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Expeditious pump rescheduling in multisource water distribution networks

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Abstract

Cost minimization is the main issue for water companies when establishing pumping regimes for water distribution. Remarkable reductions in operation costs can be achieved by optimizing the pump scheduling problem. In this paper a near optimum solution is proposed for internal multi-sources networks with a large amount of pumps per station. The proposed method is based on a local search algorithm which explores the neighborhood of an optimized solution obtained by the subdivision of the network into pumping station influence areas. A real case of study is presented and discussed, results are also compared to the solution obtained with a GA.

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Keywords: Water distribution; Pump scheduling; Optimization; Multi-sources; Graph theory; Elementary districts.

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1. Introduction

Cost minimization is the main issue for water companies when establishing pumping regimes for water distribution. Energy consumption and pump maintenance represent by far the biggest expenditure and nowadays there is an urge to optimize the costs of existing water distribution networks, as they are the result of a progressive widening due to the demographical expansion of cities. Without making changes to the basic elements of a water supply system, remarkable reductions in operation costs can be achieved by optimizing the pump scheduling (PS) problem. In most of the cases, objectives such as supply costs and leakage minimization, water quality and efficiency maximization are always coupled with pump schedule optimization.

The importance of optimizing existing water distribution networks is not recently conceived, however for many developed countries a smarter energy management is still an open issue. Since the past decades many are the techniques proposed in literature devoted to determine least-cost policies of pump scheduling. The proposed algorithms are the most different and include linear programming [1, 2]; non-linear programming [3, 4]; dynamic programming [5, 6]; heuristics [7, 8]; meta-heuristics [9, 10]; mixed integer linear programming [11] and mixed integer not linear programming [12]. The techniques developed have become more and more efficient through the years, especially when hybrid methods are implemented, [13, 14].

However, intended users (managers and policy planners) are rarely skilled in writing optimization and simulation models or in integrating the relevant technologies in a flexible and quick way in order to obtain the necessary support for decision making, [15]. Moreover the proposed techniques are in some cases ineffective to be applied to large real water distribution networks, especially in term of calculation time.

In this paper a near optimum solution is proposed for rescheduling the PS of large ground-water supply distribution networks. These systems are generally supplied by well fields connected to a pipe system to deliver water to a central pumping station.

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Central pumping stations are sparse homogenously in the areas to be served. Because of water treatment requirements, water is not delivered directly from ground water to water mains, but to a reservoir from which water is then pumped into distribution network. Therefore the delivery cost for main distribution system and well field can be separated [3], whilst of course a relationship between them exists. As these type of WDNs are characterized by a large number of pumps (lifting water to the distribution mains), corresponding to an enormous domain of possible operation patterns, it could be considered desirable to take advantage of this simplification possibility when dealing with optimization problems.

The optimization procedure proposed in this paper is focused on the minimization of energy consumption of a set of pumping stations, operating between water source (underground aquifer or reservoir) and supply WDN. In the preliminary steps, the network is subdivided into influence areas of each pumping station, called "elementary districts" from the District Metered Areas background (eDMAs). Each eDMA is singularly optimized, taking advantage of the low number of pumps per district using a graph theory algorithm. After that, the overall pumping schedule of the WDN, resulting from the combination of each eDMA schedule (ePS), is optimized by a single scheme of progressive pump switching off. One pump at a time is called out of duty in the hydraulic model of the WDN in order to achieve the greatest energy saving. The procedure is reiterated until, compatibly with pressure and flow velocity constraint, the minimum number of pumps simultaneously active in the system is reached.

The proposed optimization procedure is applied to a real case of study, the WDN of Milan which has 95 pumps distributed in 29 pumping stations. The resulting operation pattern is compared with the original PS of the network with some consideration of network performance. Moreover, the solution found is compared to the one obtained with a genetic algorithm.

Nomenclature

AM	adjacent matrix
BFS	Breadth first search
FM	flow-weighted adjacent matrix
DMA	district metered area
eDMA	elementary district metered area
N_c	number of pump combinations
NL	node list
N_p	overall number of pump
N_s	number of internal water supply sources
PS	pump schedule
ePS	elementary pump schedule
S	identification number for internal water supply sources
SL	source list
WDN	water distribution network
WDS	water distribution system
c	identification number for a generic pump combination
ΔH_k	pump head of the k_{th} pump
η_k	pump efficiency
p	nodal pressure
q_{ij}	pipe flow between the i_{th} and j_{th} nodes
q_k	flow of the k_{th} pump
w_{ij}	weight coefficients in flow-weighted adjacent matrix

2. Methodology

Rescheduling the pump schedule of an existing WDS has many economic advantages that are not merely limited to the energy saving: by reducing the system pressure and thus energy consumption, also losses and pipe bursts are lowered, reaching a higher degree of control and efficiency. However, the optimization of the system from the energy perspective can be difficult due to the interaction between several factors, such as reservoir and pump operations, constrained pressure control and variable energy tariffs. Optimization task becomes even more complex when the number of pumps increases and their types are different.

In the present paper the main focus is on those water distribution network directly supplied by a system of pumps withdrawing water from an underground aquifer. For these systems there is no such strict interaction between pump schedule and tanks, mainly for the availability of water, thus the energy optimization can be carried on separating the problems.

The methodology developed is tailored for WDNs supplied by pumping systems, facing an overall high number of pumps. The proposed method is based on a hierarchical process of progressive improvement of constrained semi-optimal solution. The aims is not to find the "best" mathematical pattern of pump scheduling often difficult to be fully implemented in the real world, but to find a robust approximation of this optimum, with an easier methodology.

The method proposed can be schematized in four main steps:

- Preliminary analysis of the network, in order to identify main supply sources, that is those regularly active at the peak demand hour, and to acquire some fundamental data, like pipe flows and sources position;
- Elementary districts (eDMAs) creation: by means of a graph theory based algorithm, influence areas of pumping stations are defined in the network. The influence areas are identified by grouping those nodes that are mainly supplied by the same source (pumping station). Considering water flows for a constant consumption, that is the demand of each time interval in which the consumption pattern has been discretized, all the possible flow-paths, between sources and nodes, are found. For each node, the most discharging paths connecting it to the network sources are selected as shortest paths, thus discriminating to which source assign it. Each influence area is a district from a functional perspective, although variable in size depending on the considered consumption pattern; and it is elementary because each area competes to a single source and thus this is also the least possible subdivision of the network into self-supplied districts.
- Elementary pump schedule optimization: the pump schedule of every eDMA is fully optimized. Thanks to the network subdivision into influence areas, each having a single pumping station, optimization is easier, faster and more robust from a computational perspective. The resulting optimized pump schedules, altogether, are called elementary pump schedule (ePS).
- Expeditious rescheduling of pumps for the entire network: the ePS found in the previous step is here applied to the entire network and it is used as initial solution for the following optimization procedure. The solution for the entire network is sought by performing a cascade switching off procedure, for every time interval of constant consumption, the number of active pumps is progressively reduced in order to decrease the overall energy consumption of the network as much as possible, compatibly with pressure and velocity constraints.

3. Preliminary analysis

A preliminary analysis of the original network configuration is carried out to acquire some topological information, among which in particular the position and number of pumping stations (N_S) and pumps (N_P) present in each station, as this information will be essential in next steps where a number of influence areas, equal to the source nodes, is defined.

Usually, a pumping station is schematized as shown in Fig. 1, a reservoir with constant head and infinite capacity is linked to some pumps in parallel with assigned characteristic curve and time pattern. All pumps convey water into a unique pipe, called delivery pipe, which conveys water into the supply network. Every first node on the delivery pipe is assumed as a source node. The total number of source nodes N_S present into the network, represent the fictitious sources (*S*) from which the DMA creation starts. There should be one source point per pumping station.

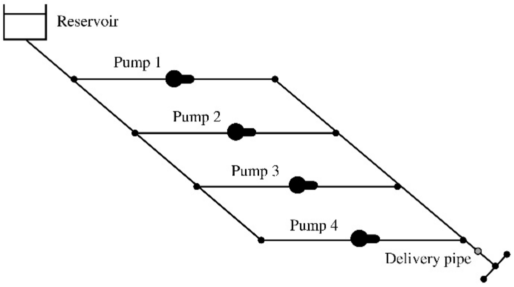

Fig. 1. Typical pumping station scheme.

Subsequently, a complete hydraulic simulation is performed at the peak hour, so that pipe flows are evaluated. Pipe flow data are used to draw the Adjacent Matrix (*AM*), which contains all the connections between network nodes, and the Flow-weighted adjacent Matrix (*FM*), which considers flow directions through some weights w_{ij}, here defined as:

$$w_{ij} = \frac{1}{|q_{ij}|} \tag{1}$$

where, q_{ij} is the flow between node *i* to node *j*.

4. Elementary districts creation

Aiming to reduce the energy consumption, the proposed method prescribes that the whole network is initially subdivided into smaller areas, called elementary districts. These areas are circumscribed by looking for influence areas of each pumping station, identified performing a prevalent supply criteria nodal search based on graph theory. A number (N_S) elementary districts will be created, equal to the number of pumping stations identified in the preliminary analysis.

The assignation of nodes to their respective influence domains is performed in four main steps. Firstly a Breadth First Search (BFS) analysis is performed on the network, using *FM* matrix just created, in order to identify which nodes are belonging to which sources. Following flow direction from a given source node *Sj*, the BFS algorithm allows to obtain a nodes list *NL* of all nodes reached from a given source. It is thus created a *NL* for every source *Sj* of the network *NL(Sj)*. If a generic node *x* is a downstream node of source *Sj*, this means that the water delivered from node *x* is supplied totally or partially from that source. However due to the looped nature of the network, generally only few nodes are reached only by a single source. More frequently, a node is reached from several sources. However a univocal assignation of every node to its main source has to be established. The adopted discriminating rule is simple: node *x* belongs to eDMA-*j* if the most of water delivered from node *x* derives from source *Sj*.

In practice this result can be achieved through the following two steps. By means of Dijkstra's algorithm [16] are identified the main paths (i.e. the shortest) connecting node *x* to its supplying sources, using the weighted adjacent matrix *FM*. Since *FM* weights are inversely proportional to the pipe flow (see Eq. 1), the shortest path resulting from the algorithm is the one made up of the most discharging pipes between a source and the given node. The main paths connecting a node to its multiple sources may have a common part, i.e. waters from the sources mix up before reaching the node. In any case to assign a node to one of its supplying sources, it is necessary to compare the discharge contributes coming from the different sources. Thus on the main paths, tracing backward the flows from the given node, at every fork (especially if a common part is present) it is followed the direction from which comes the highest flow. In this way the prevalent supplying source is found by comparing the discharges, the highest one determining the assignation source.

Lastly a correction procedure is carried on for those nodes that have not been assigned in the previous three steps, typically those nodes that are linked to the rest of the network by a non-active pipe passing thus unnoticed by the previous analysis, which is flow-driven. The unassigned or wrongly assigned nodes are corrected in order to guarantee that every influence area consists in a connected set of nodes supplied by a single pumping station.

This procedure, repeated for every node of the network, leads to a subdivision into groups of nodes. Every group of nodes is an eDMA, centered on a supply sources: at every pumping station corresponds a more or less extended influence area in which the whole network has been subdivided, see the example in fig.2.

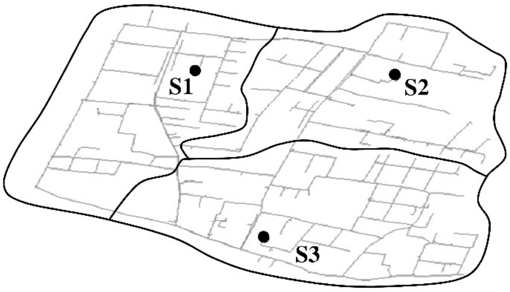

Fig. 2. Example of WDN subdivision into eDMA.

5. Elementary pump schedule optimization

At this point, the original network has been subdivided into elementary areas, each representing the influence zone of one internal source. The purpose of this sectorization, just temporary, is to optimize the operation pattern of the single eDMA taking advantage of the reduced number of combination that would be put to the test.

Therefore at this step, the optimal pump schedule of every eDMA is achieved compatibly with the constraints of respecting the pressure constrains at the lowest energy consumption possible (considering the existing set of pumps). All combination of pump are then generated and subsequently tested for the entire simulation period. However, due to the nature of the specific problem studied in this paper, the optimization procedure results further simplified as it is possible to search an optimal solution separately for every time simulated step, having separated the distribution network with its pumping station from the well fields.

At any given time step the best pump combination is selected, considering that each pump can have only two different status (*1* and *0* respectively to *on* and *off* status) and that the number of total possibilities N_c is equal to 2^{N_p}-1 (where N_p is the number of pumps in the district, the minus one term is to disregard the combination with all pumps inactive). For every solution, a hydraulic simulation is ran, computing nodes pressure and total energy consumed by the pumps. For each simulation time step (t) and for each pump schedule combination (c), the minimum pressure value ($p_{min}(t,c)$) is compared with the minimum required ($p_{min}^{*}=20\ m$): if the constraint is not verified ($p(t,c)<p_{min}^{*}$), then the combination (c) is sorted out as unfeasible. At each time step, among feasible combination, the one with the minimum total pump energy consumption is selected as optimal pump pattern. Furthermore the whole process could be improved by avoiding to check redundant pumps combinations and reducing the simulation period adding some practical consideration on the minimum period of pump continuative activity. As a matter of fact, the number of starts per day and the minimum operational time are given by manufacturers and they depend on the pump size and pump type, in any case the frequency of on-off cycles affects the life and the efficiency of a pumping system.

In the present work a minimum operation time is selected equal to one hour. Hence the entire simulation period is subdivided into hourly intervals and for each of them is worked out the best solution. Since a feasible pump combination must respect pressure requirement in every instant of the interval, the instant with the maximum demand value can be considered to carry on a pump scheduling optimization (Fig. 3). The optimal pump combination found for the maximum consumption time step of each hour is then applied to whole interval. Another option could have been selecting the average demand per hour, which is a more representative quantity of the interval, however this wouldn't have guaranteed the respect of the pressure condition in every instant of the interval. Besides, the optimization of eDMAs is just an intermediate step, thus the optimized pump schedule for the elementary districts does not represent the final solution.

The overall of optimized pump schedules for the eDMAs, in which the original network has been subdivided, is called "elementary" Pump Schedule (ePS). The elementary district optimization has been carried out independently for every eDMAs, which means with closed boundaries between the various influence areas; while in the next step the ePS will be applied to the whole network. This entails an excess of energy when the boundaries between eDMAs will be removed, however it will proved to be a good starting condition for a local search leading to sensible decrease in energy consumption for the original water distribution network.

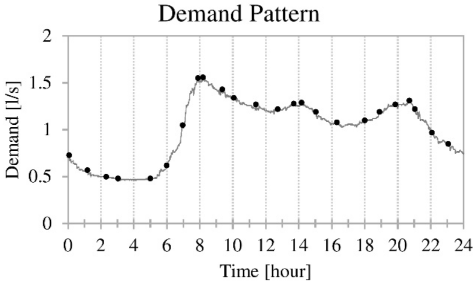

Fig. 3. Nodal demand pattern. Black dots correspond to the maximum value per hour, the optimization of eDMAs is carried out on the reduced demand pattern, i.e. only the time steps highlighted with black dots.

6. Expeditious rescheduling of pumps

The method proposed for rescheduling pumps of the existing network relies on the subdivision of the network into influence areas, eDMAs, followed by their energetic optimization that led to the elementary pump schedule (ePS) obtained with the two previous steps.

However it is the entire network that should be optimized and not the elementary districts considered as individual units. Thus the previous steps were devoted to elaborate a good starting condition for the whole network pump rescheduling. A solution for the entire network can be achieved performing a local search starting from the ePS solution, now applied to the entire network by removing the subdivision into separate districts.

Through a cascade procedure, one by one the pumps active in ePS are tentatively switched off; at every step of the cascade procedure, it sets out of duty the pump, whose switching off corresponds to the highest energy reduction, compatibly with the minimum pressure and hydraulic constraints. The turning off operation is repeated several times, every time updating the pump schedule PS with the new setup, until it is turned off the maximum number of pumps possible, see fig. 4.

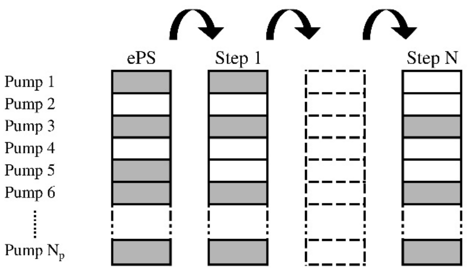

Fig. 4. Expeditious procedure: N_p pumps are represented by cells - coloured ones are active.

7. Outputs

The results of the method is a nearly optimized hourly pump schedule solution for a water distribution network. At every step of the method, it is verified that, every node is associated with a hydraulic head equal to or greater than the minimum required. If this constraint is not verified, the solution is discarded as unfeasible and other pumps configuration are selected in order to reduce as much as possible the energy consumption in the neighborhood of the fully optimized pump schedule ePS found for the elementary areas. The goodness of the resulting solution should be compared to the initial situation on the basis of performance indicators in order to determine the benefits obtained.

8. Case study

The methodology presented in this work is expressively thought for multi-sources, highly looped water distribution networks. Thus effectiveness of the proposed methodology is proved through its application to a real case study that well corresponds to this characteristics: the WDN of Milan. The network model used in the presented work is however approximated both for demand pattern and for details of pumping stations (a constant efficiency and no inverter are considered), moreover the reader should be aware that the position of tanks plotted in figures 5 and 6 has been intentionally altered, allowing to abstract from the real network, avoiding to publish sensible data, while not affecting the overall applicability of the proposed method.

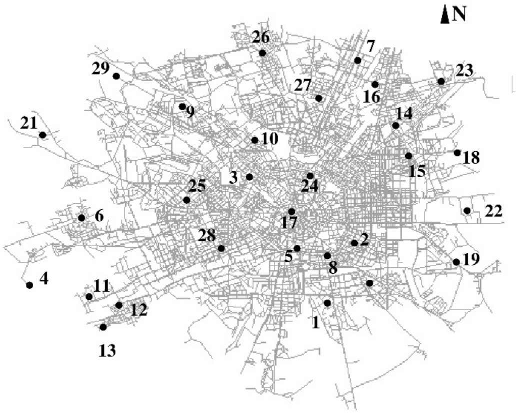

Fig. 5. Case study: water supply distribution network, scheme with 29 pumping stations.

The WDS of Milan represent a peculiar network with its web-like maze that follows the city streets layout and make it a highly looped system. In traditional supply networks water is stored outside the urban area and it needs to be carried to urban network through long pipelines. Milan water resource, instead, is stored entirely into its own subsoil, into large underground water tables that flow from north-west to south-est. The waterworks produces water for the city by pumping all of it from the underground water table. It uses a double pumping system consisting of *29* pumping stations and *95* pumps. In this sense, it can be considered a multi-sources WDN.

The rescheduling method proposed verifies every solutions in terms of feasibility by performing a hydraulic simulation by means of the software EPANET [17]; the head losses are evaluated with the Hazen-Williams formula, while other basic characteristics are reported in Table 1.

Table 1. Network characteristics.

Characteristic	Value
Number of nodes	26,937
Number of links	31,981
Number of reservoir	32
Number of pumping stations	29
Number of pumps	95

8.1. Expeditious method results

Firstly, by the procedure of elementary districts creation, the network is subdivided into *29* influence areas, corresponding to the number of internal pumping stations. Looking at the sectorization result, figure 5, the first thing that comes to mind is the diversity for shape and size of the identified areas, among which some show a fringed shape. This is mainly due to the present exploiting management of pumping stations, which can be dependent on several reasons, such as water quality and dimension of the station itself. On the other side this asset of influence areas reflects the demographic expansion undergone by the city that compelled the construction of new pumping stations in peripheral areas, less densely inhabited than city centre, which supply also to internal parts of the city through large diameter pipes. Another interesting aspect to notice is the elongation of the influence areas in the *NW-SE* direction following land orography.

Secondly, pump schedules of elementary influence areas are optimized by means a full optimization (with boundaries closed), thanks to a reduced (no more than *5*) number of pump combinations.

Lastly, boundaries of the elementary areas are reopened and the optimized elementary pump schedule (ePS) is applied to the whole network as initial condition for the cascade procedure by means of which, performing a local search, a near-optimum solution is achieved for the entire distribution network. Accordingly to the proposed procedure, the number of pumps that can be call out of duty are only the one active in the initial solution (ePS, which has *40* active pumps, see table 2), thus the search domain results greatly reduced (the search space is now reduced to 2^{40} combinations against 2^{95} initial combinations). The cascade procedure consists in a local search of a feasible pump schedule less energy consuming as possible, respecting the hydraulic constraints, at every time step of the simulation time, without having to consider the whole day consumption, thanks to the initial simplification made of separating the management of the distribution network and its pumping stations from the groundwater field wells.

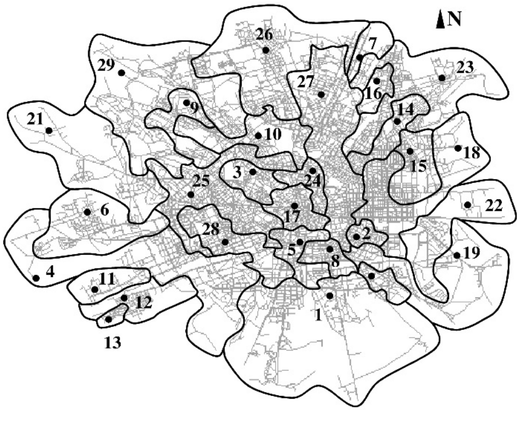

Fig. 6. Case study: influence areas, elementary areas centred on every pumping station.

The results of the two steps of energy optimization, elementary pump schedule and pump schedule for the entire distribution network, are summarized in table 2 where there are also reported the values of the original pump schedule of the network. To compare the network efficiency, three performance indices are calculated: Todini's resilience [18], entropy [19] and hydraulic performance [20]. Accordingly to the reduction of energy, of course the resilience and entropy of the network results slightly decreased while the hydraulic performance increases, being the achieved final configuration closer to the minimum pressure objectives.

Table 2. Daily average results.

Variable	Original WDN	Pattern ePS	Final PS	Units
Total energy consume	119,7	112,4	91,3	[GWh]
Energy Saving Percentage	-	6%	24%	[%]
Minimum pressure	30,57	27,49	20,00	[m]
Maximum pressure	85,51	79,82	79,84	[m]
Maximum number of active pumps	47	40	35	[-]
Minimum number of active pumps	12	17	27	[-]
Resilience index (avg)	0,865	0,880	0,881	[-]
Entropy index (avg)	8,720	8,733	8,584	[-]
Hydraulic Performance (avg)	3,389	3,430	3,609	[-]

The elementary schedule ePS corresponds to a slightly lower level of energy consumption (*112 GWh*) than the original situation (*120 GWh*), the explanation relays in a more homogeneous distribution of active pumps given by the optimization of each pumping station, even those ones that were underexploited in the original configuration. However after the cascade procedure, the resulting solution highly improves the energy use (*91 GWh*), allowing an energy saving of about *24%* of the original daily consumption. The number of active pumps is reduced during the daytime while overnight is increased, for a better spatial distribution which nonetheless allows to reduce consumption.

8.2. Genetic algorithm comparison

Finally, in order to check the goodness of the obtained result, the same optimization problem is solved by means of a genetic algorithm [21]. Each chromosome is a string of *95* binary values representing the status of the WDN pumps (*1=active*). The initial population is randomly generated, each solution is evaluated by a fitness function, clearly representing the energy consumed by the system, and they are ranked according to their performance. Selection is performed by selecting mating individuals for a mate pool, assigning a higher probability to be selected to individuals high in rank. Reproduction is performed with single point crossover. For a few number of children can happen the mutation of a single gene, flipping one bit. In addition, a percentage of best strings in each generation is elected to pass unchanged in the next generation, and another percentage is made by randomly generated new individuals. If a string is a feasible solution then its fitness value is calculated; otherwise this string is penalized. Table 3 summarizes the structure of GA individuals.

Table 3. Genetic algorithm characteristics.

GA parameter	Description
String	Binary (size: $N_p \cdot P_s$); where N_p=number of pumps and P_s is the population size
Selector	Roulette wheel
Crossover	One random point crossover
Elitism	*0.07* of best individuals in each generation is included unchanged in the next generation
New individuals	*0.15* of the new generation is randomly generated, to maintain biodiversity
Crossover probability	*0.85*
Mutation probability	*0.06*
Number of generations	*1000* (as maximum) or it stops after *20* consecutive generations of identical best individuals
Population size	$3 \cdot N_p$, where N_p=number of pumps
Fitness function	$\sum_{k=1}^{N_p} \eta_k \cdot \Delta H_k \cdot q_k$, where $\eta_k, \Delta H_k$ and q_k the efficiency , head and flow of the k-th pump

The comparison of the two methods is carried out at the peak demand interval, and a sensible computational advantage has been given to the genetic algorithm, as the main purpose is assuring that its obtained solution is in every respect a good one. Unlikely the expeditious method, no domain restrictions are applied to the genetic algorithm search, however the solution achieved is just slightly better than the one resulting by the method proposed in this paper (*5,55 MW* against *5,98 MW* of power consumption, referred to the pick daily demand). The difference in results, reported in table 4, can be considered negligible when the computational time is taken into account, in fact the presented method can carry out the entire daily solution in less than two hours (*1* hour and *51* min), a time similar to the one spent by the genetic algorithm to achieve just a single instant solution (over *24* instants in which the simulation time has been discretized).

Table 4. Peak demand condition results.

Variable	Original WDN	Pattern ePS	Final PS	Genetic Algorithm	Units
Total Power	7542,23	7081,73	5975,23	5550,06	[MW]
Energy Saving Percentage	-	6%	21%	26%	[%]
Total Computational Time	-	14	19	>120	[min]
Minimum Pressure	30,57	27,49	20,05	20,01	[m]
Number of active pumps	46	40	35	32	[-]
Resilience index	0,837	0,842	0,820	0,789	[-]
Entropy index	8,706	8,703	8,596	8,636	[-]
Hydraulic Performance	3,465	3,511	3,644	3,690	[-]

9. Conclusions

A new methodology is proposed for rescheduling large multi-sources water distribution networks, characterized by an elevated number of internal pumping stations. The delivery costs for distribution system and well fields have been separated, thanks to the topology of groundwater-supplied waterworks.

The method is partly based on graph theory: it uses graph theory principles and algorithms to determine the influence areas around every pumping station in the existing network. These areas are named "elementary" districts metered areas (eDMAs) and are used to obtain an initial pump schedule for the following cascade optimization procedure.

Every influence area belongs to a single pumping station thus, by closing its boundaries, it is possible to fully optimize the pump schedule given the reduced number of pumps to deal with. The advantage of starting from the optimized pump schedule found with eDMAs relies in the achievement of more homogeneous distribution on active pumps around the distribution network, which is a convenient initial condition for the local search performed by the expeditious method. The feasibility of every pumps combination is always controlled by performing hydraulic simulation in order to verify the compliance of the minimum pressure requirements and hydraulic constraints.

The proposed methodology is specifically tailored for large distribution network supplied by a high number of internal sources, consisting in a large amount of pumps, a complex case different from the ones usually treated in literature. In these cases the use of evolutionary search can result highly time consuming and the achievement of the optimal solution is not always guaranteed. To this regard, the expeditious method proposed in this work does not guarantee to achieve an absolute optimum, however it can be considered a fast and robust procedure to obtain a preliminary reconfiguration of the energy asset of a water distribution network with the abovementioned characteristics.

In order to test the applicability and effectiveness of the expeditious procedure it has been applied to a real case study. Results highlighted how the methodology, having firstly identified and subsequently optimized the elementary areas competing to every pumping station, successfully provides a near-optimal pump schedule for the original network allowing so save *24%* of the previous energy consumption. The influence areas are in number equal to the sources present in the system and characterized by the desired properties: appropriate size, connected with at least a water source, hydraulic independence from each other (i.e., no flow paths are available between two districts when the boundaries are closes during the second step of the procedure), and hydraulic feasibility, meaning that pressure requirements are satisfied. Moreover the procedure has been compared to the results obtained by means of traditional genetic algorithm, results show that the solution found by the expeditious method is not far from the one achieved with the evolutionary search algorithm. However the calculation time comparison supports the presented method, which could be then considered as a fast procedure to obtain a preliminary energetic reconfiguration of a water distribution network characterized by a large number of pumps.

Further improvements of the methodology could include also non-functional constraints, for example the differences in quality of the internal water sources. In the case that reservoirs and tanks should be considered into the optimization of the WDN, then it will be no more possible to consider separately the instant of the simulation period but the whole period should be considered.

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