# Water Supply

# Rehabilitation of operation regimes in aged irrigation schemes based on hydraulic simulation

Hasan Bakhoda Bishehgahi, Atefeh Parvaresh Rizi 🆔* and Amir Mohammadi

Department of Irrigation and Reclamation Engineering, College of Agriculture and Natural Resources, University of Tehran, P.O. Box 4111, 31587-77871, Iran
*Correspondence author. E-mail: parvarsh@ut.ac.ir

🆔 APR, 0000-0003-0793-6728

## ABSTRACT

The selection and employment of proper methods in water distribution causes an increase in water productivity and the level of satisfaction of water users. It is faced with more difficulties in aged irrigation projects due to temporal changes such as changes in the crop patterns, development of the command area and destruction of canals and hydraulic structures. The plan of operation methods have some hydraulic and social complexities and therefore is usually simplified or implemented experimentally. This research investigates the best options for water distribution to the paddy fields in a subunit of Sefidroud irrigation scheme based on field survey, recording real data and hydraulic simulation with the employment of a SOBEK hydrodynamic model. Different operation scenarios were defined and then simulated in the current physical state of the scheme through replacing the exhausted intake structures with sluice gates. Finally, improved operation scenarios during the irrigation season were suggested based on the distribution indices. The results show that in spite of the current situation, water loss could reach the minimum by employing modification scenarios and indices of adequacy and equity of water distribution improve.

**Key words**: fumanat region, indices of water distribution, irrigation canals, operation planning, paddy fields

## HIGHLIGHTS

- Using Hydraulic-Numerical models to assess the operation and rehabilitation phase of an irrigation scheme.
- Proposing and planning for the best operation scenarios based on the hydraulic modeling and practicability.
- Investigation of re-designing some hydraulic structures and their impacts in an aged irrigation scheme using modelling.
- With precise planning while less water is consumed, water distribution indices improve.

## INTRODUCTION

The attention to the problem of water scarcity and the occurrence of droughts, decreased precipitation, the distribution of precipitation in non-farming seasons, and the necessity for optimal operation of limited water resources, show the importance of employing proper managerial approaches in delivery and distribution of water in irrigation networks. Khepar *et al.* (2000) emphasized that equitable distribution of water is essential for increasing productivity. An improved operation can balance the existing water resources and the demands in addition to maximizing the economic benefits and social satisfaction. One of the deficiencies in the design of irrigation networks is inattention to the proper pattern of water operation and distribution by the consultants. Indeed, the most important part of the plan that ensures its success is neglected. This problem takes a new form in older networks. In these networks, there are plans implemented for water distribution and delivery over time, either experimentally or based on expert judgments. Although these plans respond from time to time, the changes in the network over time (including the changes in cultivation patterns, population growth and shrinkage of lands, sedimentation in canals and their transport capacity reductions, exhaustion and destruction of canals and hydraulic structures, unsystematic harvesting by farmers, the development of lands under cultivation, changes in operation and management structures) along with the water scarcity conditions are not parameters easy to disregard and to decide based on experience. More probably, the operation plans should be reviewed and redesigned annually based on the transformations occurring in the network.

Various factors such as planning, design, construction, operation of facilities, maintenance and application of water have an impact on irrigation schemes performance (Small & Svendsen 1990). There have been numerous indicators by researchers to evaluate the performance of irrigation schemes such as: Equity (Molden & Gates 1990; Steiner 1991; Kalu *et al.* 1995), adequacy (Wijayaratna 1986; Goldsmith & Makin 1991), productivity (Burton 1992; Kaushal *et al.* 1992), sustainability (Abernethy 1986; Bos 1997) and flexibility (Merriam *et al.* 2007). These indicators should be considered during operation (Gorantiwar & Smout 2005). Features of performance indicators have been introduced and analyzed in various research. Maintenance indicators (Bos *et al.* 1994), stability (Chambers 1988), durability (El-Awad *et al.* 1991), reliability and predictability (Makin *et al.* 1991; Oad & Sampath 1995), water availability (Plusquellec *et al.* 1990), profitability (Abernethy 1989), resiliency (Mujumdar & Vedula 1992), timeliness of irrigation (Meinzen-Dick 1995; Makadho 1996), irrigation intensity (Sarma & Rao 1997) and regularity (Lenton 1984) have been studied. The necessity of determining optimal plans for water delivery and distribution in irrigation networks has attracted the attention of many researchers. Mishra *et al.* (2001) utilized the Mike11 hydraulic model to improve the operation and management of the Kangsabati irrigation network in western India. They used the measured to planned discharge ratio as an index for evaluating the flow conveyance. Their results indicated overuse of water in upstream reaches. Unal *et al.* (2004) investigated the performance of water delivery in an irrigation network in western Turkey in terms of the competence, equity, efficiency, and reliability indices. The performance of water delivery for the investigated canals was evaluated as inappropriate in each irrigation season in terms of competence, equity, confidence, and reliability. The analysis of spatial and temporal dimensions of these indices reveals that the causative agents of these problems have their roots in the physical structure and in the management section. George *et al.* (2004) focused on the application of computational modeling for exploiting irrigation systems in the existing organizational systems in Vietnam. This process of operation improvement includes the adaptation of supply and demand during 2001 and 2002 and confirms that operation has been carried out regardless of product water demand and proper canal adjustment. Tariq & Latif (2010) used the SIC hydrodynamic model for evaluating the performance of a second level canal in California. Based on the results, the distribution of 80–90% design flow rate was suggested from May to July and 75–90% design flow rate from August to April in order to reduce water loss by a large quota of the canal. Nam *et al.* (2016) identified key issues for water management improvement in the Gimjae irrigation area located in the central region of South Korea. The results of this study classified the water delivery performance indicators in secondary canals as poor for adequacy, good for efficiency and poor for dependability and equity. The analysis of the spatial and temporal distribution of these indicators showed that a part of these deficiencies is rooted in the management and operation and the other is related to the physical structure of the irrigation network. Dejen *et al.* (2015) assessed water supply and demand of the Metahara Irrigation Scheme and evaluated the water delivery performance of 15 offtakes at head, middle and tail reaches of a 10-km long canal. In this study adequacy, efficiency, equity and dependability were used as indicators of water delivery performance. Results showed that average annual irrigation supply is 24% more than the demand. Accordingly, it seems that the major water management challenge is lack of operational rules, which made the delivery inequitable and inefficient. Given the breadth and complexity of irrigation systems, planning for the operation of available water resources is not possible manually or/and experimentally. Consequently, using the results of flow simulation can be the best solution for the planning and operation of the irrigation schemes (Afrasiabikia *et al.* 2017). Most of the time determination of a reliable operation method is not possible with the physical modelling or experimental approaches, and the mathematical models must be utilized. Afrasiabikia *et al.* (2017) conducted a research based on the hydraulic modelling and water distribution indicators to conclude the best practical operation scenarios in the Doroodzan large irrigation scheme in Iran. They also illustrated the status of water distribution in the current situation of network, especially water inadequacy and water losses in the secondary canals. Fan *et al.* (2018) conducted research in the Jiamakou Irrigation Scheme in China. They examined four indicators of adequacy, efficiency, dependability and equity. Results show that the performance of this irrigation scheme was poor in terms of water allocation, but good in terms of water delivery. They suggested that farmers should be trained in allocating irrigation water. Total project efficiency includes conveyance, distribution and field application efficiency as defined by Bos & Nugteren (1990). During comprehensive evaluation, the Varamin Irrigation scheme (Iran) was evaluated in terms of distribution (Mohammadi *et al.* 2018) and conveyance efficiency (Mohammadi *et al.* 2019). The results showed that the use of old equipment and poor management of operation and maintenance caused a decrease in productivity.

In this paper, in order to reconstruct and improve a large scale irrigation scheme, the planning and evaluation of a large scale irrigation network has been carried out using hydraulic modelling and the definition of various alternatives. Meanwhile, acceptable operation methods by water users have been considered in hydraulic modelling. In the published reports or

papers, simultaneous modeling of main canal and secondary canals for a relatively large-scale irrigation network with the aim of improving operation was not observed. Another distinguishing feature of the present study is that the criterion of a suitable plan for physical-hydraulic reconstruction of the irrigation network is the suitability of water distribution indicators. With this method, along with the executive process (which are usually repairs of canals and structures), the mentioned management indicators also improve.

Regarding various problems of operation in irrigation systems in Iran, this research tries to propose solutions for improving water distribution by applying changes in the current operation scenario along with modification of intake structures. Particularly in old irrigation projects, attention to the issue of rehabilitation of canals and hydraulic structures is crucial, for which a scientific plan should be developed. In this research, the BP29 canal was investigated located in the Fumanat F3 construction unit, within the Sefidroud irrigation and drainage scheme in the northern of Iran.

## MATERIALS AND METHODS

### Scheme scope and the studied canal

Sefidroud irrigation and drainage scheme, with an area of 284,000 hectares, is located in Guilan plain in the northern of Iran. As one of the largest and oldest modern irrigation networks in Iran, it covers paddy fields and provides a high percentage of the country's need for rice. Therefore, it plays an important role in the economic development of the region. The structure of this network has undergone some changes during the operation to such an extent that a single managerial plan cannot be responsive to operation demands. The main crop in the network is rice and regarding the water scarcity in recent years, attending to water distribution and delivery plans has become more important than ever. Figure 1 shows the F3 construction unit scope in the Fumanat network in the western part of Guilan plain. The present research was conducted on the BP29 canal in the mention unit. The design flow rate of this canal is 4.3 m³/s and has a length of 9.1 km with a trapezoidal section and concrete lining. It consists of seven duckbill weirs, five vertical drops and five crossover structures of culvert type. Twelve prefabricated intakes and sub-canals were also responsible for water distribution along the canal (Pandam Consulting Engineers 2004).

In the majority of old irrigation networks, lack or deficiency of usable data is the main plight of operations studies. This research has attempted to compensate for this shortage by monitoring information and navigating the region.

Since most of the Neyrpic module are exhausted and are virtually out of work, the possibility of substituting these intakes with sluice gates, a relatively simple and inexpensive method, was investigated and different suggested scenarios were compared. Figure 2 demonstrates the longitudinal profile route of the BP29 canal in SOBEK environment along with the structures available in its route.

### Simulation by SOBEK hydrodynamic model

The hydraulic behavior of the mentioned canal was simulated under different operation scenarios by the SOBEK model, which uses Saint-Venant equations (continuity and momentum equations; Equations (1) and (2)) in solving open
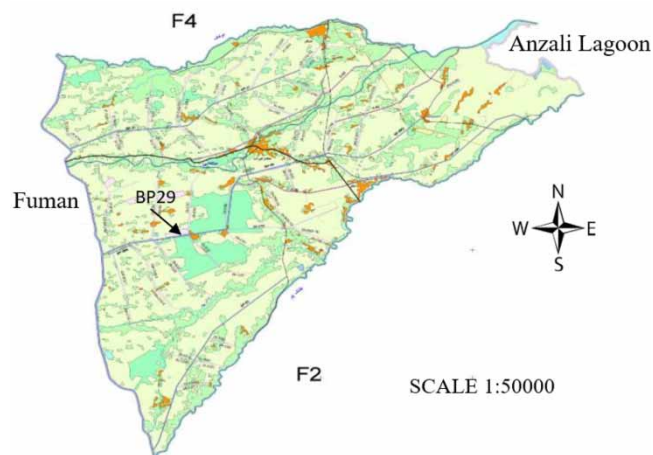


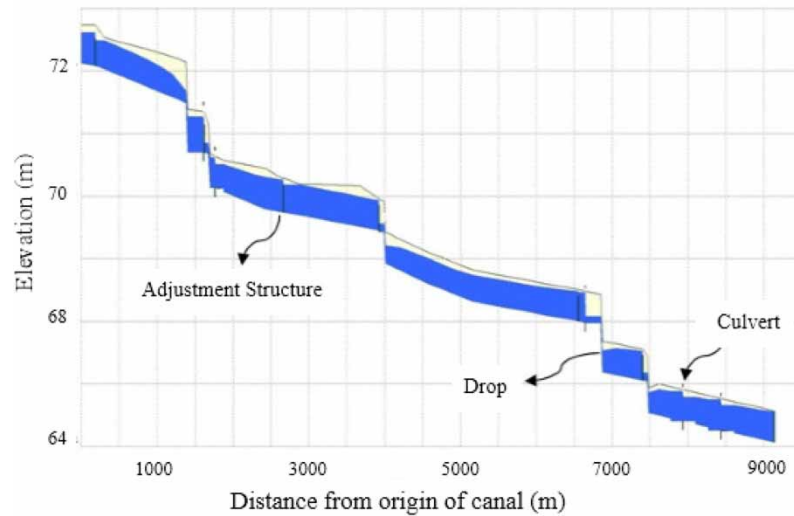**Figure 1** | The schematic view of Fumanat F3 construction unit.

**Figure 2** | The longitudinal profile of BP29 canal in Fumanat F3 unit.

channel flows:

$$\frac{\partial A_f}{\partial t} + \frac{\partial Q}{\partial x} = q_l \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A_f}\right) + g.A_f.\frac{\partial Y}{\partial x} + g.A_f.(S_f - S_b) = 0 \tag{2}$$

In the above equations, $Q$ is the flow rate, $A_f$ is the wetted cross section, $Y$ is the water depth, $g$ is gravity constant, $S_f$ is the friction slope, $S_b$ is the bottom slope of the canal, and $q_1$ is the flow rate of the sub-canal in the canal length unit. The solution of the above equations in SOBEK model is the finite difference method (Delft scheme). The SOBEK model has been presented in the form of a comprehensive package with seven different subprograms for the one- and two-dimensional simulation of irrigation networks, rivers, wetlands, and simulation of water quality, urban wastewater systems, catchment areas and prediction of flood and the online process control. In this research, the subprogram of 1DFLOW (Rural) has been used. This model was obtained in some sections of the BP29 canal and calibrated for the Manning coefficient with an average of 0.016. In addition, regarding the ability of the model for seepage loss, simulation was carried out in the canal with regard to field observations and estimation of transport efficiency provided in the reports of network improvement plan (Pandam Consulting Engineers 2004).

### Water distribution indices

The distribution adequacy: this index is an indicator of the ability of the operation method in delivering water as much as required. Equation (3) is used to quantify of adequacy (Molden & Gates 1990):

$$P_A = \frac{1}{T}\sum_T\left[\frac{1}{R}\sum_R (P_a)\right], \quad P_a = \frac{Q_d}{Qr} \leq 1 \tag{3}$$

In this equation, $P_A$ is the distribution adequacy; $P_a$ is the operation function in each point (actually defined for any intake structure) related to adequacy, $Q_d$ and $Q_t$ are the amount of delivered water (actual amount) and the amount of water required for an intake canal during the period of $T$, respectively. The ideal value of this index is 1 which indicates the complete fitness of the flow rate delivered with the one required for a certain branching. The closer this value to 1, the more appropriate the water distribution method, resulting in the reduction of water scarcity in the sub-canals.

Equity of distribution ($P_E$): Equity deals with the distribution of water between users (Sampath 1989). This index examines how much delivered and required amounts of water match each other in branches and further evaluate different time periods

(Equation (4)). The ideal value of this index is zero. Whatever value of this index closer to zero shows the fairer water distribution in the operation scenario. That means trend of water shortage or surplus is almost equal for all of them. In Equation (4), $CV_R$ $(Q_d/Q_r)$ is spatial coefficient of variation of the $Q_d/Q_r$ ratio over the region $R$ (Molden & Gates 1990).

$$P_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_d}{Q_r}\right) \tag{4}$$

Table 1 shows the performance standards proposed by Molden & Gates (1990).

The water surplus index: the results of running the SOBEK model for operation scenarios, where the existing conditions of the networks have been taken into consideration, revealed that water loss is significant in intakes due to incompetence of Neyrpic and their exhaustion. Therefore, the water surplus index defined in this research indicates the amount of water loss in the network. This index is equal to zero for intakes whose distribution competence is lower than or equal to one. It equals the adequacy index minus one for intakes with a distribution adequacy larger than one.

### Definition of the operation scenarios

These choices include determination of the value and timing of flow rates entering the canal during the operation months. These flow rates, applied to the BP29 canal input, match the actual demand for water in the region during the irrigation season of rice. The important issue about aged and exhausted irrigation scheme is their 'irrigation water requirement', which could encompass two concepts: the first one is 'the common water demand' that water users (farmers) have accepted based on the current physical structures of the scheme, water requirement changes during the operation years and the traditional knowledge about water requirement. The second concept is the actual irrigation water requirement (irrigation demand) in the region founded on evapotranspiration computations and scientific methods. Naturally, in this research, the second concept was used to develop the operation scenarios to find the best (managerial and technical) approach to confront with the water losses during the distribution process based on the physical condition of the scheme. However, it is possible to carry out the best planning of water distribution using hydraulic simulation based on any definition of irrigation water requirement.

The flow rates entering the studied canal have been obtained from NetWat Software outputs, based on the irrigation demand of rice during operation months, and are provided in Table 2.

**Table 1** | Performance standard of adequacy and equity

| Measure | Performance Classes | | |
| --- | --- | --- | --- |
| | Good | Fair | Poor |
| $P_A$ | 0.90–1.00 | 0.80–0.89 | <0.80 |
| $P_E$ | 0.00–0.10 | 0.11–0.25 | >0.25 |

**Table 2** | The value of input flow rate to the BP29 canal in different operation scenarios

| Flow (m³/s) | Scheduling period | Operation scenarios | Month |
| --- | --- | --- | --- |
| 0.7 | First 10-day period of month | 1,2,3,4 | First |
| 1.2 | Second 10-day period of month | 1,2,3,4 | First |
| 1.6 | Third 10-day period of month | 1,2,3,4 | First |
| 2 | First 10-day period of month | 1,2,3,4 | Second |
| 2.3 | Second 10-day period of month | 1,2,3,4 | Second |
| 1.7 | Third 10-day period of month | 1,2,3,4 | Second |
| 3.8 | At every turn | 1,3 | Third |
| 4.1 | At every turn | 2,4 | Third |
| 1.8 | At every turn | 3,1 | Fourth |
| 2 | At every turn | 4,2 | Fourth |

Operation scenarios have been identified as follows for the simulation of water distribution method in the canal; with considering the practicality of the scenario, flood irrigation method for rice as a typical method in the region and closeness to the current switching operation pattern (for better social acceptance):

(1) Current conditions of the network structure and the aged turnout gates are conserved. The operation approach is specification of required input flow rates in three periods (each period is 10 days) in the first and second months and determination of required input flow rates to arrange shifts of irrigation with 4-day switching (on-off) periods in the third and fourth months.
(2) Scenario 1, but with 3-day switching periods in the third and fourth months.
(3) Scenario 1 and replacement of sluice gates with appropriate opening, instead of aged turnout gates (appropriate gate opening will be computed during simulation).
(4) Scenario 2 and replacement of sluice gates with appropriate opening, instead of aged turnout gates.

For example, based on Table 2, in the third 10-days of the second month of irrigation season, the input flow rate of the main canal is adjusted at 1.7 m³/s for all operation choices. Then in scenarios 1 and 3 for the third month, the flow rate into the canal is 3.8 m³/s during a 4-day period, and for the next 4-day period, flow rate is zero.

## RESULTS AND DISCUSSION

The Fumanat irrigation scheme is over half a century old. Its hydraulic structures have been exhausted and destroyed, almost its entire Neyrpic module gates have been destructed, and there is no control over the flow rate entering the BP29 canal intakes. Accordingly, disorganized and unfair distribution of water in operation methods is not far from expectation regarding the current conditions. In these distribution methods, water losses in upstream intakes and its shortage in downstream ones is notable.

Figures 3 and 4 show the value of distribution adequacy and water surplus indices in operation scenarios 1 and 2. Accordingly, in the intakes that can prime from the canal, the flow rate delivered to the intakes does not correspond to their required flow rate (flow rate distribution among intakes is not proportionate to the demands). In other words, the canal upstream intakes are faced with considerable water loss. It is due to lack of control over the inflow to intakes as a result of their exhaustion and they get water more than their needs.

Water loss is greater in upstream intakes that cover a smaller command area and require less water (such as $O_3$, $O_4$, and $O_5$ intakes) due to exhaustion of Neyrpic modules. Meanwhile, in a number of downstream intakes (such as $O_7$ intake) which cover a large area of cultivation, water scarcity is the major concern.

Destruction of the intake gates results in surplus water distribution in the upstream section of the canal (and it means water loss) and water shortage in its downstream. The average of water surplus index is equal to 2.2 in the first operation scenario, indicating that the intakes on average receive 2.2 times as much water as their real need. This index is 2.3 for the second operation scenario as well. The delivery equity index is 1.6 for the main canal in the two mentioned scenarios in current conditions of the network, suggesting unfair distribution of water among intakes. It should be noted that these results have been
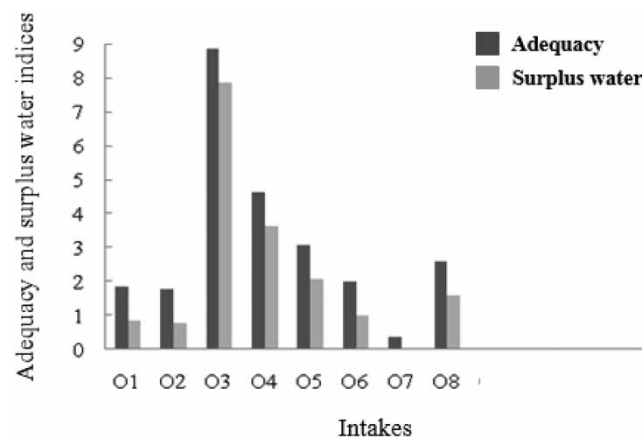


**Figure 3** | Adequacy and surplus water indices in the first operation scenario.
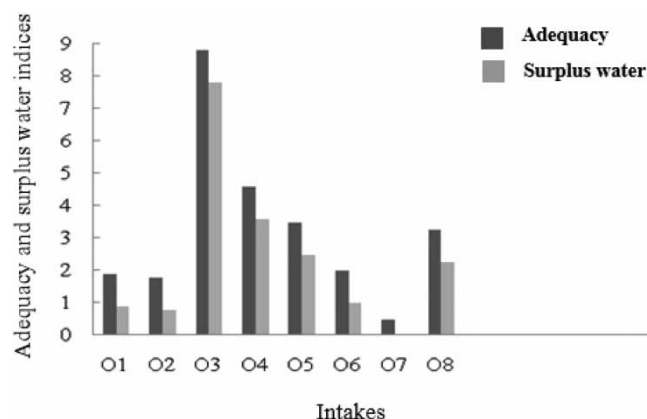
**Figure 4** | Adequacy and surplus water indices in the second operation scenario.

obtained in conditions to which the actual water demand in the region has been applied, proportional to the area under cultivation. However, in many cases and in actual operation conditions, a flow rate more than required enters the canal and thus water loss is more than these amounts mentioned here.

Simulation of operation scenarios in which the current conditions of the network and the water distribution method have been taken into account showed that water distribution enjoys high complexity and sensitivity in exhausted and aged networks. In such networks, as time goes on, canals and their hydraulic structures deform. This deformity causes water loss in upstream sections of the network and water scarcity in downstream sections. In order to improve water distribution and present a proper plan capable of mitigating the existing problems and issues in the current distribution methods and meeting the network needs, paying attention to the maintenance of these networks becomes important. In this research, the replacement of incompetent intakes with sluice gates was investigated to improve water distribution along the BP29 canal and distribution indices were further calculated. Figure 5 demonstrates the value of adequacy and water surplus indices for the third operation scenario. The only difference between this scenario and the first one is the replacement of the existing exhausted intakes with sluice gates. As can be seen, the intakes delivery adequacy is within the good range and the amount of water loss is zero in the network. The distribution equity index is good and as small as 0.05 for the main canal, indicating fair distribution of water throughout the network. Table 3 provides the data regarding how much the sluice gates open. Based on the results, if trained people in the operation company could apply these openings with acceptable precision, the performance would remarkably improve and the water loss would diminish significantly. For example, in the third operation scenario, over one irrigation season and for the entire irrigation unit, 96 times gate adjustment is required, which is simple in terms of practicality.

Figure 6 shows the value of adequacy and water surplus indices for the fourth operation scenario, in which the replacement of sluice gates has been investigated, as for the third operation scenario.
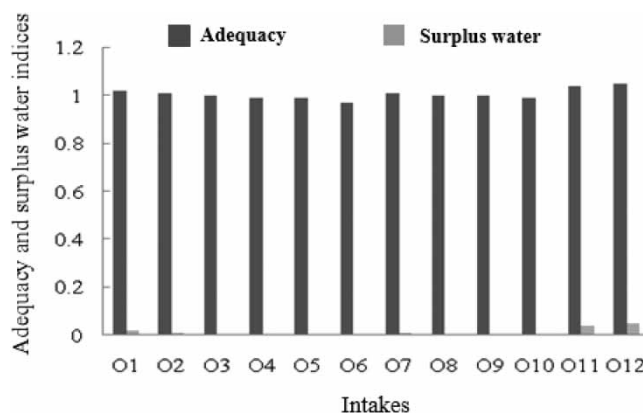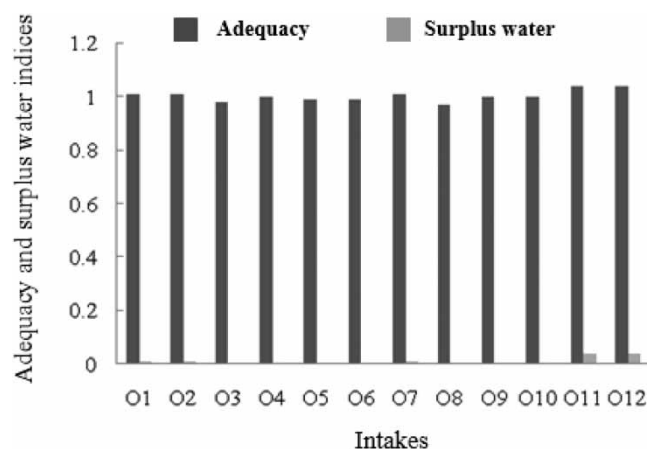


**Figure 5** | The diagram of adequacy and water surplus indices of the intakes in the third operation scenario.

**Table 3** | The amount of openings in sluice gates in the third operation scenario (cm)

| Intakes | First month | | | Second month | | | Third month at every turn | Forth month at every turn |
|---|---|---|---|---|---|---|---|---|
| | First 10-day period | Second 10-day period | Third 10-day period | First 10-day period | Second 10-day period | Third 10-day period | | |
| $O_1$ | 7 | 12 | 15.5 | 19 | 22 | 16 | 38 | 17.5 |
| $O_2$ | 7 | 11 | 14 | 16.5 | 20 | 14.5 | 32.5 | 15.5 |
| $O_3$ | 1 | 2 | 2.5 | 3.5 | 4 | 3 | 6.5 | 3 |
| $O_4$ | 2.5 | 3.5 | 4.5 | 6 | 6.5 | 4.5 | 10.5 | 5.5 |
| $O_5$ | 1 | 2 | 2.5 | 3 | 3.5 | 2.5 | 5.5 | 2.5 |
| $O_6$ | 1.5 | 3 | 3.5 | 4.5 | 5 | 3.5 | 8.5 | 4.5 |
| $O_7$ | 14 | 19 | 22 | 26 | 29.5 | 22.5 | 42.5 | 26.5 |
| $O_8$ | 1.5 | 2 | 3 | 3.5 | 4.5 | 3 | 7 | 3.5 |
| $O_9$ | 1.5 | 3 | 3.5 | 4.5 | 5.5 | 4 | 9 | 4 |
| $O_{10}$ | 1.5 | 3 | 3.5 | 4 | 5.5 | 4.5 | 9 | 4 |
| $O_{11}$ | 8 | 20 | 25 | 24 | 20 | 20 | 41 | 20.5 |
| $O_{12}$ | 12 | 31 | 40 | 40 | 31.5 | 32 | 75 | 33 |



**Figure 6** | Adequacy and water surplus indices of the intakes in the fourth operation scenario.

According to the results, with the changes of intake structure type, the distribution indices of canal are improved. The adequacy of water delivery of intakes and of the main canal is in a good range and water loss is zero in the network. The distribution equity index, as small as 0.05, lies within a good range and implies fair distribution of water. The amount of opening in sluice gates in the fourth operation scenario is provided in Table 4.

When comparing scenarios 3 and 4, there is no difference in terms of equity and adequacy, while water surplus index is slightly better in scenario 3. Scenario 3 is also simpler in terms of execution. However, since its cut/switching period is 1 day longer, it may earn a lower rank in compared with scenario 4 in terms of social acceptance.

## CONCLUSION

Regarding the restriction of water resources and the necessity for increasing the productivity of available water resources, presentation of proper delivery and distribution plans is among the first priorities of operation in irrigation networks in a way that distribution indices (such as equity and adequacy of distribution) are in a good range. In old and exhausted networks, regarding their changes over time, the water distribution plans are not responsive to the existing needs based on typical criteria of operation, which are mostly experimental. In addition to the dissatisfaction of water users, this problem results in

**Table 4** | Sluice gates openings in the fourth operation scenario (cm)

| Intakes | First month | | | Second month | | | Third month at every turn | Forth month at every turn |
|---|---|---|---|---|---|---|---|---|
| | First 10-day period | Second 10-day period | Third 10-day period | First 10-day period | Second 10-day period | Third 10-day period | | |
| $O_1$ | 7 | 12 | 15.5 | 19 | 22 | 16 | 40.5 | 19 |
| $O_2$ | 7 | 11 | 14 | 16.5 | 20 | 14.5 | 34.5 | 16.5 |
| $O_3$ | 1 | 2 | 2.5 | 3.5 | 4 | 3 | 7 | 3.5 |
| $O_4$ | 2.5 | 3.5 | 4.5 | 6 | 6.5 | 4.5 | 11 | 5.5 |
| $O_5$ | 1 | 2 | 2.5 | 3 | 3.5 | 2.5 | 6 | 2.5 |
| $O_6$ | 1.5 | 3 | 3.5 | 4.5 | 5 | 3.5 | 9 | 4.5 |
| $O_7$ | 14 | 19 | 22 | 26 | 29.5 | 22.5 | 39 | 25.5 |
| $O_8$ | 1.5 | 2 | 3 | 3.5 | 4.5 | 3 | 7.5 | 4 |
| $O_9$ | 1.5 | 3 | 3.5 | 4.5 | 5.5 | 4 | 9.5 | 4.5 |
| $O_{10}$ | 1.5 | 3 | 3.5 | 4 | 5.5 | 4.5 | 9.5 | 4 |
| $O_{11}$ | 8 | 20 | 25 | 24 | 20 | 20 | 42.5 | 21 |
| $O_{12}$ | 12 | 31 | 40 | 40 | 31.5 | 32 | 80 | 36 |

nonconformity to the equity and adequacy in water distribution throughout the network and leads to the elevation of operation loss. Old and exhausted networks face water loss in upstream regions and water scarcity in downstream ones due to deformation and the development of the area under cultivation, along with lack of control over the flow rate entering the intake canals. Even though the mentioned network is located in the north and the rainy region of Iran, it seems that water shortage is not a serious problem so far. However, the lack of water management, absence of a reliable plan for operation procedure and physical exhaustion of the irrigation scheme are the main problems. The results of this study show that by changing the priming method and replacing the existing destructed intake with sluice gates and paying attention to the network maintenance, it is possible to enhance distribution indices up to a certain acceptable degree and provide equal conditions of water distribution throughout the network. Furthermore, it is possible to match the value of flow rate delivered to intakes with the required amounts and thereby reduce water loss and water shortage in different parts of the network. The process of conducting this research and the concerns that have been considered in it can be used in other case studies with different operation alternatives.

## CONFLICT OF INTEREST

None.

## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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