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Human factors in multi-objective optimization of water supply systems

Abstract

The design of water supply systems is considered a combinatorial optimization task in which the diameter of each one of the pipes can be considered as a decision variable. The problem is to determine a set of diameters so that the cost function is minimized (depending on the length, diameter and material of the pipes) subject to hydraulic and commercial constraints. However, the chosen set of diameters will have a significant influence on the energy losses due to the hydraulic balance of the system. Therefore, it is necessary to use techniques that allow finding solutions that are viable under multiple criteria. In the present work the incorporation of the human factor in the decision-making process during the multi-objective optimization of the design of the water supply system is shown. The development of algorithms, products of the practical experience and implementation in CAD systems, influences the decrease of the search universe in the optimization as measured using the notation Big-O. Benefits provided by the CAD System to help the designer are presented. The paper ends with conclusion and recommendation of future works.

Keywords: multi-objective, decision-making, water supply

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Introduction

Due to its high cost the water supply systems are comparatively neglected areas in the rural areas of the developing countries.[1] The mathematical modeling application with the incorporation of the human factor through computer packages allowing the authorities the chance to take preventive actions in the decision-making process.[2] To solve combinatorial optimization problems, a wide variety of algorithms have been developed to try to solve them.[3–5] These algorithms can be classified as accurate or approximate;[6,7] While the former guarantee obtaining the optimum of any finite instance of the problem in a limited time, the latter place emphasis on obtaining satisfactory solutions in a short time.[8] Since a large number of combinatorial problems are NP-Complete,[9] the use of approximate algorithms is and will be an area of intense activity.[10] In the last decades, special attention has been devoted to the optimal dimensioning of water distribution networks. To this end, various optimization techniques are applied that allow a greater reduction of the capital costs of these systems.[5,11] Some of these methods are restricted in their application to branched networks. Such as, the Linear Programming model,[12] are not applicable to the design of meshed networks that, due to the need to maintain the service in any circumstance, cannot be subject to the fragility of a single supply conduit per supply area, which requires considering circuits. The use of metaheuristics is based on problems whose solution is not satisfactory by traditional methods and the implementation of exhaustive search methods is not justified in practice. So, it is applied with the objective of obtaining "good solutions" in a reasonable time.[13]

The classic objective function is considered multimodal and concave (the stationary points are maximum). The minimum of this function are not stationary points as they are in the discontinuous-derivative.[11] Although there are models that yield important results,[11,14] most are limited to networks with few circuits due to the high consumption of computational resources and do not avoid the result of the network implicitly branched. Such a design solution is not feasible in practice because the objective of meshed distribution networks is to guarantee supply even if there are factors that affect it, such as: ruptures, maintenance, or other reasons. If any of these events occur in the sections of larger diameter pipes, the flow that must flow through it will not be efficiently driven by the smaller diameters, which were the result of the optimization to close the circuits. Many researchers use only investment costs during the formulation, energy costs are rarely taken into account[11] and include a certain fixed pressure value in the supply node. For this reason, optimization leads to the "opening" of the circuits of the meshed network giving rise to branched or quasi-open networks. Other investigations devote efforts to consider the energy aspect[11,15–17] but are generally considered in terms of energy cost product to pumping, which implies, that the supply to the network is not by regulation. The formulations that present such considerations do not allow to analyze other circumstances which are the most common in practice, as is the supply through tanks.[10,18–20] On the other hand, classic optimization is based on a single efficiency indicator, the cost, with which it cannot be precisely specified, if the solution obtained is efficient from the energy point of view, when considering together with the variable costs, the fixed costs, which for the same design task, vary depending on the trajectory of the network and the combination of diameters for each section of pipe; both, in turn, influence the excavation volumes that are a function of the geological zones, the which are not usually uniform in a given physical space.

The specific objectives of this study were evaluating the benefits of CAD System to help the designer of water supply systems; additionally the efficiency and applicability of human factors inclusion in multi-objective design optimization of water supply systems are shown. The document continues as follows: costs and energy efficiency are analyzed and possible proposals for other indicators are analyzed. The performance or complexity the algorithm is measured using the notation called Big-O. The quality function of the system is proposed by means in a multi objective function. Benefits provided by the CAD System to help the designer are presented. The paper ends with conclusion and recommendation of future. In order to evaluate the energy efficiency in water distribution systems, regardless of the supply system to the network, it is proposed to consider the sum of the energy losses for the conditions in which the optimization process is carried out. For all these reasons, the following are considered as Efficiency Indicators in the mathematical formulation (Hechavarría, 2016; Hechavarría et al., 2019):[5]

a. Minimum total cost (C) of the water distribution network.
b. Minimum value of energy loss (E).

The energy loss to be considered includes the friction losses and the losses produced by singularities in the water distribution network, which will determine if the system performance, in a particular state, can be good because there is little loss of available energy ; or not so good, due to a large loss of available energy. The reduction of energy losses in a system is proportional to the guarantee of pressure height in the nodes; therefore, the minimization of this indicator is aimed at maximizing the benefit of excess pressure at the critical point. There are attempts to minimize the obtaining of quasi-open networks in optimization processes, such as, to include within the objective function other indicators such as the reliability of the pipes, in which is consideraded the time that a pipeline must be isolated by some reason.[11,21–25] Reliability is an indicator that can be quantified in various ways: take into account the type and aging of the pipes in the network, changes in demand or pressure, the type of soil, the seismic threat in the area, among other factors.[21,24,26] It can be measured from the surplus of pressure obtained in the nodes in relation to the minimum or admissible pressure value and also considers the uniformity of the diameters connected to a certain node. The increase in reliability allows the network to assume better behavior in the event of unforeseen events.

To achieve an accurate characterization of this new indicator is necessary to store large amount of information through expensive technologies and to make historical measurements to determine: the type of soil, seismic hazard area, leakage of the fluid, mechanical breakdowns, including other factors that increase the degrees of freedom and makes a reliable modeling of the system difficult.[21,26,27] Considering reliability in an optimization model is a difficult and complicated task, and there are no universally accepted definitions for its explicit expression.[21,28] On the other hand, in an objective function in which more than one criterion is present, there cannot be a solution that is the best in all the criteria. Instead, in a problem of multi objective optimization there is a set of Pareto-optimal solutions solutions or non-dominant solutions.[29–31] These solutions are superior to the rest of the solutions in the search space, when all the objectives are considered, but inferior to other solutions in one or more objectives.

Human factor in the decision-making

The optimization process proposed in[10] is supported on a CAD application that guarantees a feasible solution by decreasing the tendency to open cycles, thereby obtaining circuits that increase the reliability of the network.[32] One way of contemplating reliability in water distribution networks, without explicitly expressing it in the optimization model, is to ensure that the model cannot choose diameters with important dimensional differences for the sections of pipes that connect to the same node. The procedure that is conceived allows to choose from graphical advantages and CAD techniques a combination of diameters for each pipe section where the reliability of the circuits and other subjective aspects can be taken into account. Figure 1 shows the options of the CAD system to assign to each section of pipe a logical combination of diameters, considering the proximity to the source of supply. In practice, it is known that those sections of pipes closest to the supply source will result in the largest diameters. These diameters will decrease as they move away from the supply. From graphics benefits you can visualize the different combinations of diameter assigned to the sections of pipes that make up the hydraulic network. It can also be highlighted which of the pipes are existing recognizing them by another type of line, while the colors and thicknesses allow the classification by type of material and diameter assigned respectively, see Figure 2.

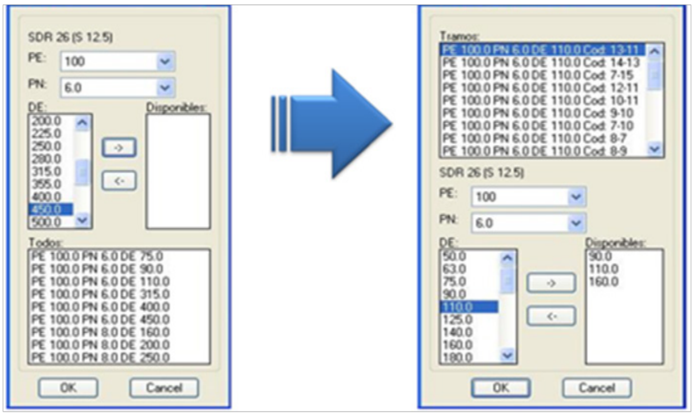

Figure 1 Selection of the variants of diameters for each section of pipe.
Source: (Hechavarría, 2009)

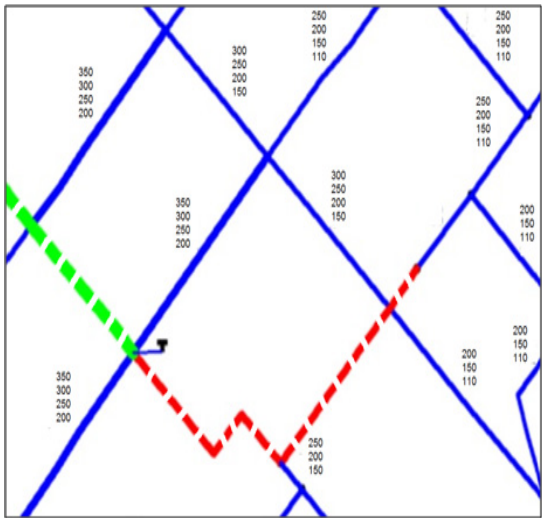

Figure 2 Graphics benefits of a CAD system in the optimization process.

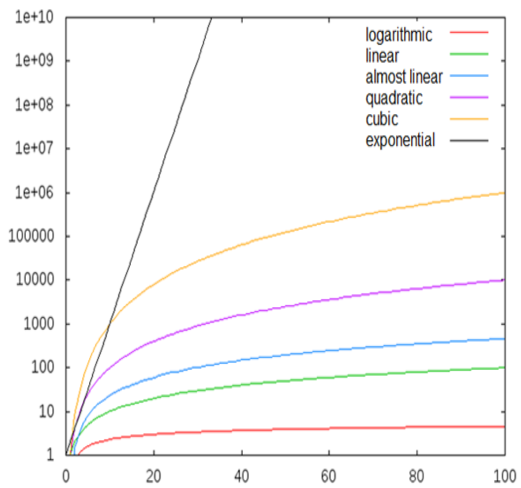

Figure 3 Growth rates according to the complexity of programming.
Source: (Villalpando & Francisco, 2003)

Source: (Hechavarría, 2009) In programming, the performance

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or complexity of an algorithm is measured using a notation called Big-O, and also known as Asymptotic Notation or Landau Notation.[33] Figure 3 shows the growth rates shown by the hierarchy of complexity of this notation, which is declared in 1. Graph algorithms present a special case regarding time complexity with, quadratic, cubit and quartic (O(n^4)) complexity common due to mainly nested loops.[34]

$$O(1) \subset O(\log n) \subset O(n) \subset O(n \log n) \subset O(n^2) \subset O(n^3) \subset O(2^n) \quad (1)$$

Generally, the publications carried out on the optimization of supply networks are made with a small number of sections of pipes and a large number of combinations of diameters are considered for each section. In practice, the designers face networks like the one shown in Figure 4 with a number greater than 70 sections of pipes. In 2 it is established that for each variant of trajectory a population of solutions of hydraulic design is obtained, considering the possible combinations of diameters for the m stretches. In this way a chain with as many digits as there are stretches is reached, where each digit encodes the diameter to be used in the corresponding section.[10] The commercial restrictions are given in the discrete values that the diameters of the pipes can take, which are in function of the availability of standardized diameters of each manufacturer. The hydraulic restrictions are in correspondence with the Law of Conservation of Mass in each node and the Law of Conservation of Energy in each circuit.

$$\pi_{i=1}^{m} opc(\mathrm{i}) \quad (2)$$

For a better understanding of how the number of combinations of diameters by pipe sections influences the increase in the search population of the optimization process, the case of a mesh network of 70 pipes with 10 combinations of diameters each is analyzed. In this case the optimization process would look for the best options in a population size of 10^{70}=1E+70. However, having graphics benefits that allow to distinguish combinations of diameters considering the proximity to the source, the complexity represented by the same algorithm is much smaller. If four combinations are considered by pipe sections notation, a population size equal to 4^{70}=1,4E+42 is obtained as a result. Table 1 shows how the increase in the number of diameter options per pipe influences the size of the search universe. The use of CAD technologies to support the decision-making process when considering a smaller number of options per section of pipe allows obtaining a considerably smaller population as shown in Table 1. When choosing variants of diameters according to the proximity of the source of supply[10] and without important dimensional differences for the sections of pipes that are connected to the same node, the tendency to open the cycles in the optimization process is reduced.[32] This guarantee obtaining reliable circuits that allow to increase the reliability of the network without having to consider it explicitly in the mathematical model as an indicator of efficiency.

Table 1 Relationship of the population with the diameter combination
Source: Prepared by the author

No.	Options	Population	Increment	% vs next
1	3	2,5E+33	-	2E-07
2	4	1,4E+42	1.39E+45	2E-05
3	5	8,5E+48	8,47E+48	3E-04
4	6	3E+54	2.96E+57	0,002
5	7	1,4E+59	1.44E+62	0,009
6	8	1,6E+63	1.65E+66	0,026
7	9	6,3E+66	6.26E+69	0,063
8	10	1E+70	9.99E+72	-

One of the most used schemes in recent years for the approximation of multiobjective function is the minimization of Tchebycheff's distance from an ideal solution (or desired) to the region of existence of the solution.[8,10,35–38] Once the reliability is considered from the graphical advantages, the probability of obtaining a better compromise between the two efficiency indicators expressed previously is increased: energy loss (E) and total cost (C). The minimization of the weighted distance of Tchebychef[5,8,38] (Z) is expressed in 4 when each parameter is affected by a weight established by the designer. In this way, the quality function of the system is proposed by means of the following equation:

$$Z = \max \left\{ w_1 \frac{E - E^{id}}{E^{id}}, w_2 \frac{C - C^{id}}{C^{id}} \right\} \quad (3)$$

Where:

Z - Quality function.
E - Loss of energy in the network.
E^{id} - Ideal or desired energy loss.
C - Total cost of the network.
C^{id} - Ideal or desired total cost.
w_1 - Level of importance established for the energy efficiency indicator.
w_2 - Level of importance established for the cost efficiency indicator.

Calculation of penalties

Every water distribution network has certain restrictions in relation to the pressure height values at the nodes and the flow velocity in the sections. For the task under study, the following are considered:

1. Pressure (Node)
2. Speed (Sections)

The above restrictions are taken into consideration by calculating the value of a function *Pen*, of penalty, expressed in (4) according to the method of JN Kelley.[37,39,40] The result of this function will increase significantly when the velocity and pressure values obtained do not correspond with the permissible parameters.

$$Pen = \sum_{i}^{n} 10^{25} \theta_i \left(p_i^{lower} - p_i \right) + \sum_{i}^{n} 10^{25} \mu_i \left(p_i - p_i^{higher} \right) +$$

$$when: \sum_{i}^{n} 10^{25} \delta_i \left(Vel_i^{lower} - Vel_i \right) + \sum_{i}^{n} 10^{25} \phi_i \left(Vel_i - Vel_i^{higher} \right)$$

$$\theta_i = \begin{cases} 1 \text{ if } p_i < p_i^{lower} \\ 0 \text{ in another case} \end{cases}; \mu_i = \begin{cases} 1 \text{ if } p_i > p_i^{higher} \\ 0 \text{ in another case} \end{cases}$$

$$\delta_i = \begin{cases} 1 \text{ if } Vel_i < Vel_i^{lower} \\ 0 \text{ in another case} \end{cases}; \mu_i = \begin{cases} 1 \text{ if } Vel_i > Vel_i^{higher} \\ 0 \text{ in another case} \end{cases} \quad (4)$$

n - Number of nodes.
m - Number of sections.

Generalized efficiency indicator

The generalized efficiency indicator (IEG) for each network variant is calculated from the quality function plus the penalties for not permissible speeds and pressures.

$$Z' = Z + Pen \quad (5)$$

When:
Z'– Generalized efficiency indicator for each design variant.
Results obtained

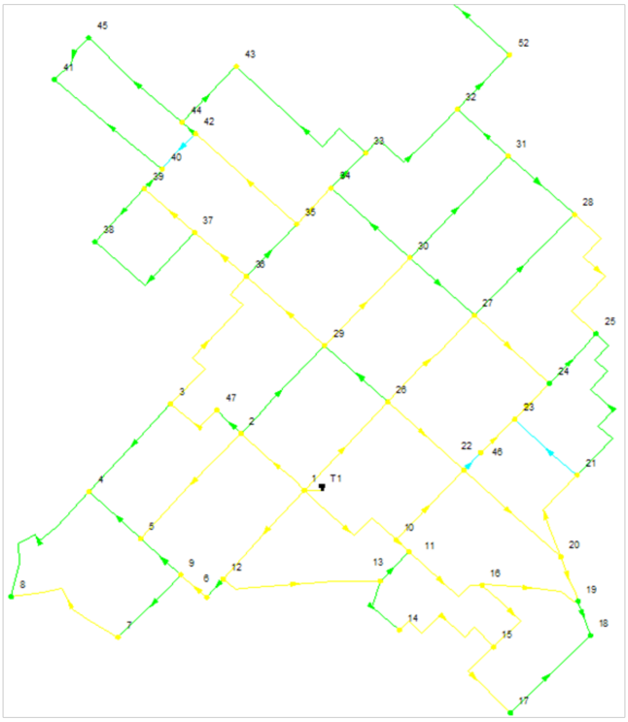

Figure 4 Representation of the hydraulic simulation of a design variant.
Source: (Hechavarría, 2009)

Results and discussion

In the doctoral thesis,[10] the importance of integrating the stages of the water supply network design process in a single CAD system was demonstrated, which allowed to reduce project delivery times and increase the quality of the solutions obtained by decreasing the probability of committing human errors. Among the activities that were computerized, the following stand out:

Benefits provided by the CAD System to help the designer:

1. Projection of the design population.
2. Determination of the flow required by the water distribution network according to population, tourism and large consumers.
3. Generation of the triangular mesh that describes the prevailing topography in the locality.
4. Definition of geological zones classified by soil types and their depth.
5. Determination of the three-dimensional location of the nodes (Hechavarría et al., 2007b).
6. Determination of the lengths of the pipes according to the trajectory made by the designer and the irregularities of the terrain.
7. Selection of the type of material and dimensions of the pipes from the market offers.
8. Definition of the areas of supply based on data on population, housing or population density as well as the demand of tourism and/or large consumers.
9. Planning of the water supply by relating the consumption elements (supply areas) with the nodes that are considered of the water distribution network.
10. Display of the classified information according to the hydraulic element that you want to analyze.
11. Obtaining the branched network that unites all the nodes of demand or supply by the minimum route (minimum network prioritized).
12. Generation of closed network variants according to permissible perimeters.
13. Proposal of variants of diameters for sections of pipes when considering the criteria of the designers and the presence of existing pipes (The experience of the designer is fundamental in the adequate decrease of the search universe, Table 1).
14. Generate a population of feasible solutions under technical-economic criteria that can be evaluated subjectively through its graphic representation inserted in the environment where it should work.
15. Automatic generation of executive plans, tables of results of the hydraulic calculation as well as technical data reports that allow elaborating the budget of the project. For the case of buried pipes
16. Edition of the topographic profile of the sections of underground pipes in correspondence with the values of the coatings in the pipes and the maximum and minimum slopes.
17. Calculation of excavation volumes when considering excavation equipment, trench parameters, type and thickness of pavement, topography and distribution of soil types from the depth defined in each geological zone.

The definition of variants of diameters for each section of pipe established in step 13 has a decisive influence on the optimization process, since the search population in the optimization process considerably reduced in step 14 decreases considerably. Table 2 & Table 3 show the results obtained of the hydraulic modeling performed on the network of Figure 4. The "Gradient Method" used for hydraulic balancing is classified as, a hybrid method of nodes and meshes and simultaneously solves the equations of continuity in the nodes and the hydraulic behavior equations of the pipelines for a given moment to call it.[38] For the hydraulic balance, the Gradient Method was used.[38] It is an efficient method of hydraulic calculation that implements a model for the resolution of piping systems under pressure, represented by a system of linear equations expressed in matrix form. Its main advantage is that it avoids the assembly of matrices, which decreases the quantity of processes to be carried out in comparison with other methods (ie, Hardy-Cross, Raman's or Tong's equivalent pipe method, etc.). As a quality criterion of the CAD application, exchange files are automatically generated that can be loaded in EPANET to evaluate the results of the hydraulic calculation.

On the other hand, it ensures a unique solution by not having convergence problems, because the solution of the system of equations to be solved, is to obtain the inverse of a symmetric and positive definite matrix. It allows to express the topology of the network, the load losses and the continuity of flows, in terms of matrix equations. It uses a real network model, incorporating the concept of connectivity matrices. It is not necessary to estimate an initial solution close to the real value. A minimum amount of data is entered relative to the nodes and sections of the network, and not explicit equations. It can be applied to meshed and/or branched networks. Which is considered advantageous compared to other iterative algorithms, which require a reformulation of the network to a set of equivalent circuits. It allows to implement hollow matrices in the solution of systems of simultaneous equations, which make the calculation extremely fast and safe.[41–44]

Table 2 Results obtained in the pipe sections
Source: (Hechavarría, 2009)
*HDPE: High density polyethylene

No.	Section	Length	Diameter	Flow	Speed	Unit losses	Rugosity	Material*	Existing	Nominal diameter	Losses
		<m>	<mm>	<L/s>	<m/s>	<m/km>					(m)
1	1-2	391,77	500	480,81	2,45	7,99	145	Fiberglass	1	500	3,13
2	2-5	671,26	184,6	32,55	1,22	6,99	145	HDPE	0	200	4,69
3	5-4	321,08	101,6	5,99	0,74	5,58	145	HDPE	0	110	1,79
4	4-8	706,35	101,6	8,85	1,09	11,48	145	HDPE	0	110	8,11
5	3-4	553,21	147,6	13,8	0,81	4,24	145	HDPE	0	160	2,35
6	7-8	587,27	101,6	10,79	1,33	16,59	145	HDPE	0	110	9,74
7	6-9	158,51	184,6	40,3	1,51	10,39	145	HDPE	0	200	1,65
8	9-7	407,64	230,8	20,3	0,49	0,98	145	HDPE	0	250	0,40
9	9-5	247,93	147,6	6,22	0,36	0,97	145	HDPE	0	160	0,24
10	12-6	111,46	230,8	40,3	0,96	3,5	145	HDPE	0	250	0,39
11	1-12	554,68	290,8	130,47	1,96	10	145	HDPE	0	315	5,55
12	13-11	189,76	230,8	35,11	0,84	2,71	145	HDPE	0	250	0,51
13	12-13	731,79	290,8	87,62	1,32	4,78	145	HDPE	0	315	3,50
14	10-11	81,83	147,6	30,91	1,81	18,89	145	HDPE	0	160	1,55
15	1-10	574,98	300	151,91	2,15	13,94	130	HDPE	1	300	8,02
16	13-14	288,02	230,8	44,55	1,06	4,21	145	HDPE	0	250	1,21
17	11-16	436,4	230,8	66,02	1,58	8,73	145	HDPE	0	250	3,81
18	16-15	414,85	184,6	32,14	1,2	6,83	145	HDPE	0	200	2,83
19	14-15	604,8	184,6	39,12	1,46	9,83	145	HDPE	0	200	5,95
20	19-18	169,21	184,6	23,31	0,87	3,77	145	HDPE	0	200	0,64
21	16-19	453,69	101,6	13,7	1,69	25,81	145	HDPE	0	110	11,71
22	17-18	511,77	101,6	8,21	1,01	10,01	145	HDPE	0	110	5,12
23	15-17	434,39	184,6	39,73	1,48	10,12	145	HDPE	0	200	4,40
24	20-21	457,78	147,6	21,6	1,26	9,73	145	HDPE	0	160	4,45
25	10-22	447,5	300	101,14	1,43	6,56	130	Molten iron	1	300	2,94
26	22-20	597,74	230,8	77,32	1,85	11,69	145	HDPE	0	250	6,99
27	20-19	222,7	147,6	41,13	2,4	32,06	145	HDPE	0	160	7,14
28	21-25	933,95	101,6	6,34	0,78	6,19	145	HDPE	0	110	5,78
29	24-25	314,22	101,6	7,78	0,96	9,05	145	HDPE	0	110	2,84
30	23-24	231,48	147,6	24,18	1,41	11,99	145	HDPE	0	160	2,78
31	21-23	384,4	147,6	4,02	0,24	0,43	145	HDPE	0	160	0,17
32	45-41	253,75	147,6	5,47	0,32	0,76	145	HDPE	0	160	0,19
33	40-41	643,64	147,6	14,53	0,85	4,67	145	HDPE	0	160	3,01
34	44-45	579,2	101,6	5,47	0,67	4,71	145	HDPE	0	110	2,73
35	42-44	81,58	147,6	8,2	0,48	1,62	145	HDPE	0	160	0,13
36	42-40	222,82	230,8	8,98	0,21	0,22	145	HDPE	0	250	0,05
37	35-42	622,64	184,6	38,94	1,45	9,74	145	HDPE	0	200	6,07
38	39-40	124,74	101,6	5,55	0,68	4,85	145	HDPE	0	110	0,61

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Table Continued....

No.	Section	Length	Diameter	Flow	Speed	Unit losses	Rugosity	Material*	Existing	Nominal diameter	Losses
		<m>	<mm>	<L/s>	<m/s>	<m/km>					(m)
39	35-34	229,53	230,8	58,8	1,41	7,04	145	HDPE	0	250	1,62
40	29-36	478,52	147,6	28,52	1,67	16,27	145	HDPE	0	160	7,79
41	29-26	390,46	184,6	31,14	1,16	6,44	145	HDPE	0	200	2,52
42	2-29	559,54	461,8	194,67	1,16	2,2	145	HDPE	0	500	1,23
43	29-30	564,05	290,8	151,97	2,29	13,26	145	HDPE	0	315	7,48
44	30-34	482,68	184,6	30,61	1,14	6,24	145	HDPE	0	200	3,01
45	30-31	651,91	230,8	49,9	1,19	5,2	145	HDPE	0	250	3,39
46	31-32	316,34	101,6	7,21	0,89	7,86	145	HDPE	0	110	2,49
47	33-32	589,35	184,6	24,27	0,91	4,06	145	HDPE	0	200	2,39
48	27-30	396,9	230,8	31,16	0,74	2,17	145	HDPE	0	250	0,86
49	27-24	467,07	147,6	37,52	2,19	27,04	145	HDPE	0	160	12,63
50	26-27	564,74	230,8	101,13	2,42	19,23	145	HDPE	0	250	10,86
51	27-28	654,63	230,8	49,22	1,18	5,07	145	HDPE	0	250	3,32
52	28-31	407,6	101,6	3,39	0,42	1,94	145	HDPE	0	110	0,79
53	25-28	791,42	101,6	10,35	1,28	15,36	145	HDPE	0	110	12,16
54	34-33	227,06	230,8	30,28	0,72	2,06	145	HDPE	0	250	0,47
55	33-43	816,63	101,6	6,01	0,74	5,61	145	HDPE	0	110	4,58
56	44-43	359,05	101,6	2,73	0,34	1,3	145	HDPE	0	110	0,47
57	26-22	469,74	184,6	56,44	2,11	19,38	145	HDPE	0	200	9,10
58	1-26	560,54	461,8	241,93	1,44	3,3	145	HDPE	0	500	1,85
59	3-36	824,46	369,4	184,49	1,72	5,92	145	HDPE	0	400	4,88
60	22-46	112,03	300	20,16	0,29	0,33	130	Molten iron	1	300	0,04
61	46-23	219,31	101,6	20,16	2,49	52,77	145	HDPE	0	110	11,57
62	2-47	153,24	500	211,3	1,08	1,74	145	Fiberglass	1	500	0,27
63	47-3	284,04	327,8	211,3	2,5	13,63	145	HDPE	0	355	3,87
64	32-52	347,61	147,6	16,56	0,97	5,95	145	HDPE	0	160	2,07
65	T1-1	5969	831,2	1040,22	1,92	2,81	145	HDPE	1	900	16,77
66	37-39	304,44	147,6	28,08	1,64	15,81	145	HDPE	0	160	4,81
67	36-37	313,02	230,8	52,5	1,25	5,71	145	HDPE	0	250	1,79
68	37-38	637,84	101,6	8,77	1,08	11,31	145	HDPE	0	110	7,21
69	39-38	333,34	101,6	6,88	0,85	7,2	145	HDPE	0	110	2,40
70	36-35	333,56	327,8	97,74	1,16	3,27	145	HDPE	0	355	1,09
	Total losses					610,09					278,91

Table 3 Results obtained in the nodes
Source: (Hechavarría, 2009).

No.	Level	Pressure	Height	Demand	No.	Level	Pressure	Height	Demand
	<m>	<m>	<m>	<L/s>		<m>	<m>	<m>	<L/s>
1	5,65	42,08	45,25	35,11	27	0,86	33,14	33,14	45,55
2	6,2	37,59	42,84	42,30	28	1,34	15,63	16,19	42,26
3	5,67	36,45	41,22	13,00	29	2,42	36,21	37,75	45,32
4	8,15	21,05	28,42	10,95	30	1,25	31,16	31,55	40,30
5	6,53	27,19	32,93	32,77	31	0,89	17	17,1	39,30
6	7,13	30,57	36,49	0,00	32	0,68	17,7	17,59	14,92

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Table Continued....

No.	Level	Pressure	Height	Demand	No.	Level	Pressure	Height	Demand
7	6,85	25,47	31,54	9,52	33	0,87	25,16	25,24	0,00
8	10,07	16,88	26,17	19,64	34	0,88	27,47	27,52	59,13
9	7,32	27,64	34,17	13,78	35	2,1	28,05	29,29	0,00
10	5,64	33,65	38,43	19,85	36	3,37	28,91	31,4	62,78
11	5,89	32,64	37,71	0,00	37	3,86	24,54	27,52	15,65
12	6,97	31,95	38,12	2,54	38	6,06	14,7	19,98	15,65
13	6,96	27,92	34,1	7,97	39	5,62	15,53	20,35	15,65
14	7,61	22,44	29,26	5,43	40	3,95	18,49	21,64	0,00
15	8,64	14,51	22,35	31,52	41	5,26	14,17	18,65	20,00
16	6,99	25,58	31,72	20,18	42	3,19	21,23	23,6	21,76
17	7,45	15,92	22,57	31,52	43	1,36	21,21	21,82	8,74
18	5,87	22,64	27,68	31,52	44	2,89	20,47	22,61	0,00
19	4,77	25,54	29,37	31,52	45	3,98	16,71	19,85	0,00
20	3,56	29,94	32,62	14,59	46	3,5	34,89	37,53	0,00
21	1,81	16,11	17,17	11,24	47	7,1	36,51	42,66	0,00
22	3,89	34,54	37,55	60,11	48	0,84	13,87	13,97	0,41
23	2,46	29,47	31,18	0,00	49	1,01	13,76	14,03	0,41
24	0,94	24,41	24,48	53,92	50	0,28	14,76	14,29	0,41
25	0,69	14,05	13,98	24,47	51	0,37	15,25	14,72	0,41
26	3,51	38	40,51	53,22	52	0,86	15,44	15,52	14,92

Conclusion

1. The energy losses (result of the hydraulic simulation) are included as an efficiency indicator in this proposal. In this way, energy efficiency can be properly evaluated during the design activity of the water distribution networks, independently of the supply system (injection or regulation).
2. During the hydraulic analysis, energy losses are traditionally represented in the pipe sections in a standardized manner (m/km), however, the unit values cannot be considered as indicators of energy efficiency in optimization processes, due to that do not correspond to the real losses (see loss totals in Table 2). The inclusion of this new indicator, from the technical and non-economic point of view, allows to evaluate during the modeling, essential benefits such as the increase of the pressure in critical points, according to the variant of diameters chosen for each section of pipe.
3. The decrease in the number of options per diameter of pipes with the use of CAD technologies permit choosing variants of diameters according to the proximity of the source and without important dimensional differences for the sections of pipes that are connected to the same node, this guarantees the obtaining of reliable circuits that allow to increase the reliability of the network without having to consider it explicitly in the mathematical model as an indicator of efficiency, which increases the probability of obtaining better optimized options regardless of the heuristic that is applied.

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Conflict of interest

The author declares no conflict of interest.

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