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ORIGINAL ARTICLE

Estimation of Channels Seepage using Seep/w and Evolutionary Polynomial Regression (EPR) modeling (Case Study: Qazvin and Isfahan Channels)

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ABSTRACT: Research and studies on the seepage of channels so far as man power and time and expense required for the experimental measurement of seepage canals or studies that require complex mathematical equations to solve difficult linear integral, need for a new and accurate way to predict the amount of seepage in canals before creation of it. Developing computer-based tools during the last two decades facilitates and develops of computational intelligence techniques. Seep/w and EPR are the new technique developed in recent years and at first it has been used for modeling environmental phenomena by providers. The use of these methods in water engineering has recently started and it is growing. However, in order to relative extent of these methods, collection efficiency in many ways remains a mystery. The results of modeling performed in seep/w for different initial conditions in canals including canal width, canal slope, water depth, the lining thickness, and depth to groundwater and accuracy of results on Qazvin and Isfahan canal were investigated.

Keywords: EPR, Canals, Seepage, Seep/W

INTRODUCTION

Seepage outflow from canals affects the efficient operation of the canal system as this water leaves the canal, moving downhill and through the soil strata, and may no longer be directly available to the water users. Also, seepage affects the effective water management criteria because it sometimes produces erosion and piping damage at control structures. In recent years, many researchers have tried to predict the behavior of a comprehensive behavioral model of seepage. It is not easy to do due to the impact of the seepage in canals and their variable. But given the changes in the initial conditions of canals including canal width, canal slope, water depth, the canal thickness, and depth to groundwater level in prediction models can be used for future designs. New methods of data mining and soft computing in recent years have been considered significantly by the scientific community. The efficiency of these methods was evaluated in many ways and found out that they are higher than fatalistic methods based on physical assumptions. Developing computer-based tools during the last two decades facilitates and develops of computational intelligence techniques. All the described methods in the seepage behavior of the channel, with the assumption being true, laws of mechanics have been developed for soil and water environment. Following the introduction of this problem and with advances in the science of computer hardware and software, new methods and semi-randomly procedures were considered and gradually entered into the water engineering. Recently, genetic and evolutionary algorithm with its derivatives in geotechnical and hydraulic issues also tested and represented high potential. The range of available tools and techniques for the genetic algorithm increases day by day, and due to it the appropriate reviewing in geotechnical and Hydraulic investigations dealing with the complexities and uncertainties of Environment have been provided. Evolutionary Polynomial Regression (EPR) presented for the first time by Giustolosi, O. and Savic, D. A. (2004) based on the idea of Rule Based Symbolic Regression (R-BSR) presented by Davidson et al. (1999) & (2000). The EPR method, similar to R-BSR, is a two-stage technique to construct symbolic models of determines structure and parameter estimation.A family of curves for flat canal banks has been presented. However, seepage from a rectangular canal cannot be computed from the analytical solution given for a trapezoidal canal. The case of a rectangular canal has been dealt with by Morel-Seytoux (1964), and the solution has been obtained by conformal mapping and the use of Green functions. The perfect lining would prevent all the seepage loss, but a canal lining deteriorates with time. An examination of canals by Wachyan and Rushton (1987) indicated that a well-maintained canal with a 99% perfect lining reduces seepage about 30–40%. The seepage loss from canals is governed by hydraulic conductivity of the subsoils, canal geometry, hydraulic gradient between the canal and the aquifer underneath, and initial and boundary conditions. The seepage loss from a canal in an unconfined flow condition is finite and maximum when the water table lies at a very large depth. Canal seepage has been estimated for different sets of specific conditions (Subramanya et al. 1973; Sharma and Chawla 1979; Wolde-Kirkos and

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Chawla 1994). Prabhata et al. (2000) designed the canals in such a shape and with dimensions that minimize the seepage loss. This research addresses the design of a minimum seepage section. Molina (2008) have estimated seepage in 39 selected reaches of 11 irrigation canals in the Logan and Blacksmith Fork irrigation systems of Cache Valley, Utah. As a result, reaches with the highest seepage losses were identified.In this study, Qazvin and Isfahan Channels (under operation) data including several cross-sections of the channels, soil hydraulic conductivity, upstream and downstream water levels were used to estimation of seepage. Seep/w software is applied for seepage simulation. Also this paper presents a method for predicting the behavior of the seepage in channels. This method, based on Evolutionary Polynomial Regression is called Genetic Algorithm and provides a comprehensive model for forecasting seepage behavior of the channel. Variables of the model are determined by the initial conditions modeling and include channel width, channel slope, water depth in the channel, the channel thickness, and depth of the groundwater level.

MATERIAL AND METHODS

Preferred Characteristics of a Channel Cross Section

Parameters were selected as reference parameters in order to create a good basis for assessing the effect of various factors on the seepage in channels. *Preferred characteristics* of channel including channel width, b side slope, m thickness, T water depth, y and depth in channels were defined with the following values: channel width corresponding to the width of the usual channels, b = 2m horizontal to vertical aspect ratio of the channel, typically channel slope, m = 1.5 , water level, y = 2m, channel thickness, t = 0. Table (1) shows the seepage for the following model defined in terms of the reference model.

Table 1. Parameters of the reference model and seepage rate

measured seepage Q (m^3/s)	Canal lining thickness (t)	Water depth y (m)	Canal slope s	Canal width b (m)
1.86e^{-4}	0	2	1.5	2

Governing equations

Deferential controlling equations for the simple saturation seepage are written in an anisotropic environment, such that:

$$\frac{\partial}{\partial x}\left(-k_x\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(-k_y\frac{\partial H}{\partial y}\right)=0 \qquad (1)$$

Where H=total head, k_X=hydraulic conductivity in x direction and k_y=hydraulic conductivity in y direction. For unsteady or transient flow condition, Eq. 1 changes to Eq. 2:

$$\frac{\partial}{\partial x}\left(-k_x\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(-k_y\frac{\partial H}{\partial y}\right)+Q=\frac{\partial\theta}{\partial t} \qquad (2)$$

where Q=flow, θ=the water volume content and t= time.

If k is assumed to be independent of x and y, that is if the region is assumed to be homogeneous as well as isotropic, then Eq. 1 transforms to Eq. 3.

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}=0 \qquad (3)$$

Introducing the EPR method

Genetic programming is based upon the principles of genetic algorithm. In summary, in this way, random mathematical functions are made for input parameters to estimate output parameters. To evaluate the fit of these functions, some of those which are able to fit more than others are selected. They produce more accurate functions of a new generation by applying genetic operators on them. This process continues until we reach a satisfactory resolution of the model. Evolutionary polynomial regression (EPR) is such combination methods that are produced by transplantation of genetic algorithm and linear regression. New modeling strategy used in this paper that achieves to an evolutionary polynomial regression (EPR) with combination of numerical regression and symbolic. Symbolic regressions are based on genetic programming and designed similar to genetic algorithms (GA) techniques, but the difference is that the provided solution in genetic algorithm are determined according to proposed problem. While in genetic programming, computer programs are derived to solve a given problem and due to strategies using polynomial structures similar to GP rules, there is no need to determine the regression model beforehand. This combined strategy or rule based genetic programming (RBGP) reduce the complexity of the estimated phrases and also the problems associated with the classical GP; besides by limiting the scope of the operations that are normally used in the symbolic regression to requested subset, it provides polynomial answers.

Evolutionary Polynomial Regression (EPR) presented for the first time by Giustolosi, O. and Savic, D. A. (2004) based on the idea of Rule Based Symbolic Regression (R-BSR) presented by Davidson et al. (1999) & (2000). The EPR method, similar to R-BSR, is a two-stage technique to construct symbolic models of determines structure and parameter estimation.The main difference between the two methods is how to find and to determine the primary structure. In EPR method a simple genetic algorithm is used instead of a tree GP used in R-BSR. In EPR at first search for symbolic structures made by GA and then the constant values are obtained by solving a linear least squares (LS) problem. This method was a transplanted of the genetic programming method and symbolic regression restricted to the addition and subtraction operations, and positive integer power, at first the initial model is obtained by GP and these models using the evolutionary process to change to the form of the right side of equation (4) by rule based program that includes 56 algebraic rules:

$$y=\sum_{j=1}^{m} a_j \cdot z_j + a_0 \qquad (4)$$

In this equation: y is the estimation of target value by least square, a_j is adjustable parameter for …..(n th) , a_0 is selective bias, m is the number of clauses or parameters, z_j is a transformed variable and function of

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the independent variables or inputs (x_1, x_2, ..., x_k) that is evaluated in J th data k is the number of input variables. To extend the evolutionary polynomial regression method, equation (4) changed into equation (5):

$$Z^j_{N\times 1} = \left[(X_1)^{ES(j,1)} \cdot (X_2)^{ES(j,2)} \cdot (X_3)^{ES(j,3)} \cdot \ldots \cdot (X_k)^{ES(j,k)}\right] \quad \forall j = 1 \ldots m \qquad (5)$$

Where, k th column of X represents variables such candidate j th equation 5.

In this equation Zj is equal to j th column vector that its elements are multiplied of candidate inputs and ES is the matrix of powers. Therefore, based on the original matrix of rule based genetic programming approach we can write:

$$Y = a_0 + a_1 \cdot Z_1 + a_2 \cdot Z_2 + a_3 \cdot Z_3 + a_4 \cdot Z_4 = a_0 + a_1 \cdot X_3 / X_1 + a_2 \cdot X_2 / X_3 + a_3 \cdot X_1 + a_4 \cdot X_1 X_2 \qquad (6)$$

The next step is calculation of adjustable parameters a_j using linear least square method by minimizing the sum of squared errors (SSE) as the cost function. Criterion of evaluation and selection of phrases produced coefficient of determination (CoD) is the following equation:

$$CoD = 1 - \frac{N-1}{N} \frac{\sum_N (\hat{y} - y_{exp})^2}{\sum_N (y_{exp} - avg(y_{exp}))^2} \qquad (7)$$

N number of data; avg (y_{exp}) actual observations mean, the value obtained from the model and the actual value is y_{exp}.

Setting algorithm parameter EPR and Program execution

In parameters environment according to the problem, settings of these parameters will be done and executed such as Type of regression function, the number phrases, solution, number of generations, the objective function and strategy. After reaching the predetermined number of generations, program stops and results in an Excel file is stored. The performance measures of production models with criterions such as sum of squared errors (SSE) and the coefficient of determination (R^2) and with their comparison, the best and most accurate model can be selected.

RESULTS

Seep/w modeling results with different initial conditions

Figure (1) shows the modeling results were compared with the experimental curve of Muscat (m= 1.5). It should be noted that the accuracy of Seep/w results is verifiable according to corresponding values obtained from Seep/w with the reference values. Figure 2 shows the variation of q/ky versus b/y ratio with different thickness. The diagram can be used to obtain the seepage for the range of 0<b/y<12 and 0 <t <0.2 for m=1/5. This chart is the same as Muscat chart and its advantages in comparison with Muscat chart is that it includes the result of t (thickness).

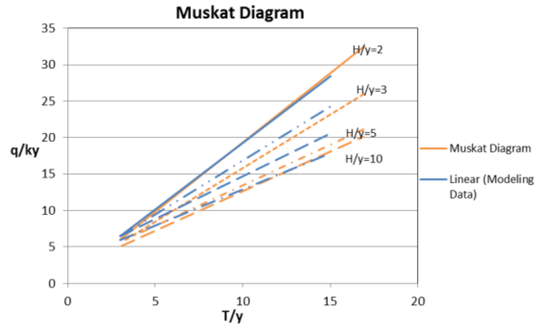

Figure 1. Comparison of Muskat diagram with Seep/w results

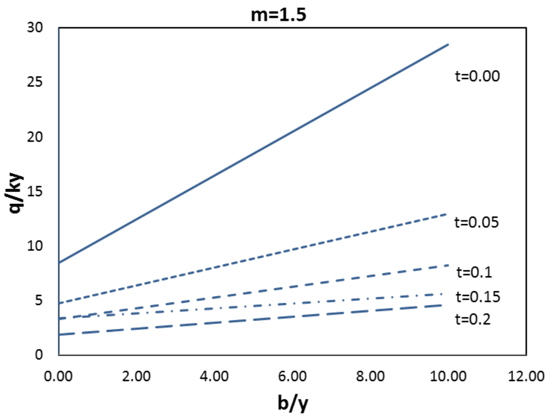

Figure 2. Variation q/ky versus b/y for different lining thickness and m=1/5

Figure 2 shows that seepage will not change for t>10 cm.

In Muscat diagram the seepage values have been obtained with the H/y and T/y (T= Width of the free surface). Regarding to Seep/w model results and comparison with Muscat chart, Accuracy and precision of Seep /w model in estimating of channels seepage can be seen. Figure 3 shows that the stimulated amounts of mq/ky were obtained using Seep/ w for the range of 0< mb/y<16 and 0<t<0.2. This chart is similar Muscat chart, with the difference of that it considers the effect of slope and thickness. Figure 4 shows the seepage values obtained by Seep/w that for 0 <b/y <6 and 0<m<1.5 and t = 0 (without lining).

Table 2. Comparison of the measured seepage and Seep/w model for Qazvin canal

No	Detail	Measured seepage m^3/s	Seepage by seep/w m^3/s
1	Main Canal,Mc3	$3.37e^{-3}$	$2.2e^{-3}$
2	Lateral Canal 1,2, L3	$1.74e^{-4}$	$8.99e^{-5}$
3	Lateral Canal 3, L32	$6.43e^{-5}$	$5.78e^{-5}$
4	Lateral Canal 4, L3-28D	$1.93e^{-5}$	$9.32e^{-6}$

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Table 3. Comparison of the measured seepage and Seep/w model for Esfahan canal

NO.	Type of lining	Measured seepage $(lit/day/m^2)$	Seepage by seep/w $(lit/day/m^2)$
1	Without lining	50-100	52.45
2	Concrete (10 cm)	2.4	3.6
3	Geomembrane	14-69	21.17
4	Clay substrate	15-45	21.95
5	Sandy substrate	21-60	25.06
6	Compacted soil	1.7-21	10.3

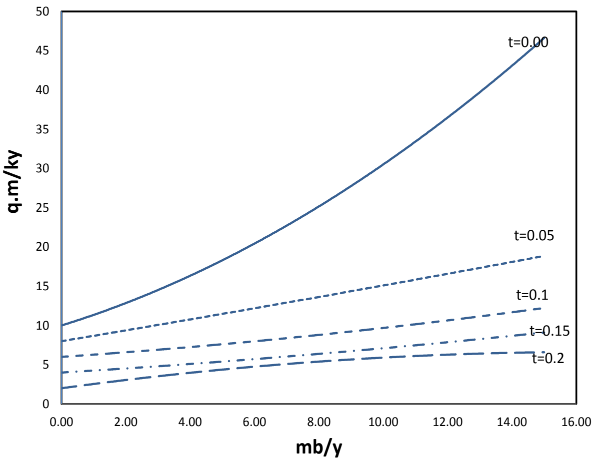


Figure 3. Variation qm/ky versus mb/y for different lining thickness

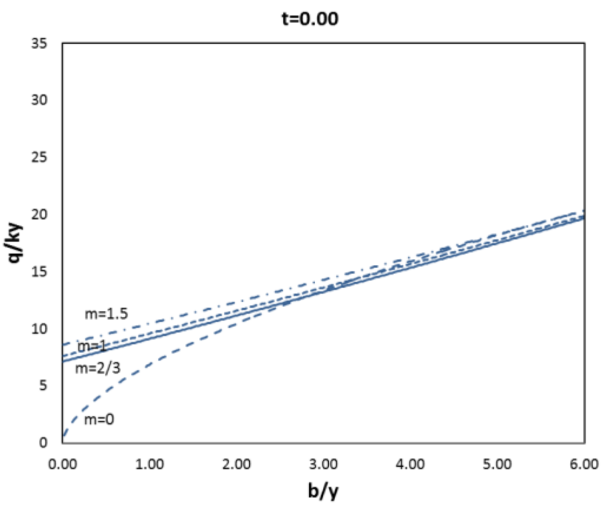


Figure 4. Variation q/ky versus b/y for 0<m<1.5, without lining

As Swami (2001) proved that for side slope, m larger than 1.5, with a reduction in channel width, optimum efficiency in reduction of the seepage leads to b = 0 (rectangular). Figure 4 shows that the lowest seepage values would be for b = 0 (rectangular) and by increasing the amount of side slope the seepage q/ky increases and channel side slopes, m would have a little effect on the amount of q/ky for b/y> 3. Figure 5 shows the values of q/ky for 0 <T/y <14 and 0 <t <0.2 with different thicknesses. The seepage is increasing with increasing of T/y values.

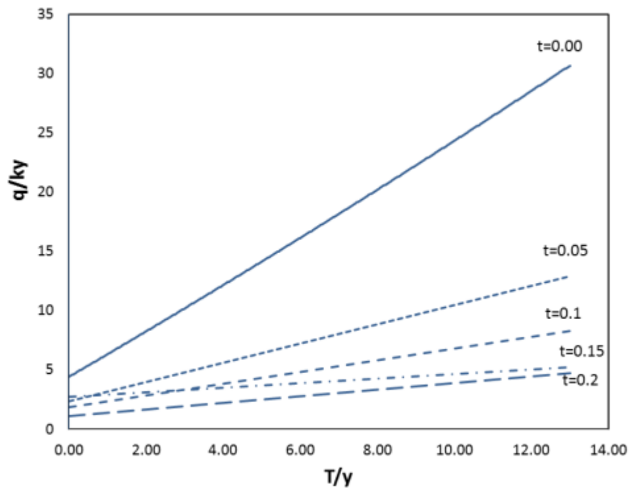


Figure 5. Variation q/ky versus T/y for different thickness lining

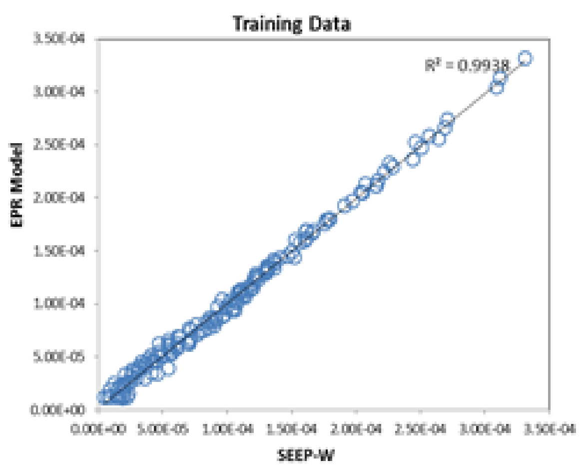
EPR modeling results for seepage in canals

In this way, multiple polynomial equations are presented with a number of different sentences and different care. Sentences were limited to a maximum of 9. By comparing the obtained equations to estimate accurately the training data and verification, to evaluate the behavior of seepage in the canal according to the provided modeling, equation is a power sentence that is represented as the simplest equation for predicting of seepage behavior in canals

$$Q = [28.7(yH)^{0.5} - 7.4(yHt)^{0.5} - 9.6\times10^{-4}m^{0.5}y^5H + 5\times10^{-5}mH^6 - 3.25bt^{0.5} + 0.69bH^{0.5} + 1.22]\times10^{-5}$$

In this equation y = the level of water in canal in meter, H= the depth of the groundwater level in meters, t= canal thickness, and m=canal side slope, and b is the canal width in meters EPR model.

Estimated results are compared with Seep w results for training and verification data as showed in Figure6. The results indicate an acceptable coefficient of determination R^2 of 0.99. An almost perfect agreement of the Seep/w values with the EPR estimations is clearly seen in Figure 6. The highest accuracy is achieved when the concentration of these data is on line y = x.



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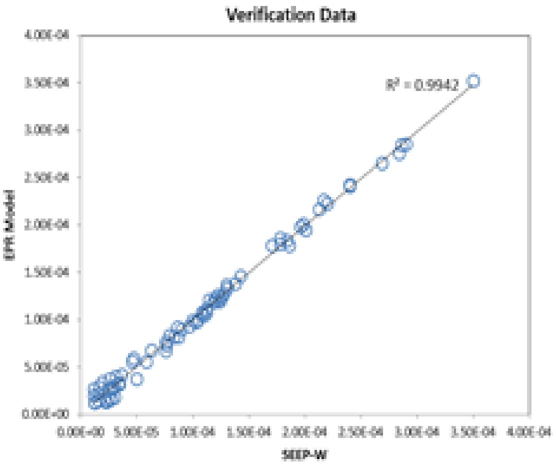

Figure 6. Comparison the seepage values using Seep/w and EPR for training and verification data

CONCLUSIONS

The Seep w and EPR models were used to determine the seepage in the canal with different cross sections and water depths. Based on Table 2 and 3, Seep/w model performance was evaluated as satisfactory for Qazvin and Efahan canals. In this study, the proposed model by using genetic algorithm (EPR), that contains accurately predict of the behavior of the seepage in canal, has been compared with Seep/w model results in order to determine seepage in canals while the easiest access, the accurate results can be estimated. As it can be seen, the EPR model can be used for predicting the seepage canals with different initial conditions. This model is acquired by using modeling results for different values, such as canal width, canal slope, and water depth in the canal, groundwater depth, and thickness of coatings. The ability to model interpolation, extrapolation and prediction of seepage in canals, and other parameters are defined in this study as well. For more accurate prediction out of the defined range, it is suggested that further modeling with different initial conditions are implemented and added.

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