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Full length Research paper

Computation of Seepage Quantity in an Earthen Watercourse by SEEP/W Simulations Case Study: "1R Qaiser Minor" - Tando Jam-Pakistan

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Various investigations of water losses of Pakistan water courses revealed that, most of water courses are improperly designed poorly maintained and carelessly operated. This results in considerable water logging and Salinity. In this research, the ability of the SEEP/W software was studied to estimate the seepage from earthen watercourse i.e. 1R Qaiser minor near Tando Jam. Seepage from five different sections was simulated with SEEP/W software and results were compared with experimental data collected by inflow-out flow and ponding method accordingly. Total discharge loss calculated by inflow-outflow method, ponding method, and SEEP/W simulations was 11.279%, 8.623%, and 8.722% respectively. The overall statistical analysis of all the research data i.e. RMSE, ME, R.E, and EF to evaluate the performance of the models are found to be 0.0265 LPS, 0.0170 LPS, 1.525% and 99.958% respectively (Table: 3.2). Hence, in contrast with different field analysis methods, SEEP/W software has a proper ability to simulate seepage from earthen watercourses however; the numerical models must be calibrated for local conditions.

Keywords: Seepage, watercourse,1R Qaiser minor, finite element modeling, SEEP/W, Geo-slope software.

INTRODUCTION

During the passage of water from the main canal to the outlet at the head of the watercourse, water may be lost either by evaporation from the surface or by seepage through peripheries of the channels. These losses are sometimes very high, of the order of 25 to 50% of the water diverted. In determining the designed channel capacity, a provision for these water losses must be made.

In Pakistan seepage losses are usually high and are about 8 to 10 cusec per million square foot of the wetted area of the cross section and amounts to 35 to 40% of diversion into the canal. Studies carried out by the WAPDA indicate a total annual loss of 10 MAF of valuable irrigation water to the ground from unlined canals in Pakistan through seepage alone. This huge loss of supplies if prevented can irrigate approximately an additional 3.0 million acres annually WAPDA (2015).

[1]Various investigations of water losses of Pakistan water courses revealed that, most of water courses are improperly designed, poorly maintained and carelessly operated. This results in considerable water logging and Salinity. The evaporation loss from any system depends upon the climatic condition of the region, and can never be prevented.

However, the factors responsible for seepage losses in watercourses are depth of subsoil water table, porosity of soil and subsoil, design of canal cross –section i.e. (depth of flow and velocity of flow), physical properties of watercourse water i.e. (temperature of water and silt suspension).

Various methods are in use for the estimation of seepage from the proposed watercourse as well as it's measurement in the existing once.

For proposed watercourses, seepage is usually estimated by empirical formulae or by graphical solution. Seepage from existing watercourses is usually evaluated by direct measurements methods i.e. inflow - outflow

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method, ponding method, seepage meter method Sarki et al., (2008).

The primary focus of this research was to investigate the seepage of an earthen watercourse by using finite element method. Seepage analyses by using computer software's are easy task for engineers when the cross-sectional configuration and the soil parameters are known Ersayin., (2006). Many computer software has come in general use, and any hard computations and simulation can be carried out through them by giving them appropriate inputs and data. These results in less error frequency and more detailed analysis when compared with field observations.

The numerical modeling computer program i.e. SEEP/W of Geo-Slope Company can be employed to carry out simulation of seepage of an earthen watercourse Imran et al., (2014).

Objectives of Study

The objectives of this research work was to study the seepage behavior of an earthen watercourse by using finite element method through SEEP/W computer program, to develop and calibrate a computer model for an earthen watercourse, to observe the velocity vectors and thereby seepage behavior for average flow depth and bed width for each cross-section, to simulate water-table depth, and to compare observed and simulated data.

MATERIALS AND METHODS

Location of Earthen Watercourse

The study on seepage estimation in an earthen watercourse has been carried out on an unlined water course (1-R) of Qaiser minor near Tando Jam by different methods i.e. inflow - outflow and ponding method accordingly.

Watercourse is located about 5 km in the east from Agriculture University.

Before starting the measurement, the bed slope, operating surface water level, the conditions of water course and soil texture were determined.

The measurement of seepage losses by inflow-outflow, and ponding methods were used. The reach of w/c was divided in to five test sections, and the length of each section was 120m.

Steps for Modeling 1R Qaiser Minor

To develop a numerical model of earthen watercourse by using SEEP/W software, in first attempt one cross sections from each of five reaches with different bed width "B" and average flow depth "D" were selected. After the selection of cross sections the SEEP/W software is used to generate FEM mesh and the seepage analysis was carried out accordingly.

After the mesh formation the boundary conditions are assigned as Dirichlet and Neumann boundary nodes. After the development of complete model, it is then verified by the SEEP/W software and computation for seepage is carried out accordingly. The material properties are then assigned and calibrated accordingly. Finally simulated results obtained from the SEEP/W software for each section are compared with the field observations obtained by inflow-outflow and ponding method.

Governing Equation

In this research work, finite element approach is employed to solve the governing differential equations pertaining to seepage through an earthen watercourse. The SEEP/W software (program) is a sub-program of the Geo-Slope (software) computer, which is used to cater for seepage problems through porous soil media. SEEP/W is a FEM based CAD type software used to analyze seepage and groundwater flow problems. Following partial differential equation (PDE) is the governing equation used for modeling of SEEP/W program:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_x \frac{\partial H}{\partial y}\right) + Q = \frac{\partial \theta}{\partial t} \quad \text{.....1}$$

Where;

H- is hydraulic head, Kx- and Ky- are hydraulic conductivity in x- and y- directions, respectively, Q- is the applied source or sink terms, t- is the time domain and θ – volumetric water content.

Calculation of Conveyance Losses

Ponding Loss Measurement Method

The most dependable and reliable method for measuring the quantity of water loss through seepage from the existing watercourses in a particular reach is by the ponding method. It consists of constructions of a temporary water tight dyke of bulk head across the watercourse.

The watercourse above the dyke is filled with water to a certain measured level. After allowing the water to stand for some time, the level of water in the watercourse is recorded.

Any drop in the level is obviously due to seepage through the section of watercourse. The watercourse is then added sufficient quantity of water to maintain its original level.

This volume of water, which is measured accurately, is equal to the total seepage loss during the particular time interval.

The volume of water divided by the time determines the rate of seepage loss through the watercourse. Formula used for this method is as under:

$$Q(lps/100m) = dd/dt * TWa * C \quad \text{.....2}$$

Q = Loss rate (lps/100m)
dd/dt = Rate of change of flow depth (cm/hr) obtained by graphical analysis.
TWa = Average top width (cm)
C = Conversion factor (0.0028)

Inflow–Out Flow Loss Measurement

We have used this method for measuring the conveyance losses.

This method involves measuring the amount of water flows into a channel at inlet of the section and amount which flows out at the tail of the section when no water is being usefully directed between the two measuring points.

The loss is the difference between these two measured points.

The measurement can be either of total volumes of water or if the channel is flowing steadily with its little change in the measured flow rate at either end directly of flow rates.

To measure steady state (constant flow) conveyance losses in a channel section, the flow measurement devices should be installed at the beginning and end of the channel section.

The same type and size of device should be used if possible, so that any biased errors in the devices are cancelled out.

The flow should be monitored in both devices until the steady flow is obtained.

The flow measurement device will generally change the depth of flow and channel storage upstream from the device, therefore five minutes to an hour may be required depending upon the slope of the channel / water course to reach constant measurements in a channel flow under steady state condition.

If the flow in channel is fluctuating, it will affect the measurements at the head of the section earlier than the downstream measurement.

The loss can be represented either in the form as.

$$QL = \frac{Q1-Q2}{L} \quad \text{.....3}$$

Where
QL = loss rate Lps/ 100 meter length:
Q1 = Flow rate in the upstream device (Lps).
Q2 = Flow rate in the downstream device (Lps) and
L = Length of the channel between the measurements 100 m (100ft.)

FEM Mesh Formation and Its Verification by Using SEEP/W Software

FEM meshes for the selected sections of each of five reaches are developed by using the SEEP/W software. The material properties for each section with proper dimensions are made as input to the software respectively and verification for each cross section has been made accordingly. The FEM mesh of all five reaches are composed of four types of elements, i.e. triangular, square, rectangular and trapezoidal type of elements of different sizes. The domain is discretised into a mesh by 412 elements through placement of nodal points 460. The bed widths of the cross sections for the five selected reaches are 1.335m, 1.305m, 1.312m, 1.295 and 1.320m respectively. Likewise the average flow depths of the cross sections for the five selected reaches are 0.194m, 0.212m, 0.205m, 0.218m, and 0.223m respectively. The general numerical model mesh for 1R Qaisar minor is displayed in (Figure.1.1). After all the necessary inputs, the computer program SEEP/W verified the mesh development and delivered report that the vertical and horizontal meshing is strong enough and there is no error in formation of mesh models. Thus the model is ready for computation and analysis of the results.

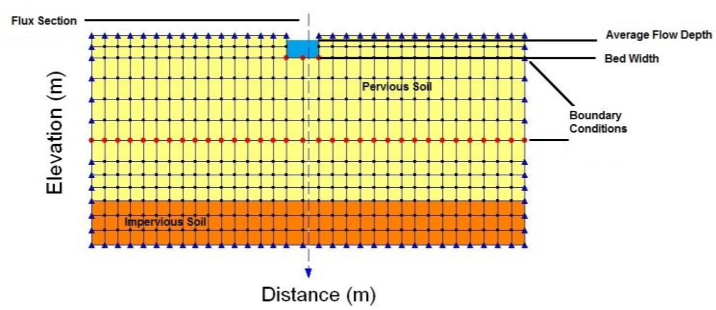

Figure. 1.1: Mesh Formation for 1R Qaisar Minor.

RESULTS AND DISCUSSION

Calibration of Material Properties of 1R Qaiser Minor

For calibration of material properties for the five selected cross sections of the 1R Qaiser minor, initially identical guess values achieved on the basis lab analysis results were specified for all the sections.

These guess values for different types of materials used in the numerical modeling are presented below in (Table.1.1). Using SEEP/W software, the material properties (hydraulic conductivities) calibrated for all the five selected cross sections are presented in (Table.1.2) accordingly.

Table 1.1: Material Properties (Guess Values)

S. No	Material type	Hydraulic conductivity (m/sec)
01	Sand	10^{-4} to 10^{-6}
02	Sandy loam	10^{-5} to 10^{-6}
03	Silt	10^{-8} to 10^{-7}

Table 1.2: Calibrated Values of Material Properties used for Numerical Modeling

S. No	Material type	Hydraulic conductivity (m/sec)	Hydraulic conductivity (m/sec)	Hydraulic conductivity (m/sec)	Hydraulic conductivity (m/sec)	Hydraulic conductivity (m/sec)
		Cross Section 1	Cross Section 2	Cross Section 3	Cross Section 4	Cross Section 5
01	Sand	5.40×10^{-5}	5.91×10^{-5}	5.87×10^{-5}	5.25×10^{-5}	5.52×10^{-5}
02	Sandy loam	5.83×10^{-6}	5.55×10^{-6}	5.13×10^{-6}	5.36×10^{-6}	5.85×10^{-6}
03	Silt	2.50×10^{-7}	2.62×10^{-7}	2.71×10^{-7}	2.51×10^{-7}	2.38×10^{-7}

Equipotential Lines, Water-Table Line, Seepage Flux and Velocity vectors

The computer program SEEP/W is used to get seepage analysis from an earthen watercourse for different reaches with different flow depths and bed widths. For this purpose, using the software flownet has been drawn for all the selected cross sections. The mesh is comprised of one flux section, which passes through the middle of cross section(s) of 1R Qaiser minor accordingly. The quantity of seepage was calculated by using GEO-SLOPE, SEEP/W software. From the Figs. it is revealed that the equipotential lines and velocity vectors are normal to each other, which conforms to seepage theory. The SEEP/W velocity vectors and equipotential lines are identical shape wise and location reference. Amongst all the cross sections the minimum seepage occurs at section-V; that is of the order of 9.749 x 10^{-6} (m^3/sec/m); and amongst all the sections maximum seepage occurs at section-I; and which is of the order of 1.487 x 10^{-5} (m^3/sec/m). The behaviour of the water table and the seepage from the cross section can be understood with the help of simulated figures (Figures 2.1 – 2.5).

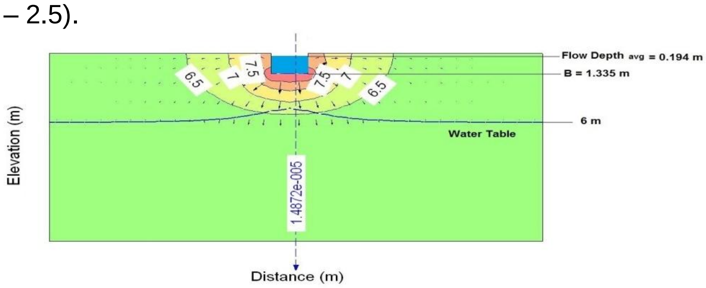

Figure. 2.1: Flownet of 1 R Qaiser Minor for Reach I (Seepage = 1.487 x 10^{-5} m^3/sec/m)

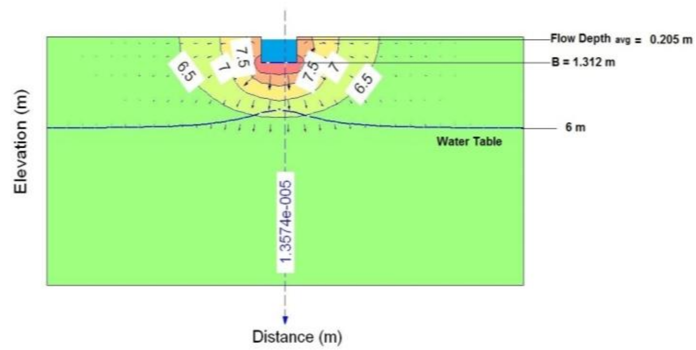

Figure.2.2: Flownet of 1 R Qaiser Minor for Reach II (Seepage = 1.357 x 10-5 m3/sec/m)

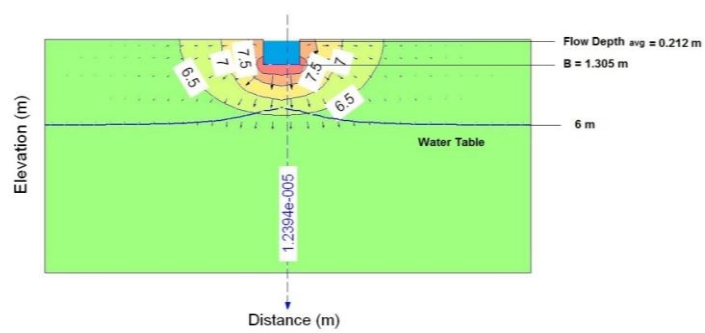

Figure.2.3: Flownet of 1 R Qaiser Minor for Reach III (Seepage = 1.239 x 10-5 m3/sec/m)

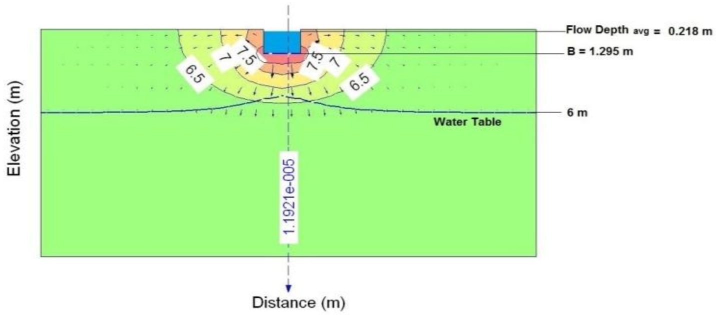

Figure. 2.4: Flownet of 1 R Qaiser Minor for Reach IV (Seepage = 1.192 x 10-5 m3/sec/m)

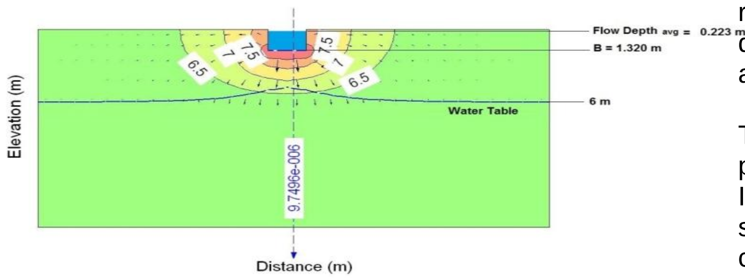

Figure. 2.5: Flownet of 1 R Qaiser Minor for Reach V (Seepage = 9.749 x 10-6 m3/sec/m)

Simulated Analysis Results

Through the computation of the models it reveals that the simulated water table for all five cross sections will remain at 6 m from the surface elevation. However, the ground surface elevation of all five cross-sections was 9.9m, 9.5m, 9.1m, 8.7m, and 8.3m respectively. In addition to this it has been observed that there was some fluctuation in water table of 0.7 m parallel to the bed width of watercourse which indicates that there is a direct impact of seepage water in the water table contribution. Furthermore, the velocity vectors indicates the direct flow i.e. almost all the water lost from the watercourse joins the ground water reservoir (water table) which conforms the percolation theory. All the field and simulated analysis results for sections I, II, III, IV and V at different flow depths and bed widths are depicted in (Table 2.1 – 2.3) accordingly.

The computed results shows that the SEEP/W computer program has evaluated the mesh model of section I, II, III, IV, and V and concluded that the modeling of the cross section is acceptable. From the above results it is also clear that the SEEP/W computer program has a good ability for the computation of the seepage from earthen watercourse.

Table .2.1: Field Results for all Cross Sections by Inflow-Outflow Method

S. No	Distance from Mogha (m)		Section Length "L"	Seepage Calculated	Total Seepage Through Given Length	Total Seepage Through Given Length	Total Seepage Through Watercourse	Total Discharge Losses (%)
	From	To	(m)	(m^3/sec/m)	(m3/sec/120)	LPS	(m3/sec)	%
1	60	180	120	0.0000240	0.00288	2.881		
2	180	300	120	0.0000175	0.00210	2.104		
3	300	420	120	0.0000165	0.00198	1.983	0.00970	11.279%
4	420	540	120	0.0000135	0.00162	1.621		
5	540	660	120	0.0000093	0.001116	1.127		

Measured Discharge: 86 LPS (0.086 m^3/sec)

Table (2.2): Field Results for all Cross Sections by Ponding Method

S. No	Distance from Mogha (m)		Test Section	Seepage Calculated	Total Seepage Through Given Length	Total Seepage Through Given Length	Total Seepage Through Watercourse	Total Discharge Losses (%)
	From	To	(m)	(m3/sec/m)	(m3/sec/120m)	LPS	(m3/sec)	%
1	60	180	30	0.0000147	0.001764	1.764		
2	180	300	30	0.0000133	0.001596	1.596		
3	300	420	30	0.0000123	0.001476	1.476	0.007416	8.623%
4	420	540	30	0.0000116	0.001392	1.392		
5	540	660	30	0.0000099	0.001188	1.188		

Measured Discharge: 86 LPS (0.086 m^3/sec)

Table (2.3): Simulated Results for all Cross Sections by SEEP/W Software

S. No	Distance from Mogha (m)		Section Length "L"	Seepage Calculated	Total Seepage Through Given Length	Total Seepage Through Given Length	Total Seepage Through Watercourse	Total Discharge Losses (%)
	From	To	(m)	(m3/sec/m)	(m3/sec/120m)	LPS	(m3/sec)	%
1	60	180	120	0.000014872	0.00178464	1.785		
2	180	300	120	0.000013574	0.00162888	1.629		
3	300	420	120	0.000012394	0.00148728	1.487	0.0075012	8.722%
4	420	540	120	0.000011921	0.00143052	1.431		
5	540	660	120	0.000009749	0.00116988	1.170		

Model Validation

Validation of any model is made by comparing predicted results against the field observations for the acceptability of the model. If the comparison shows a good coincidence, then the model developed can be recommended for practice. (Table 3.1). contains the data pertaining to observed seepage (LPS/120 m) and simulated ones and the relative error.

Results obtained from ponding method are only compared with the simulations results as they are very close to each other.

Performance of any model is evaluated on the basis of statistical parameters. Following parameters that is mean error (ME), root mean square error (RMSE) and model(s) efficiency (EF) are assessed [Willmut, 1982]; their formulation is given below:

$$ME = \frac{1}{n} \sum_{i=1}^{n} \left(Q_{si} - Q_{oi}\right) \quad \text{..... (4.1)}$$

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} \left(Q_{si} - Q_{oi}\right)^2\right]^{0.5} \quad \text{..... (4.2)}$$

$$EF = 1 - \frac{\sum_{i=1}^{n} \left(Q_{si} - Q_{oi}\right)^2}{\sum_{i=1}^{n} \left(Q_{oi} - Q_{oa}\right)^2} \quad \text{..... (4.3)}$$

where

Q_{si} is the ith value of simulated Seepage,

Q_{oi} is the ith value of observed Seepage, and

Q_{oa} is the average or mean of observed Seepage.

The EF is another parameter to evaluate the performance of the model. The overall statistical analysis of all the research data i.e. RMSE, ME, R.E, and EF to evaluate the performance of the models are found to be 0.0265 LPS, 0.0170 LPS, 1.525% and 99.958% respectively.

Additionally verifiability of the model is also made by comparing observed and simulated values of seepage (LPS/120m); such graph is illustrated in (Figure 3). The slope of the line is observed to be approximately at 45 degree; thus the Figures indicates no considerable difference between observed and simulated seepage values. Consequently, it is concluded that simulated values of seepage for the cross sections are not much different than the observed ones.

Table 3.1: Observed and simulated seepage (LPS/120 m) with statistical computational steps

S. No	Distance from Mogha (m)		Observed Seepage Qo (LPS/120m)	Simulated Seepage Qs (LPS/120m)	Relative error (%) $= \frac{(Q_o - Q_s)}{Q_o} \times 100$	$(Q_{si} - Q_{oi})$	$(Q_{si} - Q_{oi})^2$	$(Q_{oi} - Q_{oa})^2$
01	60	180	1.764	1.784	-1.170	0.02064	0.000426	0.078
02	180	300	1.596	1.628	-2.060	0.03288	0.001081	2.547
03	300	420	1.476	1.487	-0.764	0.01128	0.000127	2.178
04	420	540	1.392	1.430	-2.767	0.03852	0.001483	1.937
05	540	660	1.188	1.169	1.525	-0.01812	0.000328	1.411

Table 3.2: Summary of statistical parameters showing model performance

Statistical Parameters	Values
Mean Error (ME)	0.0170 LPS
Root Mean Square Error (RMSE)	0.0265 LPS
Models Efficiency (EF)	99.958%
Maximum relative error	1.525%

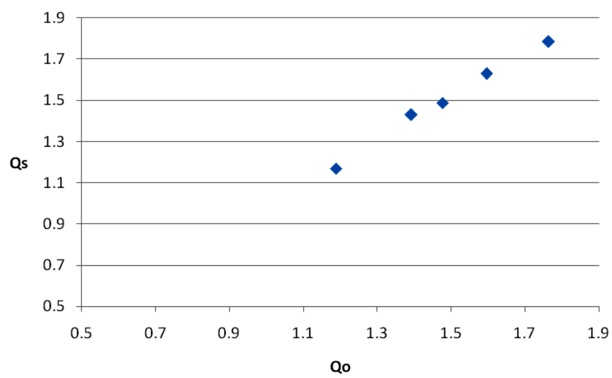

Figure. 3: Relationship between observed and simulated seepage flux LPS/120m

CONCLUSIONS

In the present research study a computer models for different cross sections of 1R Qaiser Minor based of finite element method using SEEP/W software was developed and calibrated. The models have been used to study the seepage behavior of the earthen watercourse.

The data on water losses in a subject watercourse was collected for soil type five soil samples were collected from the bed of water course at a depth of 20cm each from a distance of 100ft apart. The lab analysis results describes that the bed of watercourse vary from sandy soil to sandy loam. The bed slope of the watercourse was determined with Auto-level and it was 1:5000 = 0.0002 m/m. The watercourse was not clean and fairly maintained there was some vegetation and grasses, there was no visible leakage.

For conducting the inflow-outflow test a straight reach was selected at a distance of 60m to 660m from mogha. This reach was divided into five sections of 120m each. The loss of water (LPS/120m) in five sections measured with inflow outflow test was 2.881, 2.104, 1.983, 1.621, and 1.127 respectively (Table 2.1). Similarly, individual ponding measurements were made on the short sections of 30 m long within the inflow outflow sections of 120 m. Loss of water (LPS/120m) measured by ponding test for five sections was 1.764, 1.596, 1.476, 1.392, and 1.188 respectively (Table 2.2). Likewise, through the computation of the models it reveals that the loss of water (LPS/120m) measured by SEEP/W software for five sections were 1.785, 1.629, 1.487, 1.431 and 1.170 respectively (Table 2.3).

Through numerical modeling it had been further observed that simulated water table for all five cross sections will remain at 6 m from the surface elevation. However, the ground surface elevation of all five cross-sections was 9.9m, 9.5m, 9.1m, 8.7m, and 8.3m respectively.

In addition to this it has been also noticed that there was some fluctuation in water table of 0.7 m parallel to the bed width of watercourse in all sections; which indicates that there is a direct impact of seepage water in the water table contribution.

The behavior of velocity vectors indicates the direct flow i.e. almost all the water lost from the watercourse joins the ground water reservoir (water table) which conform the percolation theory.

The comparison of experimental and simulated data shows that the results achieved from three different methods indicate that the average ponding loss measurement is about 23% lower than the inflow-outflow loss measurement and about 2% lower than SEEP/W simulations respectively. The lower values of ponding loss measurements than inflow outflow measurements may have been due to the silt deposition in ponding sections, which might have sealed the pores in the bottom and sides of the water course, resulting in low infiltration.

The overall statistical analysis of all the research data i.e. RMSE, ME, R.E, and EF to evaluate the performance of the models are found to be 0.0265 LPS, 0.0170 LPS, 1.525% and 99.958% respectively (Table 3.2). Results obtained from ponding method are only compared with the simulations results as they are very close to each other.

Additionally verifiability of the models is also made by comparing observed and simulated values of seepage (LPS/120m); such graph is illustrated in (Figure 3). The slope of the line is observed to be approximately at 45 degree; thus the Figures indicates no considerable difference between observed and simulated values. Consequently, it is concluded that simulated values of seepage for the cross sections are not much different than the observed ones.

Hence, in contrast with different field analysis methods, SEEP/W software has a proper ability to simulate seepage from earthen watercourses however; the numerical models must be calibrated for local conditions.

SUGGESTIONS

This research study suggests that Geo-Slope SEEP/W software requires that the user to be proficient in channel design concepts.

This software can help the water resource engineer to use it in testing and analyzing any alternative design hydraulically and economically. Due to multiple advantages of SEEP/W software, it must be introduced in universities and research center's for a better understanding by students of the problems regarding seepage in canals and watercourses.

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