A software for considering leakage in water pressurized networks

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ABSTRACT

A matlab-based educational software (UAleaks) has been developed to consider the effect of water losses when solving the hydraulic problem in water pressurized networks. The results obtained are the new leaky network model and the water and energy audits calculation. This software can be used by students and practitioners.

KEYWORDS

Water pressurized networks, matlab, leakage, water audit, energy audit

1. INTRODUCTION

Water losses are probably one of the most relevant challenges that utility managers have to deal with in order to maintain an appropriate quality of service when delivering water to final consumers. This fact can be justified by the high number of approaches developed by researchers in recent years, some of them are focused on the continuous stream of data coming from sensors installed in water distribution networks (WDN) and collected by SCADA systems (Adedeji, K. B. et al., 2017; Salguero et. al., 2018), on pressure-leakage relationships (May 1994, Lambert 2001; Thornton and Lambert, 2005), on water savings associated overpressure reduction (Savic and Walters, 1996; Mutikanga et. al., 2013), on quantifying water leakage according to pipe characteristics (Germanopoulos and Jowitt 1989) or energy lost in leaky pipes (Colombo and Karney, 2002).

The use of hydraulic models of WDN has increased after the emergence of computers, which allowed practitioners and students to obtain valuable results to make the right decisions in operation and management of water utilities. Some software packages (either commercial or open-source) to analyze WDN have been developed. but from the educational standpoint, commercial packages may not be adequate as students must become familiar with the fundamental of hydraulics when running the model, and the prices of licenses for using commercial software represent a trouble for their use in public universities.

On the other hand, open source hydraulic modeling software (epanet; Rossman, 2000) does not incorporate late developments performed by researchers in recent years like considering leakage in WDN, risks of pipe failure, segmentation to identify water losses, etc... Results obtained by this demand-driven software can be considered appropriate when the system operates with pressures higher than minimum service pressure required for supplied demand— $P_{i\text{-}ser}$— (Giustolisi et. al., 2008). This means that if the pressure in the district metering area (DMA) is lower than this threshold pressure value ($P_{i\text{-}ser}$), a pressure-driven demand analysis (PDA) is required (Giustolisi et al., 2011; Muranho et. al., 2012).

Water losses are classified in background and bursts outflows (Lambert, 1994) and bursts are generally the natural evolution of background leakages generating changes of WDN hydraulic functioning, detectable as anomalies in monitored flow/pressure data. The objective of this work is to propose a matlab-based educational software which helps students to simulate homogeneously distributed water leakage (background leakage and also burst leakage flow rate) in WDN. The leakage problem is formulated at the node level, adding an emitter—a device that models the flow through a nozzle— at each node of the network (Almandoz et. al., 2006; Cobacho et. al., 2015). This problem has also been solved at pipe level for active leakage control (Berardi et. al., 2016) in an excel-based software but this development is not open source code and it is not thought for educational purposes. Some other educational software being open-source code (upstream; Emmanouil and Longousis, 2017) does not include leakage when solving the hydraulic problem. To the best of our knowledge, there is no available educational open-source software for this purpose.

Due to the widespread usage in the water sector, the Epanet software packages have been selected to perform these calculations and epanet standard input files (which describes hydraulic features of the system being analyzed) are selected for loading the model into UAleaks and also for retrieving the leaky network model. UAleaks output also calculates the water and energy audit in m^3 and kWh.

This software has been programmed with a general public license and an open source distribution to promote the download, use and share of the code and is available in a public repository. It is aimed for educational purposes, as a teaching tool which may be useful for students to understand and calculate the water losses in WDN. The reader is encouraged to download the software package and source codes available at http://rua.ua.es/dspace/handle/10045/76827. To ease the use, a graphical user interface (GUI) manages all the process guiding the users during the process and a video describing how to run the software has been released in youtube (in English and also in Spanish) (https://www.youtube.com/watch?v=Ala_2tch8yU).

Finally, once the new leaky network has been obtained, UAleaks also calculates water and energy audit (Cabrera et. al., 2010). So, students may quantify the energies involved in the water distribution process and use this information when taking management/operational decisions.

2. EDUCATIONAL FRAMEWORK

"Maintenance and operation of water distribution networks" is a course in the master's degree in civil engineering in the university of Alicante (Spain). During this course, the effects of leakage is introduced to students and also the different behaviour of the user's water consumption (simulated with coefficient modulation patterns; which consider the variation of water use with regard to time) and of the water losses (which depend on the water pressure, pipe material and type of burst).

Along with this course, some software packages for water network hydraulic modeling are presented to students. Among these, the most widely used software (Epanet; Rossman, 2000) is used by students for solving the hydraulic problem in the pressurized network (mainly in urban water distribution networks and also in irrigation networks). Moreover, it seems clear that considering the effect of pipe bursts in the WDN hydraulic behavior reflects the usual work of engineers and managers and this software package does not include a specific functionality to model water leakage.

The experience of past years has proven that it is hard for students to simulate leakages in WDN as although the process is simple, the repetition of the hydraulic calculation takes much time. Being aware of the need for students to make their own hand calculations (which allows the students to understand the leakage problem), UAleaks is provided to students after having developed their own results in a synthetic network. So, the software is used as a tool to validate students hand calculations on a first stage, letting them repeat the process with different real networks and observing and analyzing the obtained results for multiple cases afterward.

Being concerned about the need to make students simulate the hydraulic behavior of WDN and also make hydraulics easy to understand, this software may represent a first step to allow students to start using a programming software (such as matlab or any other) in hydraulics (using the epanet toolkit or others software packages).

3. METHODOLOGY

A calibrated hydraulic simulation model is required to calculate all the values required (flow rates, piezometric head, friction losses, etc. in any element and at any time) in the WDN. Since the location of background leakages is not known, it can be assumed that leakage is uniformly distributed along every pipeline of the water distribution system. Finally, the calibration of the aforementioned emitter coefficients at network nodes is performed later in order to represent leakage in the WDN model.

3.1. Simulation of the leaky network

Based on common modeling assumptions, water leakage at nodes is equal to the water losses produced in the half of all pipes connected to it. (eq. 1). Let's assume that the leakage factor γ_{pi} can just be the pipe length.

$$\gamma_{pi} = \frac{\sum \gamma_j/2}{\gamma_T} = \frac{L_1/2 + L_2/2 + \dots + L_j/2}{L_T} \qquad (1)$$

Where L_j, are the lengths of pipes connected to each node and L_T is the sum of all pipe lengths of the network. So there is a different factor for each node and must sum to one. If leakage in the DMA is not homogeneous, these γ_{pi} coefficients may adopt various values (such as the number of repairs per pipe length) with the restriction that the sum of the *n* coefficients must sum to one.

Once, the weighted leakage factor (γ_{pi}) which represents the importance of each node with regard to leakage is calculated, an emitter is added at each node of the network (Cobacho et. al., 2015; eq.2) in order to consider water leakage as pressure-dependent of node demands.

$$q_{li}(t) = C_{E,i} \cdot \left[\Delta H_i(t)\right]^{\alpha} = K_f \cdot \gamma_{pi} \cdot \left[\Delta H_i(t)\right]^{\alpha} \qquad (2)$$

Where $q_{li}(t)$ (m^3/s) is the sum of the background and bursts leakage flow rate (Fantozzi and Lambert, 2005; Lambert, 2003) at node i, $C_{E,i}$ ($m^{3-\alpha}/s$) is the emitter coefficient, $\Delta H_i(t)$ (m) is the pressure variation through the leak at time t; α is the pressure exponent that models the characteristics of the pipe material and K_f is the global value which considers the leakage level. This equation shows the dependency of the leakage flow rate with regard to pressure ($\Delta H_i(t)$), number of bursts (or pipe length) (γ_{pi}) and pipe material (α). This approach produces good results if the pressure exponent ranges between 0.5-2.95 (Van Zyl and Malde, 2017) and if the pressure in the DMA is above the threshold pressure value (normal functioning with no pressure deficient conditions). In case of pressure deficit, the pressure-driven simulation should be considered.

3.2. Water and energy audits

Once the leakage is considered in the new model, both the water and energy audit (Cabrera et. al., 2010) can be performed (eq. 3 and 5).

$$V_{inj}(t) + V_{tank}(t) = V_R(t) + V_L(t) \qquad (3)$$

Where $V_{inj}(t)$ is the volume injected into the network, $V_{tank}(t)$ is the volume injected/stored into the network by the tank (negatives values if the tank is emptying—extracting water from the network— and positive values is the tank is filling — injecting water from the network—), $V_R(t)$ is the volume delivered to users and $V_L(t)$ is the volume lost through leaks. With these figures, the student can check that the objective hydraulic performance has been obtained in the new model (considering the hydraulic performance of the network as the quotient between the delivered and injected volumes; eq 4).

$$\eta = \frac{V_R(t)}{V_{inj}(t)+V_{tank}(t)} \tag{4}$$

The amount of energy consumed in water distribution networks is also computed by UAleaks. In order to perform the analysis in an extended period (t_p , which can take values such as 1 year, 1 month, 1 day, etc.), it is necessary to divide duration time into n_i intervals of time (Δt_k ; 300, 600, 900, 3600 seconds, etc.). Thus, the total energy consumed in the extended period ($t_p = n_i \cdot \Delta t_k$) is obtained from the sum of the energies consumed in each time interval of the steady-state simulation.

From the preceding terms, where t_p is the period of calculation of the expressions, the following final balance results in eq 5:

$$E_{input}(t_p) = E_n(t_p) + E_p(t_p) \pm \Delta E_c(t_p) = E_u(t_p) + E_l(t_p) + E_f(t_p) + E_v(t_p) \tag{5}$$

Where $E_N(t_p)$ is the energy supplied by reservoirs, $E_P(t_p)$ is the energy supplied by pumps, $E_U(t_p)$ is the energy delivered to the users (throughout the water supplied), $E_L(t_p)$ is the energy lost through water losses, $E_F(t_p)$ is the energy dissipated in friction at pipes and $\Delta E_C(t_p)$ is the energy that can be stored in a compensation tank which accumulates water during low consumption hours while releasing it in peak hours.

4. SOFTWARE DESCRIPTION

UAleaks software is described in this section. Input data required to run the model, the internal process and the results are also commented herein.

4.1. Graphical User Interface (GUI)

The software consists of a variety of functions that apply the presented methodology. As it requires the application of a specific workflow, a GUI is programmed to guide the user through all the process (Figure 1). The buttons of the GUI are automatically activated after each step. Initially, the load button is active. The user can only press this button, which opens a menu to load the .inp file. Once the water network model is successfully loaded, the 'Run' button is activated. The input parameters that control the process are available as input boxes, which test if the inserted values are numbers or not and if the numeric values are within a certain range (e.g. positive numbers, percentage minor than 1, etc.). Common values are available as default values if the user does not know where to start.

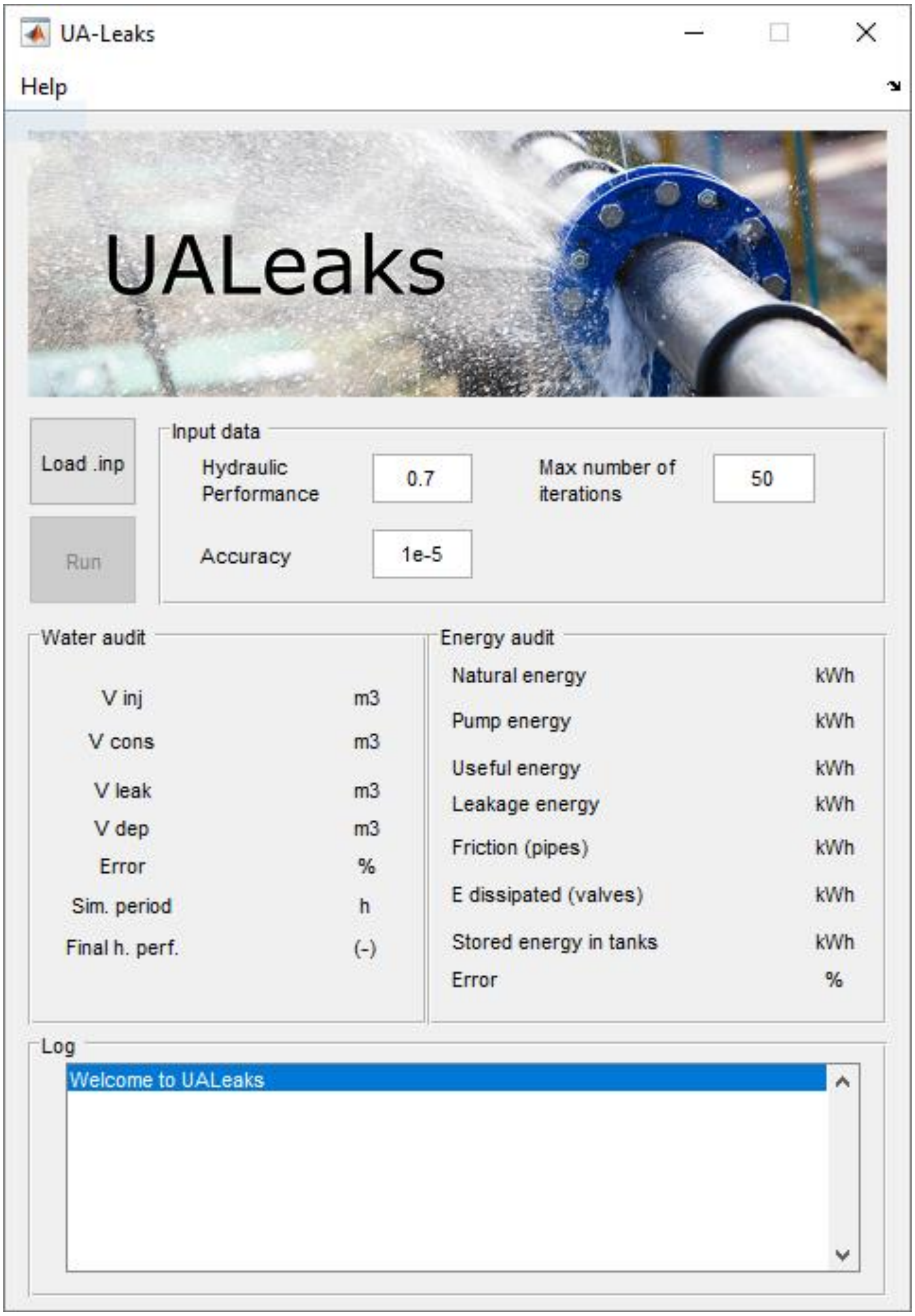

Figure 1. Screen-shot of UALeaks.

4.2. Input data

The input form data creates a GUI for the user to enter the following input values to send to the simulation program (Figure 1).

- A water pressurized network (introduced as an input file). The user can create it in two ways, by exporting the network through the application (epanet) graphic interface or by writing directly in a notepad file (inserting the data in a specific order and separated by tabs). Once the .inp file is created, no errors should appear when running this hydraulic simulation as any error in epanet returns an error in UAleaks.
- The objective value of the hydraulic performance (η_{obj} (-), a value between 0.5 and 1) which shows the relationship between the consumed volume and the injected volume (water efficiency of the network). These values are limited because due to experience, values lower than 0.5 involve that this level of leakage is not an effective utilization of water as a resource. This indicator has been selected for their wide use as it is very used for practitioners.
- The ε value (accuracy, (-)) that the user consider it as appropriate for the system to consider the final value as appropriate (default value is equal to 10^{-5}). It is not accepted values higher than 0.001 or lower than 10^{-7}. As the units of the water networks are introduced by the user in the inp file, this accuracy may adopt their values in litres per second, cubic meters per min, etc. In short, if the user requires to get their model to have a hydraulic performance of 0.7, and the accuracy is equal to 10^{-5}, UAleaks will consider adequate a value of hydraulic performance ranging between [0.69999, 0.70001]. Of course, computational times will be shorter for higher values of this accuracy parameter.

- The maximum number of iteration is a value introduced by the user that avoid the software to be in a non-exit loop. If the convergence of the method is not obtained, the system shows a warning to the user indicating that the water efficiency introduced by the user has not been reached and the software exits the loop if the number of iterations is exceeded. This situation occurs in WDN with high number of tanks (which are elements that may store huge amounts of water) and the usual way of making the system stable to analyze is to increase the time simulation period up to values in which the storage capacity may be negligible in comparison to other consumptions (human consumption, irrigation, leakage, etc… which are dependent on time).

4.3. The iterative process to simulate leakage

Once, the input data of the system are introduced, the "run" button can be pressed (Figure 1). The general flow-chart of UAleaks which visualizes the internal process of the software is shown in Figure 2.

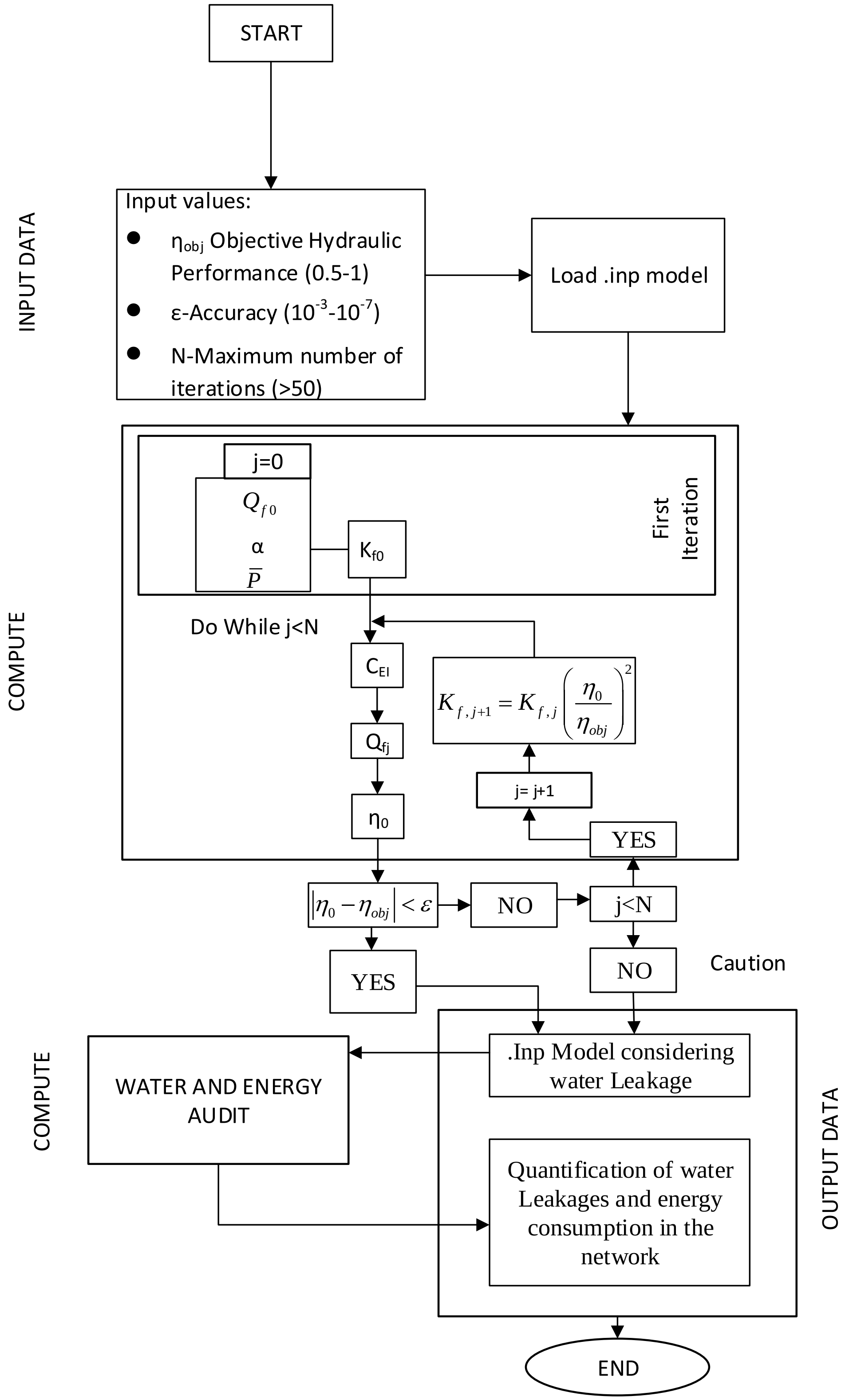

Figure 2. Workflow for the iterative process to simulate leakage.

The iterative process is described here:

Step 1: An initial value of K_{f0} the global emitter coefficient, should be introduced in the iterative process. This is calculated solving the hydraulic problem of the initial leak-free network as follows:

$$K_{f0} = \frac{Q_L}{(P)^{\alpha}} \quad (5)$$

Being P the average pressure (obtained with the pressure and water losses of every node and at every hydraulic time step) and α (-) the exponent emitter (dependent on the material of the network). The volume delivered to users ($V_R(t)$) and the volume stored/injected into the network by the tank ($V_{tank}(t)$) if any, and the can be obtained after solving the hydraulic problem. Moreover, as the objective hydraulic performance is known (inserted by the user as input data), eq 4 and 5 are used to calculate the injected volume into the network is ($V_{inj}(t)$) and the volume lost through leaks ($V_L(t)$). Finally, Q_L is calculated as the average flow rate which produces the volume $V_L(t$). Equation (5) represents the initialization value of the iterative process described here and it ensures that in the first iteration, the leakage flow rate and the volume lost through leakage were different from zero.

Step 2: The emitter coefficient ($C_{E,i}$ ($m^{3-\alpha}/s$) of every junction is calculated. Every node emitter is obtained by multiplying the weighted leakage factor (γ_{pi}) which represents the importance of each node with regard to leakage and the initial value of the global emitter coefficient ($C_{E,i} = K_{f,j} \cdot \gamma_{pi}$). In UAleaks, the leakage factor γ_{pi} can just be the pipe length as it is supposed to be used in DMAs with leakage uniformly distributed (eq (1)). These emitters are introduced in the WDN model and a new hydraulic simulation is performed.

Step 3: As the new hydraulic simulation is performed, the head at every node is retrieved for the model and the water leakage of every junction is calculated with the aforementioned Eq (2). The users should note that the exponent emitter (α) is required here. The results show water leakage in node *i* and at every interval of time Δt_k). The interval of time required for the analysis is a parameter described by the user in the .inp model. UAleaks maintains these parameters (duration of the simulation period, hydraulic time step, reporting time step, pattern time step, etc.)

Step 4: The sum of the water leakage for the whole simulation period (t_p) and for every node of the network result in the $V_L(t)$ is the volume lost through leaks. And the new model also allows calculating the volume injected into the network ($V_{inj}(t)$, Eq 3). And with these results, the hydraulic performance ($\eta_{0,j}$) of the current network (with the emitters calculated in Step 2 introduced in the model) is computed.

Step 5: The absolute value of the subtraction between hydraulic performance ($\eta_{0,j}$) obtained from the current simulation model and the objective hydraulic performance (η_{obj}; input data in UAleaks) is calculated and two situations may appear:

1. If this figure is lower than the accuracy (ε): the process is finished and the model can be stored as it incorporates the level of leakages desired by students/practitioners.
2. If this figure is higher than the accuracy (ε): The variable which counts the numbers of iterations is increased by one (in short, UAleaks know that the previous iteration did not solve the problem with the required network efficiency). And once again two situations may appear:

   a) if the number of iterations is below the maximum number of iterations (j<N; input data of the program), the global emitter coefficient for the new iteration

($K_{f,j+1}$; being j the iteration number). should be updated using the previous values of the hydraulic performance obtained (η_0), the objective hydraulic performance (η_{obj}) and the global emitter coefficient ($K_{f,j}$). The equation is:

$$K_{f,j+1} = K_{f,j} \left(\frac{\eta_0}{\eta_{obj}} \right)^2 \qquad (6)$$

UAleaks continues this process by going to Step 2 (with the new value of the global emitter coefficient $K_{f,j+1}$) and here it starts a new iteration. This equation produces a quick convergence and stable method to obtain the objective hydraulic performance. Some other equations may reach convergence to the solution (which is considering as appropriate if tolerance is lower than accuracy, ε)

b) if the number of iterations exceeds the maximum number of iterations (j>N), the software saves the result but a warning message is shown to the program users. On the other hand, the final model (reached after N iterations) are saved for checking results.

4.4. Output Data

The outputs of the graphical user interface UAleaks (Figure 3) are:

1. A new hydraulic model in the (.inp) format required by epanet which considers the level of leakage selected by the user. This model is stored in the computer in a path shown by UAleaks and is ready to be used for users and practitioners.
2. The water and energy audits are shown in the graphical user interface UAleaks in numbers and in graphs (Figure 3). With the values of the water audit, the student is allowed to check that the new model is taking into account the leakage

selected, and the energy audit is shown to make the students understand that the outcoming water through leakage has a huge effect on energy losses.

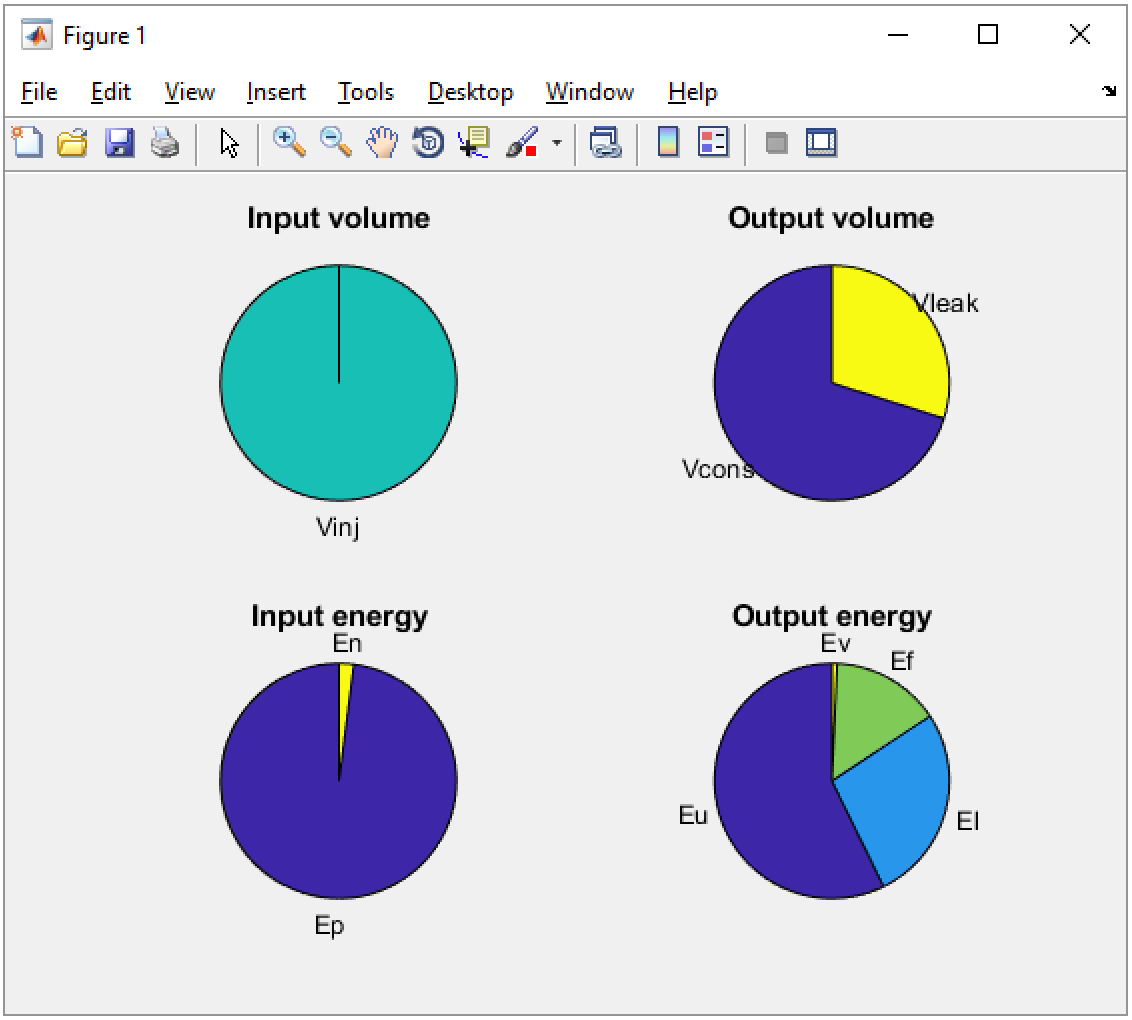

Figure 3. Results: pie charts of input and output volume and energy.

4.5. Pseudocode

The pseudocode is an informal high-level description of the operating principle of a computer program. It uses structural conventions of a normal programming language but is intended for human reading rather than machine reading. The pseudocode of UAleaks is shown in Figure 4:

Algorithm 1 Pseudocode of UALeaks

Input: Objective Hydraulic performance (η_{obj}),
Accuracy (ϵ),
Max num of iterations (n_{max}),
model of the network (.inp)
Output: Model network,
water and energy audit
procedure UALEAKS
  Load the network
  Calculate the average preassure of the network
  Calculate the weighted leakage factor γ_{pi}
  Calculate K_{f0}
  $j \leftarrow 0$
  for each j **do**
    Calculate the emitter coefficients for every node
    Introduce these values in the model
    Run the model
    Calculate the leakages rates
    Calculate the hydraulic performance $\eta_{0,j}$
    if $|\eta_{0,j} - \eta_{obj}| < \epsilon$ **then**
      Save the .inp model
      Calculate the water audit
      Calculate the energy audit
    else
      $j \leftarrow j + 1$
      $K_{f,j+1} = K_{f,j} \times \left(\frac{\eta_{0,j}}{\eta_{obj}}\right)^2$
    end if
    while $|\eta_{0,j} - \eta_{obj}| < \epsilon$ or $j < n_{max}$ **do**
      if $j > n_{max}$ **then**
        Show warning
        Save the .inp model
        Calculate the water audit
        Calculate the energy audit
      end if
    end while
  end for
end procedure

Figure 4. Pseudocode for UAleaks.

4.6. Software requirements

UAleaks have three key requirements:

- To have matlab installed in the personal computer (its performance is similar in Windows®, Mac OS® X, and Linux®).
- The programming software (matlab) requires the user to choose a supported compiler installing a new compiler or selecting one of the multiple compilers installed in the personal computer.
- To have installed the epanet programmer's toolkit, which is a dynamic link library (DLL) of functions that allow developers to customize epanet's computational engine for their own specific needs. The functions can be incorporated into 32-bit (and also into 64-bits) windows applications are written in C/C++, Delphi Pascal, Visual Basic, or any other language that can call functions within a windows DLL.

Some additional information for installing this has been released in the following link: https://personal.ua.es/en/mpardo/downloads/ualeaks/ualeaks.html. (In English and also in Spanish).

5. NUMERICAL EXAMPLE

The objective of the case studies is to demonstrate the effectiveness of the proposed software in some water pressurized networks. Case A and B are synthetic networks to help students in understanding these concepts while case C, D, and E are real cases in an irrigation network and in two cities in Spain.

5.1. Network analyzed by MSc students

The network given to students in the course “Maintenance and operation of water distribution networks” in the master’s degree in civil engineering in the university of Alicante (Spain) is presented here. Each student should find its own level of leakage rates using a hydraulic simulation software and a spreadsheet. And when getting the network model, the energy and water audits should be calculated.

This software has been used by 23 students of the course "Maintenance and operation of water distribution networks" and by some other M.Sc. or Ph.D. students (in some other countries) who have known the existence of this software after some mailings and other advertises made by the software developers'. Although the key objective of this software it has been for students, some practitioners have shown their use in professional projects when managing WDNs. The explanation of these techniques involved two sessions (4 hours) to allow students to understand this procedure and also for calculating energy audit. The key difficulty has been related to the use of the matlab software (as many students were not aware of) and the installation of the compiler but all of them informed about the good and quick results obtained in comparison with their hand calculation made. The students also commented that adding leakage to real WDN would take a huge amount of time as they spent two or three days of work for a network such as a case A. In short, the students knew how to perform the calculation and they knew the high effort to do it manually.

Figure 5 shows the network layout and **¡Error! No se encuentra el origen de la referencia.** shows the node and line data (number of nodes, n=9; number of lines, m=17). The values of the hourly coefficients, which consider water consumption at different hours of the day, are depicted in **¡Error! No se encuentra el origen de la referencia.**. Pipe roughness is 0.1 mm and the emitter exponent is α=1,2 (corresponding to a mixed pipe-network; Al-Ghamdhi, 2011; Greyvenstein and van Zyl, 2007).

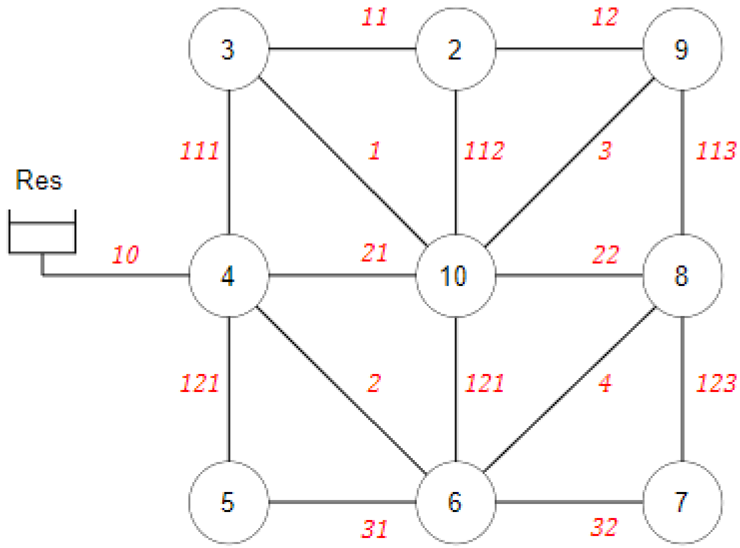

Figure 5. The layout of Network A.

5.2. Other cases analyzed

In order to show this methodology can be used in some other networks, four additional cases are presented. Figure 6 shows the layout of networks B, C, D and E. Case B is the Anytown network (a very well-known hydraulic model used in many scientific works, Walski et al. 1987, Farmani et. al., 2005) and case C is a programmed sprinkling system used for watering the garden of a university (Pardo, et. al., 2013) The network irrigates an area of 10.63 ha and consists of 326 nodes, 186 pipes, a water well, two impeller pumps running in parallel and 141 solenoid valves upstream of the water discharge outlets, which are the hydrants. The total length of the network is 4.8 km.

Case D shows a district metering area (DMA) in a western Mediterranean city of Spain (Pardo and Valdes-Abellan, 2018) and it supplies water to 10000 inhabitants and consists of 561 nodes and 617 pipes, its total length is 10,61 km. Finally, case E is located in the south of Spain (7500 inhabitants) and this WDN is formed by 563 nodes and 502 pipes (total pipe length is 58.64 km). In the four cases, the input data are: η_{obj}=0.765, accuracy ε= 10^{-4} and the maximum number of iterations= 100.

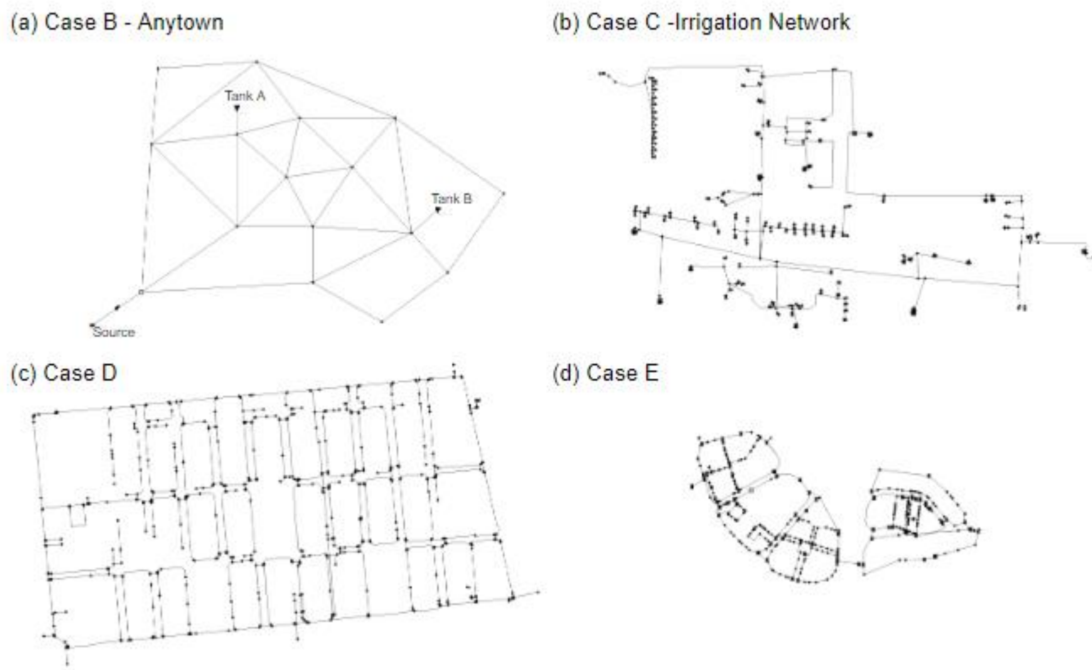

Figure 6. The layout of cases B, C, D, and E.

5.3. Results and discussion

Table 3 shows the outputs obtained when the desired water leakage is equal to 0.9 and 0.85 respectively. The computational time obtained was lower than one minute. On the other hand, students have reached the same result but they informed that they spent 4 or 5 hours performing these calculations. In order to show the differences in the calculations only two students work are shown here. Student 1 obtained his result after 9 iterations while student 2 obtained his result after 5 iterations in the loop (Figure 2). Moreover, the accuracy obtained by students is lower than the accuracy obtained by the software and students informed the iteration process was very time consuming and it made impossible to perform in usual District

Metering Areas or WDNs (in which 1000 nodes and pipes are usual values). Finally, it seems interesting to remember here that in order to perform all the calculations, flow and head losses of every pipe and the pressure and demand of every node should be retrieved from the model for every iteration process.

The new simulation models obtained include the emitter coefficients (eq, 2) for several values of leakage (Table 3). These figures should be added to the initial WDN model (input data here) to model leakage. And with these new model, the results of performing water and energy audits have been depicted in Table 4. These results highlight that the water losses in the new WDN model represent the quotient introduced by the user. Moreover, when water losses increase (in other words, when the hydraulic performance of the network decreases), the energy lost through leakage and the energy dissipated in pipes also increase (Table 4). If the network efficiency is 90 or 85%, the input energy is 536.29 and 568.47 kWh/day respectively, which means an extra energy consumption of 32.18 kWh/ day.

Anytown (network B) includes two compensation tanks and three pumps working in parallel. Tanks accumulate water during low consumption hours while releasing it in peak hours. However, the net flow of water and energy in one of these tanks, when integrated through a long enough period, is zero, and so is their contribution to the long-term analysis. In short, their influence in the water and energy audits only depends on the initial and final level of the tank (it does not depend on the simulation period and it has a maximum value corresponding to total oscillation between empty and full tanks of the whole system) and it can be relevant in short-term simulations. A threshold value which separates short term from the long term was established by imposing that the maximum compensation energy is only a small percentage (1%) of the system energy input (Cabrera et. al., 2010). In order to make long-term simulations (in which the water and energy stored in the tank can be rejected), the period of time should be increased (240 hours). Finally, it should be pinpointed that if the storage capacity is high in comparison to daily water consumption, the iterative process has convergence problems (mainly due to start and stop of water pumps to avoid emptying or overflows in the tank). Finally, if the convergence problem is not solved, the user may increase accuracy in order to help the software for reaching convergence. For future versions, this problem should be improved.

Network C represents an irrigation network where the whole water and energy is supplied by pumps and the effect of valves as a hydraulic device which dissipates energy can be observed (Table 5). These figures show that 11.61% of the input energy is dissipated by friction and 21.96% is dissipated by valves (values that students/practitioners should identify as high figures and try to reduce later distributing uniformly the flow supplied by the pumps).

Cases D and E intend to check the potential use of UAleaks in real WDN supplying water to consumers. The UALeaks user should identify these both cases are oversized (Table 5; very low energy dissipated due to friction in pipes), a usual situation when operating WDN in urban areas. Results are obtained and the computational time is less than a minute when running the software and it seems to be impossible (or at least very time-consuming) to perform these hydraulic simulations in networks with so many pipes and nodes.

6. CONCLUSIONS

This article explained the design and implementation of an engineering education software called UALeaks. Classroom experience shows that the use of this specific tool allows students to move forward the learning process and UAleaks is also currently used by professional civil and hydraulic engineers with positive feedbacks. Students have tested this software after developing their own hand calculations in a synthetic network (network A presented here). So, students have developed the iterative process (Figure 2) by themselves and they perfectly understand this process. And then, students are ready to use UAleaks as a tool to check their results. This experience makes them notice similar results are obtained using UALeaks with lower computational time (it required no more than a minute). In short, they understand that considering leakages in real networks cannot be performed with hand calculations.

This software also shows water and energy audit of the new hydraulic model as a result of this software. So, students and/or practitioners have much more information about the "real network" and they can identify the end uses of the energy entering the network and thus to define a performance assessment system that characterizes the network. Moreover, the student highlights the key idea that energy losses result not only from the energy leaving the system through leaks (which can be quite significant, e.g., desalinated water) but also the energy needed to overcome additional friction losses created by higher circulating flow rates through the pipes.

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