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Appendix

Exploring the performances of a new integrated approach of grey, green and blue infrastructures for combined sewer overflows remediation in high-density urban areas

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Appendix

The modelling approach employed in the present work describes the functioning of the grey-green-blue infrastructures system through a series of well-mixed non-linear reservoirs. As shown in the scheme of Figure 1, the FFT receives water from the urban CSS when a CSO occurs, and starts feeding the CW as soon as its maximum storage capacity is exceeded. Finally, CW discharges into the RWB. Both FFT and CW are represented by a single reservoir with a regular shape (*i.e.* each one is a parallelepiped with its own size), while the RWB is decomposed into a series of 5 irregularly shaped reservoirs. Indeed, in order to control the RWB self-depuration capacity, as well as to regulate the flow discharged downstream, the system is thought with an actual subdivision of the RWB into various compartments through the installation of weirs. Moreover, decomposing the RWB into 5 reservoirs allows to take into account that both its width and height change significantly along its 3.2 km length. In practice, considering the 5 reservoirs as irregularly shaped means that the relationship between the water level and the corresponding stored volume must be derived through a geomorphological analysis, based on in-situ surveys or LiDAR data as proposed in this study (see the Results Section for details).

Water content in the 7 non-linear reservoirs (1 FFT, 1 CW and 5 from the RWB) composing the system evolves in time according to Equations (1) to (4):

$$dV_{FFT}(t)/dt = Q_{CSO}(t) - Q_{FFT}(t) \tag{1}$$

$$dV_{CW}(t)/dt = Q_{FFT}(t) - I(t) - Q_{CW}(t) \tag{2}$$

$$dV_{RWB1}(t)/dt = Q_{CW}(t) - Q_{RWB1}(t) \tag{3}$$

$$dV_{RWBi}(t)/dt = Q_{RWBi-1}(t) - Q_{RWBi}(t) + Q_{ext,i} \tag{4}$$

where V_{FFT} and V_{CW} are the volume of water stored in the FFT and CW component respectively, and V_{RWB1} and V_{RWBi} are the volume of water in the first and i-th compartment of the RWB, with i=2, 3, 4, 5. The terms on the right-hand side of Equations (1) to (4) are water flows entering and leaving each reservoir, and are modelled as follow [Equations (5) to (11)].

$$Q_{FFT}(t) = \begin{cases} 0 \; if \; V_{FFT}(t) < V_{FFT,max} \\ Q_{CSO}(t) \; if \; V_{FFT}(t) = V_{FFT,max} \end{cases} \tag{5}$$

where Q_{FFT} is the flow leaving the FFT and entering the CW, computed as excess over the maximum storage capacity of the FFT ($V_{FFT,max}$). In practice, the flow from the CSO (Q_{CSO}) is discharged directly into the CW as the FFT reaches is maximum storage volume.

$$I(t) = min\{A_{CW} \cdot [f_c + (f_0 - f_c) \cdot \exp(-k(t - t_0))], V_{CW}(t)/dt\} \tag{6}$$

where I is the infiltration flow, modelled through Horton equation and assuming a homogeneous infiltration rate over the bottom of the CW, whose area is A_{CW}. The maximum and asymptotic infiltration rates are f_0 and f_c respectively, the decay constant is k, and t_0 is the first instant of wetting of the CW. The infiltration flow in the time step dt is limited by water availability in the CW.

$$Q_{CW}(t) = \left(2/3 \, \mu \cdot L_{CW} \cdot \sqrt{2g}\right) \cdot y_{CW}(t)^{3/2} \tag{7}$$

$$y_{CW}(t) = max\{V_{CW}(t)/A_{CW} - h_{weir,CW}, 0\} \tag{8}$$

where Q_{CW} is the water flow leaving the CW and entering the first compartment of the RWB, computed considering that the flow is regulated by a weir whose crest elevation is $h_{weir,CW}$. The other terms in Equations (7) and (8) are: the weir discharge coefficient, μ, here assumed equal to 0.6, the length of the CW weir, L_{CW}, gravity, g, and the hydraulic head over the weir crest, y_{CW}.

$$Q_{RWBi}(t) = \left(2/3\,\mu \cdot L_{RWBi} \cdot \sqrt{2g}\right) \cdot y_{RWBi}(t)^{3/2} \tag{9}$$

$$y_{RWBi}(t) = max\{h_{RWBi}(t) - h_{weir,RWBi}, 0\} \tag{10}$$

where Q_{RWBi} is the water flow leaving the i-th compartment of the RWB and entering the next one, with i=1, 2, 3, 4, 5. The flow is computed considering that the crest elevation of the weir regulating the flow, $h_{weir,RWBi}$, as well as its length, L_{RWBi}, vary between the 5 compartments. The hydraulic head y_{RWB} is derived from water surface elevation in the compartment, h_{RWBi}, which is related to the stored volume by the stage-volume relationships shown in Figure 9. Finally, the constant external inflow in the RWB, $Q_{ext,i}$, is non-null in the 4-th and 5-th compartments.

$$Q_{ext,i} = \begin{cases} 0\ if\ i = 2,3 \\ 50\ l/s\ if\ i = 4,5 \end{cases} \tag{11}$$

Concerning BOD fate and transport in the CW and RWB, all the reservoirs used to model the system are assumed to be instantaneously well-mixed, and BOD degradation is modelled through a first-order kinetic. Hence, Equation (12) is applied to any reservoir composing the CW and the RWB, specifying each term coherently with the connections and functioning previously described:

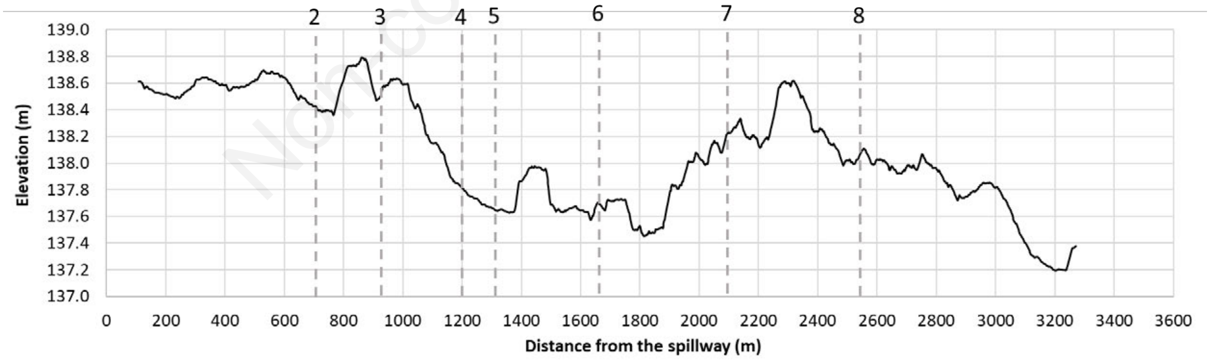
$$dC(t)/dt = C_{IN}(t) \cdot Q_{IN}(t)/V(t) - C(t) \cdot Q_{OUT}(t)/V(t) - K_{deg} \cdot C(t) \tag{12}$$

where C and V are, BOD concentration and the water volume in the reservoir respectively, C_{IN} is BOD concentration in the water flux entering the reservoir Q_{IN}, Q_{OUT} is the total water flux leaving the reservoir, and K_{deg} is BOD degradation coefficient in the first-order kinetic. In particular for the CW, the C_{IN} and Q_{IN} terms of the CW are plotted in Figure 10 as output from the FFT, assuming that FFT is completely by-passed when its maximum storage capacity is reached. Hence, BOD concentration and water flow in input to the CW are exactly those delivered by the CSO. The total outflow is the sum of the flow infiltrated into the soil, I, and the flow discharged through the weir, Q_{cw}. For the 5 reservoirs of the RWB, the input terms are the flow through the weir of the upstream component and the corresponding BOD concentration, and the output terms are the flow and BOD concentration through the local weir.

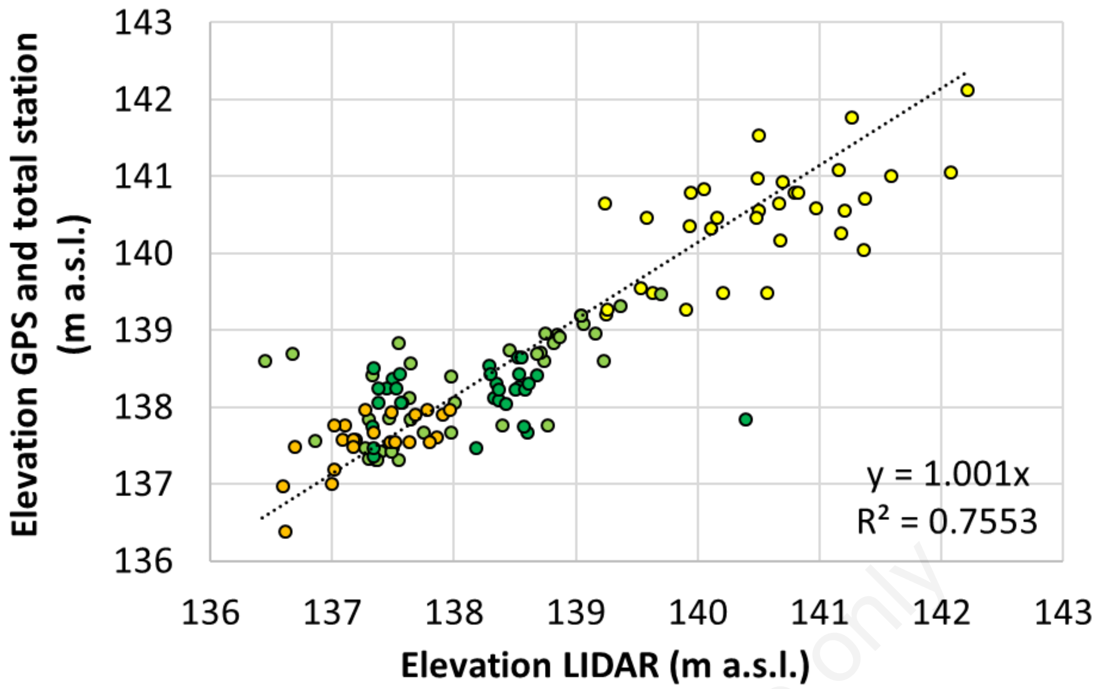
Appendix Figure 1. Interconnections between the Fontanile Casa and the irrigation network.

A **B**

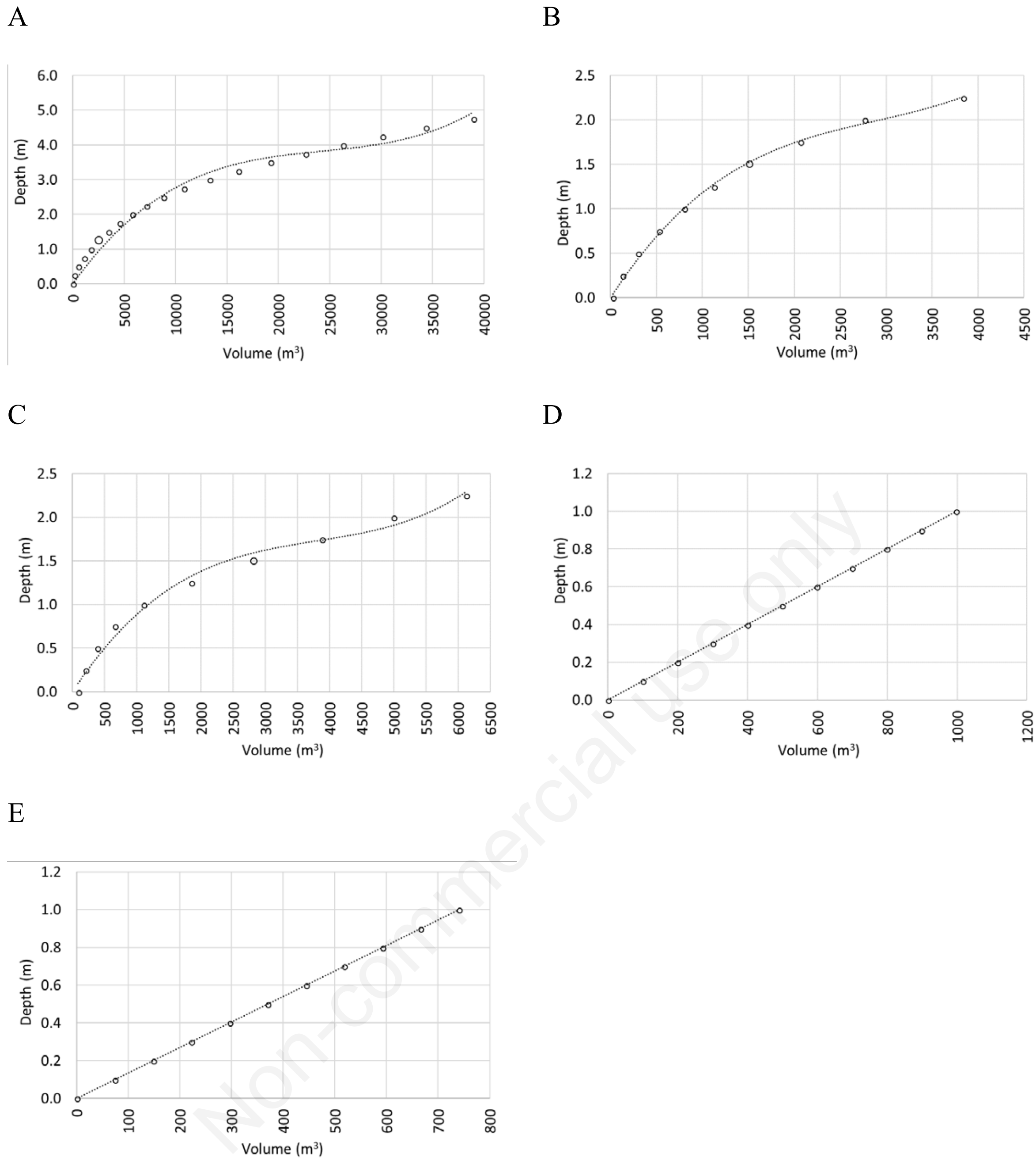
Appendix Figure 2. Example of two hydraulic structures located in the channel. (A) Culvert under a street; (B) gate for water diversion.



Appendix Figure 3. Longitudinal profile of the channel by LiDAR data.



Appendix Figure 4. Comparison between LiDAR data and *in situ* measurements. Dot colours indicate the different channel portion.



Appendix Figure 5. Stage-volume relationships for each portion. A) I portion; B) II portion; C) III portion; D) IV portion; and finally E) V portion.