A green roof experimental site in the Mediterranean climate: the storm water quality issue

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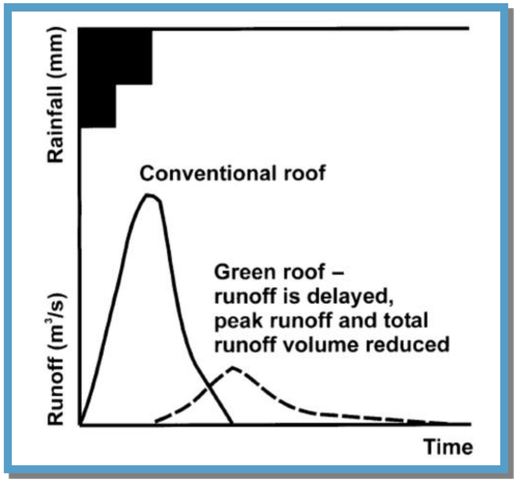
INTRODUCTION (I)

Problem OVERVIEW

→ Green roofs are used to beneficially contribute to storm water management problems since they **retain *(volume reduction)***, **detain *(peak reduction)*** and **slowly release** storm water;



→ The positive impact of green roof in term of water quantity issue is widely recognised and documented in the literature;

→ The ***quality*** of green roof outflow depends on **several factors**: the building technique, the maintenance operations, the land use characteristics, etc.

→ The behaviour of green roofs as a **source or sink for pollutants** is still a debated issue among researchers.

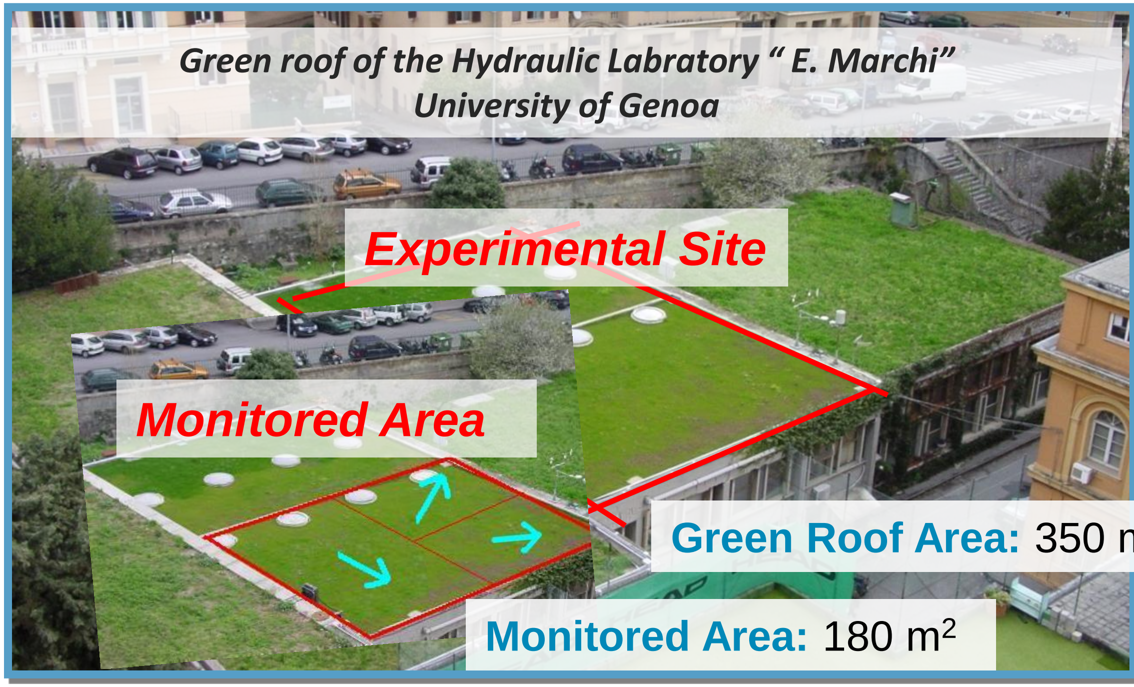
INTRODUCTION (II)

RESEARCH OBJECTIVE

→ To examine the **impact of green roofs** on the **quality of storm water** runoff based on a monitoring programme carried out at the **green roof experimental site** of University of Genoa (Italy)

- ✓ characterize the pollutant load associated with rainfall and subsurface outflow;
- ✓ evaluate if the green roof acts as sink/source of pollutant constituents

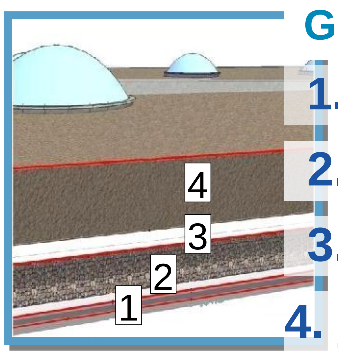
The GREEN ROOF EXPERIMENTAL SITE



The University of Genova exploited the existing green roof of its laboratory as an ***experimental site****.*

↓

The experimental site is installed in ***2007*** *by renewing the existing stratigraphy.*



GREEN ROOF STRATIGRAPHY (Depth = 40 cm)

1. Geotextile to protect the waterproof layer
2. **Lapillus** → drainage layer
3. Geotextile → filter layer
4. **VULCAFLOR** →growing layer

(blend of Lapillus, pumices and organic matter)

Lapillus *and* ***Pumice*** *are volcanic materials with high content of* Fe_2O_3, CaO, K_2O

The MONITORING EQUIPMENTS

Water QUANTITY Measure

- ✓Tipping-bucket rain gauge;
- Meteorological station (CAE SP-102)

- ✓Triangular weir coupled with a water level sensor + tipping bucket device;

Water QUALITY Measure

Precipitation:

- ✓Funnel located located at 1.5 m above the green roof surface (opening area equal to 1000 cm^2)
- ✓First storage tank (volume capacity equal to 8 l);
- ✓Second storage tank (20 l)

Green roof outflow:

- ✓Automatic sampler to take 1 litre discrete samples directly from the outfall section discharging into the flow monitoring channel;
- ✓ 24 plastic bottles (1l)

The MONITRORING PROGRAMME (I)

Water QUANTITY data

- → One minute **Rainfall data** provided by in situ rain gauge
- → Continuous water **level measurements** translated to flow rate (subsurface outflow)

Water QUALITY data

- → A single **BULK sample** (wet and dry deposition) on event basis
- → 24 composite samples of **subsurface outflow** based on uniform time pacing (max of 120 samplings taken at 5 minute frequency)

Laboratory tests performed for each discrete sample

- pH;
- Electrical Conductivity (EC);
- Total Suspended Solids (TSS);
- Total Dissolved Solids (TDS);
- Chemical Oxygen Demand (COD);
- Dissolved Metals (copper – Cu, zinc – Zn, iron – Fe, manganese – Mn, calcium – Ca, potassium – K)

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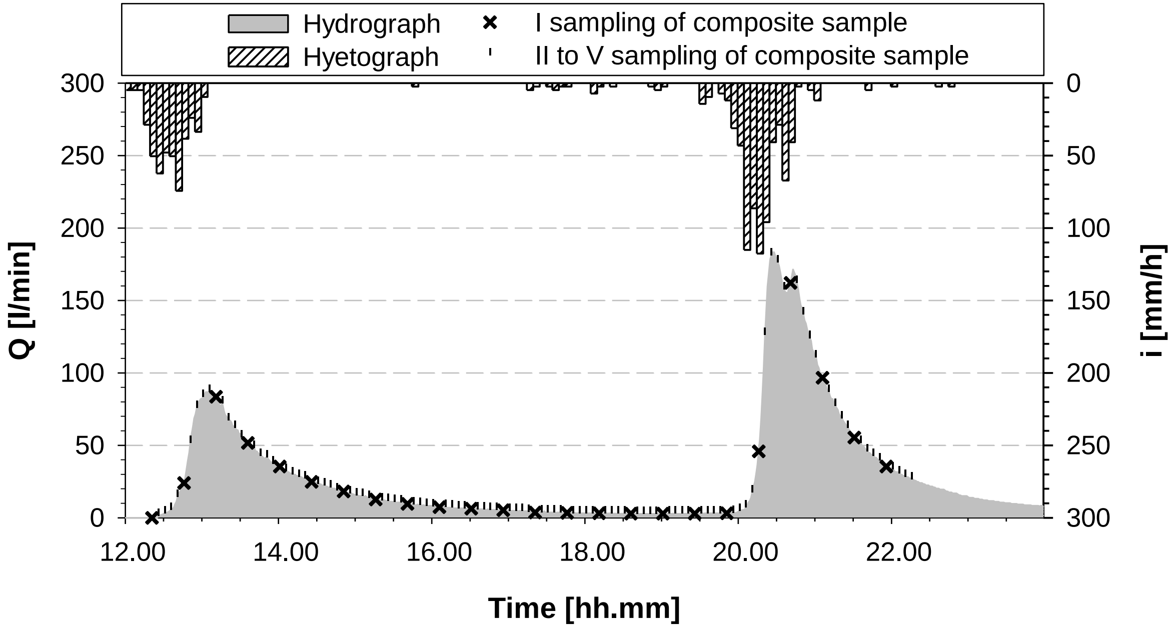
The MONITRORING PROGRAMME (II)



Monitored Event:

- → rainfall event that produced some appreciable subsurface outflow;
- → rainfall event that is characterized by an antecedent dry weather period exceeding 12 h (suitable to separate the outflow of consecutive events).

From October to December 2010 Six rainfall events were successfully monitored

The MONITORED CAMPAIGN

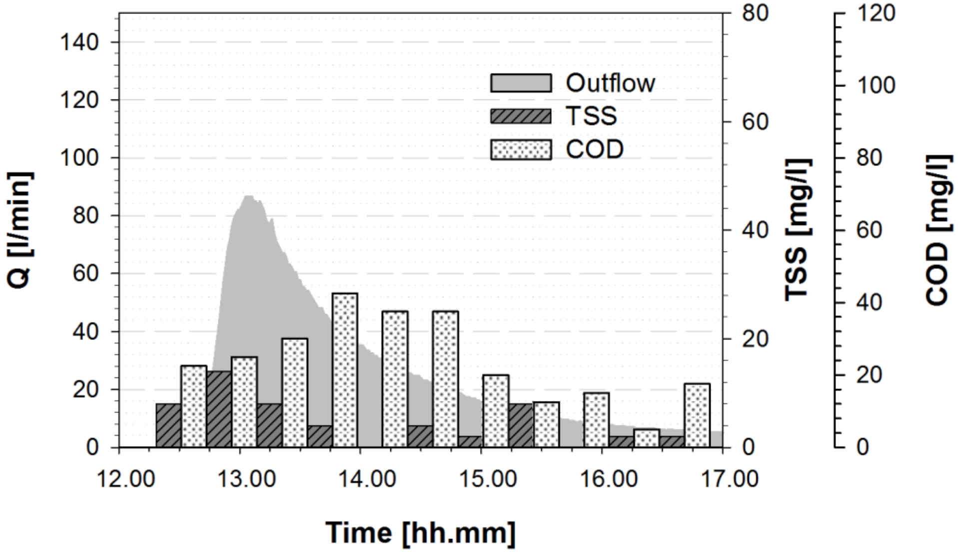
The hydrologic characteristics for each of the monitored rainfall event

Rainfall Event	H_{rain} (mm)	$i_{max\ at\ 15'}$ (mm/h)	ADWP (h)	$H_{outflow}$ (mm)	Q_{max} (l/min)
4-5 October	111.6	114.4	62	106.6	183.3
16-17 October	36.0	56	70	7.0	5.2
24-25 October	55.2	22.4	177	31.0	16.8
30 Oct.- 2 Nov.	141.0	40.8	118	119.0	67.2
30 Nov.- 1 Dec.	15.6	4.8	52	1.1	1.3
5-8 December	36.8	7.2	94	10.2	5.2
Mean	66.0	40.9	96	45.8	46.5
Std. Dev.	49.2	41.0	47	53.0	71.4

→ **The monitoring period covers the autumn season (rainy period)**

- ✓ **ADWP is generally lower than 7 days;**
- ✓ **The total rainfall depth ranges between 16 and 141 mm.**

The WATER QUALITY DATA I



A single index, **the Event Mean Concentration (EMC)**, is generally used to evaluate the pollutant load associated with each rainfall event, thus allowing comparison of pollutant concentration values from different storm events.

$$EMC = \frac{M}{V} = \overline{C} = \frac{\int_0^T c(t)q(t)dt}{\int_0^T q(t)dt}$$

The flow averaged concentration defined as the total pollutant load (mass) divided by the total runoff volume for an event of duration

1 The BULK DEPOSITION - EMC_{in}

A single sample is taken by collecting the whole rainfall depth assumed as representative on event scale

2 The SUBSURFACE OUTFLOW - EMC_{out}

The EMC values are determined based on the outflow hydrographs and the corresponding pollutographs for each pollutant constituent

The WATER QUALITY DATA (II)

1 The BULK DEPOSITION - EMC_{in}

Parameter	Rainfall Event							
	4-5 Oct.	16-17 Oct.	24-25 Oct.	30 Oct. - 2 Nov.	30 Nov. -1 Dec.	5-6 Dec.	*Mean*	*Std. Dev*
pH [-]	5.8	5.6	4.6	5.2	6.3	4.7	5.4	0.7
EC [μS/cm]	27.3	19.0	33.8	17.1	9.08	18.2	20.7	8.6
TSS [mg/l]	n.a.	10.0	n.d.	1.3	n.d	3.0	2.9	4.2
TDS [mg/l]	n.a.	10.4	26.5	17.5	34.0	14.9	20.7	9.5
COD [mg/l]	n.d.	n.d.	n.d.	0.83	15.0	n.d.	2.64	6.06
Cu [μg/l]	40	92	42	16	44	31	44	26
Fe [μg/l]	401	n.d.	n.d.	71	54	71	100	151
Mn [μg/l]	n.a.	n.a.	n.a.	4.35	3.41	2.09	3.28	1.13
Zn [μg/l]	56	26	225	53	89	15	77	77
Ca [μg/l]	2320	1497	2683	760	734	628	1437	888
K [μg/l]	236	442	516	341	867	468	478	215

→ The solid delivery (TSS and TDS) of the atmospheric deposition is negligible;

→ The concentrations of metals are generally limited even if wide range of variation is observed mainly for iron and zinc.

The WATER QUALITY DATA (IV)

2 The SUBSURFACE OUTFLOW - EMC_{out}

Parameter	Rainfall Event							
	4-5 Oct.	16-17 Oct.	24-25 Oct.	30 Oct. - 2 Nov.	30 Nov. -1 Dec.	5-6 Dec.	*Mean*	*Std. Dev*
pH [-]	7.2	7.5	7.0	6.5	7.1	7.3	7.1	0.4
EC [µS/cm]	79.9	76.7	80.6	56.2	47.5	46.7	64.6	16.2
TSS [mg/l]	9.0	2.2	2.1	2.2	0.1	1.1	2.8	3.2
TDS [mg/l]	102.5	119.8	115.3	99.3	80.9	76.0	99.0	17.1
COD [mg/l]	37.4	11.5	17.9	19.1	15.0	7.73	18.1	10.4
Cu [µg/l]	36	101	20	13	33	23	38	32
Fe [µg/l]	116	123	120	115	84	164	121	26
Mn [µg/l]	n.a.	n.a.	n.a.	2.45	1.11	1.62	1.73	0.68
Zn [µg/l]	73	23	66	13	8	9	32	30
Ca [µg/l]	4185	4091	5526	4017	5157	3549	4421	755
K [µg/l]	3877	2802	2819	3450	2558	3628	3189	533

→ Particulate mass delivery is strongly limited even with respect to the impervious rooftops;

→ The concentrations of heavy metals in green roof outflows are generally lower when compared to urban impervious surfaces.

The WATER QUALITY DATA (III)

Parameter	① EMC_{in}		② EMC_{out}	
	Mean	*Std. Dev*	*Mean*	*Std. Dev*
pH [-]	5.4	0.7	7.1	0.4
EC [µS/cm]	20.7	8.6	64.6	16.2
TSS [mg/l]	2.9	4.2	2.8	3.2
TDS [mg/l]	20.7	9.5	99.0	17.1
COD [mg/l]	2.64	6.06	18.1	10.4
Cu [µg/l]	44	26	38	32
Fe [µg/l]	100	151	121	26
Mn [µg/l]	3.28	1.13	1.73	0.68
Zn [µg/l]	77	77	32	30
Ca [µg/l]	1437	888	4421	755
K [µg/l]	478	215	3189	533

- ✓ the effect of **buffering the acidic rainfall**: rainfall pH is equal to 5.4 on average while pH values measured at the green roof outflow are greater than 7;
- ✓ **COD** values are higher in subsurface outflow than in bulk deposition;
- ✓ the concentration values of **Cu** are comparable;
- ✓ the green roof contributes to increase the concentration of **Fe**;
- ✓ the concentration of **Zn** can be mainly ascribed to atmospheric sources;
- ✓ the green roof substrate is the main source of **calcium and potassium.**

The impact on WATER QUALITY (I)

Green roof behaviour is investigated based on both **concentration and mass**

Water quality standards are generally based on concentration values

to couple the role of substrate in affecting both the quantity (i.e. retention and detention processes) and quality (i.e. adsorption and dissolution mechanisms) issues

→ Rainfall events where more than 90% of both rainfall and outflow volumes are fully monitored are selected to guarantee that water quality data corresponding to the inflowing and discharging pollutant load are consistently described.

Four over six rainfall-runoff events are examined: the 4–5 October, 16–17 October, 30 November–1 December and 5–8 December 2010

A with respect to the **concentration values**

$$\frac{EMC_{out}}{EMC_{in}} \begin{cases} < 1 \rightarrow \text{Green roof acts as a SINK} \\ > 1 \rightarrow \text{Green roof acts as a SOURCE} \end{cases}$$

B with respect to the **mass values**

$$\frac{M_{out}}{M_{in}} \begin{cases} < 1 \rightarrow \text{Green roof ...SINK} \\ > 1 \rightarrow \text{Green roof ...SOURCE} \end{cases}$$

The impact on WATER QUALITY (II)

A ... based on **concentration**

Parameter	Rainfall Event 4-5 Oct.	Rainfall Event 16-17 Oct.	Rainfall Event 30 Nov. -1 Dec.	Rainfall Event 5-6 Dec.
TSS	○	●●	○	●●
TDS	○	○	○	○
COD	○	○	○	○
Cu	●●	○	●●	●●
Fe	●●	○	○	○
Zn	○	●●	●●	●●
Ca	○	○	○	○
K	○	○	○	○

●● → Pollutant **SINK**

○ → Pollutant **SOURCE**

- ✓ Results point out that the **green roof mainly behaves as a source of pollutants** (white dots) thus contributing to deteriorate the water quality.
- ✓ The exception occurs for copper and zinc showing lower mean concentration values associated with the outflow

The impact on WATER QUALITY (III)

B ... based on **mass**

Parameter	Rainfall Event: 4-5 Oct.	16-17 Oct.	30 Nov. -1 Dec.	5-6 Dec.
TSS	○	●●	○	●●
TDS	○	○	●●	○
COD	○	○	●●	○
Cu	●●	●●	●●	●●
Fe	●●	○	●●	●●
Zn	○	●●	●●	●●
Ca	○	●●	●●	○
K	○	○	●●	○

●● → Pollutant **SINK**

○ → Pollutant **SOURCE**

Results clearly point out the different hydrologic characteristics in terms of the outflow volume → it emerges the retention effect operated by green roofs

- ✓ The **4-5 October rainfall event**: the green roof appears generally as a source of pollutants;
- ✓ the **30 November–1 December event** (→ characterized by the lowest outflow volume): the green roof behaves as a sink irrespective of the specific pollutant constituent

CONCLUSIONS

→ Water quality data point out that the pollutant load associated with the subsurface outflow from the green roof is limited if compared with the ones resulting from urban impervious surfaces and in particular with traditional rooftops;

→ By comparing the pollutant loads associated with the atmospheric deposition and subsurface outflow it emerges that the infiltration throughout the substrate generally determine increasing concentration values for solids, potassium, calcium and iron while zinc and copper are reduced;

→ Based on collected water quality data, outflows from green roofs can be suitably included among the roof-based rainwater harvesting systems (strategies), even if deeper investigation on water quality degradation is needed depending on the reuse purpose;

Findings of the present study contribute to demonstrate that green roofs beneficially contribute to storm water management issues.