SIMULATION OF INTERMITTENT WATER DISTRIBUTION NETWORKS BY EPA-SWMM: COMPARING MODEL RESULTS AND FIELD EXPERIMENTS

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Abstract: EPA-SWMM model was used for the simulation of the intermittent Water Distribution System (WDS) of a small municipality in south Italy. The model was compared with field data collected during an experimental campaign carried out in the intermittent WDS. The whole cycle of operation of the WDS was simulated, including the filling, the distribution and the emptying phases of the intermittent network. The modelling also included water leakages and private tanks that are normally interposed between network pipes and end users. Comparison of model results and experimental observations concerned water levels at the reservoirs and pressures at specific nodes of the WDS during some days of experiments.

Keywords: intermittent water supply; water distribution system modelling; EPA-SWMM model; field data

1. Introduction

Traditional hydraulic modelling software tools were developed to model continuous Water Distribution Systems (WDSs) and do not include options for modelling in a proper way intermittent WDSs. To overcome this limitation, in the recent years various researchers have modelled intermittent systems creating own software or modifying existing tools [1-6]. To different extent, previous models have been proven appropriate in the simulation of intermittent WDSs; however, much of these models have never been validated against comprehensive sets of field data. Some tests to validate the results of the use of EPA-SWMM against field observations were provided by [7]; however, the available data allowed model validation only with reference to the filling phase of the network. Moreover, water leakages and users' private tanks – normally installed by the users of intermittent WDSs – were not included in the simulation.

A recent campaign of experiments was conducted in an intermittent WDS in the south of Italy to monitor the filling, the distribution and the emptying phases of the network [8]. This work presents some of the results of the comparison of a model developed with EPA-SWMM for the simulation of intermittent WDSs with field data from the cited campaign of experiments. Water leakages throughout the network and private tanks interposed between the network nodes and the end users in the case study WDS were also included in the model.

2. Materials and methods

2.1. Case study

The case study is the intermittent WDS of Mirabella Imbaccari, a municipality of about 5000 inhabitants located in southern Italy. Two municipal reservoirs (R1 and R2 in Figure 1) are located in the area at high elevation of the town. Water sources (springs and wells) supply flow to R1 in a continuous way during the 24 hours of the day. An overflow device is positioned at 3.72 m from the bottom of R1 allowing excess water from R1 to overflow to R2. Also, outlet pipes (DN200) from R2 are equipped with gate valves and convey flow in the two outlet pipes of R1 in order to supply the network. The WDS is divided into two portions that supply zones at different elevation: the "high zone" (in red in Figure 1) and the "low zone" (in blue in Figure 1). The two zones are connected by means of a main (DN200) just downstream of the two reservoirs. A servo-controlled gate valve installed in the connection main allows to convey the whole flow to the high zone only (when required), thus disconnecting the low zone of the network during the intermittent supply.

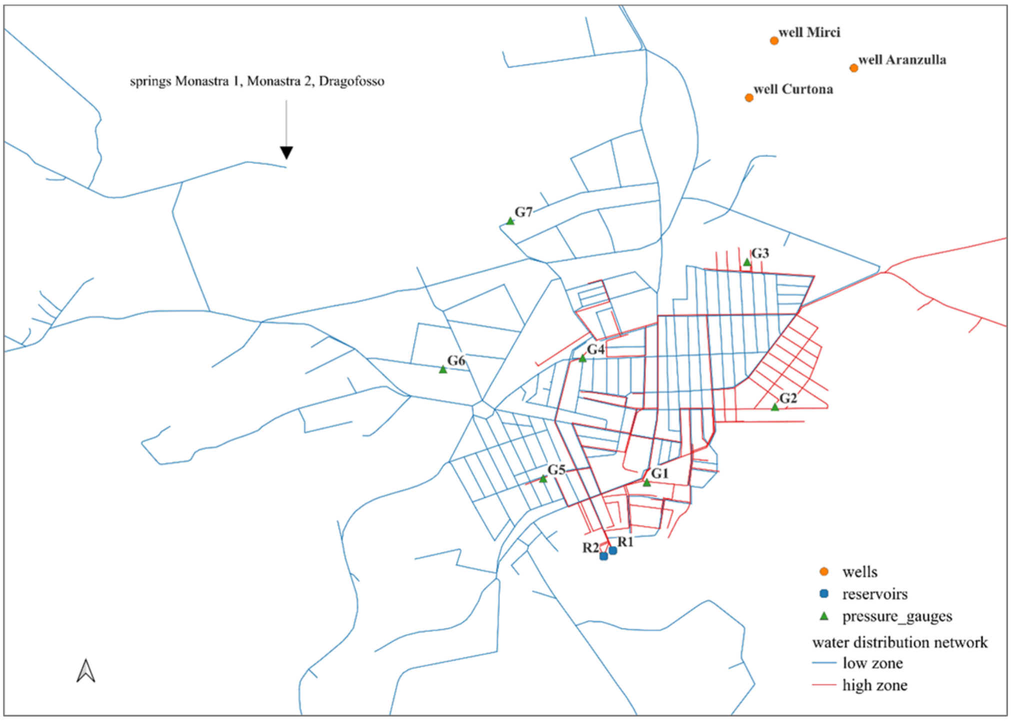

Figure 1. Water distribution system – location of springs, wells, reservoirs and pressure gauges.

The WDS provides water to the end-users intermittently. Households supplied by the WDS are equipped with private tanks to store water during supply hours and use it during non-supply periods. Normally, gate valves of the outlet pipes of R1 are opened early in the morning and the network starts to be supplied. After 3-4 hours gate valves of the outlet pipes of R1 are closed while those of R2 are opened. From this moment on, water flows to the network only from reservoir R2, while R1 is progressively refilled by the inflow from the sources. In the afternoon, the two gate valves of the outlet pipes of R2 are closed until the new opening operation of the day after. Generally, in the first 2-3 hours of the supply period the servo-controlled gate valve in the pipe connecting high zone and low zone is maintained closed to assure suitable pressure levels in the high part of the network. However, on weekend days both zones of the network are supplied simultaneously from early morning.
The campaign of field measurements in the WDS was conducted in some days of the period June-August 2019 [8]. Experimental measurements were taken during the filling phase, the phase of operation under pressure conditions, and the phase of emptying of the network. Measurements include inflow to reservoir R1 from the sources, water levels in R1 and R2, flow discharges at the outlet pipes of the two reservoirs, and pressures at 7 specific locations of the network (3 pressure gauges and 4 pressure gauges were installed in the high and low zones of the network, respectively – G1 to G7 in Figure 1). Times of opening and closure of gate valves in the WDS were also recorded. The details of the characteristics of the measurement equipment and of the field campaign are reported in [8].

2.1. Model setup
Although originally developed for the modelling of urban drainage systems, EPA-SWMM makes it possible to simulate both free-surface and pressure flow conditions simultaneously, thus allowing a proper description of the intermittent WDS behaviour where the two flow regimes may coexists. The use of SWMM for application to intermittent WDSs requires adapting/customizing the tools of the model for a correct description of the processes occurring during intermittent supply [3,4,7].
The building of the model of the WDS of Mirabella Imbaccari under EPA-SWMM environment was made by skeletonizing of the network into 922 nodes and 1073 pipes. Pipe roughness was fixed according to material and age in the different portions of the network. Private tanks interposed between the network nodes and the users were modelled assuming a one cubic meter capacity for each 4-people household. Inflow to the tanks (float valve equipped) were modelled according to [3,4]. Users demand was modelled assuming a per capita water demand of 150 L and a diurnal pattern typical of small

municipalities. Water leakages were modelled using a 2-parameters discharge-pressure relationship from literature [9]. In particular, the exponent in the water leakage relationship was set according to [9], while the coefficient was evaluated in order to obtain a good agreement between experimental and simulated values of both water levels at the reservoirs and pressures at the nodes of the network.

3. Results

The model was applied to three days of experiments of the campaign of 2019 characterized by different water demand and supply modalities.

For the sake of example, some results of the simulation of the network operation on Sunday, June 16th are shown in Figures 2. On such a day, both high and low zones were supplied from 6:00 a.m. Figure 2a reports simulated and observed water levels W (m) in the two reservoirs. At 6:00 a.m., water level in R1 is about 3.70 m. From that time until 9:40 a.m., the level decreases during the process of network filling. The switch to operation from R1 to R2 can be observed at about 9:40 a.m. At that time the operators of the WDS closed the gate valves of reservoir R1 and opened simultaneously those of R2; the water level in R1 returns to increase due to inflow from the source. Conversely, water level in R2 decreases due to outflow. At about 11:50 a.m., the gate valves of R2 are partially closed and the supply period is over. At around 4:00 p.m. R1 reached its maximum capacity and started to overflow to R2 (water level in R1 remains relatively constant while in R2 increases, see Figure 2a). Figure 2a shows a very good agreement between simulated and experimental water levels in R1 and in R2. The emptying velocity (slope of the curve) of R1 at the beginning of the supply period is reproduced relatively well by the model with correct simulation of the minimum value of water level achieved in the reservoir (1.9 m reached at 9:40 a.m.). Also the filling velocity of reservoir R1 (after that the gate valves close at 9:40 a.m.) is reproduced properly by the model. The graph shows that the model provides also reliable description of the process of overflow from R1, with the simulated water level that remains constant since 4:00 p.m., while the water level in R2 increases analogous to the experiments.

The results of the model in terms of nodal pressures h (m) in the network are shown in Figure 2b. The figure reports, as examples, pressure at gauges G2 and G6 located in the high and low zones of the network, respectively. Globally, the model reproduces correctly the behaviour of the WDS at the monitored nodes by capturing high pressure (during water supply hours) and low pressure (during no-supply hours) conditions during the day. In particular, simulated pressure values fit quite well experimental data for G2 during the whole day, including the abrupt drop in pressure after the closure of the gate valves at the reservoirs (at 11:50 a.m.). The model slightly overestimates pressure values in G6 during the supply hours and underestimates them during the non-supply hours.

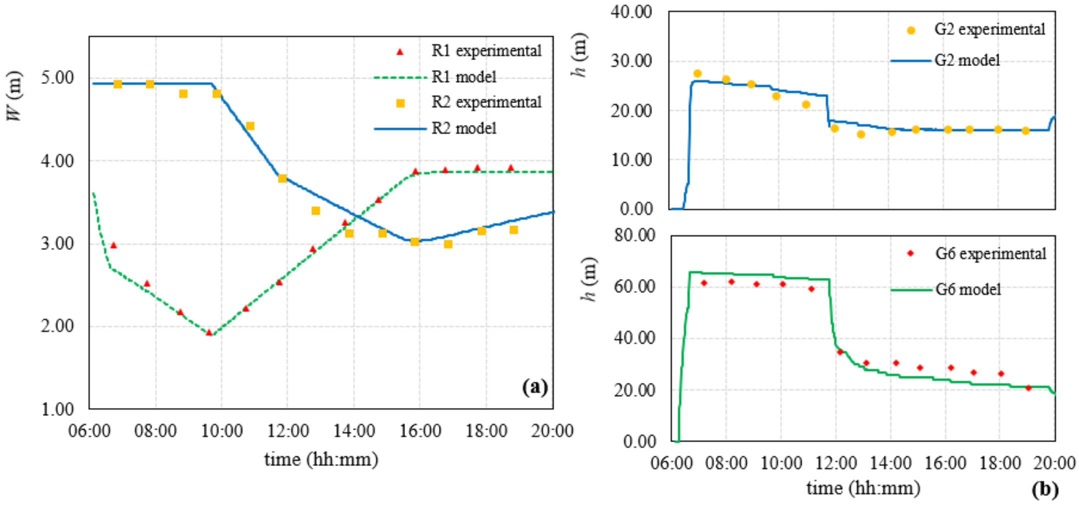

Figure 2. Experimental vs modelled: (a) water level in reservoirs R1 and R2; (b) pressure at gauges 2 (G2) and 6 (G6) on Sunday, June 16th.

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