Proceedings

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

C. Mireya Lapo P. [1], Marilyn López [2], F. Javier Martínez-Solano [3] and Ricardo Aliod [4]

[1]   Universidad Técnica Particular de Loja; cmlapo@utpl.edu.ec
[2]   Universidad Técnica Particular de Loja; mslopez5@utpl.edu.ec
[3]   Universitat Politècnica de València; jmsolano@upv.es
[4]   Universidad de Zaragoza; raliod@unizar.es
*   Correspondence:
[†]   Presented at the 1st International Online Conference on Agriculture-Advances in Agricultural Science and Technology (IOCAG2022), 10–25 February 2022; Available online: https://iocag2022.sciforum.net/.

Abstract: Agriculture is one of the axes corresponding to the development that faces innovation challenges every day. One of the most important aspects within this field is the design of pressurised collective irrigation systems. The aim of this paper is to compare the design of pressurised collective irrigation networks by using the method of optimisation of the Improved Economic Series (MSEM) with an optimisation method using Genetic Algorithm (GA). For this purpose, a methodology with an ordered sequence was developed and after the input as 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; optimisation; optimised economic series; irrigation systems; shifts

1. Introduction

Nowadays, global food security is at risk. This compared to 2019, when almost one in three people did not have access to adequate food during 2020 under the effects of COVID-19 pandemic (FAO 2021). In this scenery it is vital to seek mechanisms for efficient and optimal management of irrigation systems.

In one hand, for designing or optimal management of distribution networks, the usage of algorithms or optimization processes that provide a set of feasible solutions for areas of interest is considered (Afshar et al., 2005). 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 of irrigation networks operating on demand (Planells et al., 2007), and supply pipes with the Economic Series Method (ESM) by selecting piping diameters with increasing pressure gradient per unit of maximum cost to meet all pressure requirements (Labye, 1966), obtaining good results that are evident in the works of Karmeli et al., 1968; Calhoun, 1970; Robinson & Austin, 1976; Bhave, 1979, Pleban & Amir, 1981; Martínez et al., 1987. González y Aliod (2003) improve the MSE by using different materials and pipe sizes in the design of irrigation networks. García et al. (2011) use the MSEM method to optimize the design of shift irrigation networks. Planells et al. (2001) evaluate the energy cost during an irrigation campaign using Integer Non-linear Programming.; Theocharis et al. (2006)

dimensioned the network with the simplified Non-Linear Programming technique using independent linear equations for pipe design. Kale et al. (2008) use Linear Programming for the optimal design of lateral pipes of a parcel irrigation system. Lamaddalena et al. (2012) use 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 algorithms employed for this purpose are evolutionary algorithms, such as the Genetic Algorithm (GA) is inspired by the natural evolution of the population, as is Darwin's theory of natural selection and Mendel's theory of the transfer of genetic material (Sánchez, 2011). These algorithms evaluate thousands of solutions to determine the most feasible or real solution closest to the optimal design. (Díaz et al., 1996; Todini, 2000; Gonçalves et al., 2014). The GA that does not use integer variables results in high computational efficiency. (Sanhueza, Díaz, and Harnisch 1997) and is suitable for application to the analysis of real-size networks. Such is the case of Farmani, Abadia & Savic (2007) 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 that allows water to reach from the collection point to the user for human consumption or irrigation needs (Reca et al., 2002). A pressurized irrigation system has components such as collection, distribution lines, hydrants, etc.; which together with pressure and flow control devices facilitate good operation (Khadra & Lamaddalena, 2010). 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) (Lapo, 2019; Alandí et al., 2007).

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, the network was designed with optimization methods (Improved Economic Series MSEM and Genetic Algorithm AG), and the design results obtained with the selected optimization techniques were compared and analyzed. The Tuncarta irrigation network was used to explain the methodology (Figure 1).

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.

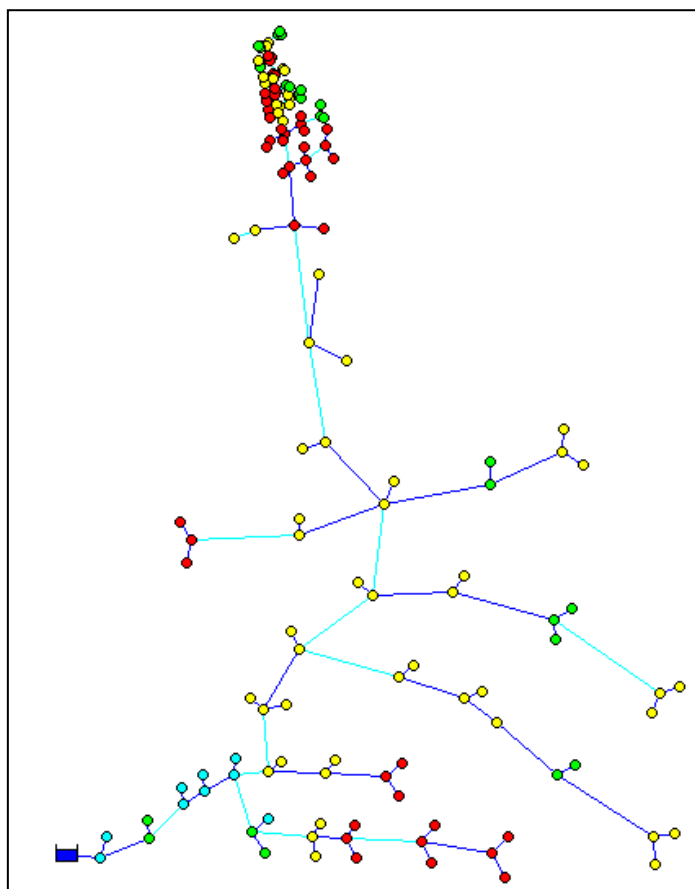| TECHNICAL DATA AND CRITERIA	
Minimum permissible speed (m/s)	0.5
Maximum permissible speed (m/s)	3.0
Dynamic flow viscosity (kg/m·s)	0.001
Flow density (kg/m^3)	1000
Pipe absolute roughness (mm)	0.0015
Amortization period (years)	25
Interest rate (%)	7

Figure 1. Tuncarta Irrigation System.

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 mm
Number of lines	140
Irrigated area (ha)	93.56
Installed capacity (m³/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 optimal MSEM sizing of the irrigation networks used in this research is summarized in Figure 2.

2.4. Parameters of the Genetic Algorithm

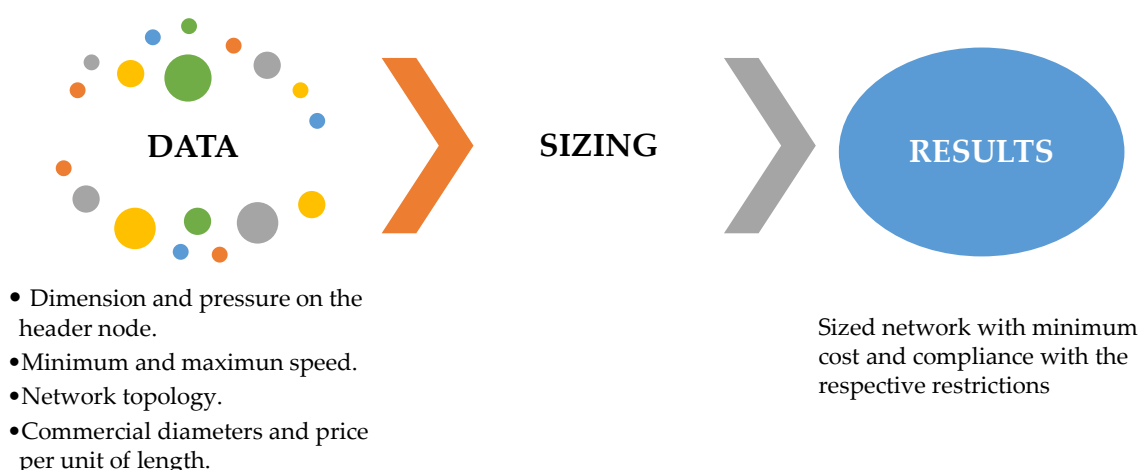Table 3 lists important GA parameters for the optimal design of the irrigation networks used in this study.

Figure 2. Process for optimal design with MSEM.

Table 3. GA input parameters.

Parameters	Value
Population Size (n_p)	180 a 840
Crossover Probability (P_c)	0.8
Mutation probability (P_m)	0.002 a 0.008
Generation	200 a 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 optimisation with MSEM. The reference design budget amounts to a total of $28,274.62 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 $32,836.25 of pipe, does not include its installation, fittings, and transport.

The design of the Tuncarta network under similar design criteria with the two optimisation methods leads to a cost of 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.

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. Referencial 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 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 optimisation 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) optimisation method and the Genetic Algorithm were highly useful for the purpose of minimising the design costs of the four networks that were selected for this study.

Institutional Review Board Statement:

Informed Consent Statement:

Data Availability Statement:

References

1. Afshar, M.H.; Akbari, M.; Mariño, M.A. Simultaneous Layout and Size Optimization of Water Distribution Networks: Engineering Approach. *J. Infrastruct. Syst.* **2005**, *11*, 221–230. https://doi.org/10.1061/(asce)1076-0342(2005)11:4(221).
2. Alandí, P.P.; Álvarez, J.O.; Martin-Benito, J.M.T. Optimization of Irrigation Water Distribution Networks, Layout Included. *Agric. Water Manag.* **2007**, *88*, 110–118. https://doi.org/10.1016/j.agwat.2006.10.004.
3. Bhave, P.R Selecting Pipe Sizes in Network Optimization by Linear Programming. *J. Hydraul. Div. (ASCE)* **1979**, *105*, 1019–1025.
4. Calhoun, C.A. Optimization od Pipe Systems by Linear Programming. In Proceedings of the Institute on Control of Flow in Closed Conduits; Tullis, J.P.; Ed.; Colorado State University: Fort Collins, CO, USA, 1970; pp. 175–192.
5. Díaz, A.; González, J.L.; Glover, F.; Ghaziri, H.M.; Laguna, M.; Moscato, P.; Tseng, F.T. *Optimización Heurística y Redes Neuronales*; Paraninfo: Madrid, Spain, 1996.
6. Farmani, R.; Abadia, R.; Savić, D. Optimum Design and Management od Pressurized Branched Irrigarion Networks. *J. Irrig. Drain. Eng.* **2007**, *133*, 528–537. https://doi.org/10.1061/(ASCE)0733-9437(2007)133:6(528).
7. FAO. El Estado *Mundial de la Agricultura y la Alimentación 2021: Lograr Que Los Sistemas Agroalimentarios Sean Mas Resistentes a Las Perturbaciones y Tensiones*; Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO): Rome, Italy, 2021.
8. García, S.; Ruiz, R., Aliod, R., Paño, J.; Sera, P.; Faci, E. Nueva Herramienta Implementadas en GESTAR 2010 para el Dimensionado de Tuberías Principales en Redes de Distribución en Parcela y Redes de Distribución General a Turnos. J. Bebel Vecino (Presidencia), Hacia un Regadío Eficiente y Rentable. Simposio Llevado a Cabo en el XXIX Congreso Nacional de Riegos. Córdoba, España. Available online: http://www.aeryd.es/escaparate/gmms/aeryd/buscadortrabajos?accion=ver&id=7355 (accessed on June 2011).
9. Gonçalves, G.M.; Gouveia, L.; Pato, M.V. An Improved Decomposition-Based Heuristic to Design a Water Distribution Network for an Irrigation System. *Ann. Oper. Res.* **2014**, *219*, 141–167. https://doi.org/10.1007/s10479-011-1036-7.
10. González, C.; Aliod, R. *Mejoras en el Método Dimensionado de Redes Ramificadas*; XXI Congreso Nacional de Riegos: 2003; pp. 1–2.
11. Kale, R.V.; Singh, R.P.; Mahar, P.S. Optimal Design of Pressurized Irrigation Subunit. *J. Irrig. Drain. Eng.* **2008**, *134*, 137–146. https://doi.org/10.1061/(asce)0733-9437(2008)134:2(137).
12. Karmeli, D.; Gadish, Y.; Meyers, S. Design of Optimal Water Distribution Networks. *J. Pipeline Div. (ASCE)* **1968**, *94*, 1–10.
13. Khadra, R.; Lamaddalena, N. Development of a Decision Support System for Irrigation Systems Analysis. *Water Resour. Manag.* **2010**, *24*, 3279–3297. https://doi.org/10.1007/s11269-010-9606-z.
14. Labye, Y. Etude des Procédés de Calcul Ayant PourBut de Rendre Minimal le Cout d' un Reseau de Distribution d' Eau Sous Presion. *La Houille Blanche* **1966**, *5*, 577-583.
15. Lamaddalena, N.; Khadra, R.; Tlili, Y. Reliabily-Based Pipe Size Computation of On-Demand Irrigation Systems. *Water Resour. Manag.* **2012**, *26*, 307–328. https://doi.org/10.1007/s11269-011-9919-6.
16. Lapo Pauta, C.M. *Diseño Óptimo de Redes de Riego a Presión Para su Explotación a Turnos [Tesis doctoral, defendida en la Universitat Politècnica de València]*; Universidad Politécnica de Valencia: Spain. 2019. Available online: https://riunet.upv.es/handle/10251/

130210 (accessed on 2019).

17. Martínez, F.; Sanz, F.; García-Serra, J.; Cerrillo, J.L. Dimensionado Optimo de Redes Ramificadas de Distribución de Agua por Programacion Lineal. *Tecnología del Agua* **1987**, *40*, 73–90.
18. Planells, P.; Martín-Benito, J.M.T.; Ortega, J.F. Optimización de Estaciones de bombeo en riego a la Demanda. *Ingeniería del Agua* **2001**, *8*, 39–51.
19. Planells, P.; Ortega, J.F.; Tarjuelo, J.M. Optimization of irrigation water distribution networks. layout included. *Agric. Water Manag.* **2007**, *88*, 110–118.
20. Pleban, S.; Amir, I. An Interactive Computerized Aid for the Desing of Branching Irrigation Networks. *Am. Soc. Agric. Eng.* **1981**, *24*, 358–361.
21. Cardeña, J.R.; López, J.M.; Cañas, J.R.; Baena, J.L.C. Análisis de La Fiabilidad de Una Red de Riego En Función de La Simultaneidad de La Demanda. *Ingeniería Del Agua* **2002**, *9*, 157. https://doi.org/10.4995/ia.2002.2612.
22. Robinson, R.B.; Austin, T.A. A Cost Optimization of rural water systems. *J. Hydraul. Div. ASCE* **1976**, *102*, 119–34.
23. Sánchez, D. Diseño Óptimo de Laminados En Materiales Compuestos. In *Aplicación Del MEF y El Método de Las Superficies de Respuesta*; 2011; pp. 98–104.
24. Sanhueza, R.; Díaz, R.; Horacio Harnisch, V. IIdefonso Un método heurístico para el Diseño topológico de redes de distribución primaria. In *Revista Facultad de Ingeniera, Núm 4, Enero-Diciembre*; Universidad de Tarapacá: Chile, 1997; pp. 27–34.
25. Theocharis, E.; Tzimopoulos, D.; Yannopoulos, I.; Sakellariou, M. Dseing of optimal irrigation networks. *Irrig. Drain.* **2006**, *55*, 21–32. https://doi.org/10.102/ird.214.
26. Todini, E. Looped Water Distribution Networks Design Using a Resilience Index Based Heuristic Approach. *Urban Water* **2000**, *2*, 115–122. https://doi.org/10.1016/s1462-0758(00)00049-2.