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Accounting for local water storages in assessing WDN supply capacity

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Abstract

In many real WDNs, as in the Mediterranean area, customers are traditionally supplied by local water storages (i.e. roof or basement tanks) fed from the top by service pipes of the urban WDN through volume-controlled orifices. The present contribution shows that the prediction of WDN water supply capacity achieved by a model accounting for the filling/emptying of local tanks, is different from both classical demand-driven analysis and the pressure-driven analysis based on Wagner's demand-pressure relationship at each node. The WDNetXL system (www.hydroinformatics.it) is used to perform multiple simulation runs to assess WDN capacity under increasing demand scenarios.

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Keywords: Water distribution system modeling; Local water storages; Presssure-driven simulation; Extended period simulation

Introduction

Assessing the supply capacity of a Water Distribution Network (WDN) in terms of its ability to fulfil customers' water requests is a task of primary importance for water utilities. An emerging issue in this regard, is the prediction of WDN capacity in face of possible increased water requests due to climate and socio-economic changes (e.g. Kundzewicz and Somlyody (1997)). In fact, the increasing concentration of people in urban areas, due to the

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growth of resident population and seasonal presence of tourists, is expected to result into insufficient water supply in the near future and motivate water utilities to design effective countermeasures.

For these reasons the development of hydraulic models to realistically predict WDN supply system capacity is essential, especially in those contexts, like in the Mediterranean regions, where the effects of socio-economic changes combines with sharper water demand peaks during the warm seasons.

Nowadays, steady-state hydraulic models of WDN are adopted by water utilities worldwide to support optimal design and management decisions. Such models entail a non-linear mathematical problem consisting of energy balance equations along each pipe and mass balance equations at each node where the head is unknown.

The classical approach to WDN modeling is based on the assumption of fixed demands at nodes, independent on network pressure status; for this reason it is designated as demand-driven analysis (DDA). Actually, the simplification of fixed nodal demands was originally justified by the preeminent need to validate design solutions for new systems, which was the main technical problem at the beginning of the last century. The increasing computational capabilities over time permitted many authors (e.g. Shamir and Howard (1968), Epp and Fowler (1970), Hamam and Brammeller (1971), Kesavan and Chandrashekar (1972),Wood and Charles (1972), Collins et al. (1978), Isaacs and Mills (1980), Wood and Rayes (1981), Carpentier et al. (1987)) to develop increasingly effective and robust solving algorithms. Todini and Rossman (2013) have recently proposed a unifying view of all these methods, further demonstrating the outstanding convergence characteristics of the global gradient algorithm (GGA) by Todini and Pilati (1988), which is implemented into the worldwide adopted EPANET software (Rossman (2000)).

Nonetheless, it was recognized that the DDA does not actually provide accurate WDN functioning prediction in those circumstances where pressure is insufficient to fully satisfy the required demand (e.g. Ackley et al. (2001), Todini (2003)). Indeed, the DDA only permits to point out the nodes with insufficient pressure, without predicting the demand which can be actually delivered to customers.

In order to fill this gap in WDN modeling, the dependence of demand on system pressure was considered first by Bhave (1981), while Wagner et al., (1988) proposed a demand-pressure relationship which was recognized to be the best suited to predict WDN pressure-deficient conditions with respect to customer water requests (Gupta and Bhave, 1996). For this reason the Wagner's model has been used in a number of successive contributions involving pressure-driven analysis (PDA) of WDNs (e.g. Giustolisi et al. (2008)), and is the state of art to analyze pressure deficient scenarios. Recently, Giustolisi and Walski (2012) examined different demand components along with relevant pressure-dependent relationships, analyzing DDA vs. PDA.

Laucelli et al. (2012) also proposed a comparison between the DDA and the PDA for predicting WDN supply capacity under uncertain alterations of peak demands due to climate and socio-economic changes and system deterioration (i.e. increase of pipe hydraulic resistance and background leakages); the Wagner's model was used to represent customers' demand in PDA. They concluded that the DDA underestimates the hydraulic network capacity with respect to PDA, as a consequence of the pressure dependence of all demand components in PDA which result into a more realistic prediction of WDN hydraulic functioning.

In this WDN modeling framework, the present contribution considers the technical circumstance where customers' are not feed directly by the WDN but, rather, are connected to a local water storage (e.g. a roof or a basement tank) which is filled from the top though a volume-controlled orifice connected to the WDN. Although this situation is not very common in the US or Northern Europe, it reflects a traditional building practice in many areas, like the Mediterranean regions, where water shortage and infrastructure deterioration motivates customers to store water in order to cope with unreliable water supply or even intermittent service.

Recently De Marchis et al. (2010) analyzed the effects of intermittent water supply on network filling process considering also the inequality in restoring the private water volumes among the users after pressure-deficient conditions. Other authors (e.g. Criminisi et al., (2009)) also considered the apparent losses due to local tanks and their effects on water consumption patterns.

From steady-state WDN modeling perspective, the filling/emptying process of tanks located between model nodes and customers depends on the opening of the top orifice and on system pressure. This is likely to affect the overall WDN hydraulic state, especially under pressure deficient conditions, i.e. the hydraulic capacity of the network is exceeded and the required demands are not met. In this case the process of filling/emptying of local tanks cannot be neglected. Accounting for local tanks, in turn, is expected to provide a different prediction of WDN supply capacity compared with the classical DDA and the PDA using Wagner's model.

In the following of the paper the formulation of a WDN model accounting for local storages feeding customers' water withdrawals is briefly reported and the relevant modifications of the GGA for WDN steady-state modeling is summarized. Such model will be then applied on a literature network under different scenarios of water requests reflecting possible alterations due to socio-economic and climate changes. The results will be compared with those obtained by performing the classical DDA and the PDA based on Wagner's demand-pressure model.

Nomenclature

$\mathbf{A}_{pn}$, $\mathbf{A}_{p0}$	topological incidence sub-matrices in the WDN model of size $[n_p, n_n]$ and $[n_p, n_0]$
$\mathbf{A}_{pp}$	diagonal matrix in the WDN model
$C(t)$	outflow coefficient of the orifice filling the tank at time t
C^{max}	maximum outflow coefficient of the orifice filling the tank
$\mathbf{d}_n$	$[n_n,1]$ vector of nodal demand components in WDN model, which may depend on nodal head/pressure
$d(t)$	required customer-demand at time t (average in Δt)
$d^{act}(t)$	actual demand supplied to customers at time t (average in Δt)
$d^{fill}(t)$	flow rate filling the tank at time t (average in Δt)
$\mathbf{D}_{pp}$	derivative of head losses with respect to $\mathbf{Q}_p$
$\mathbf{D}_{nn}$	derivative of pressure-driven demands with respect to $\mathbf{H}_n$
$\mathbf{F}_n$	temporary matrix used in the GGA
GGA	Global Gradient Algorithm
$\mathbf{H}_n$	$[n_n,1]$ vector of total network heads
$\mathbf{H}_0$	$[n_0,1]$ vector known nodal heads
iter	counter of the iterative solving algorithm
n_p, n_n, n_0	number of pipes, nodes with unknown heads and nodes with known heads
K_d^{max}	maximum multiplier of demand patterns
$P(t)$	model pressure at time t in the node (i.e. service connection)
P_{min}	minimum pressure for any water to be delivered at nodes
P_{ser}	service pressure to fully deliver the customers' requests
$\mathbf{Q}_p$	$[n_p,1]$ vector of pipe flows/discharges
$V(t)$	initial water volume in the tank at time t
$V(t+\Delta t)$	final water volume in the tank after a time interval Δt
$V^{eq}(t)$	water volume at time t for which local tank inflow equals outflow of customer-demands
V^{max}	maximum water volume of the tank
Δt	time interval of the steady-state snapshot
$\Delta t^{fill}(t)$	filling time of the tank, from empty to filled, for a given $P(t)$ and $d(t) = 0$
Δz^{orif}	difference in elevation between the connection node and the orifice feeding the tank.

2. Modeling local storages in steady-state WDN simulation

The Extended Period Simulation (EPS) usually adopted to predict the WDN functioning over an operating cycle (e.g. for management purposes) is a sequence of steady-state snapshots where the initial boundary conditions are assumed to be know (e.g. recorded) or are computed from previous simulation steps. A key assumption underlying the steady-state WDN modeling is that the boundary conditions (e.g. demands, initial level of tanks, state of valves, working conditions of pumps and so on) are slowly varying over the simulation time step Δt. Accordingly, in order to introduce local storages in steady-state WDN models, also the water balance at the local tanks feeding customers should be satisfied over Δt:

$$
\begin{aligned}
&V(t+\Delta t) = d^{fill}(t)\Delta t - d(t)\Delta t + V(t) \\
&d^{fill}(t)\Delta t = \int_t^{t+\Delta t} \sqrt{P(t)-\Delta z^{orif}}\, C(t)\,dt = \sqrt{P(t)-\Delta z^{orif}} \int_t^{t+\Delta t} C(t)\,dt
\end{aligned}
\tag{1}
$$

where $V(t)$ is the initial water volume in the local tank (i.e. at the beginning of the simulation snapshot) while $d^{fill}(t)\Delta t$ and $d(t)\Delta t$ in the first equation represent the local tank inflow and outflow respectively. In particular, $d(t)$ and $P(t)$ are the stationary values of customers' demand and nodal pressure predicted by the model at time step t. In addition, the predicted volume $V(t+\Delta t)$ cannot be lower than zero (empty tank) and cannot exceed the maximum tank storage capacity V^{max}.

The integral in second equation (1) reflects the variation of the orifice outflow over Δt, which depends on the assumed type of orifice control. Although these orifices are usually controlled by floating valves which may follows a non-linear relationship between the opening of discharge area and the local tank volume, in this work it is assumed that the outflow orifice coefficient varies linearly between a maximum value C^{max} (when the tank is empty) and zero (when the tank is full) as reported in equation (2).

$$
\begin{cases}
C(V) = 0 & V > V^{max} \\
C(V) = \dfrac{C^{max}}{V^{max}}\left(V^{max} - V\right) & 0 < V \le V^{max} \\
C(V) = C^{max} & V \le 0
\end{cases}
\tag{2}
$$

Such a simplification is actually consistent with the main aim of demonstrating here the need for explicitly considering local tanks into WDN models, without analyzing a peculiar type of floating valve. In addition, the linear assumption entails an average functioning of the valves governing the filling/emptying of local tanks and is assumed to be accurate enough considering all existing sources of uncertainty in the boundary conditions of WDN models, especially when local tanks are present, as reported in Criminisi et al. (2009).

Assuming a constant filling/emptying rate over Δt (i.e. $dV/dt = (V(t+\Delta t) - V(t))/\Delta t$), the following expressions of the flow filling the local tank (d^{fill}) and the predicted volume $V(t+\Delta t)$ can be obtained.

$$
d^{fill}(t) = \frac{2\left(V^{max} - V(t)\right) + d(t)\Delta t}{\Delta t^{fill}(t)\left(1 + \dfrac{\Delta t}{\Delta t^{fill}(t)}\right)}
\tag{3}
$$

$$
V(t+\Delta t) = \frac{\left(2V^{max} - V(t)\right)\dfrac{\Delta t}{\Delta t^{fill}(t)} - d(t)\Delta t + V(t)}{1 + \dfrac{\Delta t}{\Delta t^{fill}(t)}}
\tag{4}
$$

where the meaning of Δt^{fill} is described in the nomenclature and in equation (5):

$$
\Delta t^{fill}(t) = \left(\frac{C^{max}}{2V^{max}}\sqrt{P(t)-\Delta z^{orif}}\right)^{-1}
\tag{5}
$$

Actually, if equation (4) returns $V(t+\Delta t)<0$, it means that the tank completely empties over Δt and the condition $V(t+\Delta t)=0$ is imposed. In order to preserve the mass balance, the $d^{act}(t)$ actually available to customers is:

$$
d^{act}(t) = \frac{2V^{max} - V(t)}{\Delta t^{fill}(t)} + \frac{V(t)}{\Delta t}
\tag{6}
$$

If equation (4) returns $V(t+\Delta t)>V^{max}$, the tank becomes completely full over Δt. It can be demonstrated that such condition cannot be reached if $\Delta t \leq \Delta t^{fill}(t)$, which is the condition to not have WDN model instabilities during the tank filling process (Giustolisi e al. (2013)). Moreover, if the initial filling condition $V(t)=V^{max}$ and $d(t)$ is not null, the orifice actually opens during the Δt and an equilibrium volume $V^{eq}(t)$ is reached such that the flow rate filling the local tank equals the customers' request.

3. Introducing local storages in the GGA

The matrix form of the WDN model comprised of n_p pipes, n_n nodes (with unknown heads) and n_0 nodes (with known heads) is reported in the following equation:

$$\begin{aligned} \mathbf{A}_{pp}\mathbf{Q}_p + \mathbf{A}_{pn}\mathbf{H}_n &= -\mathbf{A}_{p0}\mathbf{H}_0 \\ \mathbf{A}_{np}\mathbf{Q}_p + \mathbf{d}_n(\mathbf{H}) &= \mathbf{0} \end{aligned} \tag{7}$$

where all symbols are reported in the nomenclature and $\mathbf{A}_{pn}\mathbf{Q}_p = [n_p,1]$ column vector of the evenly distributed pipe head losses, internal head loss of pump systems and minor losses.

The global gradient algorithm GGA permits to get the solution of the mathematical problem above by iteratively solving the following equations (e.g. Todini (2003); Giustolisi and Walski. (2012); Giustolisi et al. (2012))

$$\begin{aligned} \mathbf{F}_n^{iter} &= \left(\mathbf{A}_{np}\mathbf{Q}_p^{iter} - \mathbf{C}_n\right) - \mathbf{A}_{np}\left(\mathbf{D}_{pp}^{iter}\right)^{-1}\left(\mathbf{A}_{pp}^{iter}\mathbf{Q}_p^{iter} + \mathbf{A}_{p0}\mathbf{H}_0\right) \\ \mathbf{H}_n^{iter+1} &= \left[\mathbf{A}_{np}\left(\mathbf{D}_{pp}^{iter}\right)^{-1}\mathbf{A}_{pn} + \mathbf{D}_{nn}^{iter}\right]^{-1}\mathbf{F}_n^{iter} \\ \mathbf{Q}_p^{iter+1} &= \mathbf{Q}_p^{iter} - \left(\mathbf{D}_{pp}^{iter}\right)^{-1}\left(\mathbf{A}_{pp}^{iter}\mathbf{Q}_p^{iter} + \mathbf{A}_{p0}\mathbf{H}_0 + \mathbf{A}_{pn}\mathbf{H}_n^{iter+1}\right) \end{aligned} \tag{8}$$

where:

$$\begin{aligned} &\mathbf{C}_n = \mathbf{d}_n \quad \text{and} \quad \mathbf{D}_{nn}^{iter} = \mathbf{0}_{nn} && \text{for DDA} \\ &\mathbf{C}_n = \left(\mathbf{d}_n(\mathbf{H})\right)^{iter} - \mathbf{D}_{nn}^{iter}\mathbf{H}_n^{iter} && \text{for PDA} \end{aligned} \tag{9}$$

the elements of the diagonal matrix $\mathbf{D}_{pp}$ are the derivatives of the head loss components (minor losses, internal losses of pump systems and uniformly distributed losses) with respect to pipe flows; the diagonal matrix $\mathbf{D}_{nn}$ contains the derivatives of each demand component (in $\mathbf{d}_n(\mathbf{H})$) with respect to nodal pressures/heads.

In the case of local tanks as detailed above, the demand actually delivered to customers depends on nodal pressure and on the filling status $V(t+\Delta t)$ controlling the outflow coefficient of the top orifice feeding the local tank:

$$d^{act}(t) = \begin{cases} d(t) & 0 < V(t+\Delta T) \leq V^{max} \\ \dfrac{2V^{max} - V(t)}{\Delta t^{fill}(t)} + \dfrac{V(t)}{\Delta T} & V(t+\Delta T) \leq 0 \end{cases} \tag{10}$$

while the flow filling the local tank from WDN is:

$$d^{fill}(t) = \begin{cases} \dfrac{2\left(V^{max} - V(t)\right) + d(t)\Delta T}{\Delta t^{fill}(t)\left(1 + \dfrac{\Delta T}{\Delta t^{fill}(t)}\right)} & 0 < V(t+\Delta T) \leq V^{max} \\ \dfrac{2V^{max} - V(t)}{\Delta t^{fill}(t)} & V(t+\Delta T) \leq 0 \end{cases} \tag{11}$$

from which it is easy to compute the derivatives of $d^{fill}(t)$ with respect to nodal pressure/head to be included in $\mathbf{D}_{nn}$.

Equations (10) and (11) clearly show that $d^{act}(t)$ is quite different from Wagner's model where the water delivered to customers' depend on nodal pressure only while the mass balance at local tanks is neglected.

In addition, it is evident that a DDA accounting for local tanks could be applied only if $d^{fill}(t)$=$d(t)$ and local tank maintains the equilibrium water volume $V^{eq}(t)$. However, such a condition cannot be achieved in EPS since it requires a constant $d(t)$ and $\Delta t^{fill}(t)$ (i.e. a constant pressure value $P(t)$ at the orifice) among the steady-state snapshots. This fact causes a filling/emptying process, which does not allow DDA and the PDA needs to be used only to predict local tank behavior.

4. Assessing water supply capacity of a WDN with local water storages

The WDN model presented in the previous section will be applied on a literature medium-size network to predict its water supply capacity under multiple demand scenarios entailing possible increase of water requests due to climate and socio-economic changes. The analyzed network is named Town-C and its layout is reported in Fig.1, as displayed in the WDNetXL editing function. The network comprises 444 pipes, 388 nodes, 1 reservoir, 7 tanks and 11 pumps; in this work the data of the calibrated ("true") network are used as referenced in Ostfeld et al. (2012), as well as relevant controls of pumps and valves by water level in tanks.

The EPS was run using the 168 hours time patterns for demands in all DMAs comprising the network and for the status of pumps and valves as reported in the original data. For the sake of clarity, Fig.2 and the following figures only report the first 24 time steps.

In addition, for the sake of this work, three scenarios of possible demand alterations are considered by multiplying the original demand patters by a factor which varied linearly over the operating cycle between 1 (i.e. at minimum demand hour) and K_d^{max}=1.2, 1.4 and 1.6, respectively, (i.e. at peak demand hour). These scenarios are supposed to emulate an increase of 20%, 40% and 60% of the peak demands due to climate and socio-economic changes, while keeping unaltered the minimum (e.g. nighttime) water requests.

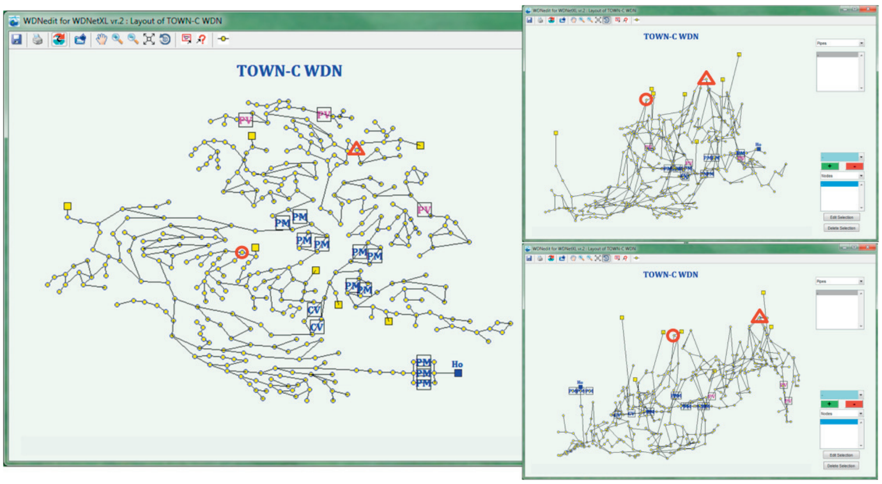

Fig. 1. Town C: layout and 2 side view (WDNetXL).

The supply capacity of Town-C, under each demand scenario, has been analyzed by performing the classical DDA, the PDA using Wagner's demand-pressure model and the model accounting for local tanks. Thus the following working hypotheses are assumed in order to permit consistent comparison between the different demand scenarios:

- the minimum pressure for any water to be delivered at nodes is $P_{min} = 0$ m and the pressure to fully deliver the customers' requests is assumed to be $P_{ser} = 25$ m;
- each node with non-null customers demand has been assumed to have a local tank whose maximum storage volume (V^{max}) equals 2 hours of the maximum customers' request (d_{max}) over the operating cycle for each assumed demand scenario.
- each local tank is fed by a top orifice with maximum outflow coefficient C^{max} computed as $d_{max}/P_{ser}^{0.5}$, meaning that when $P(t)=P_{ser}$ and the tank is empty, the tank inflow through the orifice equals d_{max}.

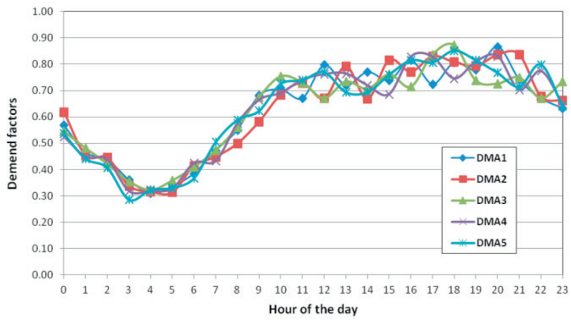

Fig. 2. Town C: time patterns of original demand factors for each DMA (first 24 hours).

Furthermore, in the case of model accounting for local tanks, three different scenarios of initial filling conditions have been considered by randomly sampling a fraction of the maximum storage capacity at each node. This random sampling is assumed to realistically represent the network conditions at the beginning of different operating cycles and permits to investigate the effect on the assessment of WDN supply capacity.

4.1 Results

In order to compare the supply capacity of Town-C as obtained by using different WDN models, the predictions of water volumes delivered to all customers at each hour of the operating cycle are considered first. In particular, Fig.3 reports the unsupplied water volumes as the difference between the water volume requested by customers and those actually delivered, as predicted by the models. Of course Fig.3 does not reports any data about DDA as customers' demands are fixed *a priori* by hypothesis and the unsupplied water volume would not provide any information on WDN supply capacity.

It is worth observing that the PDA-(Wagner) results into some unsupplied water volumes at all hours of the operating cycle, irrespectively on the demand scenario. Moreover, the unsupplied demand predicted by this model increases as customers' requests increase.

Differently, the model accounting for local tanks (i.e. PDA-(Local Tanks)) results into quite lower unsupplied water volumes than those returned by the PDA-(Wagner) at all time steps. During the off-peak hours (e.g. from hour 0 to 9), customers' requests are predicted to be fully satisfied; while during the peak hours (e.g. from hour 10 to 23), the tanks empties and only a fraction of the water request is predicted to be fulfilled. Indeed, considering the filling/emptying of local tanks means to account for local water volume which may have been stored during hours with normal pressure and feed customers during pressure deficient hours.

Interestingly, the ratio between the unsupplied volume predicted by accounting for local tanks and those using Wagners' model decrease as the peak demands increase; in particular for K_d^{max}=1.0, 1.2, 1.4 and 1.6 the unsupplied demand predicted by PDA-(Local tanks) models over the peak hours is about 70%, 65%, 60% and 50% of that predicted by PDA-(Wagner) model on average.

Fig.3 also shows that starting from different random filling conditions of local storages (i.e. C1, C2 and C3) does not significantly affect the prediction of WDN supply capacity.

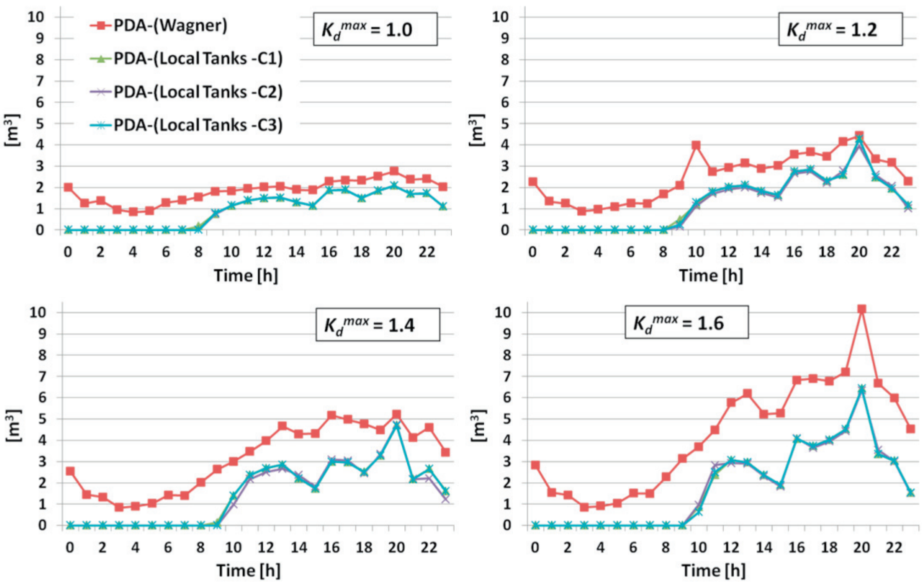

Fig. 3. Model predictions of total unsupplied water volume over the first 24 hours of the operating cycle.

From WDN hydraulic standpoint, the increase of water requests during the operating cycle causes the emptying of the tanks and the opening of the orifice. Since the flow filling each tank depend on nodal pressure, when it is above P^{ser} an equilibrium volume is reached where the inflow equals the customers' demand. *Viceversa*, when pressure is insufficient the local tank completely empties, the orifice becomes fully open and only the inflow (e.g. $d^{fill}(t)$) can be delivered to customers.

It is worth to note that, in the peculiar case of Town-C, the altimetry of and the presence of 7 tanks, permits to have a small number of nodes where customers' demand is not fully satisfied, which can be easily visualized on Town-C layout. For example, Fig.4 reports the prediction of demand supplied to customers as obtained by the different WDN models at nodes J221 and J580 indicated with a circle and a triangle in Fig.1, respectively. For the sake of the discussion here, only the simulation runs assuming K_d^{max}=1.2 demand scenario are reported; the other cases show similar behavior. For completeness, Fig.5 reports also the relevant predictions of water volume in local tanks considering the three random initial filling conditions for the PDA-(Local Tanks) models.

During the off-peak hours, the local tanks fill and empty being able to fully satisfy customers' water request (i.e. plotted as DDA demands). On the contrary, the PDA-(Wagner) model returns an insufficient water supply scenario also during these hours.

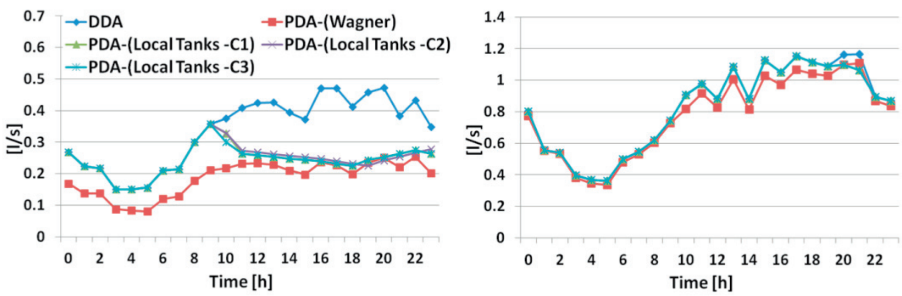

Fig. 4. Different model predictions of demand delivered to customers at node J221 (left) and J580 (right).

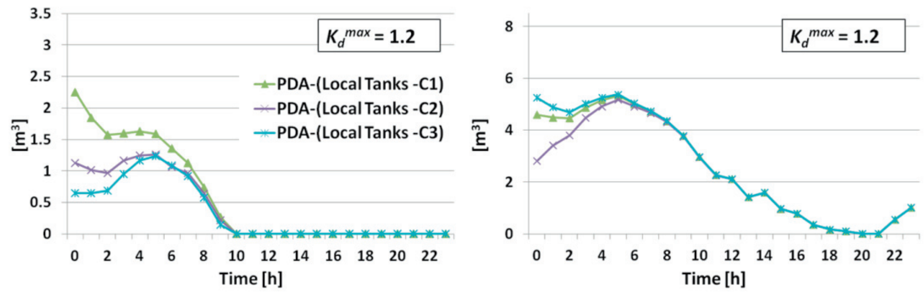

Fig. 5. Water volume in local tanks at node J221 (left) and J580 (right)

As demand increases, accounting for the presence of local tanks in WDN model results into a predicted delivered demand which is larger than that predicted by the PDA-(Wagner) case. In the peculiar case of node J221, the presence of tank is also evident from the smoother variation of the $d^{act}(t)$ predicted by PDA-(Local Tanks) models in front of the oscillations of customers' water requests (as represented by the DDA diagram).

Node J580 shows a rather different behavior, since accounting for local storage permits to fulfill almost all customers' water requests, except for two time steps (i.e. hours 20 and 21) when the tank empties. Also in this case PDA-(Wagner) model would return a more critical picture of this node starting from hour 9.

It is worth noting that the random filling conditions (C1, C2 and C3), in both nodes, just result into a transient which does not significantly affect the node behavior in the next time steps. This circumstance actually happens at all nodes and results into the negligible differences in the prediction of network supply capacity, as shown also in Fig.3 (i.e. unsupplied volumes).

The overall system behavior described by DDA, PDA using Wagner's model and the model accounting for local tanks reported herein results also into different predictions of the WDN hydraulic status in terms of pipe discharges and nodal pressure. In DDA, pipe discharges mainly depends on fixed nodal demands. In PDA, during the peak water request periods the pressure drops, so do nodal withdrawals and pipe discharges decreases.

Accounting for local tanks makes the orifice open also during the off-peak demand hours in order to restore the water storage; thus pipe discharges during these hours are usually larger than those predicted by using Wagner's model in PDA. It can be argued that these differences also affect the prediction of system water inflow which can be of primary importance in evaluating operational and management strategies in face of altered demand scenarios.

3. Conclusions

Using realistic and detailed WDN models is a prerequisite to perform reliable assessment of WDN supply capacity under present and future scenarios of water requests. This contribution presents a WDN model where the local water storages feeding customers are accounted for to predict system functioning. Indeed, the private water storages are very common in some regions of the Mediterranean area and they are likely to affect the global WDN hydraulic behavior and the actual supply capacity of urban WDN.

The case study compares the assessment of WDN supply capacity as obtained by using classical DDA, the more recent PDA with Wagner's demand-pressure model and the model reported herein. Using Wagner's model when local storages are present in the network results into underestimation of actual WDN supply capacity in terms of water volume delivered to customers. This is mainly due to neglecting the mass balance at local tanks in Wagner's models.

In addition, it is demonstrated that the prediction of WDN supply capacity accounting for inline tanks is not significantly affected by the random filling conditions for local tanks at the beginning of the extended period simulation.

Finally, accounting for local tanks in WDN models is discussed to provide a picture of system hydraulic behavior which can be significantly different from that achieved by classical DDA and PDA. This, in turns, can support decision makers in avoiding ineffective management decisions or unnecessary rehabilitation/enhancement works due to underestimating WDN supply capacity.

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