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Design Comparison between the Economic Series Method and the Heuristic Method in a Pressurized Irrigation Network †

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Abstract: Agriculture is one of the axes corresponding to development that faces innovation challenges every day. One of the most important aspects in this field is the design of pressurized collective irrigation systems. The aim of this paper is to compare the design of pressurized collective irrigation networks by using the method of optimization of the Improved Economic Series (MSEM) with an optimization method using a Genetic Algorithm (GA). For this purpose, a methodology with an ordered sequence was developed with the input of the network topology, agronomic conditions, and design parameters. Then, the respective configurations of the two optimization models used are made. Consequently, the objective function and decision variables, as well as the constraints are defined. The design results of four networks selected for this implementation and operating in shifts show that it is possible to use evolutionary algorithms and analytical methods for the economic design of irrigation networks, where we obtain significant economic and similar economical savings.

Keywords: genetic algorithm; optimization; optimized economic series; irrigation systems; shifts

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1. Introduction

Nowadays, global food security is at risk. This is compared to 2019 when almost one in three people did not have access to adequate food, in 2020, due to to the effects of the COVID-19 pandemic [1]. In this scenery, it is vital to seek mechanisms for efficient and optimal management of irrigation systems.

On one hand, the designing or optimizing of the management of distribution networks, the usage of algorithms, or optimization processes that provide a set of feasible solutions for areas of interest are considered [2]. The economic factor is an important element in the design and implementation of distribution systems, which is the reason for seeking designs that involve the minimum cost. As a first alternative, analytical optimization algorithms are considered. These have been used to obtain optimal designs for irrigation networks operating on-demand [3], and supplying pipes with the Economic Series Method (ESM) by selecting piping diameters with an increasing pressure gradient per unit of maximum cost to meet all pressure requirements [4], obtaining good results [5–10]. González and Aliod [11] improved the MSE by using different materials and pipe sizes in the design of irrigation networks. García et al. [12], used the MSEM method to optimize the design of shift irrigation networks. Planells et al. [3], evaluated the energy cost during an irrigation campaign using Integer Non-linear Programming; Theocharis et al. [13] dimensioned the network with the simplified Non-Linear Programming technique using independent linear equations for pipe design. Kale et al. [14] used Linear Programming for the optimal design of lateral pipes of a parcel irrigation system. Lamaddalena et al. [15] used Labye's discontinuous iterative method and evaluate the variability of pressure in the hydrants of on-demand pressure irrigation systems.

On another hand, another type of algorithm employed for this purpose is an evolutionary algorithm, such as the Genetic Algorithm (GA); it is inspired by the natural evolution of populations, as is Darwin's theory of natural selection and Mendel's theory of the transfer of genetic material [16]. These algorithms evaluate thousands of solutions to determine the most feasible or real solution closest to the optimal design [17–19]. The GA does not use integer variables results in high computational efficiency [20], and is suitable for application to the analysis of real-size networks. Such is the case of Farmani, Abadia & Savic [21] that assign shifts to hydrants in irrigation systems, as well as the pipe diameters, resulting in an increase in the size of the decision variables, and therefore, in the resolution time.

A distribution network allows water to reach from the collection point to the user for human consumption or irrigation needs [22]. A pressurized irrigation system has components, such as collection, distribution lines, hydrants, etc.; which together with pressure and flow control devices facilitate good operation [23]. Pressurized irrigation networks can be operated in two modalities: in shifts (they have certain restrictions during the irrigation day and the useful life of the system) and on-demand (they operate without hourly restrictions, although this means higher economic costs) [24,25].

In the current research, we propose to compare and evaluate the design results obtained using an analytical method, the Method of the Improved Economic Series (MSEM) and the genetic algorithm (GA), which have been applied to four pressurized irrigation networks operating in the shift mode.

2. Methodology

To meet the objective of this research, an ordered sequence was developed, starting with the calculation of the fictitious continuous flow; the functional hydraulic design of the networks was performed in the mode of operation of the network in shifts, and the network was designed with optimization methods (Improved Economic Series MSEM and Genetic Algorithm AG), and the design results were obtained with the selected optimization techniques and were compared and analyzed. The Tuncarta irrigation network was used to explain the methodology (Figure 1).

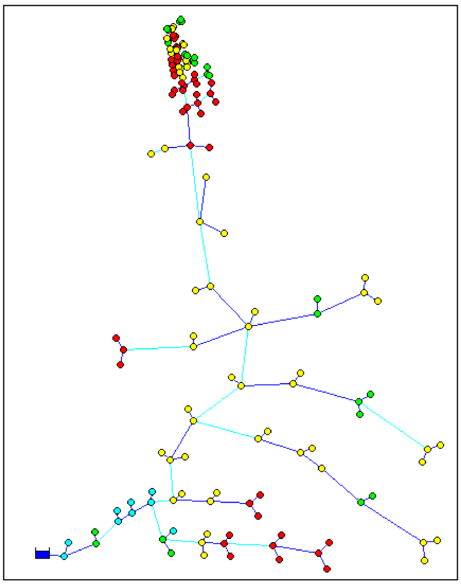


Figure 1. Tuncarta Irrigation System.

2.1. Technical Data and Criteria

The following data and criteria were considered for the design of the study networks and are shown in Table 1.

Table 1. Data and criteria for the design of irrigation networks.

TECHNICAL DATA AND CRITERIA	
Minimum permissible speed (m/s)	0.5
Maximum permissible speed (m/s)	3.0
Dynamic flow viscosity (kg/m·s)	0.001
Flow density (kg/m^3)	1000
Pipe absolute roughness (mm)	0.0015
Amortization period (years)	25
Interest rate (%)	7

2.2. Agronomic and Hydraulic Design of an Irrigation System

Table 2 presents the agronomic and hydraulic data of the Tuncarta network.

Table 2. Agronomic and hydraulic data of the Tuncarta Network.

ACTUAL IRRIGATION DOSE	
Number of hydrants	84
Number of lines	140
Irrigated area (ha)	93.56
Installed capacity (m^3/s)	0.12
Continuous notional flow rate (L/s/ha)	0.35
Set pressure (mwc)	40
Effective Irrigation Day (h)	23.82
Reservoir height free surface (mwc)	1540

2.3. Network Design with the Series Economic Method Enhanced Economic Method (MSEM)

The process for the optimal MSEM sizing of the irrigation networks used in this research is summarized in Figure 2.

Figure 2. Process for optimal design with MSEM.

2.4. Parameters of the Genetic Algorithm

Table 3 lists important GA parameters for the optimal design of the irrigation networks used in this study.

Table 3. GA input parameters.

Parameters	Value
Population Size (n_p)	180–840
Crossover Probability (P_c)	0.8
Mutation probability (P_m)	0.002–0.008
Generation	200–900
Number of shifts	2.3

3. Results and Discussion

3.1. Results

The combination of shifts in the hydrants of the study networks selected for this research is obtained from the distribution of a head-end flow where it is verified that the pressure and velocity values at the nodes of known demand are within the technical design specifications.

Table 4 presents the irrigation time and the flow rate allocated for each shift in the different irrigation networks used.

Table 4. Irrigation times per shift and transfer flows (study networks).

NETWORK	Shift 1		Shift 2		Shift 3	
	Watering Time (h)	Flow (L/s)	Watering Time (h)	Flow (L/s)	Watering Time (h)	Flow (L/s)
Inferior Callén	10.95	800.00	11.76	655.00		
Tuncarta	7.88	34.59	7.94	42.55	7.91	39.09
Cariyacu	11.99	15.51	12.00	15.18		
Cenicero	2.30	144.00	2.30	157.00	2.34	153.00

Table 5 provides a summary of the resulting design after optimization with MSEM. The reference design budget amounts to a total of $28274.62 excluding the cost of installation, accessories, and transport.

The design of the Tuncarta network by using the Genetic Algorithm is provided in Table 6, the cost of which amounts to a total of $32836.25 of pipe, and does not include its installation, fittings, and transport.

Table 5. Tuncarta network design referential budget with MSEM.

Description	Unit	Quantity	Unit Price ($)	Total Cost ($)
PVC-250 pipe 160 mm	m	338.89	19.00	6438.91
PVC-250 pipe 140 mm	m	253.91	15.83	4019.40
PVC-250 pipe 125 mm	m	210.97	12.15	2563.29
PVC-250 pipe 110 mm	m	713.60	8.37	5972.83
PVC-250 pipe 90 mm	m	290.83	5.67	1649.01
PVC-250 pipe 75 mm	m	421.84	4.48	1889.84
PVC-250 pipe 63 mm	m	740.83	3.00	2222.49
PVC-250 pipe 50 mm	m	591.89	1.98	1171.94
PVC-250 pipe 40 mm	m	1100.04	1.35	1485.05
PVC-250 pipe 32 mm	m	239.29	0.70	167.50
PVC-250 pipe 25 mm	m	727.87	0.56	407.61
PVC-250 pipe 20 mm	m	682.73	0.42	286.75
			Final Cost	$28,274.62

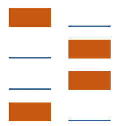
Table 6. Referential budget for the design of the Tuncarta network with Genetic Algorithm.

Description	Unit	Quantity	Unit Price ($)	Total Cost ($)
PVC-250 pipe 315 mm	m	96.17	77.29	7432.98
PVC-250 pipe 200 mm	m	25.1	27.67	694.52
PVC-250 pipe 160 mm	m	131.68	19.00	2501.92
PVC-250 pipe 140 mm	m	138.94	15.83	2199.42
PVC-250 pipe 125 mm	m	159.58	12.15	1938.90
PVC-250 pipe 110 mm	m	571.19	8.37	4780.86
PVC-250 pipe 90 mm	m	968.59	5.67	5491.91
PVC-250 pipe 75 mm	m	466.84	4.48	2091.44
PVC-250 pipe 63 mm	m	591.45	3.00	1774.35
PVC-250 pipe 50 mm	m	639.49	1.98	1266.19
PVC-250 pipe 40 mm	m	1441.15	1.35	1945.55
PVC-250 pipe 32 mm	m	800.14	0.70	560.10
PVC-250 pipe 25 mm	m	282.27	0.56	158.07
PVC-250 pipe 20 mm	m	0.10	0.42	0.04
			Final Cost	$32,836.25

The design of the Tuncarta network under similar design criteria with the two optimization methods leads to a cost that is 13.89% lower with MSEM compared to its design cost with AG. In order to perform the design using AG, around 40 simulations are made with each of the study networks, from which the design cost of the network of the iteration with the lowest cost value is adopted. The design costs of the Inferior Callén and Cenicero networks are lower with the application of the Genetic Algorithm compared to the design resulting from the MSEM optimization method.

The design costs of the study networks with the two optimization methods are presented in Table 7; column 4 (MSEM and AG network graph) indicates the method with the higher cost.

Table 7. Cost difference between SEM and AG network design.

Networks	MSEM Cost [$]	AG Cost [$]	Network Design MSEM and AG
(C1)	(C2)	(C3)	(C4)
Inferior Callén	1,925,878.00	1,907,353.82	
Tuncarta	28,274.60	32,836.25	
Cariyacu	9708.50	11,443.86	
Cenicero	371,171.10	304,211.89	

3.2. Discussion

The design of the Callén Inferior and Cenicero networks with the Genetic Algorithm presented a cost reduction of 0.97% and 18.04%, respectively, in relation to the design cost with the MSEM. The resulting design cost for the Tuncarta and Cariyacu networks with the MSEM was 14% and 15% lower than the design cost with the Genetic Algorithm, respectively.

In the four network designs, the set point pressures at each of the hydrants in the different shifts, as well as the flow velocity ranges were found to be within the design parameters.

4. Conclusions

The designs of the four irrigation networks under study with the two optimization methods used in this research fulfilled the technical design specifications for the set point pressures at the nodes of known demand, as well as the ranges of flow velocities.

It was revealed that both the Series Economic Enhanced Method (MSEM) optimization method and the Genetic Algorithm were highly useful for the purpose of minimizing the design costs of the four networks that were selected for this study.

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