ABSTRACT

Despite the extensive application of check and offtake structures in irrigation canals, their periodic assessment is generally not included in water management plans, especially in Iran. This issue would be more important when there are many problems in water distribution in irrigation projects. In this study the performance and operating status of different hydraulic structures in the Varamin irrigation scheme were evaluated using a precise flowmeter. Results show that Neyrpic modules have an error in range of $8$ to $83\%$ and these structures, on average, delivered $22\%$ more water. The discharge coefficient of duckbill weirs has changed considerably as well and they are not able to regulate the water level appropriately, because of ageing and physical destruction. The results showed that to achieve an acceptable performance of Neyrpic modules in this scheme it is essential to perform some physical modifications, such as cleaning and sealing the gates, removing sediment around the gates, replacing old gates and continuous inspection of infrastructure. A series of measurements to estimate water losses during the conveyance process show that the conveyance efficiency for each 1000 m length of main, secondary and tertiary canals are respectively $95.0$, $91.5$ and $89.3\%$. Consequently to achieve a suitable water distribution pattern, preventive maintenance should be considered. © 2018 John Wiley & Sons, Ltd.

KEY WORDS: conveyance efficiency; hydraulic sensitivity; Neyrpic modules; performance assessment; water level regulation

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RÉSUMÉ

Malgré l’application étendue des structures de régulation et de prise d’eau dans les canaux d’irrigation, leur évaluation périodique n’est généralement pas incluse dans les plans de la gestion d’eau, particulièrement en Iran. Ce problème serait plus important lorsqu’il y a beaucoup de problèmes dans la livraison et la distribution d’eau dans les projets d’irrigation. Dans cette étude, la performance et l’état de fonctionnement de différentes structures hydrauliques ont été évalués dans le schéma d’irrigation à Varamine en utilisant un débitmètre précis. Les résultats démontrent que les modules de Neyrpic (ayant un emploi généralisé en Iran) ont des erreurs dans la gamme de $8$ à $83\%$ et qu’elles dépassent en moyenne $22\%$ d’écoulement d’eau. Le coefficient de débit des déversoirs en bec de canard a également considérablement changé et ils ne peuvent pas contrôler convenablement le niveau d’eau à cause du vieillissement et de la destruction physique. Les résultats ont aussi montré qu’afin d’atteindre une performance acceptable des modules de Neyrpic dans le schéma d’irrigation de Varamine, il est essentiel d’effectuer des modifications physiques, tel que le nettoyage et le scellage des portes, l’enlèvement des sédiments bloqués autour des portes, le changement des portes et le contrôle régulier des infrastructures. Une série de mesures pour estimer la perte d’eau dans le processus de transport démontre que l’efficience du transport pour chaque 1000 m de longueur des canaux principaux, secondaires et tertiaires est respectivement de 95,0, 91,5 et 89,3\%. Par conséquent, afin d’atteindre à un modèle approprié de la distribution d’eau, il faudrait considérer une maintenance préventive. © 2018 John Wiley & Sons, Ltd.

MOTS CLÉS: efficience de transport; sensibilité hydraulique; modules Neyrpic; évaluation des performances; régulation du niveau d’eau

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†Perspective de la distribution de l’eau basée sur la performance des structures hydrauliques dans le cadre du programme d’irrigation de Varamin (Iran)

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INTRODUCTION

Regulation, distribution and conveyance structures are the main components of any irrigation canal system and are responsible for delivering water to different command areas. The proper functioning of an irrigation system depends on the acceptable performance of the various parts of the system, especially regulation and distribution structures. Evidence, documentation and performance assessments of irrigation systems have shown that most of these structures face numerous problems during operation (Mohammadi et al., 2017). Practical assessment instruction is necessary for irrigation projects (Biswas, 1984). Evolution of an irrigation scheme, as part of demand assessment and management, is an important factor in the efficient and effective use of water resources and in minimizing water losses (Asres, 2016). Performance assessment is an effective tool for identifying problems in managing irrigation schemes and determining what actions should be taken to improve deficiencies (Rodríguez-Díaz et al., 2008). Due to the importance of the hydraulic structures in the management of an irrigation scheme, some researchers have focused on their issues like performance, design and operation methods. The results of research by Kaviani Kosarkhizi and Parvaresh Rizi (2011) on a number of irrigation schemes in Iran showed that the use of Neyrpic modules is favoured by operators, but carelessness in their construction, installation, operation and maintenance cause a lot of error in the water distribution process. It is remarkable that they are usually used and known as measuring structures instead of delivery structures. In research conducted by Dejen et al. (2015) in Ethiopia, the water distribution performance of 15 off-takes was evaluated. In this study, in order to determine water delivery performance, indicators of adequacy, equity and reliability were used. The results showed that the average annual irrigation allocation was 24% more than the demand. Abbasi and Rahimi (2006) investigated the conveyance and distribution efficiency of water in the Qazvin irrigation scheme. They showed that the major part of the problem is due to incorrect operation of the gates installed on the canals. Disruption and blockage of gates and Amil regulators by water users have been a common problem in the Qazvin irrigation scheme. Kusre et al. (2013) conducted a comprehensive assessment of an irrigation project in north-eastern India and evaluated parameters such as water losses, distribution efficiency and water availability. In their study the average distribution efficiency of the system was 35.3%. They introduced improvements in the water management and distribution systems as a fundamental effort to obtain equity in distribution.

Problems due to the improper performance of conveyance, regulation and distribution structures end up causing inappropriate and unfair distribution of water. Memon et al. (2013) during research on the Dadu canal in Pakistan concluded that by lining the canals, seepage losses decreased from 50 to 40% and conveyance efficiency increased from 70 to 90%. The results of the evaluation of the Gezira irrigation scheme in Sudan indicated that water availability is greater than demand. Also, inequity in the conveyance system was introduced as one of the main factors reducing scheme performance (Al Zayed et al., 2015).

Zhang et al. (2016), while pointing to the difficulty of calculating the exact amount of seepage in irrigation canals, reported that field experiments and direct measurements provided more accurate results compared to other methods (empirical equations and software methods). Accordingly, in the present study, the performance of the water regulation, distribution and conveyance structures in the Varamin irrigation scheme (one of the largest schemes in Tehran province) was assessed. Although the Neyrpic module as well as the duckbill weir were designed many years ago they may not have been considered in new irrigation projects. In many developing countries, including Iran, these structures are used extensively and may be used and operated for several years. Thus their performance assessment is a necessity, even though they are not normally considered for new projects in Iran. Identification of physical and management weaknesses of these structures and providing appropriate solutions for removing defects and improving them are the aims of this research. In this regard, the necessary information was collected by investigating documentation, conducting field observations and taking accurate measurements. Then the efficiency, executive problems, operation and maintenance of related structures were analysed.

DESCRIPTION OF THE STUDY AREA: VARAMIN IRRIGATION SCHEME

The irrigation and drainage scheme of Varamin is located on the southern slope of the Alborz Mountains, 40 km south-east of Tehran (Figure 1). The Varamin irrigation scheme was designed about 40 years ago and the age of its hydraulic structures is more than 30 years. Water in this area is supplied via two diversion dams and the outflow of a wastewater treatment plant located south of Tehran (the capital of Iran). In some parts, groundwater resources are also used. Upstream control and a rotational water delivery method are the specifications of this irrigation scheme. In most irrigation schemes in Iran like Varamin, water distribution is based on the land area under the ownership of each farmer. It is a traditional rule and is still followed, even in modern irrigation projects. It is agreed based on the area of the farm and may be closer to on-demand-based water delivery methods from the viewpoint of delivery process.

dam and the wastewater treatment plant) are managed by the government. The cost of the project is also funded by the government. Water distribution management in the main canals and their associated structures is carried out by a semi-private operation company (which is common in Iran). The farmers are responsible for water delivery and distribution in tertiary canals (often in a traditional manner). In order to meet the cost of irrigation services, farmers pay to have water rights. This irrigation system lacks a water users’ association and does not have effective and continuous training for the farmers. This has meant the latter do not play a role in the planning of water distribution, and also they are not keen to contribute to maintaining system facilities.

The command area of this scheme is about 60 000 ha. The Varamin irrigation scheme consists of six main canals, AMX (length: 16.6 km, range of design discharge: 1.4–17 m$^3$ s$^{-1}$), AU branch (length: 4.3 km, range of design discharge: 0.8–2.8 m$^3$ s$^{-1}$), BY branch (length: 8.4 km, range of design discharge: 1.1–3 m$^3$ s$^{-1}$), BV branch (length: 8.1 km, range of design discharge: 1.3–1.8 m$^3$ s$^{-1}$), CNZ branch (length: 20.6 km, range of design discharge: 0.7–9 m$^3$ s$^{-1}$) and the CW branch (length: 8.2 km, range of design discharge: 0.36–3.5 m$^3$ s$^{-1}$). In this research, the evaluation process was conducted in an area of more than 50 000 ha in six branches. In the data collection phase, all main canals, nearly 70% of secondary canals and a part of the tertiary canals were surveyed. During the assessment process, the discharge of more than 200 selected points was measured by ultrasonic flowmeters, and quantitative and qualitative data were obtained from sections and reaches. Sometimes, high water turbidity and sediment accumulation in the canals did not allow determination of the exact cross-sectional area of the flow and eliminated information of some areas. Finally, 15 XX$_2$ Neyrpic modules, 3 L$_2$ Neyrpic modules, 3 C$_2$ Neyrpic modules and 7 duckbill weirs were used in the final analysis. In order to assess the conveyance efficiency, 12 reaches from tertiary canals, 6 from secondary canals and 3 of the main canal were used in the final analysis. These reaches were on average 1000 m long. In choosing the points, we tried to evaluate the distance, which is an example of the general conditions of the canals.

**MATERIALS AND METHODS**

**Neyrpic module offtake**

A Neyrpic distributor (orifice module or baffle distributor) is a structure for regulating and distributing water flow. This structure performs flow distribution more precisely when water level fluctuation is within the allowed limit. These gates are available in five different types and sizes, with a sign indicating the nominal discharge per width, in the form of X type with 10 l s$^{-1}$ per 0.1 m width, XX type with 20 l s$^{-1}$ per 0.1 m width, L type with 50 l s$^{-1}$ per 0.1 m width, C type with 100 l s$^{-1}$ per 0.1 m width and CC type with 200 l s$^{-1}$ per 0.1 m width. All of the evaluated Neyrpic gates were of the double baffle type. According to the required volume of water in the command area, each of them has a number of blade distributors (for example, the dimensions of the distributors in the XX$_2$ module with a nominal discharge of 90 l s$^{-1}$ are equal to: a 5 cm width, 10 l s$^{-1}$; a 10 cm width, 20 l s$^{-1}$ and two 15 cm widths, 30 l s$^{-1}$).

The original configuration of these modules consists of a fixed weir on the upstream side, a 12$^\circ$ slope in the
downstream over the weir crest, and one or two fixed baffles with a slope of 35° are embedded (Bos, 1989). When the level of the water is lower than the baffle edge or the baffles, the gate operates like a weir. However, the operating conditions of a module as a discharge stabilizer are provided when the level of water reaches the bottom edge of the baffle; in this case, the gate turns into an orifice and the flow is a function of water behaviour in orifices under pressure (Ankum, 2002). The nominal water level over the weir crest in all XX2 type gates is 28 cm. This value is 51 cm for L2 type gates, and 81 cm for C2 type gates. Nominal discharge means the amount of flow that the structure must pass in the defined operating conditions. It is determined based on the type of structure, dimensions and number of open slide gates. The nominal discharge can be modified by knowing the water level over the weir crest and using the Neyrpc module depth–discharge curve. These values are presented as calculated discharge. If the nominal and actual (measured) water level over the crest is the same, the nominal and calculated discharge value will also be the same. Knowing the water level over the weir crest and using the Neyrpc module’s characteristic curve, the nominal discharge can be modified. These values are presented as calculated discharge. To modify the nominal discharge and achieve the calculated discharge, the depth–discharge curve of the double baffle distributor is used (Figure 2). This form of the characteristic curve presented by the manufacturer is divided into five homogeneous regions and shows the discharge change percentage compared to the nominal discharge as compared to the water level over the weir crest.

Hydraulic sensitivity indicator

Flexibility between the inlet and outlet variables in an irrigation system and the impact of the hydraulic structure against the fluctuations is expressed by a hydraulic sensitivity indicator. The sensitivity of an irrigation system is defined as the ratio of the absolute or relative variation of the outlet flow to the absolute or relative variation of the inlet flow. This index is defined as follows for offtakes (Renault and Hemakumara, 1999):

\[ S_{offtake} = \frac{dq}{q} \frac{dh_{us}}{dh_{us}} \]  

In this equation, \( S_{offtake} \) is the relative sensitivity indicator of the offtake structure, \( \frac{dq}{q} \) the relative variation of delivery discharge and \( \frac{dh_{us}}{dh_{us}} \) the absolute variation of the water level upstream of the offtake structure. Water delivery structures should be designed in such a way as to have the least impact on the changing hydraulic conditions of the flow. The baffles used in the Neyrpc module offtake control the flow against the impact of upstream water level fluctuation by altering the energy loss. Therefore, it is expected that this structure will not be sensitive to upstream level changes, and by increasing or decreasing water levels does not have large variation in flow discharge.

Water level regulation structures with fixed weir

A rigid duckbill weir provides a relatively constant level of water in irrigation canals (Figure 3): \( \beta \) is the angle between the weir wall and the longitudinal axis of the canal. For angles (\( \beta \)) less than 45°, an oblique weir is used, and for angles (\( \beta \)) between 45° and 70°, a duckbill weir is preferred (Ankum, 2002). Most of the water regulation structures used in the Varamin irrigation scheme are duckbill weirs.

In these weirs, discharge is calculated using the general formulation of flow over the weir (Equation (2)):
where \( Q \) is the flow discharge over the weir (m³ s⁻¹), \( L \) is the effective length of the weir (m), \( H_e \) is the level of water over the weir (including the height from kinetic energy line) (m), and \( C \) is the discharge coefficient for free flow. The amount of the coefficient of the flow in fixed weirs depends on the weir type, shape of the crest (sharp, inclined or rounded) of the upstream entrance (Parílková et al., 2012) and \( \beta \) angle. Its amount for \( \beta > 45° \) is shown in Table I (based on Kraatz and Mahajan, 1975).

**Water conveyance efficiency \((e_c)\)**

In many cases, a portion of the water allocated to an irrigation scheme is lost during the conveyance process and wasted in various forms. The classical definition of conveyance efficiency is the ratio of water diverted to a field unit at a specific time interval, to the water taken from the main source for the same field unit within the same time interval (Israelsen, 1932). Since measuring the volume of water losses during the conveyance process is not possible in terms of time and cost, the sample points and reaches are chosen to measure the required information. Selected reaches in canals should be representative of the general characteristics of the canal, and be appropriate in terms of accessibility, length and flow control ability. The amount of water seepage in these reaches is measured by the difference between water volume in inlet and outlet sections. Conveyance efficiency can be calculated by Equation (3) (Howell, 2003):

\[
e_c = \left( \frac{V_d + V_2}{V_c + V_1} \right) \times 100
\]

where \( V_c \) is the volume of diverted water from the source (m³), \( V_d \) is the volume of water delivered to the distribution network (m³), \( V_1 \) is the flow of the inlet from other sources to the network (m³) and \( V_2 \) is water supply for non-irrigation purposes (m³).

**Seepage losses and measurement**

The amount of seepage from the sides and bottom of canals is required when determining the conveyance and distribution efficiency in irrigation schemes. The best method for determining seepage is to measure it along the water flow path. To determine the seepage, Equation (4) is used (Birara and Halefom, 2017):

\[
s = \frac{86.4 \times \Delta q}{P \times L}
\]

where \( S \) is the seepage loss (m³ m⁻² day⁻¹), \( \Delta q \) the difference between discharges from the inlet to outlet section of each reach (l s⁻¹), \( P \) the wetted perimeter (m) and \( L \) the length of the canal between the measuring points (m). Here the seepage (or wetted) surface is the area of the canal lining that directly touches the water flow. These values were obtained by multiplication of the wetted perimeter at the selected canal length.

Measuring the discharge in open canals involves different methods. In hydraulic systems, simple equipment such as a flume, weir, Venturi and orifice is used (Michalski, 2000). In these methods sediment deposits and some garbage can accumulate in the vicinity of measuring equipment and reduce the accuracy of the measurements. To overcome this problem in this research, a Doppler ultrasonic flowmeter, specially for field application, was used. Ultrasonic technology acts as a powerful tool in measuring water flow (Eckert et al., 2015), and numerous experiments and verifications have proven its accuracy.

The flowmeter used in this research is called Mainstream. It is portable and can be used in open channels with a geometric cross section. This device consists of a velocity probe (for estimating average flow velocity) and a pressure transducer (for estimating the flow height). The velocity probe estimates the flow velocity by emitting ultrasonic waves in the opposite direction of flow (based on the Doppler principle). The flow rate is obtained from the product of the velocity at the flow cross section. This device is capable of reporting a flow rate with 2.5% error. To ensure the performance of the device, its calibration was carried out at different stages of data acquisition. All sections of the flow, the discharge of which was measured by an ultrasonic device, had a trapezoidal cross section. This device is located in lined canals, downstream of the offtakes, at the nearest possible distance after the Neyrpic gates to measure the flow discharge. It should be mentioned that in this study the discharge measurements at all data points and downstream of all studied structures, flow was free (without submergence).

**RESULTS AND DISCUSSION**

The results of this research are presented in three sections: performance assessment of the distribution structure (Neyrpic module), regulation structures performance assessment (duckbill weir) and performance assessment of the conveyance structures.
Performance assessment of Neyrpic gates

The results of actual discharge measurement of XX2 type Neyrpic gates (Nos 1–15), L2 (Nos 16–18), C2 (Nos 19–21) and comparing them with the nominal and calculated discharge are shown in Figure 4. Comparison of the measured discharge with the nominal and calculated discharge shows that, in most cases, Neyrpic gates deliver an excessive water volume over the amount defined by the operator. This difference can be due to the design, installation and inappropriate operation of the structure. Each of these factors can reduce the offtake’s efficiency; however, among them, problems related to improper operation are more important.

In order to provide a better vision of the other influential factors, the effect of water level over the weir crest was eliminated. Equation (5) is used to determine the performance with respect to calculated discharge for each Neyrpic offtake:

\[ D_d = \frac{D_m - D_c}{D_c} \times 100 \]  

(5)

In this equation, \( D_d \) is efficiency between measured and calculated discharge (%), \( D_m \) is measured discharge (l s\(^{-1}\)) and \( D_c \) is calculated discharge (l s\(^{-1}\)). According to Figure 5 (which indicates the variation of measured discharge to calculated discharge), most of the gates do not perform properly because of structural and operational problems. Apart from the three gates (Nos 8, 14 and 19) that are faced with a shortage of water, the other gates (more than 80%) deliver more water than the defined amount. Most gates do not have a proper seal. This has undesirable effects on management scenarios and causes water shortage at the end branches, such as AMX and CNZ. For example, gate No. 19 (C2 type) has 40% water deficiency because of water shortage in the upstream canal. It has changed from a submerged orifice to free weir. Ageing and physical changes of gates over time, wrong installation of the gates, improper regulation of the water level by the regulating structure, sedimentation in some sections of the canals and manipulation by non-specialists are other factors that increase the amount of error.

Due to the more extensive use of the XX2 type Neyrpic gate in the Varamin irrigation scheme, its expected performance is evaluated in detail. Figure 6 shows the variations in hydraulic sensitivity for the XX2 type Neyrpic distributor. These variations start at a level of 20.2 cm (for -10% of nominal discharge) over the weir crest and reach 48.4 cm.

Figure 4. Comparison of nominal, calculated and measured flow rate for Neyrpic modules (type XX2, L2 and C2)

Figure 5. Difference between measured and calculated flow rate for Neyrpic modules (type XX2, L2 and C2)
(for +10% nominal discharge) in increments of 0.4 cm per step. Fluctuation in the hydraulic sensitivity indicator is indicative of two points:

- In Neyrpic gates within the range of ±10% of nominal discharge, with increasing water level over the weir crest, the average amount of hydraulic sensitivity in each zone (compare the previous zone) is reduced. It means that flow is controlled in several steps and along with increasing water level, discharge does not essentially increase;
- Based on the XX2 Neyrpic module design criteria, flow control is achieved by the second baffle and begins at the level of 28 cm over the weir crest. According to Figure 6, the hydraulic sensitivity parameter has a downtrend up to 26 cm of the water level and then increases. In other words, the first baffle cannot control the changes in the water level alone, and after the height of 26 cm, the structure is actually more sensitive to water level variations. To solve this problem, the second baffle runs at a level of 28 cm, and with a gradual increase in energy losses, at 30.5 cm, reverses the sensitivity changes and reduces the hydraulic sensitivity. This condition continues until the flow level reaches 35.8 cm. Afterwards, with a decreasing effect of energy losses, the hydraulic sensitivity increases again; however, it does not increase in the case of a single baffle.

Based on local interviews, the most common reason for dissatisfaction of water users is their lack of knowledge about low water levels upstream of the Neyrpic weir crest! So they almost try to change the water level upstream of the regulation structures. This is when the Neyrpic gate has a zigzag characteristic curve (Figure 2), and with an increasing water level upstream of the gate, discharge does not necessarily increase. For example, in the XX2 type Neyrpic gate, as the water level over the weir crest increases from 30 to 35 cm, the passing flow decreases by 10%. It seems that non-technical interference can be greatly reduced by training the water users. In Figure 7, the measured water level over the XX2 type Neyrpic weir crest is shown. In spite of

Figure 6. Hydraulic sensitivity of XX2 Neyrpic module in the range of ±10% nominal discharge

Figure 7. Comparison of nominal water level for the nominal discharge, with measured water level over the XX2 type Neyrpic weir crest
installation and design criteria, in some gates the water level exceeded 28 cm (nominal water level for the nominal discharge), which can be analysed from two viewpoints:

- **Installation the gates at the improper level:** In some cases, the Neyrpcic gates are installed at an inappropriate level. This has the consequence of an unacceptable increase in the water level upstream of the gate and sometimes overflow occurs. On the other hand, installation of a gate at a higher level leads to an inappropriate water level upstream of the gate and the structure changes from orifice to weir;

- **Inappropriate performance of the regulation structure:** The regulation structure will increase the water level to the required volume, so that the intakes can pass the determined volume of water. Any weaknesses in the performance of these structures will directly affect the water level upstream of the gate. Sedimentation at the entrance of the intakes have an undeniable role in increasing the water level upstream of Neyrpcic gates. In Figure 7, the chart and gate dimensions are equal, and the bar chart shows the actual level of the water over the Neypcic weir crest. It is obvious that apart from gates 4 and 8, in other gates water level exceeds the first baffle and the water flow is controlled by the second baffle. This shows that using double baffle gates gives better control of the flow with rising water levels.

To understand the most important factors affecting the performance of the Neyrpcic offtake, we have compared a number of gates (Figures 5 and 7). In order to eliminate the effect of the regulation structure and the installation level of the Neyrpcic gate on offtake performance, gates with the same recorded water level over the weir crest are compared. Gates 6 and 13 are in the same situation in terms of theoretical conditions, and normally they should have equal delivered flow rates and nominal flow rates. But they show 20 and 36% difference compared to the nominal discharge respectively, and 16% difference related to each other. Similarly, in the same situation, gates 7 and 11 are different in delivered flow rate. The greatest difference is observed between the gates 4 and 8. Based on the relations of the characteristic curve, these two gates are allowed to show up to 4% difference compared to the nominal discharge. This is while in gate 4, delivered water is 77% more than the nominal discharge, and it is 6% less than the nominal discharge in gate 8. This evidence shows that a large part of the error occurs regardless of hydraulic sensitivity and changes in the level of the water upstream of the gates. It is directly affected by ageing the physical structure and improper operation and maintenance of the gates. Therefore, the preparation and implementation of the operating and maintenance instructions should be considered by the operator. In this study, acceptable performance of the Neyrpcic offtakes is related to fundamental modifications such as sealing the gates, repairing seams and joints, removing trapped sedimentation around the gates, switching the old gates and continuous monitoring of the related facilities.

**Performance assessment of conveyance structures**

The results of the evaluation of seepage losses and conveyance efficiency for the length of selected reaches are presented in Figure 8. They show that the tertiary canals have an average of 0.63 (m³ m⁻² day⁻¹) water losses, and this value varies from 0.27 to 1.51 (m³ m⁻² day⁻¹). In the secondary canals, the average seepage rate is 1.18 (m³ m⁻² day⁻¹), and it varies from 0.72 to 1.81 (m³ m⁻² day⁻¹). Secondary canals are also found with damaged joints and wide fractures in some zones. In the main canal, the average seepage rate is 1.22 (m³ m⁻² day⁻¹). Big and small fractures and the presence of successive drop structures are the main reasons for losses in these canals. Related to the flow rate in each canal, the seepage loss may varies. In this research the measurements had been planned in the flow rates which are closer to the operation discharges.

**Figure 8. Conveyance efficiency (for each 1000 m length of the canals) and average seepage losses for each level of canals**

The assessment results of canals show that the average value of conveyance efficiency for each 1000 m length of the main, secondary and tertiary canals are 95.0, 91.5 and 89.3%, respectively.

According to Figure 8, the main canal with 95% conveyance efficiency is typically in a better situation compared to the others, but the maximum absolute seepage is in the main canal with a value of 1.22 (m² m⁻² day⁻¹). For each area unit of the wetted surface of the canals, the average amount of seepage in the main canal is more than the secondary canals. Also it is more in the secondary canals related to the tertiary canals.

**Performance assessment of duckbill weirs**

Table II represents the comparison between the actual discharge (measured discharge) and the calculated discharge of duckbill weirs from Equation (2). According to Table I, the amount of the discharge coefficient of the duckbill weir in an unrounded crest is 1.42 and is 1.60 for a rounded crest. The weirs investigated were of the unrounded crest type but most of them have lost their sharpness over the time. So the discharge coefficient for them is more than 1.42. Of course, at the moment, it is not possible to call them a rounded or unrounded crest, especially since the sharpness of their weir is not the same throughout the crest. Therefore, the actual discharge, which has been measured with high precision, is diverted from the nominal discharge in the unrounded crest and approaches the nominal discharge rate in the rounded crest. In fact, the discharge coefficient of each weir is also increasing simultaneously with deterioration of the duckbill weir. In the last column of Table II, the actual value of the discharge coefficient for each weir is calculated.

Management practices along with physical reforms will play a significant role in improving the performance of the Varamin irrigation scheme. For management practices to be effective, it is necessary to use tools that control and record the time, place and exact amount of water delivered. Another problem is that there is no comprehensive monitoring and evaluation plan in managing irrigation schemes in Iran, and it is often limited to research cases. Therefore an annual evaluation of the studied case can bold the problems and prioritizes the managerial issues. In the current configuration of this irrigation system, worn-out offtakes with manual control (Neyrpic modules) and rigid regulators (duckbill weirs) do not have the ability to adapt to the conditions created over time. Consequently another management proposal might be automation at the level of main canals. In this case, simpler structures (such as sliding gates) are replaced as intake structures. They have greater manoeuvrability and vary according to different operational conditions.

**CONCLUSION**

Results from the assessment of the hydraulic structures of Varamin irrigation scheme indicate that most of them are exhausted and have changed physically over time. Inappropriate sealing of the Neyrpic modules has caused large amounts of water loss and consequently low reliability of water distribution. In some cases, the installation of gates at an inappropriate level has disrupted the performance of the offtake structures. Comparison of the actual and the nominal water level upstream of the Neyrpic modules shows that in 67% of the cases studied, the actual level is greater than the nominal level and in 24% of cases studied is less than its nominal value. It implies that these structures were installed on an incorrect level. The difference between the actual and the designed discharge through the Neyrpic modules causes them to distribute on average 22% more than the desired amount of water. Investigating the theoretical hydraulic sensitivity and its effect on the actual flow error of each gate indicates that the hydraulic sensitivity fluctuation of the gates is a small part of the flow error. In other words, the effect of imperfections in operation and maintenance of gates in flow error is much greater than the effect of the change in hydraulic indicators of the flow. The assessment of the conveyance structures indicates that the conveyance

Table II. Discharge measurement and analysis results in duckbill weirs

<table>
<thead>
<tr>
<th>Total water head over the weir crest (cm)</th>
<th>Crest effective length (m)</th>
<th>Nominal discharge for $C = 1.42$ (l s⁻¹)</th>
<th>Actual discharge (l s⁻¹)</th>
<th>Difference between nominal and actual discharge for $C = 1.42$ (%)</th>
<th>Actual discharge coefficient</th>
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efficiency for main, secondary and tertiary canals in a given range is 95.0, 91.5 and 89.3% respectively. Furthermore, the amount of seepage losses for main, secondary and tertiary canals is equal to 1.22, 1.18 and 0.63 m³ m⁻² day⁻¹ respectively. In regulation structures, any problem in the duckbill structure affects the performance of the offtakes. The change in their condition from an unrounded to a rounded crest has led to an increase in the discharge coefficient. Obviously, deterioration of the crest of the duckbill weir will reduce the water level over it. But contrary to expectations, the real water level upstream of the Neyrpic gate is often more than its nominal value in this irrigation scheme. This indicates a lack of a match between the regulation (duckbill weir) and distribution structure (Neyrpic gate) when they were being installed. Sediment accumulations in the canal and subsequently, overflow from the intake gates result in inappropriate Neyrpic performance and interrupts a fair water distribution. In this study discharge measurement was carried out using ultrasonic instruments which are not normally available in irrigation schemes in Iran. Data analysis was carried out with a new approach and the actual discharge coefficient was obtained in the regulators, which can be reliable in irrigation management for a time interval.

In order to improve the current status and the possibility of canal operation in the future, it is necessary to allocate enough funds. It should be a priority for the government in an era of water crisis. In the next step, effective and continuous training should be considered for farmers and operators. Modification of those hydraulic structures with considerable error (at least the problematic structures which were found in the present research) must be implemented.

It is recommended to use monitoring systems and routine measurements to ensure correct operation of the structures as well. This is despite the fact that there is no effective scheduling for periodic visits to do maintenance in this large-scale project.

Water scarcity is a national problem in Iran. In spite of this problem, there are many losses in the agricultural water section. In addition, because of poor management, there is no reliable mechanism for volumetric delivery of water. Thus we recommend providing suitable maintenance, revival of infrastructures and a reliable discharge monitoring system to supply water for a greater percentage of the command area and to deliver the exact amount of water needed for irrigation. Automation and equipping the irrigation scheme with control and monitoring tools, and registering the documentation, will help effective management as well. Also, in order to improve performance, the operator should emphasize repair and maintenance priorities to conserve and control these large infrastructures; defective hydraulic structures must be repaired at the first opportunity and worn-out structures should be replaced; all cracks and fractures of canals should be repaired immediately; dumped sediment and aquatic plants in canals should be cleaned away; it is necessary to create a database and to record all the problems and weaknesses of the irrigation scheme; also, continual monitoring of system performance will prevent new problems. Maximum effort for the participation of operators in system management is essential as well to identify the water distribution network as a part of their own capital so they try to protect it.

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