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Simulation of seepage from earthen canals of Moghan irrigation and drainage network using seep/w model

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ABSTRACT
Estimating the amount of water seepage of earthy channels due to considerable volume of water loss, reduced quality of lands around channels, as well as technical justification of channels have always been intentioned. One existing approach in this area is applying empirical equations for certain obtained areas, using of which requires validity and reliability. This study used input-output flow method and QLiner flow meter approach to measure losing water seepage in Moghan main irrigation and drainage channel. Experimental equations were also applied following calibration and coefficients adjustments. In addition, amount of water seepage was estimated through using Seep/w software modeling. The results were immediately compared to water balance results indicating that Moritz equation of the 4 evaluated experimental equations had the least error in water seepage estimation; moreover, Seep/w software model was highly effective relative to experimental equations.
Keywords: *seepage, experimental equations, calibration, Seep/w, Moghan.*

INTRODUCTION

Seepage in irrigation channels, in general meaning, refers to water inward and outward movement through porosity of channel bed consisting substances. Factors influencing seepage loss in channels can be associated to channel bed-soil characteristics including porosity, graining, permeability, chemical characteristics, water depth inside channel, and distance of underground water from channel base, weed at channel base and walls, water temperature, channel inadequate slope, manufacture quality, channel lifetime, utilization methods, maintenance operations, and the amount of water sediment [1].
Major water losing in irrigation channels often occurs as seepage phenomenon. According to USBR studies, uncovered channels lose up 50% transferred water through the very seepage. Thus, optimal management of agricultural water consumption and reduced water losses play critical roles in irrigation projects. Besides water losses resulted by seepage, major significant factors of studying seepage amount include reduced quality of land and soil around channel and regional environmental threats. Therefore, decreasing water losses to a minimum, in particular, in arid and semiarid regions is critically important causing experts focus on qualitatively and quantitatively studying of channels' water seepage and its related issues [2].

There are several methods for estimating irrigation channels' seepage, which classified into three categories as following:
Channels' seepage theoretical estimation methods
Channels' seepage experimental estimation methods
Channels' seepage practical measuring methods

Of aforementioned methods, channels' seepage practical measuring methods are more functional and accurate, which can be used in different situations through pool experiments, measuring input, and output flows. Input/output flow method is used in channels in operation with no possibility of water outage and measuring seepage by pool method. Input/output flow method is measuring inflow of channel selected range and output flow, as well as obtaining their differences. If the length of selected range is large and seepage intensity is high, there will be no water removal within selected range. This method is the best alternative for measuring water seepage losses. Water flow is measured by using various flow transmitters including impeller flow transmitter, magnetic flow transmitter, ADCP, etc and/or through hydraulic structures such as weirs, Parshall flumes [3].
Rostamian and Koupaie (2011) estimated water seepage of terrestrial channels of Zayande Roud irrigation network through SEEP/W software; furthermore, meanwhile measuring the amount of seepage through SEEP mathematical model and various experimental equations, seepage was also measured by input-output method through using propeller current. Research results demonstrated disadvantage of experimental equations and Seep model high capability. Further, results also revealed that in a case where experimental equations are used for assessment and estimation of seepage level, it is necessary to verify and calibrate them for local conditions [2].
Ghobadian and Khalaj (2012) studied numerical estimation of seepage level of terrestrial channels in Nazelou, Uremia and finally adjusted seepage experimental relations. Thus, seepage level computed by developing computerized model as field measurements are expensive and time-consuming, as well as the necessity of calibrating experimental equation coefficients for local condition. Research findings showed that the presented numerical model with an error of less than 5% estimates discharge value of channels' seepage. There is seen a considerable difference between early coefficients and adjusted coefficients of seepage measurement experimental equations in understudied region. The findings also demonstrated that all studied experimental relations underestimate seepage discharge value preceding fixed coefficient adjustment; then, Ingham and Davis Willson better predicate the measured discharge [4].
Christoph- Ditrij Kinzeli et al (2010) measured seepage level by input-output method using ACDP technology (Acoustic Doppler Current Profiler); then, introduced a relation based on current rate and channel locus in order to estimate channel seepage [5].
Kazemi Azaar et al (2014) studied water seepage losses in macro channels irrigation by input-output method through using ADCP technology and showed higher efficacy of this technology to other measuring devices in terms of measuring rate, convenience, and accuracy [3].
This study beside measuring water seepage losses through using ADCP technology and applying experimental equations following calibration and adjusting equation coefficients, used Seep/w software modeling to assess and estimate water seepage level of terrestrial channels' irrigation and drainage network in Moghan; next, the results will be compared to water balance results.
Theoretical methods of channels' seepage estimation
Seepage discharge follows Darcy's law:

$$q = kA\frac{\partial h}{\partial l} \qquad (1)$$

Where, q is seepage discharge (m^3/s), k indicates permeability coefficient (m/s), A is water and soil current cross-sections (m^2), and $\frac{\partial h}{\partial l}$ is currently hydraulic slope.

Water flow equation in porous medium is Poisson's equation, which is extended form of well-

$$k_x\frac{\partial^2 h}{\partial x^2} + k_y\frac{\partial^2 h}{\partial y^2} = q \qquad (2)$$

k_x and k_y are horizontal and vertical soil hydraulic directions in term of m/s, respectively; h is water potential in soil (m), and q represents mass soil input current discharge in m^3/s per unit area. If there exists an input discharge to mass soil, q will be positive; conversely, if there is output discharge, then q is negative. This relation is consistent for permanent conditions, current and homogenous soil; and for non-permanet condition we have:

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y\frac{\partial h}{\partial y}\right) = q + \frac{\partial \theta}{\partial t} \qquad (3)$$

Where $\frac{\partial \theta}{\partial t}$ is humidity volume changes to time.

As solving Poisson equation is a complex mathematic problem; however, numerical methods use as a mean to solve differential equations and turning them into algebraic equations. By emerging computers and their wide application, numerical methods were largely intentioned. A large set of algebraic equations can be solved through some techniques based repeated methods and or matrix methods by using computer [2].

MATERIALS AND METHODS

The area under study is Moghan irrigation and drainage network located in the north of Ardebil, Iran, west of Caspian Sea, at 47.5 to 48 meridian east and 39.2- 39.42th meridian north. Moghan irrigation and drainage with 72000 hectare is considered one of the largest irrigation networks in country supplying water through Araas dam and Mill and Moghan diversion dam. Total length of Moghan irrigation and drainage major channel is 178 km, which is mostly terrestrial implemented in concrete coverage in 40 km since its operation from 1973. Channel main capacity was 80 m/s at entry; 1’000’000’000 m3 water annually enters into more than 90000 hectares agriculture areas to supply required water of agriculture, drinking water, industry, and Moghan hydroelectric power plant [6].

In measurement stations, it is required to consider that bridges and channels’ arches are adequately distant such that rate is almost uniformly distributed at that section. Thus, it has been attempted to select direct paths to measure discharge direction. Since it was not possible to vary main channel and establish different discharges in all sections, on seepage ranges of main channel was selected in 35+000 to 36+800 km (Figure 1). Then, two measurements were done, one in non-operation season (December) where there is channel minimum discharge, and the other one in operation season (March and April) where there is maximum discharge in channel. Geology profiles at this range of major channel indicate that soli type of CL, which was constructed in excavation.

Figure 1. Selected range to measure water seepage

Measuring water flow

Water flow characteristics were measured using QLiner portable flow meter, which is based on ADCP (Acoustic Doppler Current Profiler) technology. In this method, flow cross-section divides into some vertical sections according to channel or river geometry. QLiner measures water depth and vertical distribution of water flow rate in each section. The major advantage of this method comparing others including Molinet is that it measures average velocity in more than 10 points; then, calculates the mean; whereas, in Molinet, current velocity is measured at two points of 0.2 and 0.8 and the mean is used as velocity mean at that point. These data transform into velocity mean and partial discharge of that section within a computational process in accordance to EN ISO 748 (Mid section method). Total discharge is calculated as sum of all partial discharges once measuring completes in vertical cross sections [7].

Computing water seepage losses

Channel water seepage obtain by establishing water balance (Figure 2) and measuring input-output current range using (4) and (5):

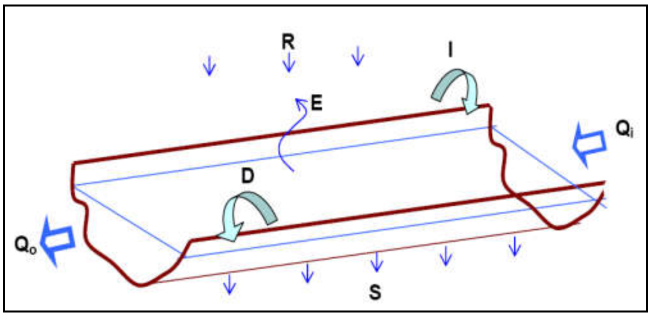

Figure 2. Water balance of input and output current for one range of channel

$$S = Q_i + R - Q_o - D + I - E \quad (4)$$

Where, S is seepage intensity, Qi represents input current, R is rainfall, Q0 output flow, D is channel obtained flow within the range, I is input flow within range length, and E is surface evaporation [as cited by 3].

Since range (interval) is selected such that water removing and entering is not possible within range length, and evaporation is trivial, seepage discharge within selected range obtain as follows:

$$S = Q_i - Q_o \quad (5)$$

Water seepage experimental relations in channels

There have provided many experimental methods and equations to approximate channels water seepage in different countries, some of which are as follows [2]:

Davis- Wilson equation

$$q = 0.45C \frac{P_W L}{4\times10^6 + 3650\sqrt{V}} \sqrt[3]{H_w} \quad (6)$$

Where q is channel seepage level (m3/s) in channel length L; C is a coefficient that varies from 1 to 70 depending on bed material. Pw is wet area per m, L channel length in m; Hw is channel water depth in meter, and V represents channel water flow velocity in m/s.

Mols-Worth- Yennidumia

$$q = 86.4C\sqrt{R} \quad (7)$$

Where, q is channel seepage in m3/m2/day; C is constant coefficient which is 0.0015 and 0.003 for clay and sandy soil, respectively; and, R is hydraulic radius in m.

Moritz relation

$$q = 0.0186C\sqrt{(Q/V)} \quad (8)$$

Where

q: seepage level of one-kilometer channel in m3s;

Q: water flow discharge inside channel in m3s;

V: water velocity inside channel in m/s;

C: constant coefficient for clay and clay loam walls which is 0.41 and 0.66, respectively.

Ingham equation

$$q = 0.55 \times 10^{-6} CPL\sqrt{H} \quad (9)$$

Where q shows channel seepage level in m3/s along channel length; p is wet area (m); L channel length in (m); H is channel water depth in m; C is the coefficient which varies from 1.5 to 5.5 depending on bed material.

Seep/w software

To apply software Seep/w modeling, the problem was defined in model following data collection. Four-point networking method was used to illustrate limited difference network. Once networking and bed materials were described, boundary condition is defined in model. First boundary condition is for channel submerged inner points. Some values of total load equals water height inside channel relative to water table level were attributed to these points. Second boundary condition relates to balanced water table points, which were assigned zero pressure loads. Figure 3 shows defined cross-section and networking.

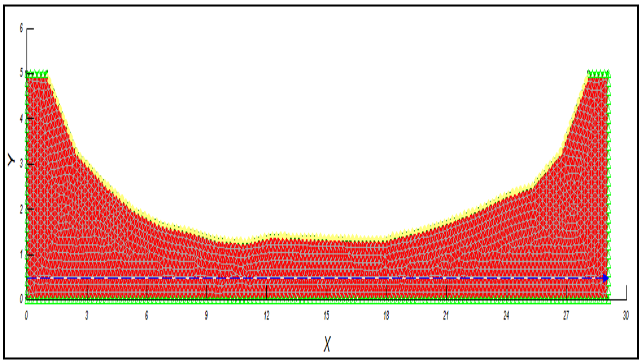

Figure 3. Research terrestrial channel section and rating elements

RESULTS AND DISCUSSION

Table 1 illustrates measured seepage level in minimum and maximum discharge in the selected range with 1800 m length. As seen, seepage level is 0.174 and 0.267 m3/s in minimum and maximum discharges, respectively. Initial C coefficient values of experimental equations select according to Channel bed soil classification (CL); then, adjusted regarding water seepage losses in minimum discharge showing in Table 2. As it shows, there is a huge difference between adjusted coefficients and initial coefficients indicating the necessity of calibrating these coefficients in using experimental equations of water seepage estimation.

Table 3 illustrates results of water seepage using experimental equation (4) and adjusted C coefficients, as well as using Seep/w software model regarding average hydraulic characteristics at the beginning and ending to compare computational error of experimental equation accuracy with seepage measured value. It seems that of 4 studied experimental equations, Moritz equation assessment with 25.8 has the least error (%) and Seep/w software with 22.41% had the least error comparing to experimental equations. Therefore, it can be seen that Seep/w model outperforms experimental equations in estimating region water seepage. Other advantages of Seep/w model include model high ability in graphically designing current direction, distributing pressure potential, and seepage current boundary in soil profile (figure 4). This model leads to studying channels' various aspects, with no much time needed, according to underground water, soil texture, and current discharge in order to decrease seepage and increase performance.

Table 1: Water seepage measurement results

Seepage		average					Output flow					Input flow				
q(Lit/day/m^2)	q(m^3/s)	H	P	A	V	Q	H	P	A	V	Q	H	P	A	V	Q
390	0.174	2.32	21.41	34.72	0.088	29.72	2.66	21.74	40.145	0.071	2.885	1.98	21.08	29.298	0.104	3.059
582.8	0.267	2.65	21.99	40.2	0.455	0.581	2.62	21.95	40.04	0.454	0.447	2.67	22.03	40.395	0.456	18.714

Table 2: Initial and Adjusted coefficients of sediment experimental equations

Experimental formula	Initial C coefficient	Adjusted C coefficient
Ingham	3	5.39
Mols-Worth-Yennidumia	0.0015	0.00355
Moritz	0.41	0.894
Davis-Wilson	4	30.3

Table 3. Experimental equations and Seep/w model error (%)

Estimation method	Computational seepage	Real seepage	Error percentage
Ingham	0.191	0.267	28.46
Mols-Worth-Yennidumia	0.189	0.267	29.2
Moritz	0.198	0.267	25.8
Davis-Wilson	0.135	0.267	49.5
Seep/w	0.213	0.176	22.41

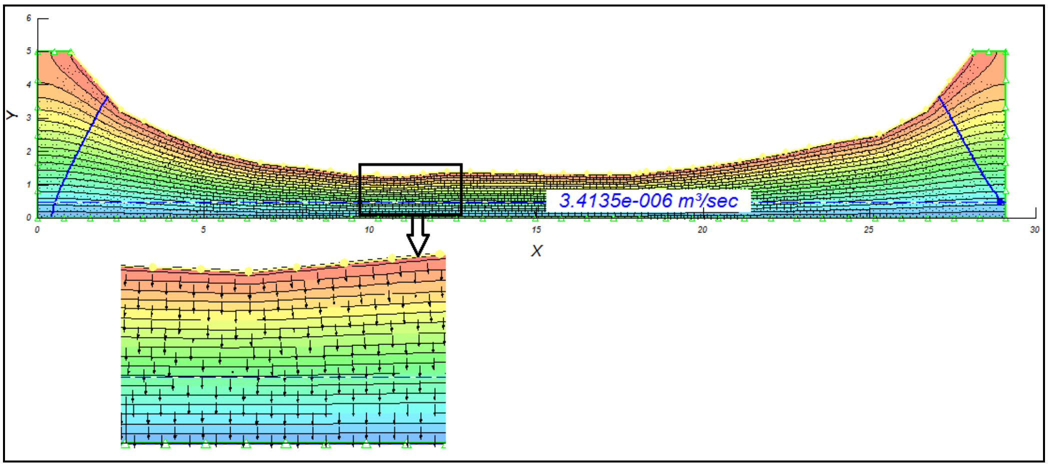

Figure 4. Current direction, pressure potential distribution, and seepage current boundary

CONCLUSION

Moghan irrigation and drainage network with 92000 hectares gross land area and 180 km length of major channel is included in the largest irrigation networks in country. As more than 1'000'000'000 m3 water annually enters into network for agricultural, drinking, and industry applications, 140 km terrestrial channel can lead to considerable amount of water through leaking.

Results of empirical equations in estimating water seepage of Moghan irrigation and drainage of terrestrial channels demonstrate that using experimental formula once associated coefficients were adjusted can lead to acceptable and efficient results. According to region physical soil characteristics, other hydraulic considerations, as well as channel implementation condition, Moritz with 25.8 % error is applicable in estimating water seepage among the 4 studied experimental equations. In addition, Seep/w software estimated seepage value at 22.41% error which is highly accurate in estimating water seepage level in comparison to aforementioned experimental formulas.

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