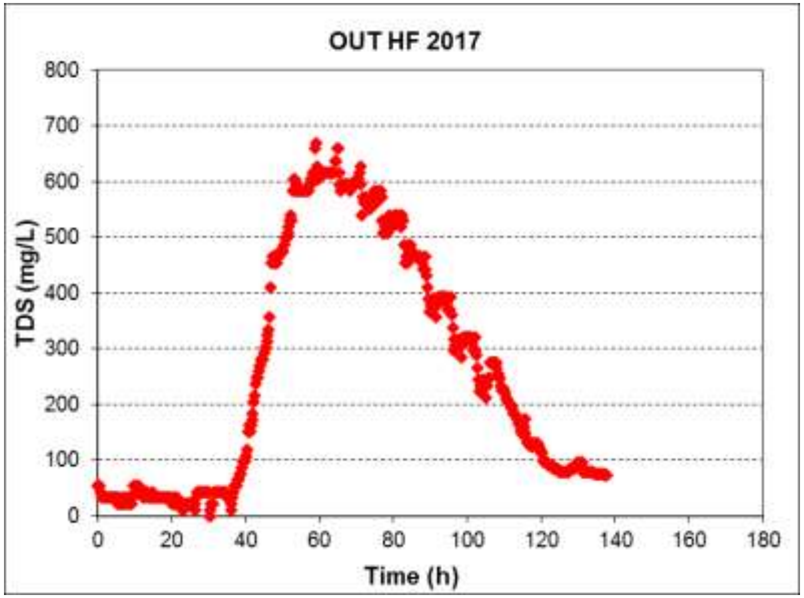
Ks_{2016} = 270.3 (± 127.3) m/d

Ks_{2017} = 170.5 (± 89.8) m/d

In 2017 **Ks** values at the **inlet zone** were about 1 order magnitude **lower** respect those of the other transects, as a consequence of clogging of the granular medium

Clogging investigation: HF unit – Tracer test





good hydraulic efficiency as values are 0.5 ≤ λ < 0.75

significant degree of deviation from PF, *D* > 0.025

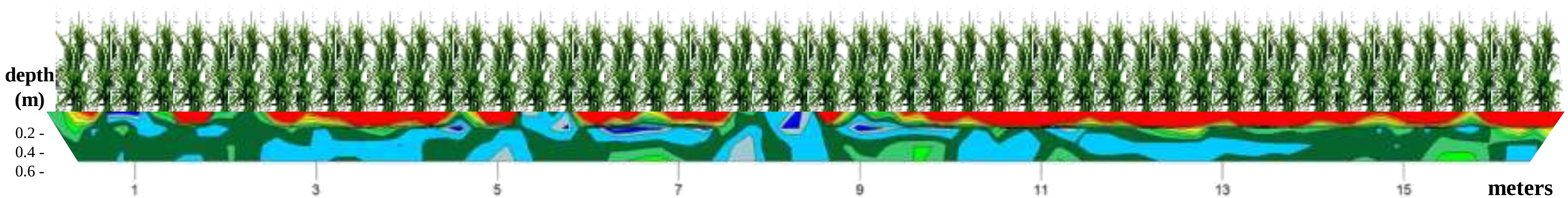
	Bed characteristics			Moment analysis results					
	Operation time (years)	Area (m^2)	Nominal porosity	Q (m3/h)	HRT (h)	τ (h)	t_p (h)	λ (%)	D
2016	2	400	0.47	1,1	88	74	51	0,58	0,07
2017	3			1,0	92	89	59	0,64	0.05

2-D electrical resistivity tomography (ERT)

Overall, ERT patterns in the two tests are very similar, although in ERT1 the resistivity values are higher on the surface and therefore indicate the presence of unsaturated zones (the first 15 cm) of the substrate. But these zones could be also "death zones" due to the clogging or the effect of water uptake by root apparatus. In the ERT2 test, the lower resistivity values indicate a greater presence of water and/or sediments.

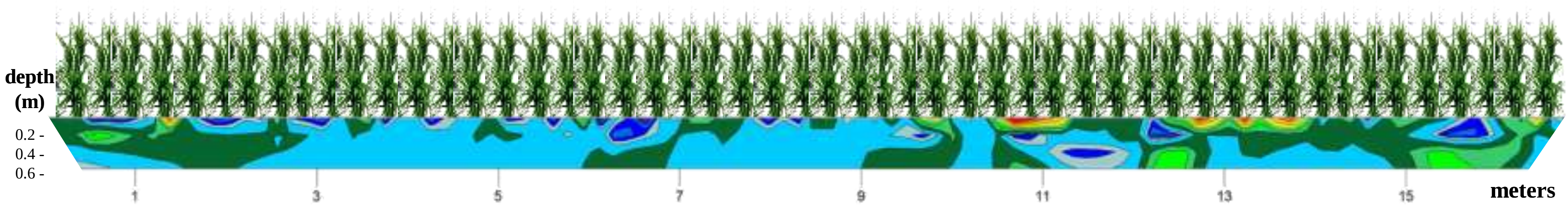
May 19, 2017 (ERT1)

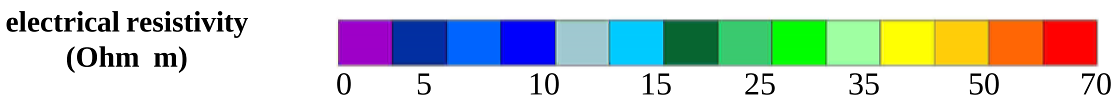
Mean electrical resistivity: 20.8 ± 7.5 Ohm m



July 14, 2017 (ERT2)

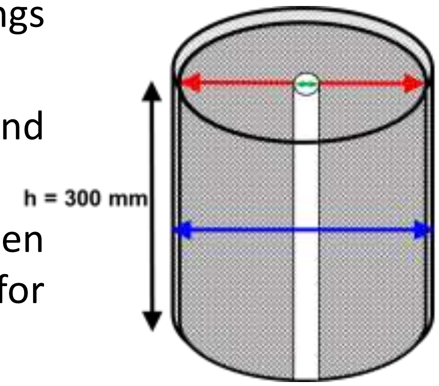
Mean electrical resistivity: 19.2 ± 4.6 Ohm m *

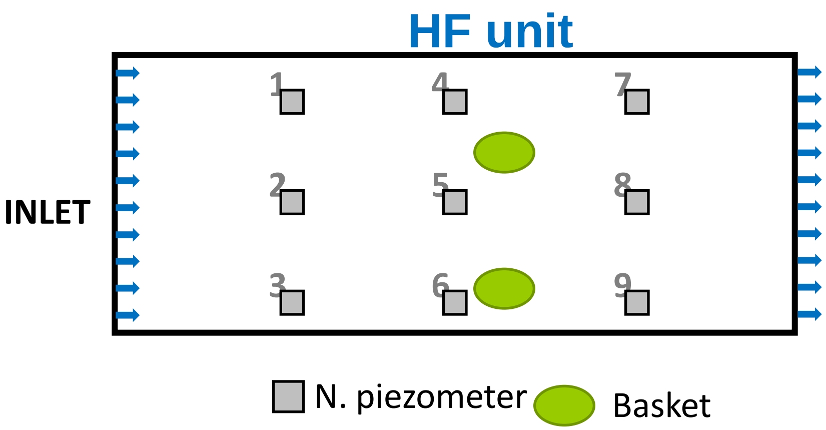




Clogging investigation: K_s measurements

- 4 mobile baskets (28 cm in diameter, 30 cm in height and laterals with openings spaced at 0.5 x 0.5 cm) were inserted within a HF.
- They were filled with the same substrate and palnted in the same way of HF and remained inserted in the wetland bed at the same height
- They were positioned at 22 m from the inlet of the units since May 2017, then will be removed from wetland and will be taken to the laboratory for measurement of *ks*





Barreto A. B. , Vasconcellos G. R., M. von Sperling, Kuschk P. , Kappelmeyer U. and Vasel J. L. (2015) Field application of a planted fixed bed reactor (PFR) for support media and rhizosphere investigation using undisturbed samples from full-scale constructed wetlands. © IWA Publishing 2015 Water Science & Technology | 72.4 | 2015

Conclusions

- The hybrid constructed wetland (horizontal subsurface flow + vertical subsurface flow + vertical subsurface flow) system, built for the treatment of wastewater produced by IKEA in Catania, efficiently removed main pollutants and it has been able to manage the pollutant load and hydraulic peaks.

- The hybrid constructed wetland was able to achieve high disinfection level (up to 4 Ulog), satisfactory removal of organic content and suspend solid (up to 70%) and good nitrification level (80%).

- The design system tested has proven to be a reliable treatment for the decentralised wastewater treatment (wastewater discharge and irrigation reuse standards almost satisfied)

- The assessment of the clogging risk of the TW system, by methods based on Ks measurements, tracer tests and ERT provide useful information. But in some cases they don't fit in the same direction. Some of these methods are "time consuming" and may cause some disturbance of the TW beds, the minimally invasive ERT techniques could be a valid alternative, however further investigations are needed.

Thank you for your attention!!!

Giuseppe Cirelli

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22-26 August 2017
Big Sky Resort, Montana, USA