Multi-criteria optimization of supply schedules in intermittent water supply systems

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Abstract

One of the problems for water supply systems with intermittent supply is the peak flow produced at some hours of the day, which is usually much larger than that in a system with continuous supply. The main consequence is the reduction of pressure and flow at the ends or highest points of the system network. This, in turn, generates inequity in water supply and complaints from users. To reduce the peak flow, some sectors of the system must be assigned a different supply schedule. As a result, the supply curve is modified, and the peak flow is reduced. This reorganization seeks some optimal allocation schedule and must be based on various quantitative and qualitative technical criteria.

This paper hybridises integer linear programming and multi-criteria analysis to contribute with a solution proposal to the technical management of intermittent water supply systems, which provides short-term results and requires little investment for implementation. This solution does not seek perpetuating intermittent water supply. On the contrary, this methodology can be a useful tool in gradual transition processes from intermittent to continuous supply.

Keywords: Intermittent water supply, water supply schedule, multi-criteria analysis, optimization.

Introduction

Intermittent water supply (IWS) is the way in which millions of people worldwide have access to water currently [1]. Some researchers suggest that the increasing water scarcity due to the climate change, and the increasing demand caused by the upsurge in population, may lead to a more frequent use of intermittent supply [2]. However, intermittent water supply should be the very last step to take in terms of water scarcity. This situation should be avoided by proactive planning and appropriate responses to critical conditions [3].

A water supply system is considered to provide IWS, when the supply of the service is performed for a limited period of time. Water is generally supplied daily. However, in extreme cases, this period may be longer than one day. In many small towns with IWS, the service is performed for some hours for the entire network regardless any sector differentiation. However, supply in larger cities is performed by sectors (also called district metered areas) with different delivery schedules. We address here this last situation.

When water companies opt for IWS, they generally aim to reduce the *per capita* water demand with the idea of saving in capital and operating costs. However, IWS brings negative consequences that prevail over the positive factors instead of being a smart strategy [4,5]. Thus, intermittent supply is adopted by necessity rather than by design [6].

Due to the limited hours of supply, and the establishment of delivery schedules with little technical criteria, the peak factor (ratio of peak flow with respect to average flow) increases to values up to 4-6 [7]. As a result, much larger flowrates are delivered during peak hours in comparison with flowrates delivered in continuous systems [8]. This greatly impairs management since, among other drawbacks, it implies greater storage volume and larger diameters in the network to meet hydraulic and demand requirement. Several studies also show that intermittent systems produce insufficient pressure in unfavourable areas or sectors [9,10], generating dissatisfaction and complaints among users.

There is abundant literature on planning, design, operation and maintenance of systems with continuous supply. However, the operation of IWS systems is mainly based on personnel experience, and simple water supply and demand trade-off analyses.

This paper proposes a tool to aid technical management of IWS systems, built on a methodology to manage supply schedules for every sector of the network to improve the conditions of service based on multi-criteria optimization. The objective is to reduce the peak flow produced by the simultaneous supply of sectors by optimally assigning delivery schedules based on technical criteria that can be quantitative and qualitative. These criteria include pressure, amount of available water, effects of pressure increase or decrease, number of users, delivery times, and ease of sector operation, among others. In addition to various engineering variables, the technical expertise of the personnel of the water supply company is included into the optimization process through their opinion, using the Analytic Hierarchy Process (AHP) [11,12] as a multi-criteria decision technique.

In general, IWS is developed in scenarios of physical scarcity, economic scarcity and mismanagement [7]. Generally, the water companies that manage IWS have fewer economic resources. Therefore, proposals to improve the system performance must consist of alternatives that involve minimum human and economic resources. This is a crucial idea that has very important implications in the setting of the problem.

The case study we present corresponds to one of the subsystems of the water supply system of Oruro city (Bolivia), consisting of 15 sectors fed by a single tank.

Methodology

In this section, we detail our approach to optimal allocation of supply schedules to the network sectors with the final aim of efficiently maximizing the quality of service. The building elements are the *supply blocks*, which are first defined, then the criteria for block allocation are stated and, finally, the optimization problem is proposed.

Definition of supply block

In IWS, the pattern of supply tends to be constant by the presence of household deposits. Large flows occur in the first minutes and then flows are reduced at the end of the delivery period. The flow variation is not large, ranging from 20% to 30%. Therefore, the problem can be simplified by calculating the average volume per delivery period (*Vs*) [13], which we call *supply block*. For a given sector, *j*, of the network it is defined by

$$Vs_j = \frac{\text{daily volume supplied to sector } j}{\text{number of supply hours}}. \tag{1}$$

Supply blocks must be allocated to sectors and suitably organized in a new optimal schedule, which meets some technical requirements previously defined. These requirements are derived from a number of criteria, which we consider next.

Criteria for block allocation

Not only quantitative but also qualitative criteria may be used to decide the block allocation into a supply schedule. Quantitative criteria are typically normalized on the basis of values measured for each of the network sectors. Qualitative criteria are dealt with through surveys to experts who are responsible for IWS operation. To deal with qualitative criteria the AHP methodology is used in this paper. Four criteria in total, C1 to C4, are considered here.

The quantitative criteria are the three following.

C1: Pressure. Pressure is an important variable to select the sectors whose water schedule must be modified. We consider that those sectors that have lower operating pressure are the ones that first should change their schedule. We assume that users with lower pressure accept the measures taken to improve their service conditions. The variable used on the basis of this criterion is pressure, with values, pv_j, measured at the inlet of each sector $j = 1, \ldots, n$. However, more adequate values may be introduced by considering the lack of satisfaction of a maximum pressure, $pv_{\max}$, since this better expresses lack of service quality, here in terms of pressure. So, first, pressure values are transformed into new (positive) variables, noted here p'_j,

$$p'_j = pv_{\max} - pv_j . \tag{2}$$

Then, these values are normalized with respect to the *n* sectors:

$$p_j = \frac{p'_j}{\sum_{j=1}^{n} p'_j}. \tag{3}$$

These normalized values are the components of vector

$$P = (p_1, p_2, \dots, p_n)^T , \tag{4}$$

which will be used later.

C2: Number of users. This sector element, nu_j, is important because the more users one sector has, the lower the suitability of changing the sector supply schedule. We seek for improvement by affecting the current conditions of the smallest possible number of people. It is also an indirect variable that can be transformed into a direct variable, noted l'_j,

$$l'_j = \frac{1}{nu_j} , \tag{5}$$

and then normalized, l_j:

$$l_j = \frac{l'_j}{\sum_{j=1}^{n} l'_j} , \tag{6}$$

Again, a vector L accounts for these normalized values:

$$L = (l_1, l_2, \dots, l_n)^T . \tag{7}$$

C3: Number of supply hours. We assume that a sector with fewer supply hours, nh_j, has greater flexibility in assigning a new schedule, mainly, because, as said, schedules must be managed in supply blocks. The related variable with supply hours affects once more inversely to the objective function. We also transform it into a direct variable, r'_j:

$$r'_j = \frac{1}{nh_j} , \tag{8}$$

then normalized, r_j:

$$r_j = \frac{r'_j}{\sum_{j=1}^{n} r'_j} , \tag{9}$$

and, finally, assembled into vector R:

$$R = (r_1, r_2, \dots, r_n)^T . \tag{10}$$

The qualitative criterion is now described.

C4: Ease of operation of the sectors. It depends on such various factors as availability, proper performance and accessibility of sectorisation valves; working difficulty for operators, mainly manual operation; complaints from the users; and others. To assess on this qualitative variable, experts from the water company are consulted following the AHP methodology. The weight of this variable for every sector is the normalized geometric mean of the eigenvectors of the pairwise comparison matrices issued by the experts [14], thus producing the vector E of weighted priorities expressing easiness in operating each sector

$$E = (e_1, e_2, \ldots, e_n)^T \ . \qquad (11)$$

Let us compile these four vectors, (4), (7), (10) and (11), by columns, in a matrix

$$C = (P; L; R; E) \qquad (12)$$

of *raw* criteria per sector.

Since four criteria, which are not easily comparable, are considered, experts are also consulted about the weight that, under their expertise, each criterion should be assigned in the optimization problem. Using again the geometric mean of the eigenvalues for the comparison matrices of the experts, weights for pressure, *wp'*; number of users, *wu'*; supply hours, *wh'*; and ease of operation, *wo'*, are derived. Let us consider the matrix

$$W' = \mathrm{diag}(wp', wu', wh', wo'). \qquad (13)$$

The product of matrix C in (12) and this weighting matrix, W' in (13), results in a new matrix, $W = CW'$, of *weighted* criteria per sector. Just for convenience, let us note W by columns,

$$W = (wp; wu; wh; wo). \qquad (14)$$

These weights are used in the objective function, as explained below.

Optimization problem

After defining the weights for each of the variables by sectors, which correspond to problem data, we proceed with the optimization problem consisting in the allocation of optimal new schedules for each sector. For this process, we propose the use of binary variables introduced in the objective function in combination with the weights for the criteria by sectors already considered (14). These binary variables, which are the decision variables of our problem, are collected in a matrix V of size $m \times n$, where m is the total number of periods (typically hours) per day, and n is the total number of sectors. A value $v_{ij} = 1$ in this matrix indicates the start of supply for sector j at period i. A zero value shifts to no-supply. For financial and technical reasons, in the line of the last idea issued in the introduction, a given sector is supplied only once per day. This makes that only one entry of each column of V is non-zero. This is forced by one of the problem constraints detailed later.

In addition, in the process of reallocation of supply schedules, as said before, we consider movements in blocks within the entire supply period for a sector j, regardless of its duration, h_j. To this purpose, we propose the use of supply pattern matrices for each sector j. Such a supply pattern matrix $U^{(j)}$ is a circulant[1] matrix, of size $m \times m$, defined by the m-vector

$$u^{(j)} = (1, \ldots, 1, 0, \ldots 0)^{\mathrm{T}}, \qquad (15)$$

where the number of 1's is h_j, the number of periods (hours, in general) of supply for sector j.

For example, for $m = 12$ (two-hour periods of supply in a day) and $h = 4$ (corresponding to a sector with 4 supply periods), one such matrix is:

[1] A circulant matrix, U, is fully specified by one vector, u, which appears as the first column of U. The remaining columns of U are each cyclic permutations of the vector c with offset equal to the column index.

$$U = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \end{pmatrix}. \tag{16}$$

We have so many U matrices of type (16) as sectors, which differ in the number of supply periods of each sector, that is to say in the number of 1's in each of its rows. These matrices enable us to calculate the supply schedule vector X_j for each sector j:

$$X_j = U^{(j)} V_j , \tag{17}$$

where V_j is the j-th column of V. Coordinates equal to 1 in X_j indicate supply periods for sector j, while coordinates equal to 0 correspond to no-supply periods for the same sector. Let us call X the matrix whose columns are X_j.

The main goal of our problem seeks to maximize the quality of service in terms of 1) pressures close to some reference pressure, 2) nuisance for the lower amount of consumers, 3) modification of shorter supply schedules, and 4) ease in sector operation. These specific goals enter the main part of the objective function through maximizing the sum of all the entries of the matrix, XW, the product of matrix X of sector schedules, with columns given by (17), and matrix W (14) of weights associated to those sectors and the considered variables. For the sake of clarity we explicit this objective:

$$\sum_{i=1}^{m} \left(\sum_{j=1}^{n} wp_j \cdot x_{ij} + \sum_{j=1}^{n} wu_j \cdot x_{ij} + \sum_{j=1}^{n} wh_j \cdot x_{ij} + \sum_{j=1}^{n} wo_j \cdot x_{ij} \right). \tag{18}$$

However, other additional goals must be achieved.

First, in order to minimize the number of changes with respect to the current schedule, we try to adhere as much as possible to this schedule. To this purpose we use a binary matrix S of size $m \times n$, whose columns define the current delivery schedule of each sector ($s_{ij} = 1$ in hours with water supply).

We must also include in the objective function the information of the water volume per hour entering the tank. The normalized value for this volume is denoted by t_i. The hours in which more water enters the tank will be thus prioritized, which is crucial in solving this problem.

Finally, there is also the possibility of sectors operating in cascade [15]. We consider here the supply hour s_{ix} and supply volume x_{iy} of the sector y cascading from sector x.

These elements enable us to configure the complete optimization problem. The entire objective function is obtained by adding to (18) terms corresponding to these additional goals. The problem may be stated as:

Maximize:

$$\sum_{i=1}^{m}\left(\sum_{j=1}^{n} wp_j \cdot x_{ij} + \sum_{j=1}^{n} wu_j \cdot x_{ij} + \sum_{j=1}^{n} wh_j \cdot x_{ij} + \sum_{j=1}^{n} wo_j \cdot x_{ij} + \sum_{j=1}^{n} s_{ij} \cdot x_{ij} + t_i \cdot \sum_{j=1}^{n} x_{ij} + s_{ix} \cdot x_{iy}\right) \quad (19)$$

Subject to:

$$\sum_{i=1}^{m} v_{i1} = 1;\ \sum_{i=1}^{m} v_{i2} = 1\ ;\ \ldots ;\ \sum_{i=1}^{m} v_{in} = 1$$

$$\sum_{j=1}^{n} x_{1j} \le SS\ ;\ \sum_{j=1}^{n} x_{2j} \le SS\ ;\ \ldots ;\ \sum_{j=1}^{n} x_{mj} \le SS\ . \quad (20)$$

$$\sum_{i=1}^{n} b_{1i} \le VS\ ;\ \sum_{i=1}^{n} b_{2i} \le VS\ ;\ \ldots ;\ \sum_{i=1}^{n} b_{mi} \le VS$$

The first set of constraints in (20) limits the number of supply periods per day. Thus, as said before, each sector has only one supply period.

In the second set of constraints, the number of sectors that can work simultaneously (*SS*) is limited in order to reduce peak flows and to improve the operation tasks.

The output volume of the tank, *VS*, generates a crucial constraint in the optimization process. This value allows us to rearrange the supply schedule of each sector and to find scenarios with better service conditions. By multiplying the hourly volume Vs_j (1) by the supply schedule vector X_j (17) correspondingly, we obtain the volume delivered to each sector in the corresponding period, represented by vector B_j:

$$B_j = Vs_j \cdot (x_{1j},\ x_{2j},\ \ldots,\ x_{mj}) = (b_{1j}, b_{2j}, \ldots, b_{mj}), \quad (21)$$

appearing in the last set of constraints.

This completely defines the optimization problem, which is now solved by using integer linear programming.

Eventually, all the solutions must be validated using a hydraulic simulator. For the hydraulic simulations of the network we use EPANET 2 [16] modified by Pathirana [17]. Network modelling and simulation using DDA (Demand Driven Analysis) is difficult due to the periods without supply [18] and the presence of household tanks. Consequently, for hydraulic verification of periods with pressure we use a PDD model (Pressure Dependent Demand o Pressure Driven Demand) [10,17,19,20].

Case of study

The proposed methodology is applied to the south subsystem of the supply network of Oruro city (Bolivia). This network is configured by fifteen sectors with a single feed point (tank).

Daily volume supplied, current supply schedule (Figure 1), number of supply hours, pressure, number of users of each of the sectors and volume entering the tank each hour (Figure 2) are known.

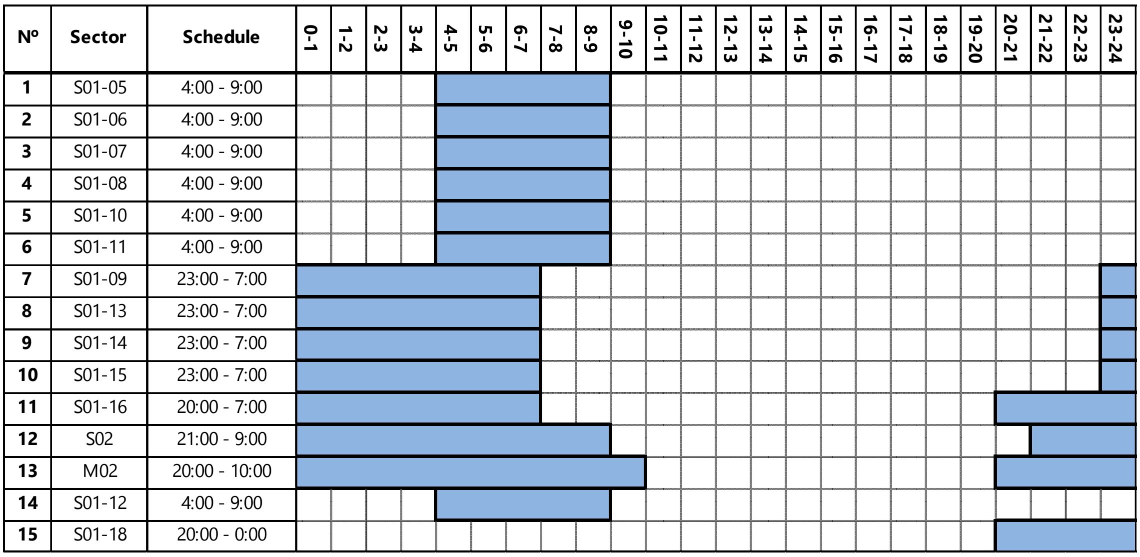

Figure 1. Supply schedule of each sector, south subsystem Oruro.

With information related to the supply volume in each sector, the supply hours and the supply schedule, we can calculate the supply blocks (Table 1) and the current supply curve (Fig. 2). In this curve a peak factor of 3.6 is obtained. This peak factor poses serious problems to water supply management of the subnetwork.

Table 1. Average flow of the period of supply or supply block in each sector

Sector	*Number of supply hours*	*Daily volume supplied to sector (m^3/d)*	*Vs (m^3/h)*	*Vs (l/s)*
S01-05	5	75.99	15.2	4.22
S01-06	5	230.46	46.09	12.80
S01-07	5	342.86	68.57	19.05
S01-08	5	182.08	36.42	10.12
S01-10	5	139.65	27.93	7.76
S01-11	5	110.1	22.02	6.12
S01-09	8	196.03	24.5	6.81
S01-13	8	341.32	42.66	11.85
S01-14	8	91.7	11.46	3.18
S01-15	8	89.54	11.19	3.11
S01-16	11	184.46	16.77	4.66
S02	12	292.88	24.41	6.78
M02	14	142.18	10.16	2.82
S01-12	5	590.97	118.19	32.83
S01-18	4	168.62	42.16	11.71
Total		**3178.83**	**517.73**	

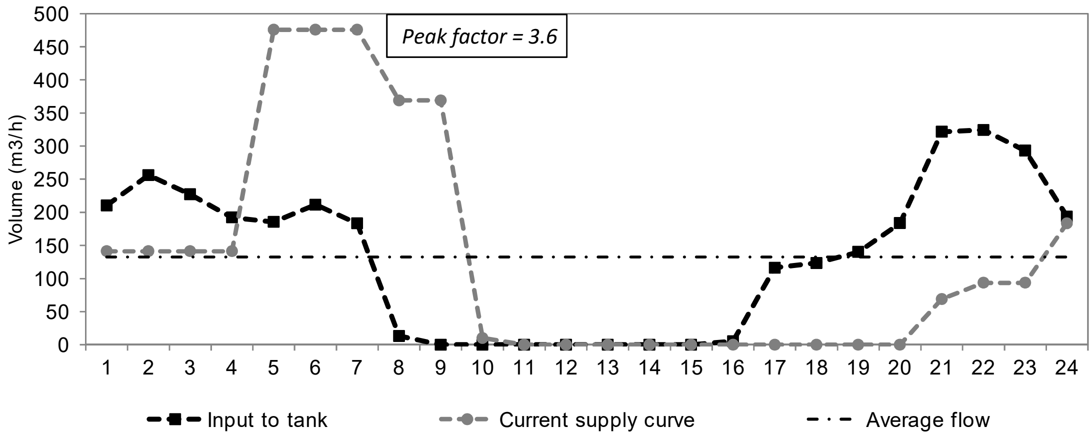

Figure 2. Volume entering the tank and IWS current supply curve

Quantitative variables are normalized in Table 2.

Table 2. Normalization of quantitative variables

Sector	vp_i *(m)*	p'_i	p_i	nu_i	l'_i	l_i	nh_i	r'_i	r_i
S01-05	40.03	1.67	0.005	147	0.0068	0.164	5	0.20	0.083
S01-06	16.83	24.87	0.075	467	0.0021	0.052	5	0.20	0.083
S01-07	19.44	22.26	0.067	593	0.0017	0.041	5	0.20	0.083
S01-08	22.1	19.6	0.059	437	0.0023	0.055	5	0.20	0.083
S01-10	20.06	21.64	0.065	385	0.0026	0.063	5	0.20	0.083
S01-11	11.95	29.75	0.089	244	0.0041	0.099	5	0.20	0.083
S01-09	30.02	11.68	0.035	515	0.0019	0.047	8	0.13	0.052
S01-13	4.44	37.26	0.112	1065	0.0009	0.023	8	0.13	0.052
S01-14	15.56	26.14	0.079	276	0.0036	0.087	8	0.13	0.052
S01-15	15.67	26.03	0.078	211	0.0047	0.114	8	0.13	0.052
S01-16	0	41.7	0.125	918	0.0011	0.026	11	0.09	0.038
S02	41.7	0	0	575	0.0017	0.042	12	0.08	0.035
M02	26.12	15.58	0.047	237	0.0042	0.102	14	0.07	0.03
S01-12	2.01	39.69	0.119	1085	0.0009	0.022	5	0.20	0.083
S01-18	26.77	14.93	0.045	385	0.0026	0.063	4	0.25	0.104
Total:		**332.8**	**1**		**0.0414**	**1**		**2.4**	**1**

To deal with the qualitative criterion, namely, ease of operation of the sector, three experts who manage the IWS subsystem of Oruro are consulted. Pairwise comparison matrices, using techniques for consistency improvement (see [21, 22]), if necessary, achieve consistency ratios (*CR*) lower than 10%, which support experts' priorities through the corresponding eigenvectors (Table 3).

Table 3. Eigenvector of each expert for ease of operation criterion

Sector	**Expert 1**	**Expert 2**	**Expert 3**	**Geometric mean**
S01-05	0.0915	0.0924	0.0904	0.0915
S01-06	0.0350	0.0384	0.0313	0.0348
S01-07	0.0317	0.0322	0.0317	0.0318
S01-08	0.0786	0.0791	0.0791	0.0789
S01-10	0.0698	0.0701	0.0703	0.0701
S01-11	0.0736	0.0739	0.0740	0.0738
S01-09	0.0895	0.0862	0.0922	0.0893

S01-13	0.0922	0.0929	0.0923	0.0925
S01-14	0.0922	0.0929	0.0962	0.0938
S01-15	0.0922	0.0929	0.0923	0.0925
S01-16	0.0572	0.0542	0.0533	0.0549
S02	0.0405	0.0417	0.0412	0.0411
M02	0.0100	0.0097	0.0107	0.0101
S01-12	0.0535	0.0577	0.0526	0.0546
S01-18	0.0922	0.0858	0.0923	0.0901
Total	**1.000**	**1.000**	**1.000**	**1.000**

The weight for each criterion is also calculated using the AHP methodology; as an example, Table 4 presents the pairwise comparison matrix for the four criteria according to expert 1, which reaches a *CR* of 1.2%. In Table 5 the total weight of each criterion is calculated. With these values and the normalized quantitative variables we can calculate the weight of each sector according to each criterion (Table 6).

Table 4. Pairwise comparison matrix, Expert 1

	C1	C2	C3	C4	Eigenvector
C1	**1**	1	1	1/3	0.1581
C2	**1**	**1**	1	1/3	0.1581
C3	**1**	**1**	**1**	1/5	0.1401
C4	**3**	**3**	**5**	**1**	0.5437

Table 5. Eigenvector of each expert and weighting for each criterion

Criterion	Expert 1	Expert 2	Expert 3	Geometric mean	Normalized weight	Weight
C1	0.1581	0.2098	0.1684	0.1774	0.1784	wp'=2.6765
C2	0.1581	0.1579	0.1869	0.1671	0.1680	wc'=2.5203
C3	0.1401	0.1069	0.0746	0.1038	0.1043	wh'=1.5651
C4	0.5437	0.5255	0.5700	0.5461	0.5492	wo'=8.2380

Table 6. Weights of each sector according to each criterion

Sector	C1 *wp*	C2 *wu*	C3 *wh*	C4 *wo*
S01-05	0.013	0.414	0.131	0.754
S01-06	0.200	0.130	0.131	0.287
S01-07	0.179	0.103	0.131	0.262
S01-08	0.158	0.139	0.131	0.650
S01-10	0.174	0.158	0.131	0.577
S01-11	0.239	0.249	0.131	0.609
S01-09	0.094	0.118	0.082	0.736
S01-13	0.300	0.057	0.082	0.762
S01-14	0.210	0.220	0.082	0.773
S01-15	0.209	0.288	0.082	0.762
S01-16	0.335	0.066	0.059	0.452
S02	0.000	0.106	0.054	0.339
M02	0.125	0.257	0.047	0.083
S01-12	0.319	0.056	0.131	0.450
S01-18	0.120	0.158	0.163	0.742

Results and discussion

Multiple values for restricting the output volume of the tank, which create different scenarios, are adopted. The lower the output volume the more sectors have to modify their supply schedule and the lower the number of sectors working simultaneously. The results are summarized in Table 7.

Table 7. Scenarios for different output tank volumes

Scenario	*VS (m3/h)*	*SS*	*Calculated output volume (m^3/h)*	*Calculated output flow (l/s)*	*Peak factor*	*Volume of the tank (m^3)*	*Simultaneous sectors*	*Number of modified sectors*
Initial	500	15	475.58	132.1	3.59	1767.15	14	0
1	450	15	357.38	99.27	2.70	1539.18	13	1
2	350	15	314.72	87.42	2.38	1090.86	12	3
3	300	15	288.81	80.23	2.18	748	11	3
4	250	15	246.15	68.38	1.86	1296.3	11	3
5	200	15	183.31	55.39	1.38	816.8	9	8
6	150	15	147.44	40.96	1.11	1196.74	7	11

The optimization process selects sectors that must change their schedules moving supply blocks to reach an optimal schedule based on quantitative and qualitative criteria. Thereby, we reduce the peak flow that is characteristic of intermittent supply systems. As an example, scenario 2, for a tank volume of 350 m^3/h, produces the schedule reconfiguration shown in Figure 3.

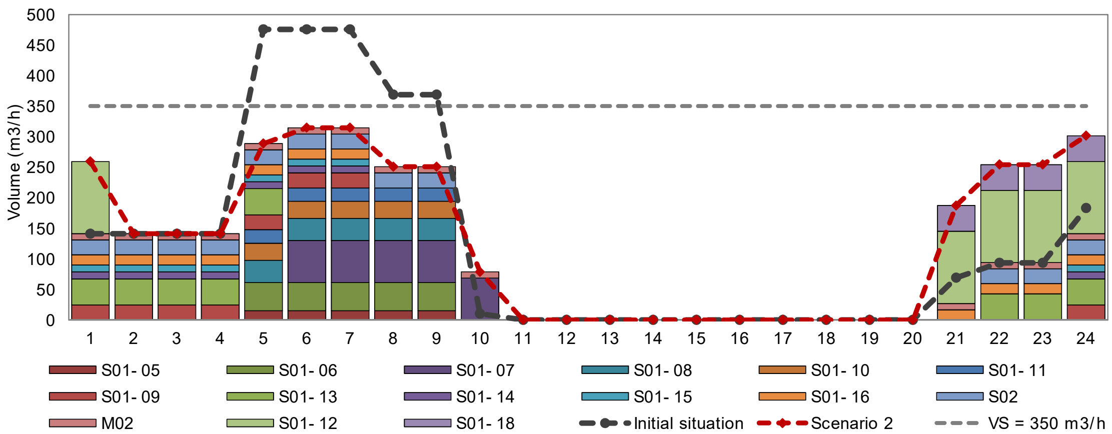

Figure 3. Optimizing supply schedules for scenario *VS* = 350 m^3/h

Suitably reorganizing supply schedules tends to a horizontal supply curve. However, in this way a larger number of sectors have to modify their schedule, which can affect users and complicate the operation of the network. In any case, selecting the best scenario will eventually be a decision of the water company.

After setting the new supply schedule and the corresponding supply curve, we proceed with the necessary hydraulic verifications, using peak flows occurring in the peak hour of every scenario. The hydraulic calculations show that pressures improve with the optimized change of sector schedule (Table 8). The method used for calculating pressure is PDD.

Table 8. Calculation of pressure (m) at peak hour for each scenario

Sector	*Actual PDD*	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*
S01-05	40.03	39.71	40.59	43.60	45.19	46.62	48.82
S01-06	16.83	19.22	22.06	25.17	26.23	-	35.99
S01-07	19.44	19.77	20.42	-	-	-	-
S01-08	22.10	24.51	26.54	30.17	31.42	33.49	-
S01-10	20.06	23.83	26.64	30.23	31.37	33.63	-
S01-11	11.95	14.68	16.40	18.60	19.28	20.65	28.26
S01-09	30.02	29.33	29.81	31.44	33.09	-	-
S01-13	4.44	6.43	-	-	-	-	-
S01-14	15.56	19.21	21.93	25.40	26.49	28.64	41.07
S01-15	15.67	20.01	22.50	25.67	26.66	28.62	-
S01-16	-	0.17	2.10	4.53	5.30	6.86	15.22
S02	41.70	40.87	41.47	43.12	44.77	47.04	48.80
M02	26.12	28.94	31.31	35.50	36.74	38.81	50.21
S01-12	2.01	-	-	-	-	-	-

Conclusion

Supply schedule management does not seek to perpetuate IWS. It is intended as a short-term technical management solution, which seeks to improve the conditions of service and therefore improve the quality of life of the population. It is also a useful tool for the gradual transition from intermittent to continuous water supply.

Solutions to make IWS systems work better do not necessarily require the construction of new infrastructure. IWS systems with economic scarcity have reduced economic resources. Accordingly, solutions must be found based on the existing infrastructure, thus demanding minimal human and economic resources.

As a part of the linear programming problem, we propose the use of supply pattern matrices, which play an important role in their resolution. They allow to change sector schedules in blocks. Therefore, they are very useful for this kind of problem. To suitably weight non-comparable criteria use has been made of AHP as a multi-criteria technique.

The change in supply schedules defines a new storage volume in the tank due to the objective function in which the water inlet hours are prioritized. Reorganizing schedules reduces the storage volume, thus the system capacity increases.

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