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Articles

Hydraulic modeling and calibration of drinking water distribution networks

Modelación hidráulica y calibración de redes de distribución de agua potable

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Abstract

The objective of the study was to model and analyze three drinking water distribution networks, calibrate them with Epanet Calibrator software and compare their results with Darwin Calibrator. An ultrasonic flowmeter and pressure data loggers were used, which were configured to record data every ten minutes, the mean of the flows at each node of interest in the network was obtained. The pressure data was used to adjust each network and by varying the roughness, the model could be calibrated and adjusted, among those mathematically simulated with the data obtained in the field. Using this information, equations and calibration curves were established to discriminate the discrepancy between what was modeled and what was observed in the field. Hydraulic calibrations were performed using the Darcy-Weisbach and Hazen-Williams formulas. The results show for each network a variation in the calibrations of 35, 15 and 10 %. It is concluded that these two computational applications show similar results between the simulated and observed data, with the difference that calibration in Epanet is carried out node by node, while in Darwin Calibrator it can be performed by means of groups of calibrations in a given sector.

Keywords: Hydraulic networks, calibration, genetic algorithms, hydraulic simulation, network analysis.

Resumen

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El objetivo del estudio fue modelar y analizar tres redes de distribución de agua potable; calibrarlas con el *software Epanet Calibrator*, y comparar sus resultados con *Darwin Calibrator*. Se utilizaron un caudalímetro ultrasónico y *data loggers* de presión que fueron configurados para registrar datos cada diez minutos; se obtuvo la media de los caudales en cada nudo de interés de la red. Se utilizaron los datos de presión para ajustar cada red; al variar rugosidades se pudo calibrar y ajustar el modelo entre lo simulado matemáticamente con los datos obtenidos en campo. Mediante esta información se establecieron ecuaciones y curvas de calibración para discriminar la discrepancia entre lo modelado y lo observado en campo. Las calibraciones hidráulicas se hicieron mediante las fórmulas de Darcy-Weisbach y Hazen-Williams. Los resultados muestran para cada red una variación en las calibraciones del 35, 15 y 10 %. Se concluye que estas dos aplicaciones computacionales arrojan resultados similares entre los datos de lo simulado y lo observado con la diferencia de que la calibración en *Epanet* se hace nudo por nudo, mientras que en *Darwin Calibrator* puede efectuarse mediante grupos de calibraciones en un determinado sector.

Palabras clave: redes hidráulicas, calibración, algoritmos genéticos, simulación hidráulica, análisis de red.

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Introduction

Mathematical models, as well as computational models applied to water network distribution systems, have achieved great acceptance by the scientific community, becoming a fundamental tool for their design and management (Bosch-Fuentes & Recio-Villa, 2014) by allowing a truthful representation in space and time of what happens in the process (Pérez-Arellano, Roldán-Cañas, Moreno-Pérez, & García-Alcubierre, n.d.). The American Water Works Association (AWWA) explains that the calibration consists of a comparison of the final model with the measurements obtained in the field, making adjustments to the network parameters ((Martínez-Solano, Iglesias-Rey, & Molina-Arce, 2015), in order to provide specific records of pressures in knots, speeds and flows throughout the simulation period ((Bartolín-Ayala & Martínez-Alzamora, 2013). These calibrations determine physical and operational characteristics of a system, which when entering the information to the computational model provide realistic results (Iglesias-Rey, Martínez-Solano, & Ribelles-Aquilar, 2017).

Saldarriaga and Jurado (2008) consider that the calibration consists of finding a hydraulic model that requires the data of the existing network in order to use the model successfully. Morelos and Ramírez Hernández

(2017); Walski, DeFrank, Voglino, Wood, and Whitman (2006) state that in a hydraulic simulation of a constructed drinking water network it is necessary to investigate all the characteristic variables of the network, such as its topology, demand nodes, roughness in pipes and pressures, in order to obtain a reliable result in the study area.

On many occasions, the calibration of a drinking water distribution system makes it difficult to solve analytically all the parameters of the hydraulic system, because it has a large number of unknowns such as roughness and emitter coefficient (Guerrero-Angulo & Arreguín-Cortés, 2002; Wu *et al*., 2002). Early methods for calibrating models often used an approach where the number of unknowns (roughness and emitter coefficient) matched the number of observations so that a solution could be determined (Ormsbee, 2006). This requires a thorough analysis to determine how to group the number of unknowns that a network might have. Therefore, it was necessary to use optimization in hydraulic models in some way in order not to solve an extensive number of equations equal to the number of unknowns (Walski *et al*., 2006).

Bentley (2008) on his page makes a comparison between the efficiency of these two programs and mentions that the methodology on which they are based is that of the calculation called conjugate gradient, based on genetic algorithms, as also described by Datta and Sridharan (1995) ;) Walski *et al*. (2006); Wu *et al*. (2002) that Darwin Calibrator has integrated system software with three parts: a genetic algorithm module, a hydraulic simulation module, and a calibration module.

Ormsbee (2006), and Ormsbee and Lingireddy (1997) applied optimization to calibrate the models of their hydraulic networks, on the other hand Lansey and Basnet (1991) developed an optimization model that could match the field of observations, but noted that sufficient amounts of data were needed high quality to make it work well. This coincided with the observation of Walski (1983), and Wu, Arniella, and Gianella (2004) that a sufficient pressure drop is needed in the system for automatic calibration to work, which was successfully illustrated in a sample system (Walski *et al*., 2006).

The modeling and calibration of pressurized water distribution networks and pipe flows in Epanet is used as a fundamental tool for improving the management, operation and maintenance of the water supply system (Alves, Muranho, Albuquerque, & Ferreira, 2014; Anisha, Kumar, Ashok-Kumar, & Suvarna-Raju, 2016; Koppel & Vassiljev, 2012; Murray, Walsh, Kelliher, & O'Sullivan, 2014). These hydraulic simulations allow them to be more reliable and valid, with accurate data that resemble reality for making pressure decisions in network nodes (Alves *et al*., 2014; Bosch-Fuentes & Recio-Villa, 2014). Epanet runs simulations of the hydraulic behavior in extended period and of the water quality in pressure networks, with a wide application of sampling, model calibration, chlorine analysis and the assessment of the risk that consumers are involved in (Abdy Sayyed , Gupta, & Tanyimboh, 2014; Agency, 2000; Pacchin, Alvisi, & Franchini, 2017), compares results of hydraulic simulation, with respect to the field information through evolution curves and calibration reports, in which the variation is analyzed pressure at different nodes of the network (Agency, 2000; Escobar, 2010; Pacchin *et al*., 2017). The calibration problems are formulated as an optimization of objectives, where the model estimates parameters of the distribution network minimizing the square deviation between the observed and the simulated data (Dunca, Piraianu, Roman, Ciuc, & Georgescu, 2017).

The main objective of the study was to model the network and calibrate it using the Epanet Calibrator computer program and compare its results with Darwin Calibrator, which is another computer application used for modeling (Iglesias-Rey *et al*., 2017; Murray *et al*., 2014) of drinking water distribution networks, by means of static and dynamic modeling, analyze their variables and find the respective roughness that increases over time due to the deterioration of the pipe (Bartolín-Ayala & Martínez-Alzamora, 2013).

The calibration study was carried out in three cities of Ecuador, two networks in the North zone and one network in the South zone of the country. The data used in this study were pressure and flow, which were taken at different points in each network.

Materials and methods

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To obtain the pressure results, an automatic data logger type IP68 Lolog recorder was used, with a capacity to store 16000 readings, designed to monitor pressure. The flow values were sensed with a non-invasive double frequency portable "doppler flowmeter" electronic equipment, with which the flow of the network was recorded in each study sector.

The flowmeter was configured to record data every 10 minutes (Muniz *et al*., 2015), the average of the flows in each node of the network was obtained. The pressure data were used to adjust the network, and vary the roughness to calibrate and obtain the desired value in the simulated with what was obtained in the field.

The Epanet Calibrator computer application was created to calibrate hydraulic models (Agency, 2000; Iglesias-Rey *et al*., 2017; Muranho, Ferreira, Sousa, Gomes, & Marques, 2014). The use was essential for the processing of the information obtained in field measurements. The computer system allowed the estimation of roughness of the pipe and coefficients of the nodal emitter by group of pipes that are defined by the user at the time of the calibration analysis in order to reach the desired adjustment. The observed data consist of the pressure (Abe & Cheung, 2010).

Darwin Calibrator provides tentative calibrations, supported by a multiple bell data set, brings the speed and efficiency of genetic algorithms to the calibration of your hydraulic system, and presents several calibration alternatives that the program considers for system optimization. Darwin's calibrator can configure a series of calibrations, which can have numerous results with different patterns and scenarios in the study (Hooda & Damani, 2017).

Data and study area

The study area is located in three cities in Ecuador: Loja, Ibarra and Quito, where they are supplied with urban water distribution systems, delimited by topologically isolated networks or by border valves, operated as hydrometric sectors where the measurement of water is facilitated. injected flow rate and operating pressures. For the purposes of this study, the zones are identified as sector 1, sector 2 and sector 3, respectively. These Andean cities are characterized by their very irregular mountainous area, which must be taken into consideration, so as not to interfere with the final result of the calibration (Saldarriaga & Jurado, 2008).

Sector 1

It has 111 nodes and 92 pipes. The hydraulic line that connects from the main network to the main tank in its longest trajectory is a 100 mm diameter ductile iron pipe (FD) and reaches the reservoir with a 90 mm polypropylene pipe (PPR).

The calibration in Epanet was carried out based on the pressure taken at each node of the supply network. This sector is supplied from the public supply system of the drinking water master plan —managed by the Municipal Unit of Potable Water and Sewerage of Loja (UMAPAL)—, with a polyethylene matrix line of 300 mm in diameter and at an average depth 1.70 meters.

The main storage node (upper tank) of the drinking water distribution network of the sector under study is located at elevation 2156 meters above sea level, with a storage capacity of 100 m^3, which regulates the injection into the network that supplies, such as shown in Figure 1.

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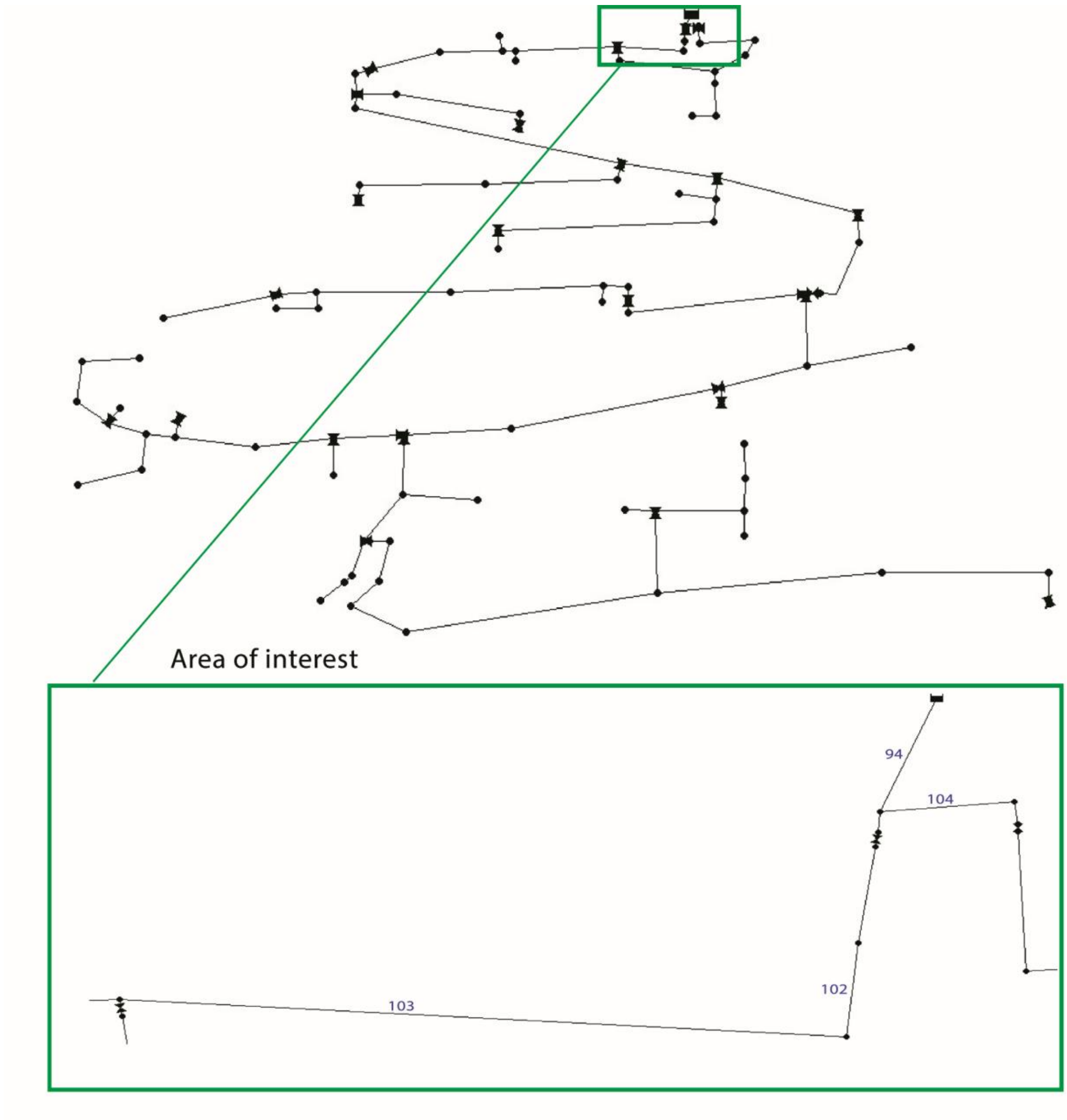

Figure 1. Sector 1 distribution network graph.

Sector 2

Sector 2 is supplied by a reserve tank, which is fed from the main treatment plant through a bypass pipe.

Sector 2 has 629 nodes and 811 pipes and comprises an area of 82 hectares. This hydrometric network supplies 3,651 users in the sector, with an average flow of 11.7 liters per second. The material of the pipes for the distribution of drinking water is PVC (polyvinyl chloride) and its length is 8151 m, with diameters that vary between a minimum of 40 mm and a maximum of 110 mm. The inhabitants of the sector use the drinking water distributed by EMAPA (Empresa de Agua Potable y Alcantarillado), which provides potable water service 24 hours a day to the entire sector. It has a minimum, average and maximum pressure of (1.46, 28.00, and 62.65) meters of water columns. The calibration in Epanet was carried out based on the pressure taken at each node of the supply network. Figure 2 shows the hydrometric network of sector 2.

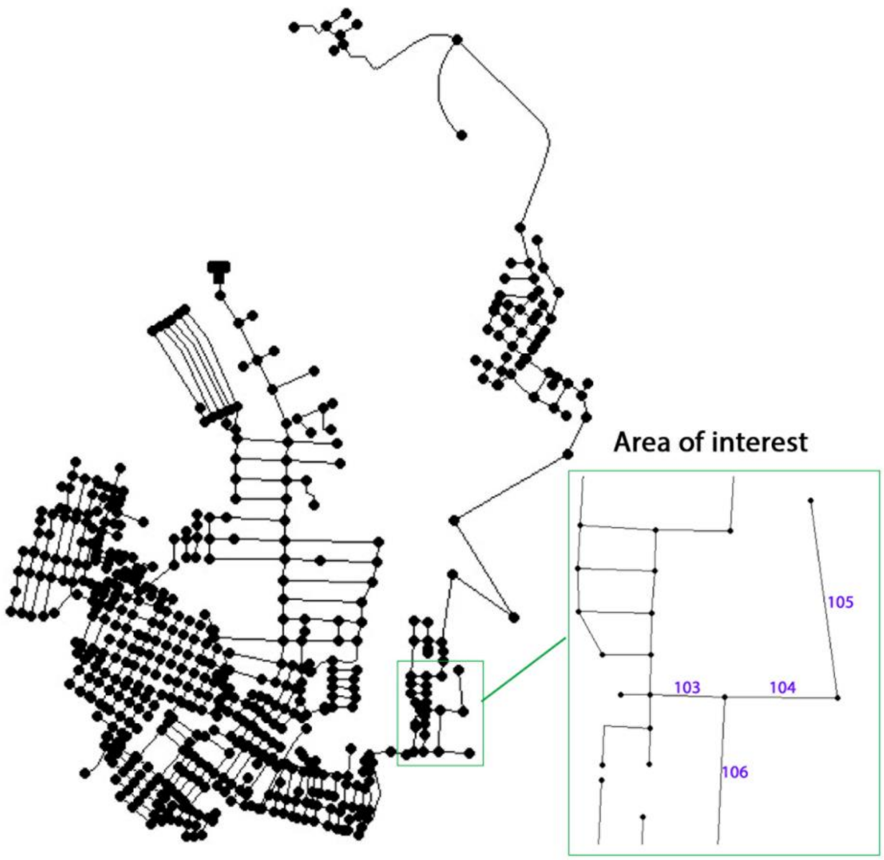

Figure 2. Sector 2 distribution network graph.

Sector 3

The inhabitants of the sector use the water from EPMAPS (Metropolitan Public Water and Sanitation Company) that supplies a surface of 73.6 ha.

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As can be seen in Figure 3, this hydrometric network has 83 nodes and 94 PVC pipes ranging from 7.5 mm to 300 mm in diameter. The maximum, average and minimum flow range from 13.93, 8.38 and 4.52 m^3/s, respectively.

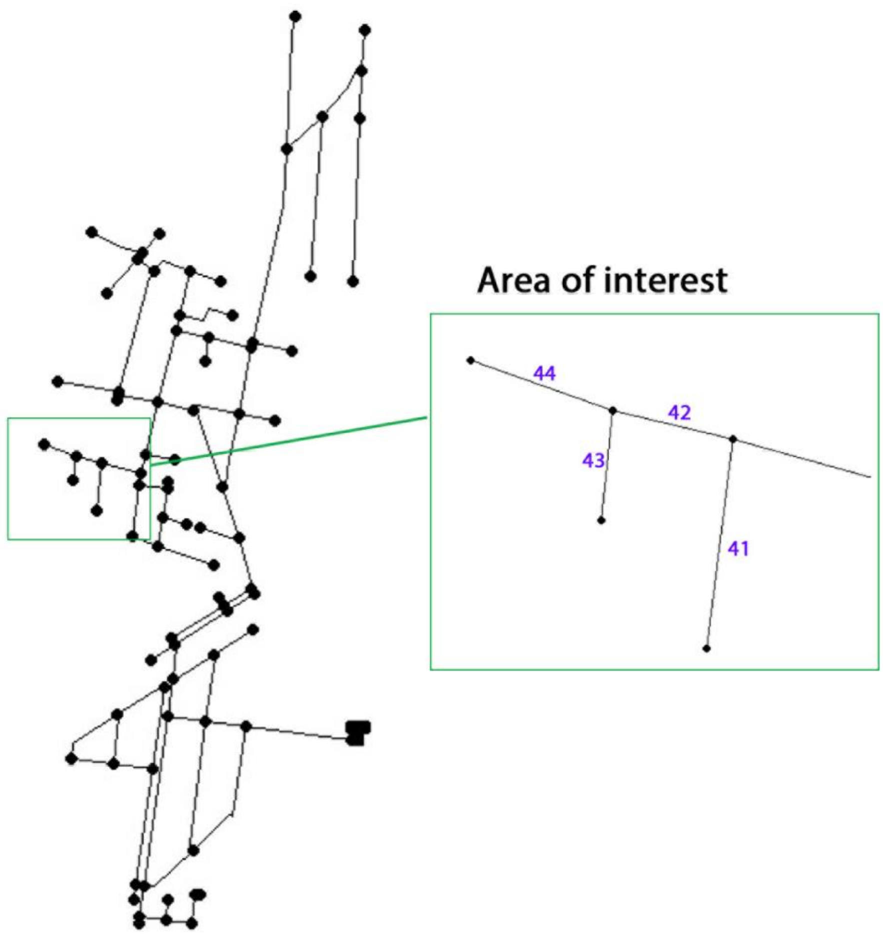

Figure 3. Sector 3 distribution network graph.

Parameter estimation

The estimation of the system parameters is determined by the minimum deviation between the simulated values and the observed values, under variable conditions of time. This parameter estimation has been formulated mathematically by regression statistical theory (Abe & Cheung, 2008; Abe & Cheung, 2008, 2010; Jorgensen, 1983).

$$y = f(\beta) + \epsilon \qquad (1)$$

In Equation (1), *y* represents the observed values; *f*(β) represents the model estimate of *y*; β is the vector model parameter, and ϵ is the random measurement error vector. These equations are the ones that the Epanet program uses internally for the analysis (Martínez-Solano *et al*., 2015). Probability maximization (Equation (2)) provides an argument for least squares problems (Abe & Cheung, 2010; Iglesias-Rey *et al*., 2017):

$$MaxL(\beta) = min\,\frac{1}{2}(y - f(\beta))^T Cd^{-1}(y - f(\beta)) \qquad (2)$$

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The problem of parameter estimation is to determine the optimal values of roughness and emitter coefficients from countless observations in the field (Abe & Cheung, 2008; Iglesias-Rey *et al*., 2017). The least squares approach is used to represent the deviation of the simulated values with the observed ones, where it can be expressed with Equation (3):

$$Min = \sum_{i=1}^{N} \left[\frac{\Delta Pi}{\frac{\sum_{i=1}^{N} Pi'}{N}} \right] + \sum_{j=1}^{M} \left[\frac{\Delta Qi}{\frac{\sum_{j=1}^{N} Qj'}{M}} \right] \quad (3)$$

In Equation (3), *Pi´* (meters of water column) and *Qj´* (liters per second) represent the pressure and flow values, respectively. Δ*Pi* is the pressure difference between the simulated data and those recorded in the field, *ΔQi* is the difference in flow between simulated and observed data. N is the number of nodes and M is the number of monitored pipes.

The drawings of the sectorized water distribution networks were exported from AutoCAD (Autodesk, 2010) to a file with .DXF format, later these digital files were imported from the Darwin Calibrator (Alves *et al*., 2014; WaterGEMS, 2009), computer application where the hydraulic analyzes were performed with their respective calibrations. Upon completion of this step, the resulting file for each sector was saved in digital file format ".INP" to be able to import it from Epanet 2.0 and thus perform the respective comparative hydraulic analysis.

The dimensions of diameter, length, and other characteristic parameters that represent each investigated sector were adopted to submit them to the respective analysis in the calibration modules, both from Darwin and Epanet Calibrator (Boczar, Adamikiewicz, & Włodzimierz, 2017). With the first results of the analysis, the pressure data sensed in the nodes of interest were entered for the respective calibration. To optimize the calibration times, a text file was created in which the pressures of each node of each network were organized to facilitate the entry of information into Epanet (Abdy Sayyed *et al*., 2014; Gençoğlu & Merzi, 2017).

Validation

The modeling in Epanet Calibrator was performed in the same way as in Darwin Calibrator, in order to validate the results of the simulation of the hydraulic system in both calibration tools.

Darwin Calibrador, is the genetic algorithm program that allows to calibrate a water distribution model with practical conditions that include the combination and aggregation of the model parameters in multiple demand load conditions, with various scenarios of system limits and boundaries, manual adjustment and sensitivity analysis of calibration solutions (Abdy Sayyed *et al*., 2014; Walski *et al*., 2006; WaterGEMS, 2009). The Darwin Calibrator uses an algorithmic approach developed by Wu *et al*. (2002), and Wu, Walski, Naumick, Dugandzic, and Rob (2005).

Once the model of a water distribution system has been built, field data was entered, then the parameters that can be adjusted to achieve calibration and any boundary conditions associated with the system at the time are decided upon. field data were collected, such as flows, heights of the hydraulic gradient line (LGH), boundary conditions related to water levels in reservoirs and the operational status of the valves (Wu *et al*., 2004; Wu *et al*., 2005).

Darwin Calibrator has a modeler to select three types of combinations in each model, with parameters such as the roughness of the pipe as a function of the Hazen-Williams, Darcy-Weisbach and Chézy-Manning pressure drop equations (Walski, Wu, & Hartell, 2012; Wu *et al*., 2004), pressure loss calculation methods that are also available by Epanet Calibrator (Abe & Cheung, 2010; Agency, 2000; Iglesias-Rey *et al*., 2017; Waikhom & Mehta, 2015).

The pipes of each sector were grouped by the type of material, in polyethylene pipes and asbestos-cement pipes, in order to obtain a single calibration link, which is assigned a new roughness coefficient established to all the pipes in it group. The unions that have similar demand patterns and within the same topological surface, were also added as a calibration union, so that it is calculated with the same demand factor. The calibration parameters are delimited by the borders (upper and lower) indicated in the patterns in the network.

Incremental value

For this case, a Hazen William value - “coefficient C” for a pipe or a group of pipes will be computed within a range of a minimum of 40 and a maximum of 140 with an incremental of 5. The demand multiplier may vary from 0.8 to 1.2 and increases by 0.1 (Wu *et al*., 2004).

The accuracy of the solutions obtained by genetic algorithms is quantified using what is called "fitness" of the solutions. Fitness is based on the difference between the observed and simulated values for the hydraulic grade line and flow (Walski *et al*., 2006). There are typically three methods for calculating fitness: least squares, minimum absolute difference value, and minimum maximum error. The method used in this work is that of least squares, where fitness is determined with Equation (4):

$$F = \frac{1}{Wh}\sum(H_{mod} - H_{obs})^2 + \frac{1}{Wq}\sum(Q_{mod} - Q_{obs})^2 \quad (4)$$

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Where F is the fitness of the model or result; H_{mod} is the simulated value of the hydraulic head or head; H_{obs} is the observed value of the hydraulic head or head; Q_{mod} is the simulated value of the flow; Q_{obs} is the observed value of the flow; W_h is the weighted factor of the hydraulic head or head and W_q is the weighted factor of the flow. This mathematical expression of least squares is considered by Darwin Calibrator for the calibration of networks (Walski *et al*., 2006).

In this work, a set of pressure measurements distributed throughout the system was performed and the flow of the main pipeline was recorded. The roughness factors for the tubes of the network are initially estimated as a value of the Darcy-Weisbach roughnesses of 0.0250 mm (Wu & Clark, 2008; Wu *et al*., 2002). In order to calculate the physical state of the network, the formula of the minimum square error is used, and the given weighting of the piezometric head load (García Alcaraz & Castillo Elsitdié, 2006).

Both Darwin Calibrator and Epanet Calibrator work with genetic algorithms (Abe & Cheung, 2008; Iglesias-Rey *et al*., 2017; Pérez, Sanz, Cugueró, Blesa, & Cugueró, 2015). The calibration process carried out by each program through iterations makes it possible to find the optimal solution for the water networks studied. Darwin Calibrator has a "favorable" feature, as it shows three possible optimal solutions, which can be adapted in the calibration of the pipes. In the case of Epanet, the calibration is manual, so the roughness value approximation process is difficult, reaching over or underestimating this value for the adjustment as mentioned Bentley Systems, I. (2005), WaterGEMS (2009), and Wu *et al*. (2004).

Results

Sector 1

Hydraulic calibration was carried out using the Darcy-Weisbach formula, and based on the pressure taken at different nodes (Figure 1). The roughness factor for the analysis was initially estimated as 0.0250, while the calibration performed by Darwin Calibrator shows two solutions with an average increase of 35 % more, as shown in Table 1. The physical resolution of the hydraulic network is calculated using the minimum squared error formulation and the weighting of the measurements of the LGH (Hydraulic Gradient Line) and flow, respectively (García-Alcaraz & Castillo-Elsitdié, 2006; Molina-Arce, Iglesias-Rey, & Martínez-Solano, 2014).

Table 1. Roughness Adjustment Results for Sector 1 Pipes.

Solution 1

Roughness adjustment percentage Darcy-Weisbach					**1.44**
Group adjustment	**Link**	**Flow (l/s)**	**Pressure (mwc)**	**Initial roughness (mm)**	**Rugosity tight (mm)**
Pipeline	94	5.21	1.56		
Pipeline	102	4.59	5.72	0.025	0.036
Pipeline	103	4.59			
Pipeline	104	0.63			

Solution 2

Roughness adjustment percentage Darcy-Weisbach					**1.26**
Group adjustment	**Link**	**Flow (l/s)**	**Pressure (mwc)**	**Initial roughness (mm)**	**Rugosity tight (mm)**
Pipeline	94	5.21	1.56		
Pipeline	102	4.59	5.72	0.025	0.032
Pipeline	103	4.59			
Pipeline	104	0.63			

Figure 4 shows the correlation coefficient between the Epanet Calibrator (4.a) and Darwin Calibrator (4.b) programs, respectively. It is observed that the two programs show an R-squared adjustment coefficient greater than 0.90, especially the calibration carried out by Darwin Calibrator (4.b) with an R-square of 0.97 showing a reliable model approaching the needs of the hydraulic network.

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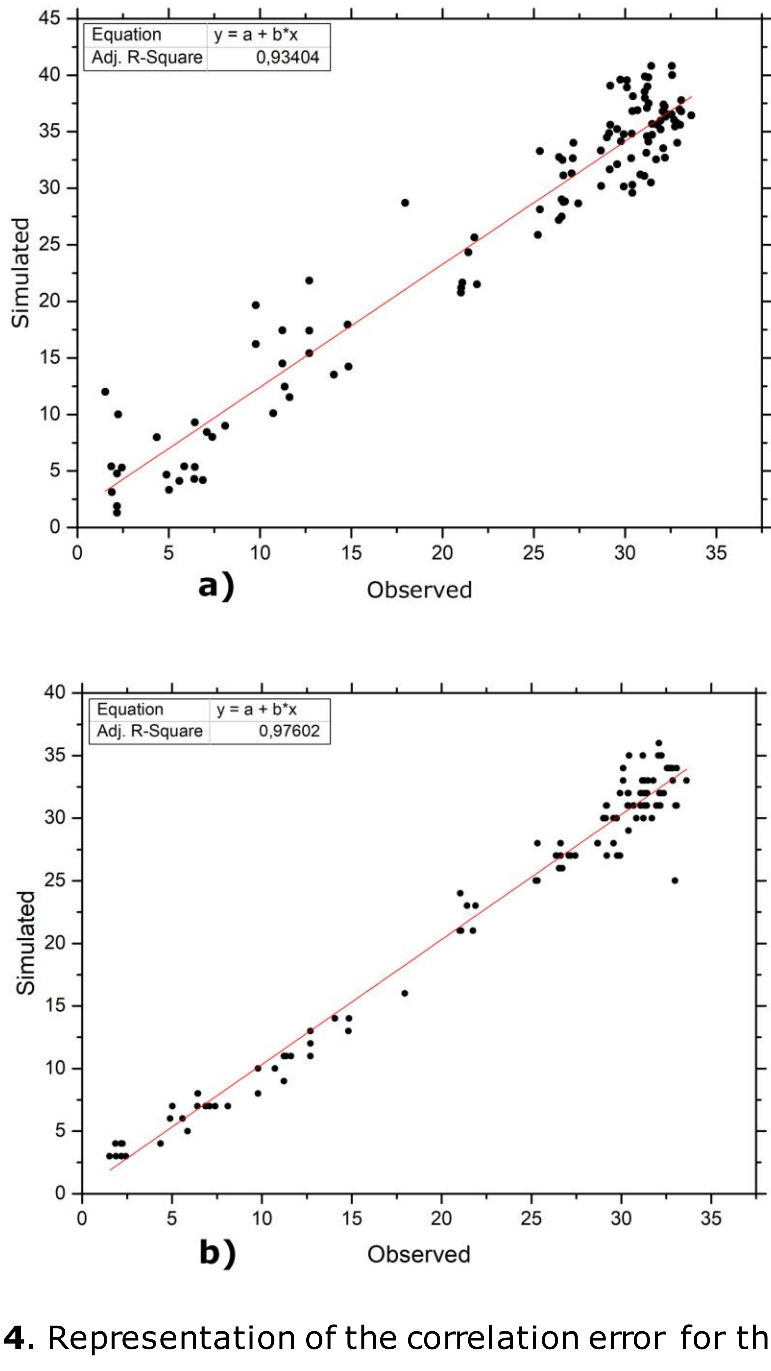

Figure 4. Representation of the correlation error for the correct calibration solution Epanet Calibrator and Darwin Calibrator (Darcy-Weisbach; sector 1).

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Sector 2

The design of the pipeline was carried out using the Hazen-Williams formula (Wu *et al*., 2004; Wu & Clark, 2008), and based on the pressure taken at different nodes (Figure 2). The Hazen-Williams roughness factors for the pipes in this analysis are initially estimated as C = 130, while the calibration performed by Darwin Calibrator shows three ideal solutions with a 10 % decrease in roughness that is detailed in Table 2. The physical solution of the hydraulic network is calculated using the least squared error formulation and the weighting of the LGH and flow measurements respectively (García Alcaraz & Castillo Elsitdié, 2006; Molina-Arce *et al*., 2014).

Table 2. Roughness adjustment result for sector 2 pipes.

Solution 1

Roughness adjustment percentage Hazen-Williams				**0.90**
Group adjustment	**Link**	**Flow (l/s)**	**Pressure (mwc)**	**Rugosity Tight**

				Initial roughness (*C* value)	(*C* value)
Pipeline	103	6.44	9.02	130	117.26
Pipeline	104	3.11	9.02		
Pipeline	105	4.82	9.02		
Pipeline	106	5.63			

Solution 2

Roughness adjustment percentage Hazen-Williams					**0.90**
Group adjustment	**Link**	**Flow (l/s)**	**Pressure (mwc)**	**Initial roughness (*C* value)**	**Rugosity Tight (*C* value)**
Pipeline	103	6.44	9.02	130	117.13
Pipeline	104	3.11	9.02		
Pipeline	105	4.82	9.02		
Pipeline	106	5.63			

Solution 3

Roughness adjustment percentage Hazen-Williams					**0.9**
Group adjustment	**Link**	**Flow (l/s)**	**Pressure (mwc)**	**Initial roughness (*C* value)**	**Rugosity Tight (*C* value)**

Pipeline	103	6.44	9.02				
Pipeline	104	3.11		9.02		130	117.39
Pipeline	105	4.82			9.02		
Pipeline	106	5.63					

Figure 5 shows the correlation error between the Epanet Calibrator (Figure 5a) and Darwin Calibrator (Figure 5b) programs respectively. The results show an adjustment coefficient greater than 0.90, so it is a reliable result for the permanence in time of the drinking water distribution network, especially the calibration by means of Darwin Calibrator with an R-square of 0.99 as can be seen in Figure 4b.

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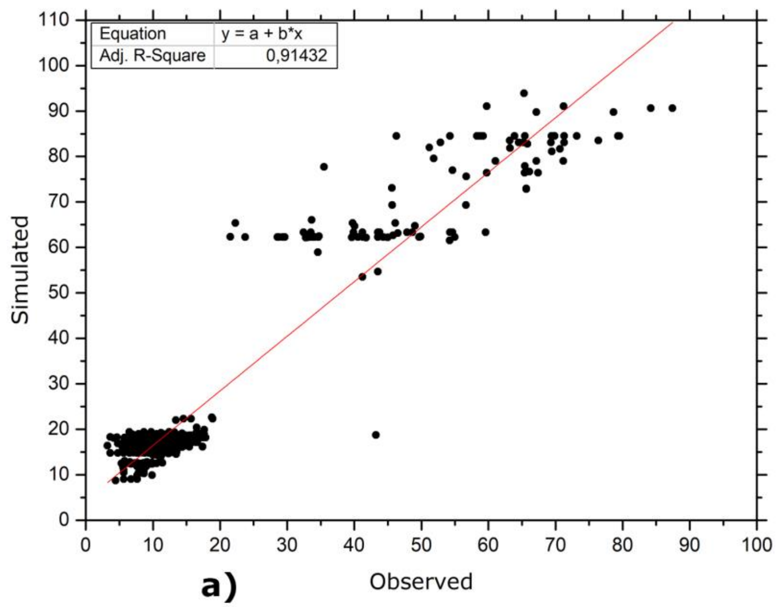


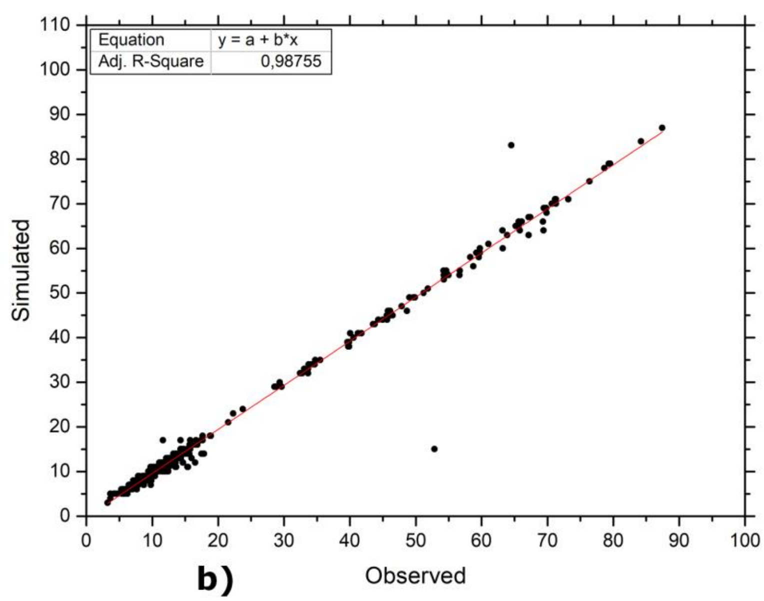


Figure 5. Representation of the correlation error for the correct calibration solution Epanet Calibrator and Darwin Calibrator (Hazen-Williams; sector 2).

Sector 3

The analysis was carried out using the Hazen-Williams formula, and based on the pressure taken at different nodes (Figure 3). The Hazen-Williams coefficient C in this analysis is initially estimated with a value of 130. The calibration performed by Darwin Calibrator shows two ideal solutions with an average 15 % decrease in roughness detailed in Table 3. The physical solution of the hydraulic network is calculated using the least squared error formulation and the weighting of the LGH and flow measurements respectively (García-Alcaraz & Castillo-Elsitdié, 2006; Molina-Arce *et al*., 2014).

Table 3. Result of adjustment of the roughness coefficient of pipes of sector 3.

Solution 1

Roughness adjustment percentage Hazen-Williams				**0.90**
Group adjustment	**Link**	**Flow (l/s)**	**Pressure (mwc)**	**Rugosity Tight**

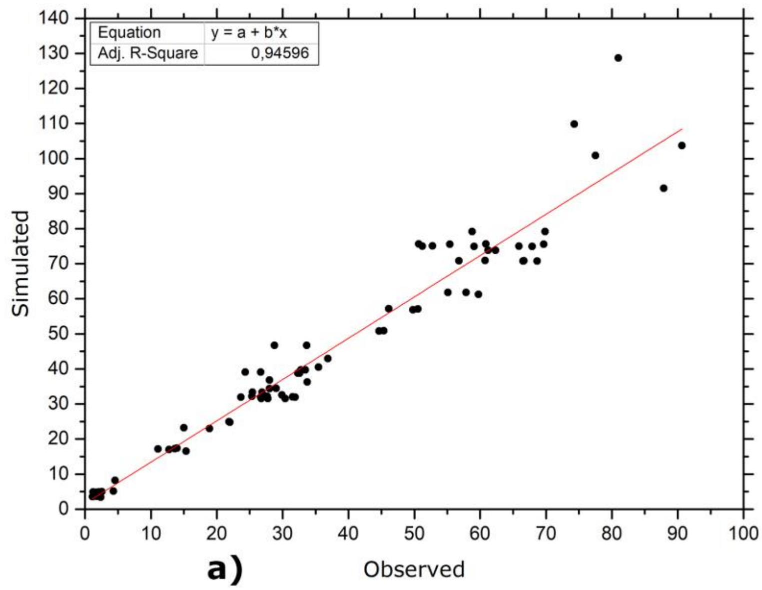
				Initial roughness (*C* value)	(*C* value)
Pipeline	41	1.22	3.65	130	117
Pipeline	42	3.46	3.60		
Pipeline	43	1.21	3.60		
Pipeline	44	1.21			

Solution 2

Roughness adjustment percentage Hazen-Williams	**0.80**

Group adjustment	Link	Flow (l/s)	Pressure (mwc)	Initial roughness (*C* value)	Rugosity Tight (*C* value)
Pipeline	41	1.22	3.65	130	104
Pipeline	42	3.46	3.60		
Pipeline	43	1.21	3.60		
Pipeline	44	1.21			

Figure 6 shows the correlation error between the Epanet Calibrator (Figure 6a) and Darwin Calibrator (Figure 6b) programs, respectively. The results show an *R*-squared adjustment coefficient greater than 0.90, which indicates a favorable result for the hydraulic network.



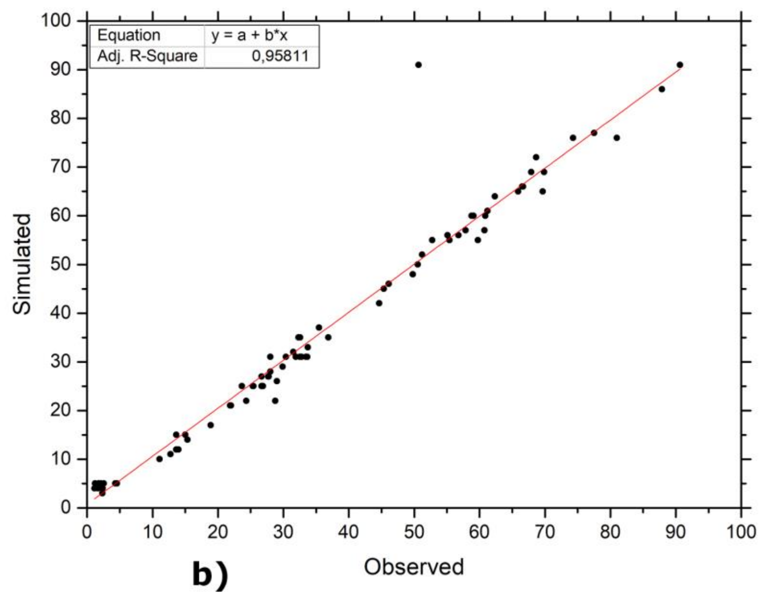


Figure 6. Representation of the correlation error for the correct calibration solution Epanet Calibrator and Darwin Calibrator (Hazen-Williams; sector 3).

Discussion of results

The results corresponding to the comparative calibrations between Epanet Calibrator and Darwin Calibrator show correlation coefficients greater than 0.90, which indicates a good calibration, an excellent distribution and a good application of parameters applied in the network, as was also demonstrated by Walski *et al*. (2006), Wu *et al*. (2002), and Wu *et al*. (2005). Calibration using Darwin Calibrator allowed grouping in different combinations of possible roughness in pipes. The analysis process of the two programs (Epanet Calibrator and Darwin Calibrator) allowed a search process to interact to provide the most optimal solution, which incorporates the status of the valve, flows and demands. The two tools are effective in network calibration, but they maintain a difference, in that data entry, handling and analysis can be performed in more detail in Darwin Calibrator than in Epanet Calibrator (WaterGEMS, 2009). Multiple parameters and the boundary conditions of the hydraulic network were taken, such as demand and pressures (Lansey & Basnet, 1991; León-Celi, Iglesias-Rey, & Martínez Solano, 2017), to provide an accurate representation of the network.

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The load condition of the demands in each of the sectors could be modified globally for the hydraulic systems at different times of the simulated day. The settings of the pressure control valve can also be taken into account in the calibration of each hydraulic network of the different sectors, therefore, the precision is improved by providing a result close to reality, when operating at every instant of time of the simulation.

These simulations of each of the hydraulic networks showed an adjustment coefficient greater than 0.90. Sector 1 yielded an R-square of 0.97, very similar to that of sector 2 with an *R*-square of 0.98. On the other hand, sector 3 showed a coefficient of 0.95, much less than sector 1 and sector 2; this can be related to the running time in the network pipes (age of the network).

The method of automatic calibration of a water distribution model provides maximum flexibility to configure a calibration in practice (Boczar *et al*., 2017; Lansey & Basnet, 1991), for example, a modeler can choose the parameters of the model, including pipe roughness coefficient, node demand and operational status of pipes and valves, or any combination of these parameters. This choice of parameters made it possible to shorten the time spent in the calibration with Darwin Calibrator by having a group analysis between network elements, while the calibration by Epanet Caibrator increased the solution time in the study, being a program that limits these options that Darwin Calibrator has. Consequently, it is possible to input data observed in the field such as quantities of pipe pressure and flow, which can be weighted at the node or at several nodes to focus the calibration on different data points.

Conclusions

It was observed that Epanet Calibrator and Darwin Calibrator are two efficient computational tools for the calibration of hydraulic network models, by incorporating genetic algorithms. They have the ability to determine values of roughness of pipes, demands and pressures. Epanet Calibrator shows a single result by which values for roughness, demands or pressures must be entered, individually in the nodes or pipes, while Darwin Calibrator facilitates it by doing it automatically and as a result presents three feasible cases where the roughness coefficients of the pipes may vary, in such a way that these values are adjusted to the desired calibration.

Finally, it is concluded that the genetic algorithm promotes an efficient search and optimal location process, with a number of parameters and models of various solutions. The integrated calibration also includes an automatic system that allows a calibration task in a faster way, improving productivity in the process.

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