

Evaluation of Hydraulic Sensitivity Indicators for Baffle Modules (Case Study: Varamin Irrigation and Drainage Network)

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Abstract

Measuring sensitivity of hydraulic structures is considered as an approach for evaluation of water projects performance, due to lower distribution efficiency in Irrigation and Drainage project schemes. Sensitivity analysis approach for irrigation structures is one of flow analysis methods which are developed in recent years in order to measure the behavior of flow in hydraulic structures in an irrigation network. This study examines the sensitivity of offtake structures in Varamin irrigation and drainage network project, which is one of the modern networks in Iran. The sensitivity measurement was carried out by the use of collected data from field in years of 2010, 2011 and 2012, and compared them with the water requirement for crop pattern calculated by CROPWAT model. Flow channel simulation was conducted in the project to identify the most sensitive offtake structures, due to inappropriate allocation of water particularly in downstream of network. Simulation and evaluation were carried out using SOBEK hydrodynamic model, and relationships introduced for sensitivity measures for offtake structures. Investigations and sensitive analysis on hydraulics structures in Varamin Irrigation network showed that Baffle modules have significant sensitivity. According to reviewed equations, sensitivity of Baffle modules is related to upstream depth, and opening of NEYRPIC module gates; which occurred more in terminal structures. The best way to have an optimal operation in this network is supply of required water depth in downstream of each canal. In these circumstances, the water depth in all offtakes is provided, and does not make any changes in the opening modules also.

Keywords: Sensitivity Analysis, Hydrodynamic Modeling, Turnout, Operation, Flow simulation.

1. Introduction

Measuring the sensitivity of hydraulic structures is considered as an approach for evaluation of operation of water projects performance, due to lower distribution efficiency in Irrigation and Drainage project schemes. Operation of irrigation systems, is the result of a decision making process; where the three elements of physical condition of the structures, control capacity, and hydraulic performance of the system play a key role. Efficiency of water distribution of irrigation networks is low in some cases. Despite the modernization of irrigation and drainage networks in Iran, the overall irrigation efficiency is low due to poor network performance, resulting in very high losses of water in agriculture sector. Due to the variety of hydraulic structures and operation methods, it is manually difficult to control the behavior of various structures in an irrigation network. Since proper use and appropriate operation of these structures has made network management possible, water allocation on time and reduced losses, it seems that the identified deficiencies and structural problems in the selection, design, construction, installation and operation of networks will greatly help to prevent water loss and increase efficiency. Flow through irrigation canals can be studied by steady or unsteady state flow relationships. The steady state flow relation is often used in the design of irrigation systems, and is realized by professional designers as well as custodian operators. Whoever, to run Irrigation schedules and operation tasks will cause unsteady flow in irrigation network schemes;

which may not be analyzed by steady states flows. Unsteady flow relations, despite particular complexities, have ability to analyze the flow and also have limited widespread use. Hydrodynamic models are well able to simulate the flow through the network, to evaluate network performance and monitor hydraulic performance of structures. However, limited availability, complexity and the need for high expertise, caused operators of irrigation systems to have little desire to use these models [9].

Sensitivity Analysis Approach as a new intermediate method between these two methods is presented. Sensitivity analysis method for irrigation structures, is one of flow analysis methods that have been developed in recent years in order to assess the flow performance in irrigation networks, and has been used in several irrigation canal networks of the world [7].

Hydraulic Sensitivity Index of an irrigation structure is defined as the relative or absolute changes of OUTPUT hydraulic parameters of the structure to relative or absolute changes of INPUT parameters of hydraulic structures [9]. Accordingly, sensitivity analyses need to be undertaken considering a range of units, from a single structure to an irrigation system, and with regard to both delivery and conveyance.

In this method, evaluation of the system's response to input changes and disturbances, and also flow analysis are discussed by using steady flow relations and the physical structure of the network [11].

Flexibility and sensitivity of irrigation offtakes (outlets) has been considered by Mahbub and Gulhati, and Horst [4 and 5]. Mahbub and Gulhati (1951) offered definition of sensitivity for channel outlet; and then they were used to evaluate the channel outlet in several canals in Indian irrigation networks. According to their definition, the sensitivity of outlets were introduced as relative changes in discharge rate, relative to changes in flow depth to normal depth [5].

Horst (1983) studied the sensitivity of irrigation structures, and extended the concept to the level of canals; and defined the flexibility index to study the propagation of changes in input discharge to canals. Horst defined the flexibility index as the ratio of relative Changes in discharge canal feeding into the relative change in current flow [4]. By his theory that was named system response

theory, the response of offtakes to changes in discharge was studied by the flexibility index. Horst considered the changes in the flexibility index as a function of structure type, which depends on the type of regulating structures and flow condition, which may have a values of zero, one, and larger or smaller than one.

The sensitivity indicators used by Mahbub and Gulhati (1951), and Horst (1983) only consider the water depth as an input and the delivery as an output. Renault and Hemakumara [8]. suggested a broader framework to examine offtake sensitivity which incorporated the conveyance effect (i.e. the influence of the outlet flow variation on the on-going discharge). They applied it to the study of channels in Mahavil & Kirinedoya Network in Sri Lanka and Fordova Network in Pakistan.

Albinson [1] carried out a study on the sensitivity of offtake and Cross-Regulator structures. He presented an analysis on combined effects of sensitivity of the adjacent structures to regulating structure. Instead of normal depth Shanani [10] replaced actual depth of flow in the upstream offtake in the relationship given by Mahbub and Gulhati (1951), and proposed them as sensitive indicators for offtakes.

Renault [9] presented several analytical relationships for canal reaches, and attributed the performance of distribution in system to the reach sensitivity.

Manual Flow control, in an irrigation and drainage network led to unfair distribution of water among the applicants. Hence the progress of science and the development of computer and their great impact on analysis of numerical problems has made it possible to simulate an Irrigation and Drainage network by developed hydrodynamic models for fair distribution of water for applicants in the network ; and optimal operation type to be determined.

This paper aimed to evaluate the sensitivity of the offtake structures at Varamin Irrigation and Drainage Network, which is a modern network in Iran. Due to improper water allocation, especially in downstream of the network, this paper deals with the simulation of flow in network canals and identification of more critical offtake structures. Based on these results, a new schedule of water allocation is presented to water users to manage and optimize utilization.

2. Materials and methods

Irrigation systems are made up of three main components, canal reaches to convey water, cross-regulators to control water depth within the canal and, offtakes to distribute water to dependent canals and downstream users [9]. Operating an irrigation system consists essentially of performing on specific structures (i.e. cross-regulators and offtakes), to ensure targeted change in deliveries, and to react to unexpected perturbations occurring along the system.

Measuring sensitivity of hydraulic structures is considered as an approach for evaluation of a water projects performance, due to lower distribution efficiency in Irrigation and Drainage project schemes. This study aimed to assess the sensitivity of the offtake structures found in Varamin Irrigation and Drainage Network (VIDN).

3. Study area

Varamin Irrigation Network is one of the modern irrigation networks in Iran which is located in Plains of Varamin. The Plains is located in the northern part of the southern slopes of the Alborz, which is located about 40 km southeast of Tehran at $40^{\circ} 51' E$ and between $05^{\circ} 35'$ north latitude and $30^{\circ} 35'$. Varamin Irrigation Network consists of 760 km of Irrigation and drainage canals; which includes approximately 500 km of third and fourth degree canals; and also includes 2,000 hydraulic structures. A view of Varamin Irrigation and Drainage Network (VIDN) is shown in Fig1.

The incoming flow and subsequently delivery flow to the farmers is varied during the different growing season and years. In other words, the network is experiencing problems with the regulation and distribution of water temporal and spatial. The local farmers' dissatisfaction has been considered as the most important challenge facing network authorities.

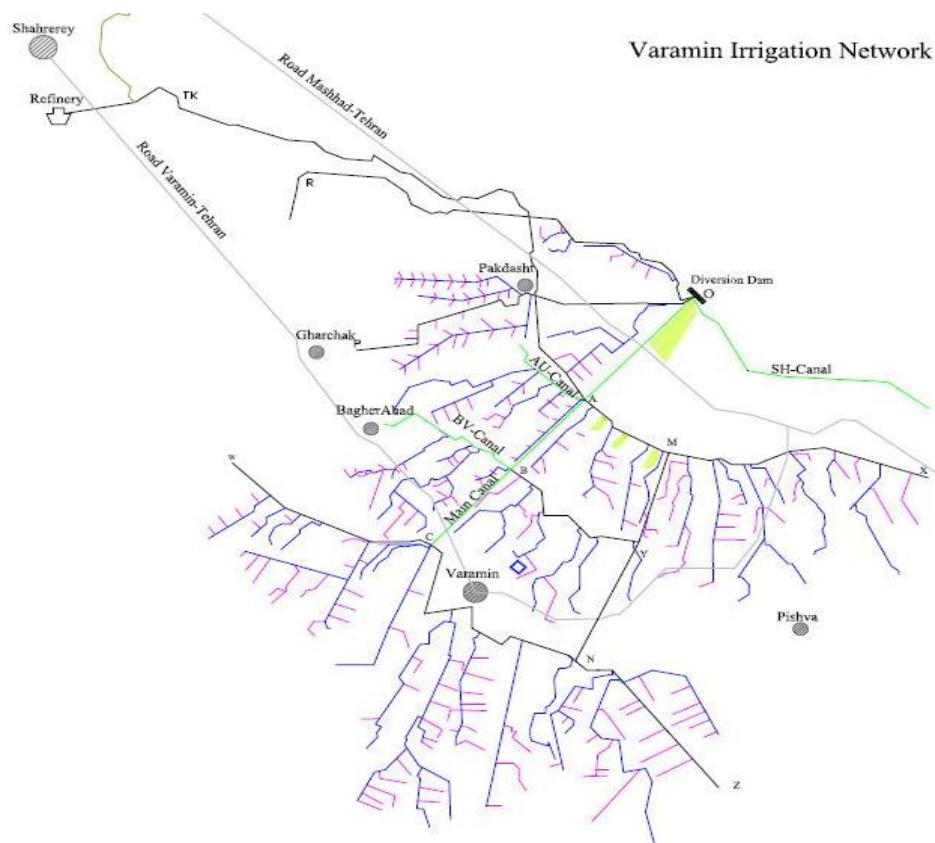


Fig. 1 A view of Varamin Irrigation Network

This paper intends to evaluate the Network performance in three secondary canals located in first, middle and end of Varamin Irrigation and Drainage Network (VIDN). Thus the work was carried out on three secondary canals namely Sharif Abad canal (SH), AU canal and BV canal, which are located within early, middle and end of Varamin Irrigation and Drainage Network respectively. Among the hydraulic structures, the baffle sluice module and Duckbill weir have a significant impact on increasing the water use efficiency. Duckbill weir (weir with fixed long length of crest) is usually used as a cross regulator, to provide proper water level for Baffle-modules; and the Baffle Modules as offtake structures are used as the most appropriate means of flow regulation and distribution at control conditions.

4. Offtake structures

A baffle sluice module (*Neyrpic orifice module*) minimizes water delivery deviation for relatively large upstream flow depth variations. The baffle modules are used as offtake structures in Varamin Irrigation Network. The module is an intake for distribution canals as well as a farm outlet or farm turnout (offtake). It is a metering device and is suitable when water is supplied on a volumetric basis. In order that the module may

draw the amount of water for which it has been designed, the water level in the parent canal should be more or less constant (FAO [3]).

The module consists of a *sill*, and a downstream *glacis*, upon which is placed a fixed metallic plate or baffle. The *sill* and the *fixed plate* (or *baffle*) is enclosed between two vertical, parallel walls, and this arrangement creates an *orifice* which can be closed by a sliding plate or shutter. The module functions only when the sliding plate is raised completely[2].

A distributor usually includes a number of modules, connected together, each one of different width and allowing the passage of a pre-determined discharge, the volume of which is indicated on the corresponding sliding plate. By combining the raising of different sliding plates, the required discharge can be obtained.

A view of Neyrpic modules is shown in Figure 2, and a sample distributor of Neyrpic orifice module in Varamin Network is presented in Figure 3. The position, number and type of distributors (modules) which are located in secondary canals of Sharif Abad canal (SH), AU canal and BV canal, in Varamin irrigation network are presented in tables 1 to 3 respectively. The location of the channels and offtake structures are shown in Fig 4.

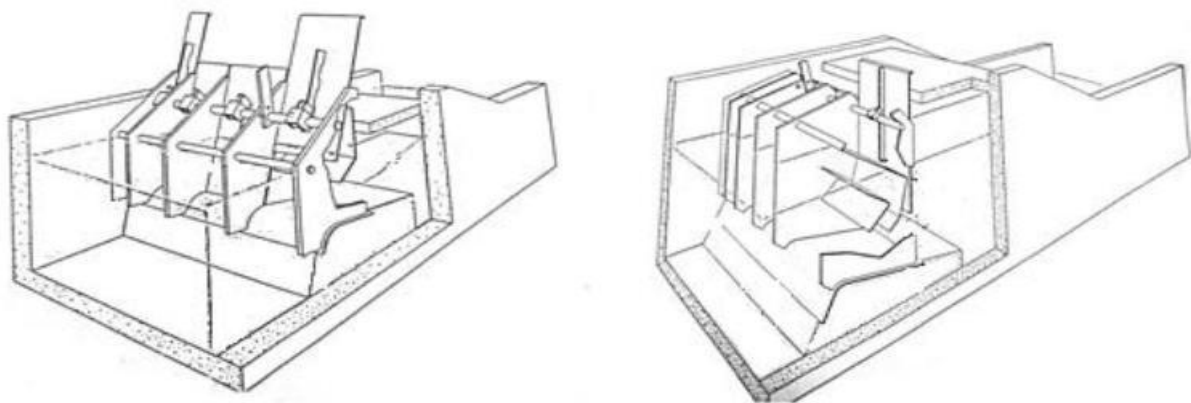


Fig. 2 View of Neyrpic modules

Table 1 Specification of Channel SH

Station (KM)	Offtake	Module	Q (lit/s)
0+800	SH1	XX2	420
1+100	SH2	XX2	180
1+700	SH3	XX2	180
2+900	SH5	XX2	180
4+300	SH7	XX2	180

Table 2 Specification of Channel AU

Station (KM)	Offtake	Module	Q (lit/s)
0+038	U1	XX2	240
1+262	U2	XX2	480
1+613	U3	XX2	300
3+124	U4	XX2	180
4+293	U5	XX2	300

Table 3 Specification of Channel BV

Station (KM)	Offtake	Module	Q (lit/s)
0+040	V1	XX2	420
2+217	V2	C1	1500
3+784	V3	XX2	300
4+678	V4	XX2	360
6+086	V5	XX2	360



Fig. 3 A sample distributor of Neyrpic orifice module in Varamin Network

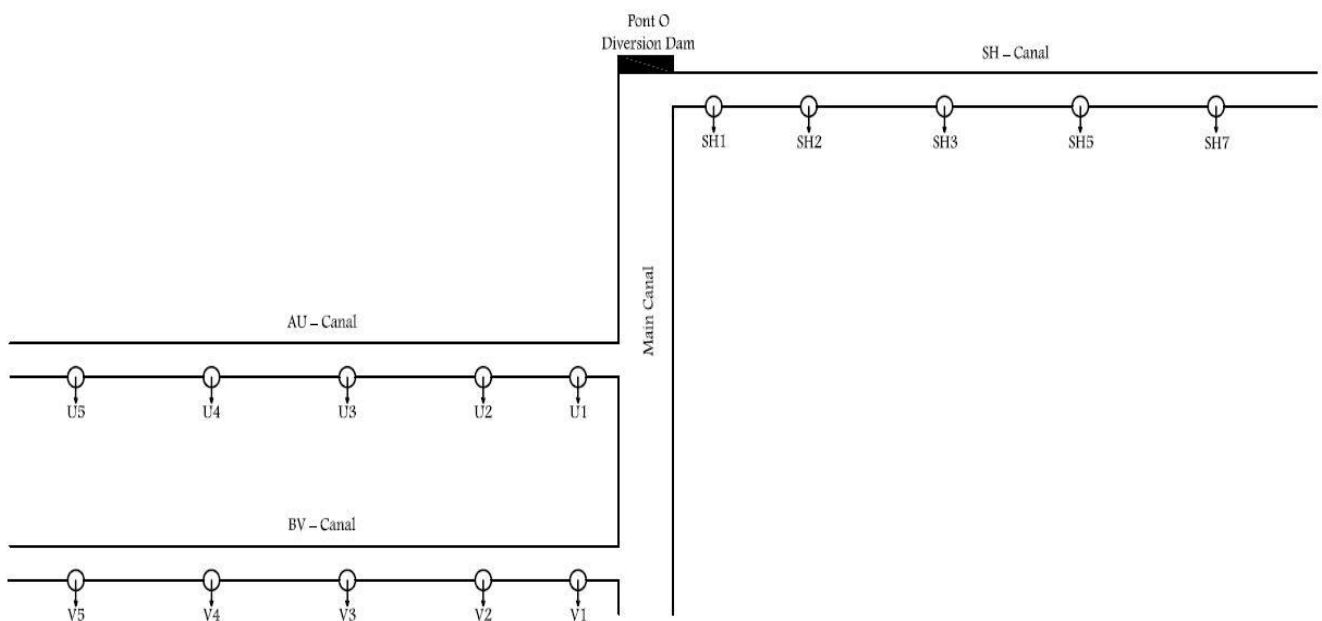


Fig. 4 A view shows the location of the channel and structures

5. Hydraulic structure sensitivity indicators

Hydraulic sensitivity Indicators can be extended in levels of structure, reach, and a set of reaches. An irrigation structure sensitivity indicator can be defined as equation one:

$$S_{IO} = \frac{\partial O}{\partial I} \quad (1)$$

Where, S_{IO} , is indicator of hydraulic sensitivity of output variable to the input variable, ∂O and ∂I are output- and input hydraulic parameters changes respectively.

In fact, hydraulic sensitivity indicator shows if the input hydraulic variable of ΔI is changed, then the output hydraulic variable to what extent will change. Renault [11] has provided the same hydraulic sensitivity Indicators as follows:

$$S_{IOa} = \frac{\partial O/O}{\partial I} \quad (2)$$

$$S_{IOr} = \frac{\partial O/O}{\partial I/I} \quad (3)$$

In the above equations S_{IOa} is absolute sensitivity indicator and S_{IOr} is relative sensitivity indicator.

6. Offtake sensitivity to the absolute change of ongoing flow

Flow through the offtake, in free-flow conditions, is a function of upstream water depth and the gate opening. So that if the gate opening is fixed and does not change the upstream depth of offtake due to flow disturbance while entering to the parent canal, flow rate passing through the offtake will change, and hydraulic performance of the network is affected. Using equation (4) can be considered the effect of variations of upstream depth on the offtake discharge.

$$S_{hq} = \frac{dq_0/q_0}{dH_{us(0)}} \quad (4)$$

In the above equation q is initial discharge, dq , is changes in upstream discharge, dH_{us} is changes in upstream water depth.

7. Offtake sensitivity to variation in opening of gate

the modules due to combination types of these structures. There is an option in the model as a

Opening regulation of an offtake gate by hand is always with error and, this error has an impact on the discharge of intended offtake and also on the discharge of other offtakes. offtake sensitivity indicator with respect to the gate opening, S_{Wq} , is presented according to equation (5).

$$S_{Wq} = \frac{dq_0/q_0}{dW_0} \quad (5)$$

where, q is offtake discharge and W is opening of the gate. The structure has, low sensitivity if the indicator is less than 1, moderate sensitivity if it is between 1 to 2 and, high sensitivity if it is greater than 2.

8. Sobek hydrodynamic model

The Sobek Hydrodynamic model was used to simulate the hydraulic performance in irrigation network in this study. This model is a powerful tool with seven different modules for the simulation of one-dimensional and two-dimensional flow, which the combination of these modules could also be used for simulation purposes. This program is an open-channel dynamic numerical modeling system, which is able to solve the equations that expresses unsteady water flow, sediment transport, water quality, morphology and salt intrusion. SOBEK simulates the flow using the St. Venant continuity equations and calculates besides discharge values, water levels and flow velocities. It uses the implicit finite difference scheme [12]. SOBEK is a powerful tool to simulate and solve problems in river management, flood protection, design of canals, irrigation systems, water quality, navigation and dredging. The SOBEK model can be used for all hydraulic adaptation measures, such as dike heightening and retention areas. As boundary conditions, the results from the coupled atmospheric - hydrologic model runs are used.

Analysis the network performance

The network has been visited, to collect the correct data required to simulate the structures in the model. A view of the structure is shown in Figure 3. The weir symbol is not used to simulate

Compound Structure, which can simulate these structures accurately. This option

requires the initial data including bed grade line, canal side slope and elevation of bed in structure location.

Given that Varamin irrigation system is not providing enough water to water users in downstream, in order to analyze the network performance, the two types of flow were simulated. To investigate the initial designing and existing conditions, simulations have been carried out for the available flow in network and, flow requirements for water users, according to water requirements for their cropping patterns.

Simulation of flow in the network was carried out for unsteady-state in steps of 5 minutes; for a period of maximum consumption (May), based on real data collected from operation stage, and data calculated from cropping pattern. For simulation in SOBEK hydrodynamic model and measuring the structure sensitivity in network, the intended scenario is simulated based on 7-day irrigation which is considered in basic network design.

9. Results and discussion

Sensitivity analyses, applied to irrigation systems, focuses primarily on the delivery and control structures (i.e., offtakes, turnouts and check structure); with the aim of appraising the system performance consequential from a perturbation in the input. So far, most of the studies on this subject have dealt with local sensitivity analyses.

Indicator of offtake sensitivity to the absolute change of upstream water depth shows the changes in discharge passing through the structure due to variations in upstream of depth.

In this study, simulations were carried out by both real and calculated data to enable us to compute the sensitivity of delivery to absolute deviation for offtake structures in Varamin irrigation network. The offtake sensitivity of delivery to absolute deviation of water depth resulted by actual and calculated data are shown in Fig 5 and Fig 6 respectively.

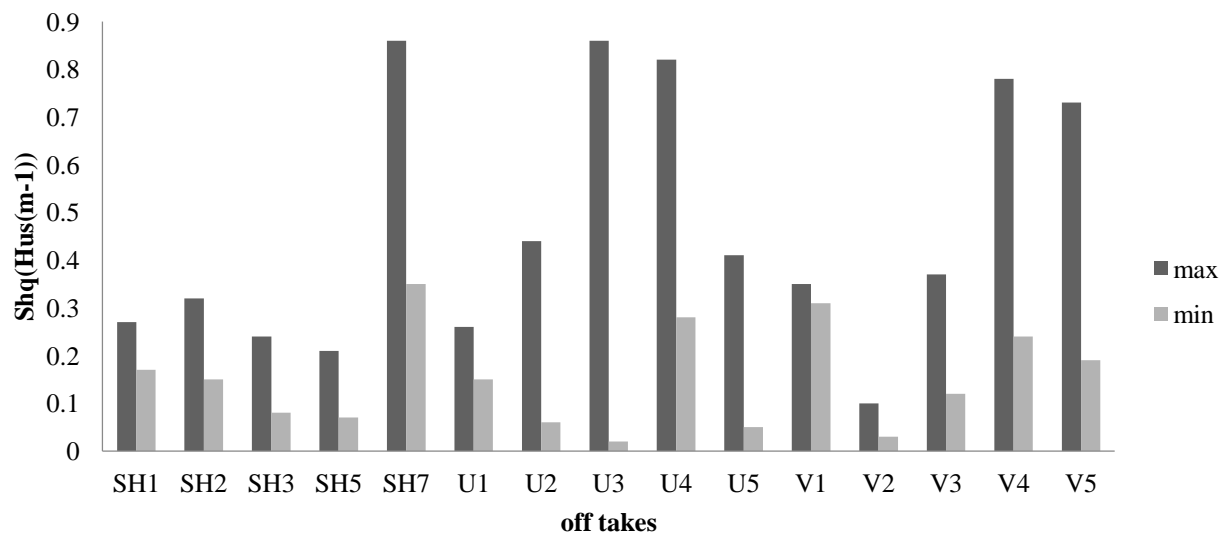


Fig. 5 Offtake sensitivity of delivery to absolute deviation of water depth Index (Real Data)

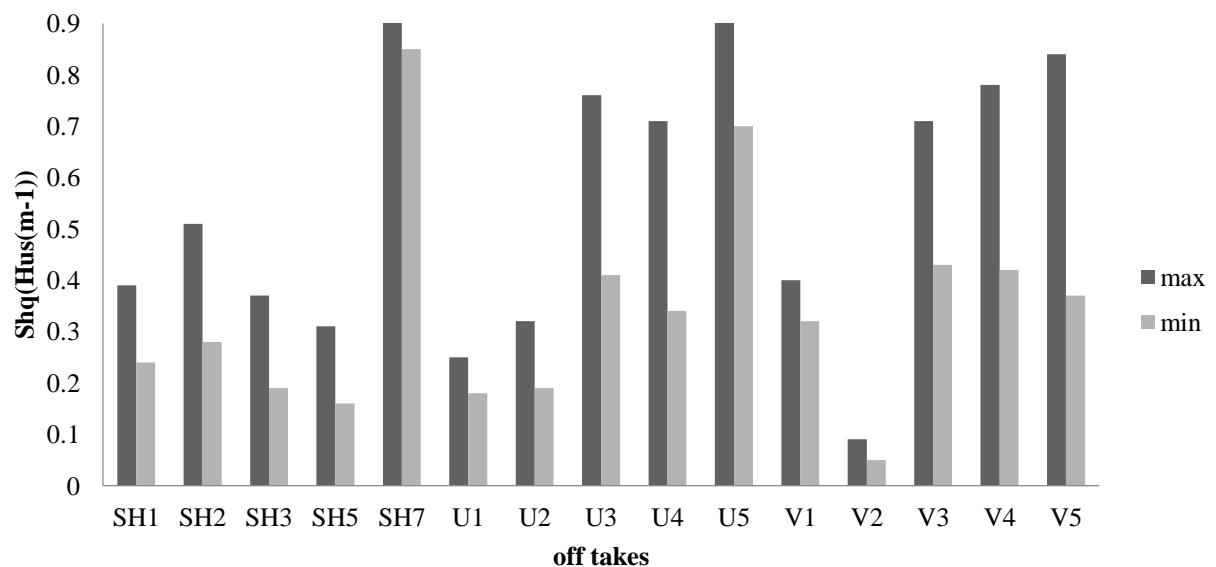


Fig. 6 Offtake sensitivity of delivery to absolute deviation of water depth Index (Calculated Data)

Baffle module as an offtake is designed so that the delivery discharge through structure has not large changes compared to variations of upstream depth of water. It is expected that this structure does not show a significant sensitivity to changes in upstream water depth (S_{hq}). In AU channel, according to diagram 5, offtake U_3 with $S_{hq} = 0.20$ is less sensitive compared to other structures. All of these values are in the range of low sensitivity. As the U_3 offtake is in middle of the AU channel, its sensitivity is low. Because upstream cross regulator can provide the required water depth in right time, so there is not much changes in depth. But on overall results, we can say that the offtake structure U_3 is the most sensitive structure in the network (with $S_{hq} = 0.86$ when using real data). In channel BV, offtake structure V_2 is the least sensitive to *absolute deviation of upstream water depth* (with $S_{hq} = 0.05$) among all structures existing in channel BV. Because in baffle modules,

increasing in capacity reduces the sensitivity, and offtake structure V_2 which is module distributor of C1 type, among BV canal structures has the highest capacity due to high coverage lands.

According to the results for channel SH, it is observed 0.01 m increase in upstream depth of water causes *delivery* rate rises to 1.4 percent in offtake structure SH7; which indicates that the structure is located in middle range of sensitivity. This value is the highest sensitivity value among the sensitivity values obtained from the SH channel structures. The high sensitivity of baffle module SH7 can be attributed to low water depth in the channel, which cause weir flow occur through the module. Because the depth of water in canal is not high enough to allow the blades of module to control the flow and to reduce the impact on the increasing discharge; as a result, the structure acts as a weir. This issue can be seen in Fig 7.

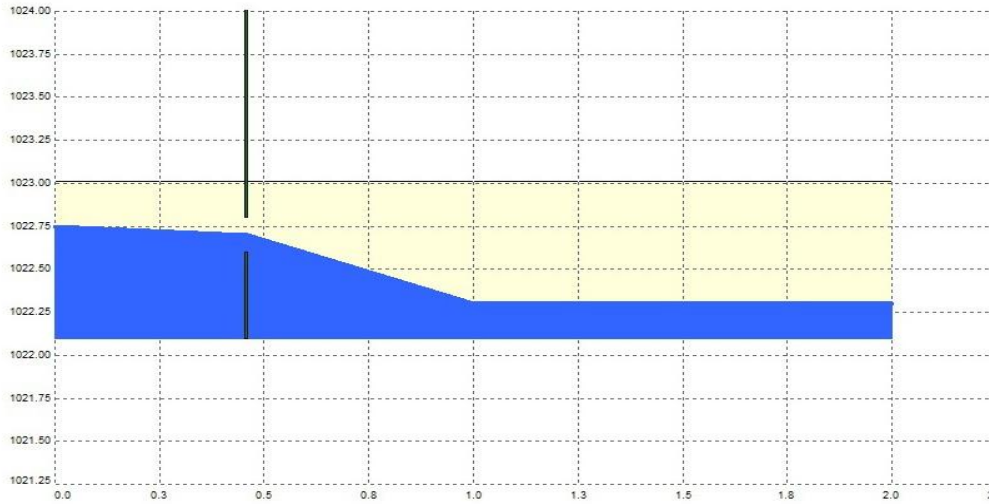


Fig. 7 Structure performance SH7 baffle module in Sobek model
(The baffle is not working due to the flow low depth)

The offtake sensitivity to variation in opening of gate resulted by actual and

calculated data are presented in Fig 8 and Fig 9 respectively.

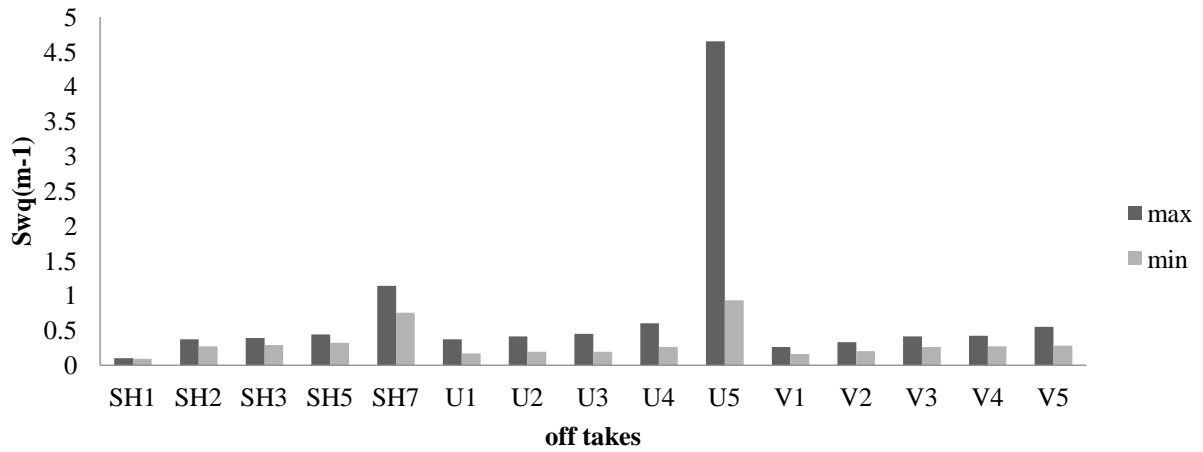


Fig. 8 Offtake sensitivity of delivery to gate opening Index (Real Data)

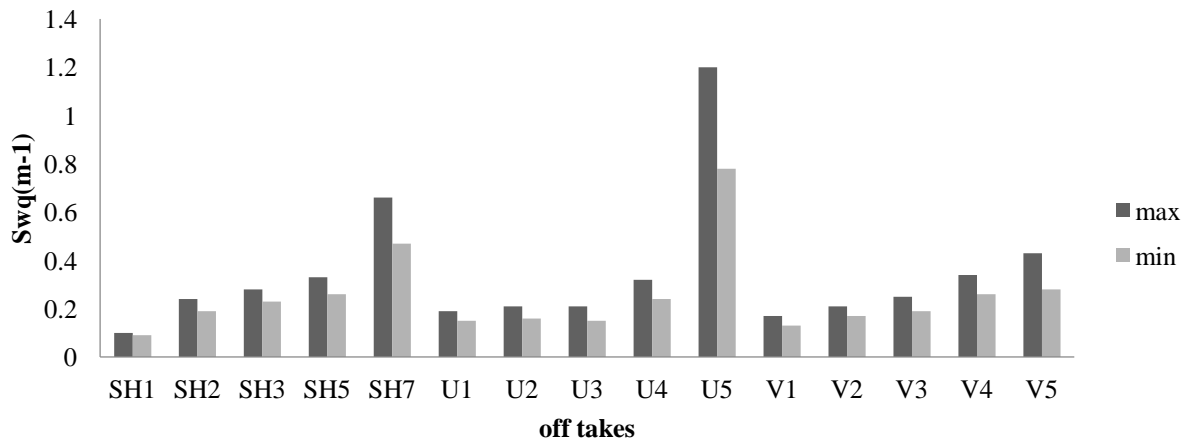


Fig. 9 Offtake sensitivity of delivery to gate opening Index (Calculated Data)

In channel AU, offtake structure U5 shows the most sensitive to variation in opening of gate (with $S_{wq}=4.65$ when using real data and $S_{wq}=1.20$ when using calculated data) among all structures existing in channel AU.

This high sensitivity indicates that the gate opening of the structure, is lowered from the upstream water level, and the results will be dramatic changes in *delivery* flow rate. Offtake structure U1 in the channel AU has lowest sensitivity to gate opening; which the values were $S_{wq}=0.17$ when using real data and $S_{wq}=0.15$ when using calculated data. The low sensitivity to variation in opening of gate for offtake structure U3 is due to locating it in the beginning of AU channel. Therefore, suitable adjustments are made by division structure in channel AU for offtake structures U1. Therefore variations on water depth only occurs in regulating structure of offtake channel AU and has no effect on offtake structure U1. In channel SH, highest and lowest offtake sensitivity to variation in opening of gate is owned to module structures of SH1 and SH7, respectively. Offtake structure SH1 in the channel SH has highest sensitivity to variation in gate opening by values of $S_{wq}=1.14$ when using real data and $S_{wq}=0.66$ when using calculated data. According to sensitivity indicators values resulted from calculated data and the range between these values, we can conclude that, If the amount of water delivered to module structures is equal to the amount of water needed for structures based on cropping pattern, then there is no variation in delivery discharge even for the most sensitive structure as well. Module structure SH1 with $S_{wq}=0.09$ has less sensitivity to gate opening in resulted by both actual and calculated data; and delivery discharge through the structure has not changed a lot.

Analysis of the results of the channel BV shows structure module V5 is the most sensitive offtake structure with sensitivity indicators values resulted from real and calculated data values of $S_{wq}=0.55$ and $S_{wq}=0.43$ respectively. According to the results, it should be stated that the highest change in delivery discharge affected by changing in gate opening is related to the calculated data. Module structure V1 with sensitivity values of 0.16 (actual data) and 0.13 (calculated data)

has shown the least changes in the delivery discharge through the opening of the gate, and low sensitivity to changes in gate opening. Less sensitive to the structure changes in gate opening of Varamin irrigation network is structure module SH1. Low sensitivity of this module structure is due to the fact that it is located at the beginning of main feeder canal in the network. So, in any event, the required delivery discharge is provided. And therefore does not cause large changes in passing discharge, and consequently in the amount of the gate opening.

10. Conclusions

The studies and hydraulic sensitivity analysis on baffle modules within the Varamin irrigation and drainage network showed that these structures have significant sensitivity. According to the equations, sensitivity of baffle modules to upstream depth, occurred in structures which located further downstream of a canal reach. In this research, module-SH7 in the SH channel, module-U3 in AU channel, and module-V5 in BV Channel showed highest sensitivity to upstream depth, according to both real and calculated data, which are located in most downstream, middle and most downstream of their reach respectively.

High sensitivity to change in upstream depth means that a modules which is located in the end and/or in the middle parts of a canal act as an weir because in these conditions water depth in the channel upstream of structure is low and discharging flow through the structure is below the baffle blade.

In other words, the depth is not completely enough to enable baffle-blades to control the passing flow, and to reduce the influence of water depth changes in the channel. In general, the studies conducted on offtake sensitivity indicator with respect to the gate opening reveal that the most sensitive structures are located at the end of each channel, and structures located in the beginning of a channel have very little sensitivity to the opening.

According to the results, we can conclude that, gate openings must be set so that the required discharge would be delivered through the entire off takes to be supplied. Furthermore, the opening of each module should be in coincidence with downstream

required capacity. Because, in operation mode, all structures in the network are opened equally. However, there is the possibility of overdose delivery in some offtakes. As a result, the required water in downstream of the network is not provided, and there is too much water loss in upstream also. Based on these results, a new schedule for the delivery of water can be suggested to Varamin irrigation network management.

For optimal operation in network, distribution of water to water users should be based on the required downstream capacity. As a result, structures which are located in further downstream, show more sensitivity; based on both equations of sensitivity to variation in upstream depth and sensitivity to variation in opening. As a result, the best way to provide suitable depth of water in downstream of each channel is by distributing and delivering water based on downstream requirements. In this situation, the required depth of water in all the off takes are provided and does not make any change in the opening of the gate, and no change occurs in the opening of the gate.

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