12th International Conference on Computing and Control for the Water Industry

(CCWI 2013)

Procedia Engineering Volume 70

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2 – 4 September 2013

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12th International Conference on Computing and Control for the Water Industry, CCWI2013

Preface

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This volume contains almost all the papers presented at the 12th edition of the International Conference on "Computing and Control for the Water Industry. Information for Water Systems and Smart Cities (CCWI2013)" held in Perugia (Italy), September 2-4 2013. The texts have been reviewed by the International Scientific Committee made up of some of the most reputable worldwide researchers in the field of Urban Hydraulics today.
The conference was established in 1991 in the United Kingdom, with an agreement between several Universities which alternately hosted it, and became a well-established series of bi-annual meetings. An idea of the increasing success of the CCWI conferences is given in Fig. 1 where the number of papers published in the proceedings of the last nine editions is shown. CCWI2013 authors provenience (Fig. 2) confirms the European character of CCWI conferences, even if the contribution of the other continents is remarkable considering the reduction of funds to Universities and research centers and the economical crisis.

The 12th edition is the first time the conference has been hosted abroad and this is a source of pride and a challenge for the Italian community dealing with these themes. The conference coincided with an increased interest in the analysis, planning and management of urban water systems. This was demonstrated by the large number of presentations (more than 200), which was excellent considering the specificity of the field and the presence of so many young researchers. The 12th edition is also the first one where the papers have been published online – *Procedia Engineering* on the Elsevier site – with perpetual open access providing maximum impact.

The paradigms of information and communications technology are changing both society and the technical world, and at the same time urbanization is increasing globally. As a consequence, so smart cities are becoming increasingly more important in optimizing resources management through stakeholder involvement and the conservation of opportunities for future generations. Water resources and asset management are relevant issues in the smart city archetype, and the water industry is increasingly committed to playing a central role. Information technology applied to water issues, also known as hydro-informatics, is an intensely inter-disciplinary field, linking water and environmental problems with various computational modelling methods and fast-developing information and communications technology.

The conference has emphasized the integration between the more conventional themes of water system planning and information technology opportunities which offer design solutions and innovative models for the challenging problems of water system management in an urban perspective, a key concept for smart cities. This element has emphasized the need for close collaboration between senior and young scientists, software developers, specialists and

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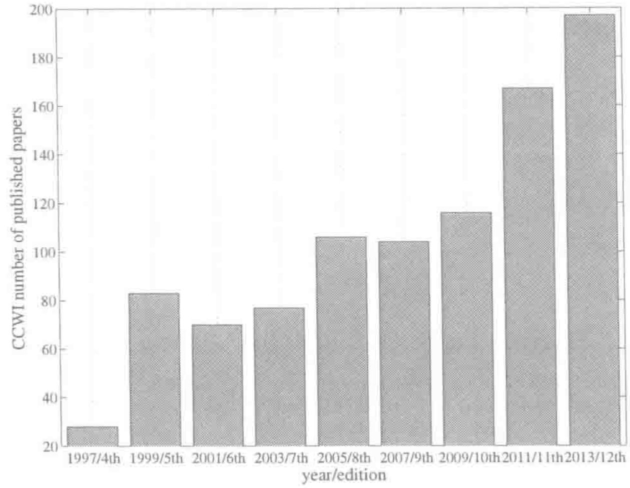

Fig. 1. Number of papers published in the proceedings of the last nine editions of CCWI conferences.

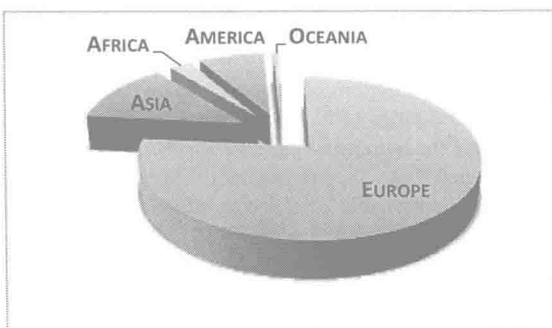

Fig. 2. CCWI2013 authors provenience.

stakeholders from public and private organizations. The conference has contributed towards the development of future key solutions sharing them with the participants who were present, from four continents and 36 different countries.

The main focus of the conference was on water supply and distribution, and urban drainage and sewerage systems, as used in the following areas: water engineering solutions for smart, liveable and sustainable cities; systems modelling, optimization and decision support; asset management and performance modelling; demand forecasting; leakage and energy management; innovative techniques for the diagnosis of pipe systems; real time monitoring and modelling, prediction control and data management; the impact of climate change on urban water management; sustainable urban water management; storm water control in urban areas including blue-green solutions; water and wastewater treatment modelling, optimization and control; water quality modelling including sediment and pollutant transport; advances in sensors, instrumentation and communications technology; data management including SCADA and GIS; security, reliability and resilience; case studies and practical applications; modelling tools for nearshore hydrodynamics.

An important contribution to the success of the event was given by the keynote lecturers: Joby Boxall of the University of Sheffield, Enrique Cabrera Marcet of the Universitat Politècnica de València, Mohamed S. Ghidaoui of the Hong Kong University of Science and Technology (this lecture was delivered by Bryan Karney), Zoran Kapelan of the University of Exeter, Bryan W. Karney of the University of Toronto, and Juan G. Saldarriaga Valderrama of the Universidad de los Andes. They gave brilliant, state-of-the-art lectures on some of the most important branches of

Fig. 3. *La Sala dei Notari* during the CCWI2013 opening session.

Urban Hydraulics, in the amazing Italian Renaissance setting of *La Sala dei Notari* in the centre of Perugia (Fig. 3): "What's in the pipeline?" (J. Boxall), "Towards an energy labelling of pressurized water networks" (E. Cabrera), "Smart Water Systems (SWS): potentials and challenges" (M.S. Ghidaoui), "Advanced modelling for real-time management of smart water systems" (Z. Kapelan), "Energy accounting as an integrated and comprehensive spatial and temporal management tool for characterizing water supply system operation, performance and design" (B.W. Karney), and "Historical development of power use methods for WDS design and their evolution towards optimization metaheuristics" (J. G. Saldarriaga).

The contribution of the younger researchers was remarkable and the *Early Career Award* competition was very hard-fought with two tie breaking winners: Ina Vertommen of the University of Coimbra, and Robert Sitzenfrei of the University of Innsbruck.

We cannot overlook our debt of gratitude to our colleagues and friends of the *Centre for Water Systems* at the University of Exeter – Dragan Savic and Zoran Kapelan – for their constant support; to Marco Ferrante, Silvia Meniconi, Luigi Berardi, Daniele Laucelli, Alberto Campisano – co-editors of these proceedings – and Caterina Capponi who contributed to the event with invaluable expertise and boundless enthusiasm.

Before handing over to the papers themselves, something about their editing. We tried to fulfill Eldevier template requirements and we hope that the final result is satisfactory. Just for fun: before reviewing the papers, we could not guess how many ways the instruction *Author name* – at the top of each page starting from the second one – could be followed. Here below, as an example, the case of two author papers:

- *N. Tizio and N. Sempronio / Procedia...*
- *Tizio and Sempronio / Procedia...*
- *Tizio & Sempronio / Procedia...*
- *N. Tizio & N. Sempronio / Procedia...*
- *Tizio/ Procedia...*
- *N. Tizio / Procedia...*
- *Name Tizio and Name Sempronio / Procedia...*
- *Name Tizio & Name Sempronio / Procedia...*
- *Author name / Procedia...*

according to factorial (at the end we choose *Tizio and Sempronio / Procedia...*).

Finally we would like to once again thank the President of the Italian Republic, Giorgio Napolitano, for giving his huge patronage to this conference.

We greatly look forward to seeing you all in Leicester for the 13th edition of the CCWI conferences in 2015.

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12th International Conference on Computing and Control for the Water Industry, CCWI2013

Optimization and reliability assessment of water distribution networks incorporating demand balancing tanks

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Abstract

This research aims to incorporate demand balancing tanks in network optimization and reliability assessment running extended period simulations. A tool called NORAT (**N**etworks **O**ptimization and **R**eliability **A**ssessment **T**ool) has been developed, which determines the required balancing volume, optimizes pipe diameters and tank elevations, and finally calculates the total costs. NORAT further assesses the hydraulic reliability of the network. The tool has been illustrated on a synthetic network by applying different combinations of topography, supply schemes, and locations of water sources and tanks. The results prove the ability of NORAT to employ balancing tanks, both in optimization and reliability assessment processes.

Keywords: Optimization; Reliability; Demand balancing tanks; Water distribution networks.

1. Introduction

Water distribution networks (WDN) are vital part of urban infrastructure and require high investment, operation and maintenance costs. Their design is a complicated task due to strong interconnections between the network components and hydraulic parameters such as nodal pressures and demands. In theory, the design of a simple network consisting of only one water source and ten pipes by considering just three available pipe diameters comprises 3^{10} possible solutions. If the network is larger and includes other components such as pumps and tanks, the design process becomes additionally complicated. Traditional way to approach it in engineering practice is by trial and error while using rules of thumb and safety factors that usually provide non-optimal solutions. Motivated

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by these shortcomings, many optimization approaches have been proposed in the literature, such as linear and non-linear programming, heuristic approaches and global optimization algorithms. However, a completely efficient and accepted approach to optimize WDN layout is not yet available, Banos et al. (2010).

Due to high costs, optimization process of WDN usually starts by finding a least-cost solution that satisfies the required design criteria. This initially yields less attention to other aspects of WDN management, such as network reliability. Nowadays, the reliability of WDN has become a matter of concern for water utilities and researchers. Table 1 includes some of reliability definitions frequently mentioned in the literature.

Table 1: Definition of WDN reliability

Researcher	Definition
Tung (1985)	'Probability that flow can reach all the demand points in the network'.
Cullinane et al. (1992)	'Ability of the system to provide service with an acceptable level of interruption in spite of abnormal conditions of water distribution system to meet the demand that are placed on it'.
Goulter (1995)	'Ability of a water distribution system to meet the demands that are placed on it where such demands are specified in terms of the flows to be supplied (total volume and flow rate) and the range of pressures at which the flows must be provided'.
Xu and Goulter (1999)	'Ability of the network to provide an adequate supply to the consumers, under both regular and irregular operating conditions'.
Tanyimboh et al. (2001)	'Time-averaged value of the flow supplied to the flow required'.
Lansey et al. (2002)	'Probability that a system performs its mission under a specified set of constraints for a given period of time in a specified environment'.

Due to difficult process of both the optimization and reliability assessment of WDN, most of the researches focused only on the piping system, omitting other network components such as balancing tanks, pumps or valves. Despite the benefits that the tanks may bring, WDN are usually optimized without incorporating them into analyses. The objective of this research was to create a toll that will consider the demand balancing tanks in the optimization and reliability assessment processes to find out their influence on the total cost and service levels for given demand scenario on a typical consumption day.

2. Demand balancing tanks

Demand balancing tanks play an important role in WDN. They enable demand management, assure water supply during system failures and reserve water for emergency cases such as fire fighting, and allow for pump flow rate modulation. Tanks represent quite a small part of the whole network cost. Nevertheless, they have a significant impact on the overall network performance. If they are well-designed and located, they may improve the overall network performance and reduce the total cost. On contrary, they can increase the total cost of the network and reduce its performance. For instance, if the tank elevation is too high, the pressure in pipes can be also high, which increases the probability of pipe failure and water losses. If the elevation is too low, the pressure delivered can be insufficient and leads to hydraulic failure, Vamvakeridou-Lyroudia et al. (2007).

Batchabani and Fuamba (2012) discuss different approaches used in the design of demand balancing tanks. Accordingly, the tanks should be designed to compromise between minimizing the investment and operational costs and maximizing the network reliability. Design of any tank generally involves the following decision variables: supply volume (balancing, fire, and emergency volumes), hydraulic variables (maximum and minimum water levels), operational variables (maximum, minimum and normal operational levels) and construction variables (shape, type, location, and configuration of the outlet and inlet pipes). Tanks have been traditionally designed based on the local design guidelines (regulations) of the country. Guidelines are simple to implement, require less data collection, and useful to provide quick cost estimation during the design process. The weakness of the guidelines is that they usually focus on tank volume and not on the other variables such as elevation and location. In addition, they may cause a risk of tank over-sizing even if the WDN can operate efficiently with less storage volume.

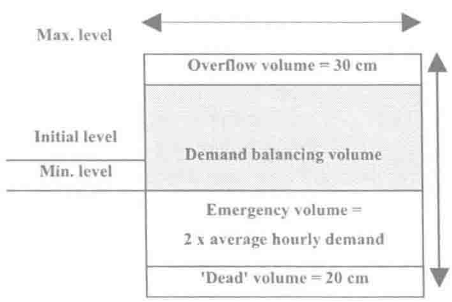
Common optimization algorithms are suitable in principle to design the tanks considering all the decision variables mentioned above. However, increasing the number of decision variables complicates the optimization and increases the number of possible solutions exponentially. On the other hand, if too many decision variables are ignored, the optimization model can produce solutions that may be inapplicable technically and commercially.

3. Framework of NORAT

NORAT (**N**etworks **O**ptimization and **R**eliability **A**ssessment **T**ool) is a decision support tool able to optimize, calculate the cost and assess the reliability of WDN. The tool consists of two models; network optimization model (NetOpt model) and network reliability assessment model (NetRel model). NORAT has been developed in C++ language code with integrating the EPANET programmer's toolkit functions for hydraulic analysis. The optimization algorithm used is Evolving Objects (EO) of Keijzer et al. (2002), which is an unconstrained single-objective GA optimization algorithm.

3.1. NetOpt model

NetOpt starts with calculation of the required tank volume (currently, the model can deal only with one tank), then optimizes the pipe diameters and tank elevation, and finally calculates the total cost of the network. The tank volume is calculated as mentioned in Trifunović (2006) assuming to have a cylindrical shape. This volume is consisting of the following volumes (Fig 1-a):



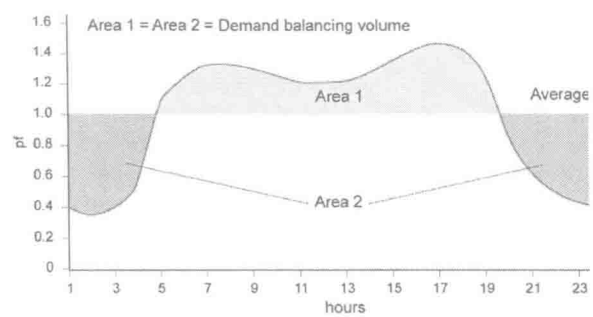


Fig. 1. (a) Required tank volume; (b) Demand balancing volume (adapted from Trifunović, 2006)

1. Demand balancing volume: equals the total water volume accumulated when the demand is below the required average value, which will be used later when the demand is above the average, Fig. 1(b).
2. Emergency volume for maintenance works, pipe failure events, fire fighting, etc.: assumed arbitrarily at twice the average hourly demand.
3. 'Dead' volume/depth to protect the tank from staying dry: assumed arbitrarily at 20 cm.
4. Overflow volume/depth protect the tank against the overflow: assumed arbitrarily at 30 cm.

By assuming the height (maximum level) of the tank, the model determines the required pipe diameters, minimum water level and initial water level at the beginning of the simulation. After calculating the required tank volume, NetOpt starts the optimization process, performed by using the EO algorithm. The optimization includes the pipe diameters and tank elevation based on minimizing the total cost. The optimization is constrained by minimum nodal pressure, maximum pipe unit head-loss and tank inflow/outflow that preserve the demand balance in the network.

The optimization process is done by generating many solutions (populations) and then selecting the best solution based on the objective function. In each population generation, the objective function firstly calculates the total cost of the pipes. Then, the function checks if the optimization constraints are satisfied or not with this population. If the constraints are not satisfied, the objective function will add a proportional penalty cost to the total cost. Finally, the objective function returns the total cost (including the penalty costs) to be evaluated. The optimal solution will be in this case the least-cost one that satisfies the optimization constraints. The whole process of the objective function is summarized in Fig. 2. There: D and L are the diameter and length of m pipes, respectively; $Q_{avl/req}$ is the available/required tank flow (inflow/outflow), where the required tank flow is determined during calculating the demand balancing volume; $P_{avl/min}$ is the available/required minimum nodal pressure; $H_{avl/max}$ is the available/maximum pipe unit head-loss. $F1$, $F2$ and $F3$ are factors determined in advance by trial and error approach until reaching the best values that guide to the optimal solution.

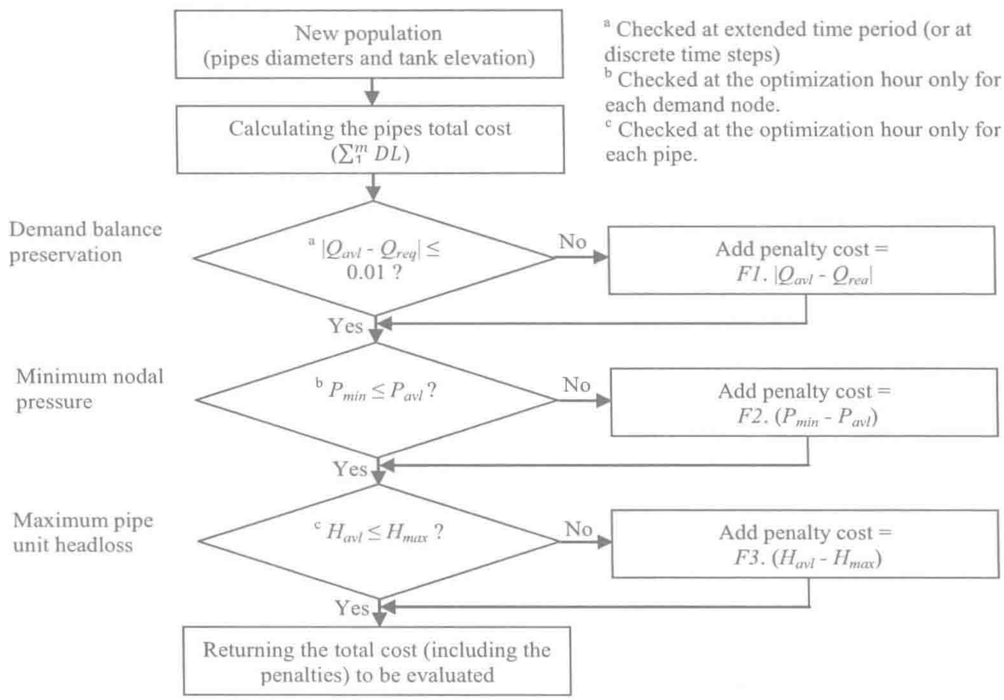


Fig. 2. Objective function in EO algorithm (NetOpt model)

Finally, NetOpt model calculates the total cost of the network based on the unit cost of each component, interest rate and design/repayment period. Cost calculations include calculating the total investment cost, operation and maintenance costs (O&M). The annual loan repayment is calculated using the annuity equation:

$$A = \frac{r(1+r)^n}{(1+r)^n - 1} P \tag{1}$$

where A is the equivalent annual cost of the present investment cost P, n is the project life in years, and r is the interest rate.

3.2. NetRel model

NetRel model assesses the hydraulic reliability of WDN by using the following three indices; Available Demand Fraction, *ADF*, of Ozger and Mays (2003), Network Buffer Index, *NBI*, of Trifunović (2012) and Network Resilience, I_n, of Prasad and Park (2004).

ADF is a reliability index that expresses the demand proportion still available in the network after pipe failure events. The calculation starts with non-failure condition and then by failing the pipes in sequence, calculating the network ADF for each one (Equation 2), and finally calculating the average value of *ADF* for the entire network (Equation 3).

$$ADF_{net} = \frac{\sum_{all\ nodes} Q^{avl}}{\sum_{all\ nodes} Q} \tag{2}$$

$$ADF_{avg} = \frac{1}{m}\sum_{j=1}^{m} ADF_{net,j} \tag{3}$$

In the above equations: Q^{avl} is the available demand after pipe failure, Q is the demand under normal conditions, $ADF_{net,j}$ is the ADF_{net} corresponding to the failure of pipe j, and m is number of pipes.

NBI of Trifunović (2012) is derived graphically from his hydraulic reliability diagram (HRD). By adding the weighting proportional to the pipe flows under regular supply conditions, NBI can be calculated as in Eq. (4).

$$NBI = 1 - \frac{\sum_{j=1}^{m}\left(Q_{tot} - Q_{tot,j}\right)}{\sum_{j=1}^{m} Q_j} \tag{4}$$

In the above equation, Q_{tot} is the total demand in the network under normal supply, $Q_{tot,j}$ is the total demand in the network after the failure of pipe j, Q_j is the flow in pipe j under normal condition, and m is the total number of pipes.

To determine the available demand in both *ADF* and *NBI* considerations, the hydraulic analysis should be performed by the pressure-driven demand simulation (PDD). The PPD simulation in NetRel is done by using the algorithm of Pathirana (2010). This algorithm considers three demand conditions:

1. Full demand: if $P_i \geq ECUP$, $Q_{i,PDD} = Q_{i,DD}$
2. Partial demand: if $0 < P_i < ECUP$, $Q_{i,PDD} = k_i P_i^{\alpha}$
3. No demand: $P_i \leq 0$, $Q_{i,PDD} = 0$

P_i is the pressure at node *i*, *ECUP* is threshold pressure, $Q_{i,PDD/DD}$ is the demand at node *i* which is calculated by PDD and DD simulation respectively, and *k* is the emitter coefficient which can be estimated by Equation 5:

$$k_i = \frac{Q_{i,DD}}{ECUP^{\alpha}} \tag{5}$$

Prasad and Park (2004) upgraded the resilience index I_r of Todini (2000) to their network resilience I_n, based on the concept of the power balance:

$$I_n = \frac{\sum_{i=1}^{n} C_i Q_i \left(H_i - H_i^*\right)}{\sum_{s=1}^{l} Q_s H_s + \sum_{p=1}^{k} Q_p h_p - \sum_{i=1}^{n} Q_i H_i} \tag{6}$$

In the above equation, $H_{s/i}$ indicates the piezometric heads at l sources (which includes all the reservoirs and tanks that supply the network), and the piezometric heads at n nodes (which includes all the demand nodes and tanks supplied from the network) respectively. H_i^* is the minimum piezometric head required to satisfy the demand at node i. Furthermore, $Q_{s/p/i}$ is the corresponding supplying flow (s), pump flow (p), and nodal demand flow (i), respectively. The adaptation of the Todini's index includes the index C_i which takes care about the nodal uniformity, according to Equation 7 where D_j is the diameter of m pipes connected to node i:

$$C_i = \frac{\sum_{j=1}^{m,i} D_j}{m_i \max\left\{D_j\right\}} \tag{7}$$

4. NORAT Application

The case study selected to apply NORAT is Safi town network demonstrated as a design exercise in Trifunović (2006). The layout of the network is shown in Fig 4(a) including the baseline demands (l/s) and pipe lengths (m). All the nodes follow the diurnal demand pattern shown in Fig 4(b), except the factory that is working from 7 am to 7 pm with constant consumption. The seasonal peak factor is 1.406, which includes 10% water loss.

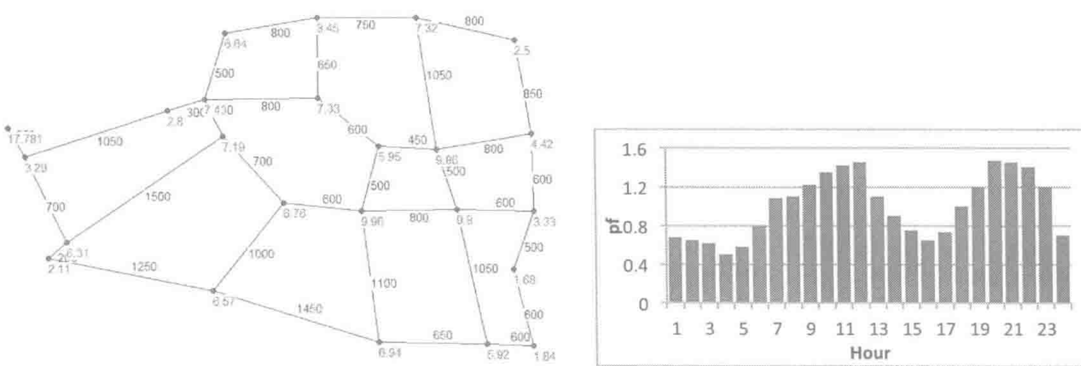


Fig 4. (a) Layout of Safi town network (including nodal base demands and pipes lengths); (b) Domestic demand pattern.

4.1. Scenarios

The original network layout has been transformed into 12 variants by combining:

1. Three topographic terrains; flat, hilly and valley, as shown in Fig 5.
2. Two pipe configurations: fully-looped and quasi-looped, shown in Fig 6(a) and (b). The quasi-looped cases have adapted total demand for the factory node is removed. To avoid possible confusion, the fully-looped and quasi-looped schemes are further named as 'looped' and 'branched', respectively.
3. Two source locations; at the edge and in the middle of the network, shown in Fig 6(a) and (b).

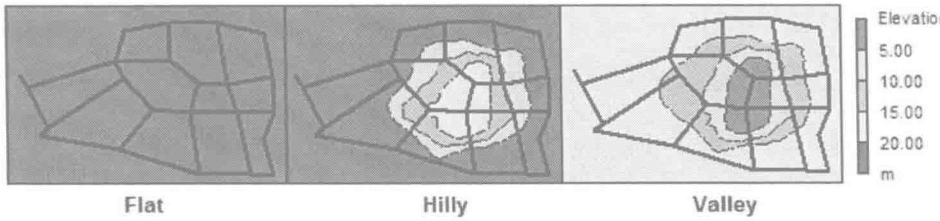


Fig 5. Topographic terrains.

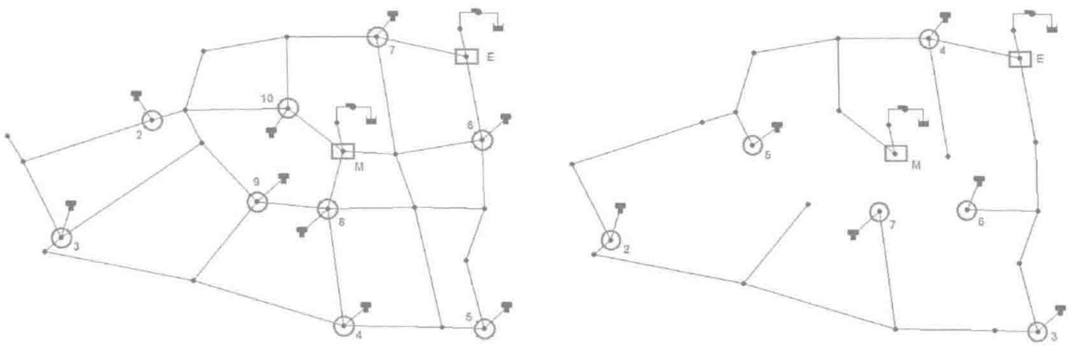


Fig 6. (a) Looped scheme with source and tank locations; (b) Branched scheme with source and tank locations.

In each of the 12 cases, the network is firstly analyzed with the existing water source and then by incorporating demand balancing tank at different locations in the network; nine locations in the looped networks and six locations in the branched networks. The locations of the tanks are selected at the border and in the middle of the network, to be close/far from the water source. The sources and tanks are connected to the by 300 and 500 m pipe respectively, and have elevations equal to the network nodes they connect. In total, 102 network variants are generated from the original network.

Each network is named as XYZN, where X denotes the topography (F - flat, H - hilly, and V - valley), Y is the network scheme (L - looped and B - branched), Z is the source location (E - edge and M - middle), and N is the tank location number as in Fig 6(a) and (b) (N is 1 if there is no tank incorporated in the network).

4.2. Application steps

Each network variant has been a subject of the following steps:

1. The required pumping capacity: number of pumps, duty heads and flows and pumping operation schedule have been specified and based on the pump efficiency pattern as shown in Table 2.

Table 2: Pumps efficiency

Flow (Q)	0.25 Q_{duty}	0.5 Q_{duty}	1.0 Q_{duty}	1.5 Q_{duty}	1.75 Q_{duty}
Efficiency (%)	20	60	75	65	30

2. NetOpt optimisation based on the settings shown in Table 3.