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Effect of Bridges on the River Hydrograph Characteristics along the Ephemeral Rivers System

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Abstract: Present study efforts have been made to apply a mathematical model to be able to simulate flow through ephemeral rivers and the purpose is to study the effect of transmission losses on the time base of hydrographs and the time of their peak discharge and also the effect of bridges on transmission losses and the time base of hydrographs in the Khoshk River system, which is an ephemeral river, by applying MIKE11. Structures such as bridges in the seasonal rivers affect flow characteristics in different ways. Two scenarios are defined to be simulated applying MIKE11. *First scenario*: Computing the transmission losses in the Khoshk River system without any bridges; Second scenario: Computing the transmission losses in the Khoshk River system with bridges and their influences on the flow characteristics. Flow analysis in the Khoshk River system as an ephemeral river would be carried out by the one-dimensional numerical model by solving the fully dynamic wave model for the two mentioned scenarios and their related scenarios and the results will be compared with some observed data. As a result, the effect of bridges on transmission losses and the time base of hydrographs would be answered quantitatively.

Key words: Ephemeral River · Transmission losses · MIKE11 · Time of peak discharge · Time base

INTRODUCTION

Parts of flood infiltrate ephemeral channels, recharging local and regional aquifers and these are the main water sources in hyper arid regions. When flood happens in an arid region, flow volume, by moving toward the lower reach, decreases due to infiltration into the bed. This volume reduction is called transmission losses [1].

Transmission losses (TL) is a complicated phenomenon that characterizes the processes of evapotranspiration and infiltration as water moves down a channel. Infiltration-based losses maybe results of runoff overtopping channel banks and storage in depressions [2]. Water infiltrates ephemeral channels and then reaches local and regional aquifers. It is necessary to mention that this water is one of the main water sources in hyperarid regions. Quantitative estimations of these resources are limited by the scarcity of data from such regions [3].

Although transmission losses have been an important matter since years ago, there is not much information available concerning the process leading to the formation of these losses [4].

Different software has been developed for flow simulation in the river system but none of them has been tried in the seasonal river. Therefore, there is less articles which have focused on this subject. Furthermore, the presences of such river in arid and semiarid regions due to lack of hydrometric stations make transmission estimations difficult to do [5]. An alternative approach to estimate TL in ephemeral streams is to develop a simplified procedure. Where data are available on upstream and downstream gages, it is desirable to estimate TL as the difference in flow volume at these tandem gages [2]. The previous studies have presented in dry environments, peak discharges and flood volumes are often reduced downstream when water flows over ephemeral alluvial channels [6,7]. summarized studies of transmission losses in arid rivers of Australia, India, Saudi Arabia and Arizona and reported a downstream reduction between 8% and 95% of flood volumes and peak discharges [8-10].

So carrying such projects out in a country like Iran which has an arid and semiarid climate with many ephemeral rivers, seem to be necessary. In this study Khoshk River of Shiraz, an ephemeral river whit a length

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of 60 km, is chosen. For the simulation of floods in this river, MIKE11-HD, which is a one-dimensional numerical modeling, has been performed. For hydraulic flood routing, the mentioned model, using implicit finite difference scheme through 6 point Abbott net, solves equations of continuity and momentum, which are known as Saint Venant equations. This model is calibrated with Manning and Leakage coefficients. Transmission losses are computed through a comparison between upstream volume and downstream volume for the flood with different return periods. And also the effect of transmission losses and bridges on the time base of hydrographs is studied.

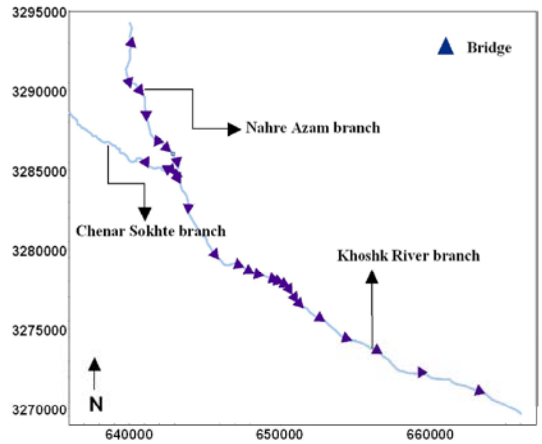

Fig. 1: River branches in the study area, Shiraz

MATERIALS AND METHODS

The Khoshk River: The average altitude of the region is 1540 m. Khoshk River system is a combination of two eastern and western branches, the former is called Nahr-e-Azam and the latter is called Chenarsokhte. Khoshk River basin is located in 52°12'30"-52°41'30" eastern length and 29°34'17"-29°58'7" northern width coordinates and has an area of about 900.3 km^2. Khoshk river basin is one of Maharloo's sub-basins. It should be mentioned that about 74.9% of the area is covered by vegetation. Nahr-e-Azam branch has a length of about 11 km and a slope of about 0.00825 and Chenarsokhte has a length of about 13 km and a slope of about 0.0153. These two branches intersect in Shiraz and make the Khoshk River with an approximate slope of 0.00556. The river is canalized in this reach and all the banks are isolated by walls and after a distance of 33.5 km, it discharges in Maharloo Lake. This river is approximately 60 km long and indeed many of the floods in this basin are collected by this river and discharge in Maharloo Lake. Figure 1 shows the plan view of the Khoshk river system.

The hydrometric stations used in this study are as follows:

- Nahre Azam hydrometric station: this station is situated on Nahre Azam branch before the junction where this river meets Chenar Sokhte branch. This station is located in 52°28' eastern length and 29°42' northern width coordinates and its altitude is 1650 m. The area of basin is 392.8 km^2 up to the above station. Figure 2 displays the hydrographs for different return periods in this station.
- Chenar Sokhte hydrometric station: This station is located in 52°26.5' eastern length and 29°42.5' northern width coordinates and it has an altitude of 1650 m. The area of the Chenar Sokhte basin is 144.2 km^2up to this station. Figure 3 displays the hydrographs for different return periods in this station.

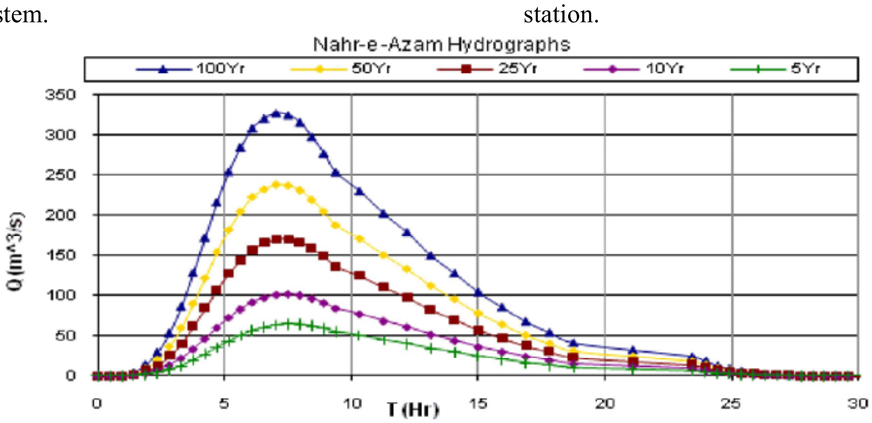

Fig. 2: Hydrographs of flood on Nahre Azam branch

Figure 2 displays the hydrograph of flood on Nahre Azam branch with different return periods based on hydrometric station reports. As a matter of fact, since the return period rises, the discharge increases too.

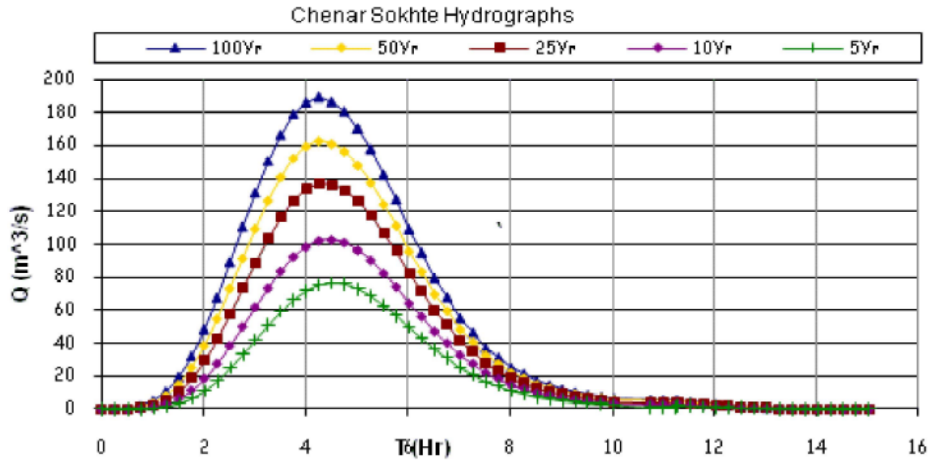

Fig. 3: Hydrographs of flood on Chenar Sokhte branch with different return periods

Figure 3 displays the hydrograph of flood on Chenar Sokhte branch with different return periods based on hydrometric station reports.

- Eghbal Abad hydrometric station: this station is located at the end of the Khoshk River before the spot where it discharges in Maharloo lake and is located in 52°40.7' eastern length and 29°33.65' northern width coordinates and has an altitude of 1490 m. The basin area is 900 km^2 up to this station.

Model Description: The flood routing in the Khoshk River is done by means of the hydrodynamic module of MIKE11 computer model. MIKE11 HD was applied with the dynamic wave method which integrates continuity and momentum equations (Saint Venant equations), base on the following assumptions:

- Water is incompressible and homogeneous, i.e. negligible variation density
- The bottom-slope is small, thus the cosine of the angle it makes with the horizontal may be taken as 1
- The wave lengths are large in comparison with the water depth. This ensures that the flow can be regarded as having a direction parallel to the bottom, i.e. vertical accelerations can be neglected and a hydrostatic pressure variation along the vertical can be assumed
- The flow is subcritical

In hydrodynamic module, first as Saint Venant equations applies implicit finite difference scheme and digitized form are written and then the digitized equations are solved by means of a net of points in different lengths and times. To achieve this goal, H and Q grids are chosen. H points are depth knots and the water levels in these points are computed in different time steps by the program. Q points are knots between two points of H, in which discharge is computed in different time steps. To solve the equations numerically, implicit finite difference method through Abbott 6 points net is used [11,12].

Saint Venant Equations:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(a\frac{Q^2}{A}\right)}{\partial t} + gA\left(\frac{\partial h}{\partial x} + S_f\right) = 0 \tag{2}$$

Where x is length along the channel axis (m), t is time (s), Q is flow discharge (m^3/s), A is the wetted cross-sectional area (m^2), q is lateral flow (m^2/s), s_f is the friction line slope, α is velocity distribution coefficient and g is acceleration due to gravity (m/s^2Model inputs include flood hydrographs of Nahre Azam and Chenar Sokhte branches as upstream boundary conditions. Rating curve is chosen as downstream boundary condition at the end of the Khoshk River is computed by model. The selected hydrograph belonged to 100 years return period for simulation and this is due to its further effects on transmission losses. According to Lang's studies, transmission losses are higher when a flood occurs with a higher peak discharge. These studies also suggest that the recharge of ground water due to huge flood is more than the recharge resulting from several frequent floods [4]. For the simulation of flow in Khoshk River, the information used were geometric information concerning cross sections which have been obtained by surveying, in this respect, the information from 467 cross sections

Table 1: The characteristics of selected bridges

Bridge ID	Branch Name	Chainage	Bridge Length(m)	Waterway Length(m)	Bridge pier(m)	Waterway Blocked %
2	Nahre Azam	3869.02	18.47	7.97	1.29	0.162
4	Nahre Azam	6474.60	12.39	9.65	1.18	0.122
6	Nahre Azam	9137.41	13.45	13.78	1.80	0.131
8	Nahre Azam	11242.72	45.88	17.67	1.00	0.057
10	Chenar Sokhte	8529.63	48.96	22.00	6.25	0.284
12	Khoshk River	9518.23	60.80	59.45	8.00	0.135
14	Khoshk River	15090.94	24.27	44.82	2.47	0.055
16	Khoshk River	17753.37	10.18	60.07	2.94	0.049
18	Khoshk River	19444.48	38.20	57.54	3.16	0.055
20	Khoshk River	20238.83	24.88	37.60	18.43	0.490
22	Khoshk River	21344.32	2.50	65.05	3.04	0.047
24	Khoshk River	23567.46	29.04	60.91	3.01	0.049
26	Khoshk River	27956.60	31.30	44.10	1.98	0.045
28	Khoshk River	35552.34	8.06	16.88	0.64	0.038

Table 2: Calibration results for Manning's roughness coefficients

Chenar Sokhte station		Nahre Azam station		Eghbal Abad station	
n	RMSE	n	RMSE	n	RMSE
0.04	0.12997	0.012	0.22035	0.029	0.2262
0.045	0.11827	0.016	0.20235	0.031	0.2175
0.048	0.10357	0.019	0.17935	0.033	0.1882
0.051	0.11127	0.022	0.15195	0.035	0.17704
0.053	0.12107	0.024	0.13435	0.039	0.2132
0.056	0.13627	0.027	0.19945	0.043	0.2364
0.059	0.15927	0.029	0.22965	0.047	0.242455

i- The minimum of RMSE for Chenar Sokhte station

i- The minimum of RMSE for Nahre Azam station

iii- The minimum of RMSE for Eghbal Abad station

along the river (88 cross sections from Chenar Sokhte, 71 cross sections from Nahre Azam and 308 cross sections from Khoshk River) and the characteristics of structures along the different rivers have been included. There are 28 structures which include 3 bridges on Chenar Sokhte branch, 8 bridges on Nahre Azam branch and 17 bridges on the Khoshk River. The characteristics of selected bridges have been presented in table 1. Different parameters which affect Manning coefficient (n) are linked to each other by means of Cowen equation and the Manning coefficient value of the river is determined by the following equation:

$$n = k\,(n_0+n_1+ n_2+ n_3+n_4) \qquad (3)$$

Where n_0 is a base value of n for straight, uniform, smooth channels in natural materials (0.012 to 0.07), n_1 is the correction factor for the effect of surface irregularities (0-0.02), n_2 is the value of variations in shape and size of the channel cross-section (0-0.015), n_3 is the value for obstructions (0-0.05), n_4 is the value of vegetation and flow conditions (0.002-0.1) and *k* is a value for meandering of the channel (1-1.3). By considering the mentioned parameters based on the field observations at the bed river and the results from soil classification, Manning coefficient is estimated between 0.012 and 0.029 for Nahre Azam branch, between 0.04 and. 059 for Chenar Sokhte branch and between 0.029 and 0.048 for Khoshk River branch. And the accuracy of the value ranges is specified by calibration. The value of Leakage coefficient depends on soil texture, type of stream and local vegetation is usually considered between 10^{-4} and 10^{-7}. The model was calibrated to Leakage coefficient.

Model Calibration and Validation: Calibration of the model was done based on a comparison between the simulated rating curves using different Manning coefficient and observed rating curves for a flood with a 100 years return period. Rating curves were compared by means of statistical function-root mean square error (RMSE):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(c_i - o_i\right)^2} \qquad (4)$$

Where C_i is the computed parameter value for event I, O_i is the observed parameter value for event I and n is the number of events. The results of comparison have been presented in the table 2.

Table 3: Calibration results for the leakage coefficients in Nahre Azam and Chenar Sokhte stations for Eghbal Abad station

Nahre Azam station		Chenar Sokhte station	
Leakage coefficient (l/s)	RMSE	Leakage coefficient (l/s)	RMSE
0	0.13365	0	0.1025
1.0E-07	0.13307	1.0E-07	0.1019
1.0E-06	0.132	1.0E-06	0.09712
5.5E-06	0.12044	5.5E-06	0.09013
1.0E-05	0.11237	1.0E-05	0.0898
5.5E-05	0.12842	5.5E-05	0.09505
1.0E-04	0.13443	1.0E-04	0.10181

I- The minimum of RMSE for Chenar Sokhte station
ii- The minimum of RMSE for Nahre Azam station

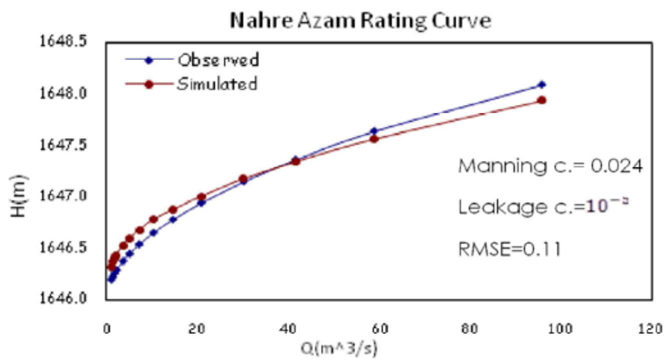

Fig. 4: Chart of rating curves in Nahr-e-Azam station

Figure 4 displays the comparison between simulated rating curve and observed rating curve for Nahr-e-Azam station.

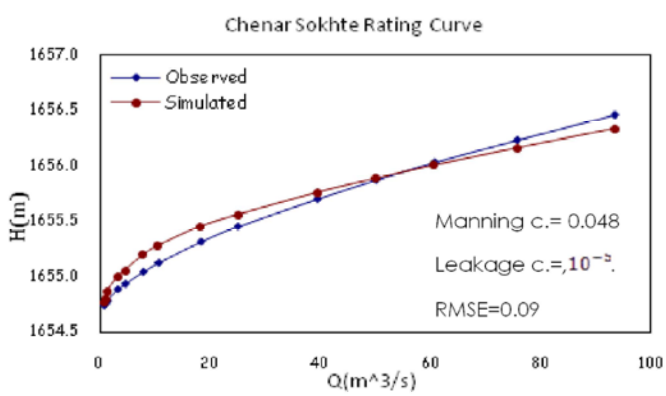

Fig. 5: Chart of rating curves in Chenar Sokhte station

Figure 5 displays the comparison between simulated rating curve and observed rating curve for Chenar Sokhte station.

The obtained Manning coefficient values for Nahre Azam, Chenar Sokhte and Khoshk River branches were 0.024, 0.048 and 0.035 respectively. The model was also calibrated to the Leakage coefficient for Nahre Azam and Chenar Sokhte branches, the best value which was agreed with the field characteristics is 10^{-5} (l/s). The results have been showed in the table 3 and the charts of comparison between simulated rating curve and observed rating curve for Nahr-e-Azam and Chenar Sokhte stations have been presented in the figure 4 and the figure 5 respectively. The considering the Leakage coefficient was selected equals to 10^{-5} for Eghbal Abad station, which is located at the end of the river. The validation of model was performed too. Table 4 shows the validation of leakage coefficient for this station and also the chart of comparison between simulated rating curve and observed rating curve for Eghbal Abad station have been presented in the figure 6. Validation results showed

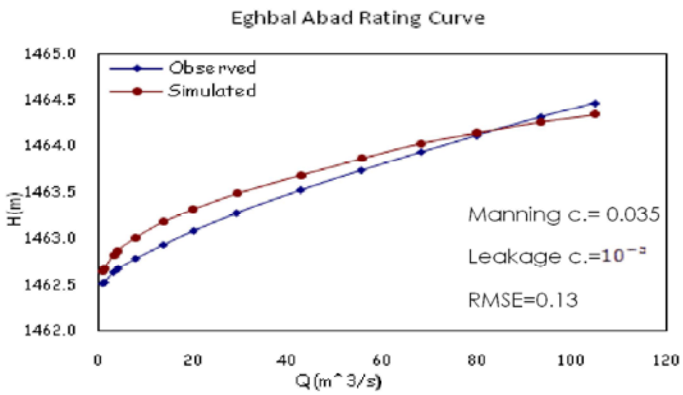

Fig. 6: Chart of rating curves in Eghbal Abad station

Figure 6 displays the comparison between simulated rating curve and observed rating curve for Eghbal Abad station.

Table 4: Results of Leakage coefficients validation Eghbal Abad station

Leakage coefficient (l/s)	RMSE
0	0.1448
1.0E-07	0.14207
1.0E-06	0.1396
5.5E-06	0.13415
1.0E-05	0.1316
5.5E-05	0.1338
1.0E-04	0.14902

I-The minimum of RMSE for Eghbal Abad station

that the calibration of the model to the Leakage coefficient leads to an improvement in its results and the model is accurate enough to simulating ephemeral rivers. The obtained Manning coefficient values for Nahre Azam, Chenar Sokhte and Khoshk River branches were 0.024, 0.048 and 0.035, respectively. The model was also calibrated to the Leakage coefficient for Nahre Azam and Chenar Sokhte branches. Calibration was done twice; first time without any bridge consideration and next time, with bridge consideration. The best value was equal to 10^{-5} with bridge consideration. The Leakage coefficient was selected equal to 10^{-5} for Eghbal Abad station, which is located at the end of the river. The validation of model was performed too. Validation results showed that the calibration of the model for the Leakage coefficient for both circumstances with and without the bridge, lead to accurate response by the model which reflects the ability of MIKE11 for simulation for two different considered conditions.

RESULTS AND DISCUSSION

Floods are a vital source of water in arid regions. This scarce water resource is mostly exploited from the local or regional alluvial aquifers which are recharged by flood in?ltration along alluvial ephemeral river's beds. In this study for flood routing, MIKE11 software model has been applied to solve continuity and momentum equations. The mentioned model has been calibrated with Manning coefficient by considering guessed values for the Leakage coefficient. It was calibrated to the Leakage coefficient again, which showed a higher correspondence of the model with the results from field observations. The results for validation for Eghbal Abad station showed that the selected numerical model has been able to rout floods in ephemeral rivers and to analyze such flows; the mentioned model can be utilized. Due to the steep slope of river and average length, evapotranspiration was not considered in flow surface. Flow hydrographs in all three branches, i.e. Nahre Azam, Chenar Sokhte and Khoshk River were produced by means of the input and output. Flow volume at the beginning and at the end of the branches can be estimated by computing the difference of input and output flow volume, losses volume can be computed. In this way, transmission losses in Nahre Azam, Chenar Sokhte and Khoshk River for floods with 5,10,25,50 and 100 years return periods was computed for two scenarios. Figure 7 displays the predicted hydrographs for different return periods at the end of Khoshk River system. The percentage of infiltration volume for each branch was computed and the results of transmission losses computations and percentage of infiltrations for different return periods for first and second scenarios have been presented in table 5 and table 6 respectively. According to the outputs of the model, bridges cause the transmission losses values to increase. Bridges do not allow water to flow normally and cause delay in flow and as a result, the depth of water before every bridge increases up. As a result, water infiltrates more into the bed. The values of infiltrations

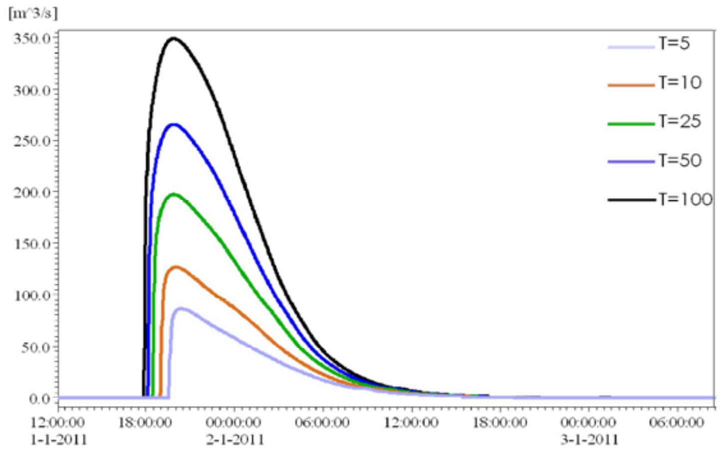

Fig. 7: Predicted hydrographs for different return periods at the end of Khoshk River system

Figure 7 displays the predicted hydrographs by numerical modeling for different return periods for Khoshk River system.

Table 5: Results of transmission losses computations and percentage of infiltrations for different return periods for first scenario

Section	5 years volume infiltration (m^3)	5 years infiltration %	10 years volume infiltration (m^3)	10 years infiltration %	25 years volume infiltration (m^3)	25 years infiltration %	50 years volume infiltration (m^3)	50 years infiltration %	100 years volume infiltration (m^3)	100 years infiltration%
Nahre Azam 10944.33 km	104232.76	5.69%	122501.48	4.28%	189353.32	3.98%	240742.76	3.61%	290604.12	3.20%
ChenarSokhte 9212.32 km	68301.72	6.37%	84978.04	5.80%	104133.96	5.30%	117984.48	5.03%	132488.08	4.85%
Khoshk River 38700.89 km	553904.72	20.30%	755332.44	18.35%	1005475.51	15.67%	1209567.6	14.03%	1453217.52	12.79%

Table 6: Results of transmission losses computations and percentage of infiltrations for different return periods for second scenario

Section	5 years volume infiltration (m^3)	5 years infiltration %	10 years volume infiltration (m^3)	10 years infiltration %	25 years volume infiltration (m^3)	25 years infiltration %	50 years volume infiltration (m^3)	50 years infiltration %	100 years volume infiltration (m^3)	100 years infiltration%
Nahre Azam 10944.33 km	117485.92	6.45%	163362.52	5.70%	247169.24	5.20%	321863.36	4.83%	406501.24	4.48%
ChenarSokhte 9212.32 km	70178.76	6.55%	87825.52	5.99%	108436.56	5.52%	123566.92	5.26%	138237.72	5.06%
Khoshk River 38700.89 km	589854.04	21.91%	775157.84	19.08%	1054417.48	16.47%	1273488	14.93%	1530981.56	13.63%

Table 7: The times base of hydrographs for different return periods, including both when transmission losses are ignored and when transmission losses for both scenarios are brought info consideration

Sections	5 years Without leakage	5 years 1E-05 (L/S) Without bridges	5 years 1E-05 (L/S) With bridges	10 years Without leakage	10 years 1E-05 (L/S) Without bridges	10 years 1E-05 (L/S) With bridges	25 years Without leakage	25 years 1E-05 (L/S) Without bridges	25 years 1E-05 (L/S) With bridges	50 years Without leakage	50 years 1E-05 (L/S) Without bridges	50 years 1E-05 (L/S) With bridges	100 years Without leakage	100 years 1E-05 (L/S) Without bridges	100 years 1E-05 (L/S) With bridges
Nahre Azam 10944.33 Km	1604	1472	1837	1624	1497	1864	1645	1519	1873	1666	1534	1899	1687	1549	1914
Chenar Sokhte 9212.32 Km	1108	967	1101	1123	985	1119	1136	1001	1134	1144	1010	1143	1151	1018	1150
Khoshk River 38700.89 Km	3914	3292	3894	3946	3307	3927	3976	3326	3957	3994	3345	3973	4009	3393	3989

Table 8: The times of peak discharge of hydrographs for different return periods, including both when transmission losses are ignored and when transmission losses for both scenarios are brought info consideration

Sections	5 years Without leakage	5 years 1E-05 (L/S) Without bridges	5 years 1E-05 (L/S) With bridges	10 years Without leakage	10 years 1E-05 (L/S) Without bridges	10 years 1E-05 (L/S) With bridges	25 years Without leakage	25 years 1E-05 (L/S) Without bridges	25 years 1E-05 (L/S) With bridges	50 years Without leakage	50 years 1E-05 (L/S) Without bridges	50 years 1E-05 (L/S) With bridges	100 years Without leakage	100 years 1E-05 (L/S) Without bridges	100 years 1E-05 (L/S) With bridges
Nahre Azam 10944.33 Km	20:34	20:34	20:45	20:26	20:26	20:37	20:02	20:02	20:26	19:54	19:54	20:06	19:52	19:52	20:03
Chenar Sokhte 9212.32 Km	17:07	17:07	17:11	17:00	17:00	17:03	16:48	16:48	16:56	16:46	16:46	16:50	16:43	16:43	16:48
Khoshk River 38700.89 Km	2:12	20:22	20:32	19:56	20:02	20:27	19:48	19:52	20:08	19:48	19:52	20:08	19:48	19:50	20:07

when bridges exist are more than 1 percent. This difference which is a major volume of the flood leads to feed underground flow and it can be considered as a major source of water. As the number of bridges increases in different branches, the values of losses rise too. In Chenar Sokhte branch, which has only 3 bridges, the amounts of transmission losses and infiltration rates did not vary considerably. But in Nahre Azam branch and specially Khoshk River which have many bridges, the bridge effect not only has influenced the flow characteristics, but also it has major effects on infiltration up to 190000 m^3 for period return of 100 years. This value is about 50000 m^3 for return period of 5 years. Decrease in return periods for both of scenarios causes less infiltration into the bed. Considering the predicted by the model hydrographs reveals that transmission losses lead to a dramatic decrease in time base in hydrographs and this decline is by far more Khoshk River branch, which is longer. Furthermore, in the second scenario in which bridges are added to the model the time base of hydrographs increases. The increases in the time base of hydrographs in Khoshk River branch, over which there are 17 bridges, is considerable. The increase in the time base in Nahre Azam branch, over which there are 8 bridges, is less and reaches its lowest amount in Chenar Sokhte branch. Time base for different return periods are illustrated in table 7. The changes in the time base of the hydrographs are rather the same in different return periods. Transmission losses in Nahre Azam and Chenar Sokhte branches cause no change in time of peak discharge and the changes in Khoshk River branch can be overlooked. In the second scenario, adding the bridges to the model results in an increase in the time of peak discharge in the Nahre Azam and Khoshk River branches. But in Chenar Sokhte branch, time of peak discharge undergoes not very considerable changes. Times of peak discharge for different return period are shown in table 8. The times base of hydrographs for different return periods, including both when transmission losses are ignored and when transmission losses for both scenarios are brought info consideration.

CONCLUSION

In this article flood routing was studied in the Khoshk River of Shiraz and the transmission losses were computed and discussed for both scenarios; furthermore, the effect of these scenarios on the time base of hydrographs and the time of peak discharge were investigated. According to what aforementioned above, following conclusions can be drawn:

The results of calibration for two scenarios showed that bridge consideration has a significant influence on hydrograph concluded from model and the recorded hydrograph. The differences of RMSE without bridge consideration are about 3% in comparison with the recorded observations.

The effect of bridges on Q-h curve not only affected the flow characteristics near the bridge, but also they affected on flow along the branches. This influence is more significant in Khoshk River, where there are more bridges.

The results of model confirm that MIKE11 is a suitable model to reflect the effects of bridges on flow characteristics.

The bridges along the rivers have considerable consequences on transmission losses. The most considerable effect is on return period with 100 years which the volume of losses is about 199410m^3 and for 50 years return period 150623 m^3. This value for 25 years is 111060.5 m^3 and 63533.9 m^3. The least value of transmission losses belong to 5 years return period with 51079.5 m^3.

Transmission losses cause the time base of hydrographs in Nahre Azam, Chenar Sokhte and Khoshk River branches to decrease by 130 min,136 min and 635 min, respectively.

The bridges cause the time base of hydrographs in Nahre Azam, Chenar Sokhte and Khoshk River branches to increase by 360 min,133 min and 615 min, respectively. Transmission losses make no changes in the time of peak discharge but bridges cause an increase in the time of peak discharge.

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