Estimating of Manning's Roughness Coefficient for Hilla River through Calibration Using HEC-RAS Model

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ABSTRACT

The appropriate value of Manning's roughness coefficient (n) is chosen through the process of calibration; i.e., the value which reproduces observed data to an acceptable accuracy. In the present study, the HEC-RAS unsteady flow model is applied to Hilla river (upstream Hilla city) to predict the value of Manning's coefficient through the calibration procedure. The data are taken for the period from 20 August 2008 to 12 September 2008 and divided equally into two sets; the first set is for calibration purpose; i.e., estimation of (n) and the rest for verification which is the process of testing the model with actual data to establish its predictive accuracy. It is found that the value of Manning's roughness coefficient (n) for Hilla river which shows good agreement between observed and computed hydrographs is (0.027).

KEYWORDS: Manning's roughness coefficient, Open channel, Flow resistance, Hilla river, Calibration, HEC-RAS model.

INTRODUCTION

Estimation of Manning's roughness coefficient (or Manning's n) is very important to simulate open channel flows. As an empirical parameter, the roughness coefficient actually includes the components of surface friction resistance, form resistance, wave resistance and resistance due to flow unsteadiness (Ding and Wang, 2004). Direct determination of the roughness coefficient is almost impossible in studying natural river flows, including unsteady channel network flows. In the practice of model calibration, the roughness coefficient is estimated through a procedure of trial and error involving comparisons between field measurements and computations of stage and discharge. The roughness coefficient (n) in natural channels is difficult to determine in field. Various factors affecting the values of roughness coefficients were presented by (Chow, 1959). The friction slope may thus be seen as a very important parameter whose value must be chosen very carefully. Although conditions of unsteady flow simulation may require special treatment of the friction slope, most works in this area find the use of Manning's equation for steady uniform flow acceptable in this case (Chow et al., 1988). The typical value of (n) for natural irrigation channels is (0.025) (Fenton, 2002) and for earth channels ranges from 0.022 to 0.033 (Gupta, 2007). Past experience of flow in Iraqi natural rivers indicates that the value of Manning's (n) may vary between 0.025 and 0.033 (BWRD, 1998).

Accepted for Publication on 30/10/2012.

HEC-RAS Model

The Hydrologic Engineering Center River Analysis System (HEC-RAS) model was developed by the U.S. Army Corps of Engineers. This software is a professional engineering software package which allows to perform one-dimensional steady flow and unsteady flow simulation. It is much used by Norwegian consulting companies and water authorities (Olsen, 2002). HEC-RAS model is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. Fig. (1) shows the main menu of HEC-RAS model.

The Hilla Unsteady Flow HEC-RAS Model

Hilla river (case study) is divided into (6) reaches. Five main irrigation canals withdraw water from the left side of Hilla river as shown in Table (1). Based on the available data for (50) cross-sections, these (6) reaches are divided into (49) subreaches. The HEC-RAS schematization of Hilla river is listed in Table (2).

Table 1. Five main irrigation canals withdraw water from the left side of Hilla river

No.	Canal name	Location on Hilla river (km)	Design discharge (m^3/sec)	Design water level upstream its head regulator (m.a.s.l.)
1	Mahaweel	9+080	10.75	30.95
2	Khatoniya	23+000	1.4	29.6
3	Fandiya	23+480	0.9	29.5
4	Neel	25+017	3.5	29.3
5	Babil	29+335	10.5	29.2

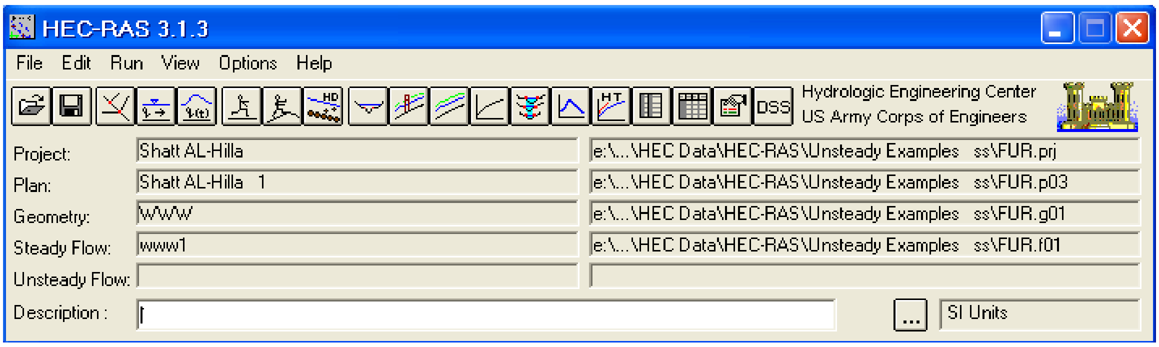

Figure 1: Main menu of HEC-RAS model

Depending on schematization of Hilla river and branching canals illustrated in Table (1), a schematic diagram of the Hilla system is drawn as shown in Fig.(2). All reaches are drawn from upstream to downstream (in the flow direction). After the Hilla system schematic is drawn, the next step is to enter the necessary geometric data which consist of connectivity information for the stream system (Hilla river schematic); i.e., cross-section data. Cross-section data represent the geometric boundary of the stream. The required information for a cross-section consists of the river reach, the river station identifiers (station and elevation points) as well as lengths of subreach and main channel bank stations. The information required is displayed on the cross-section data editor as shown in Fig.(3).

Calibration and Verification of the Hilla HEC-RAS Model

In the present study, the data are taken for the period from 20 August 2008 to 12 September 2008 and divided equally into two sets; the first set is for calibration purpose; i.e., estimation of (n) and the rest for verification .The upstream boundary condition for unsteady flow model consists of the observed discharge hydrograph, Fig. (4), at station (1) which was measured at daily intervals. Observed stage hydrograph at station (50) as shown in Fig. (5) is used as the downstream boundary condition.

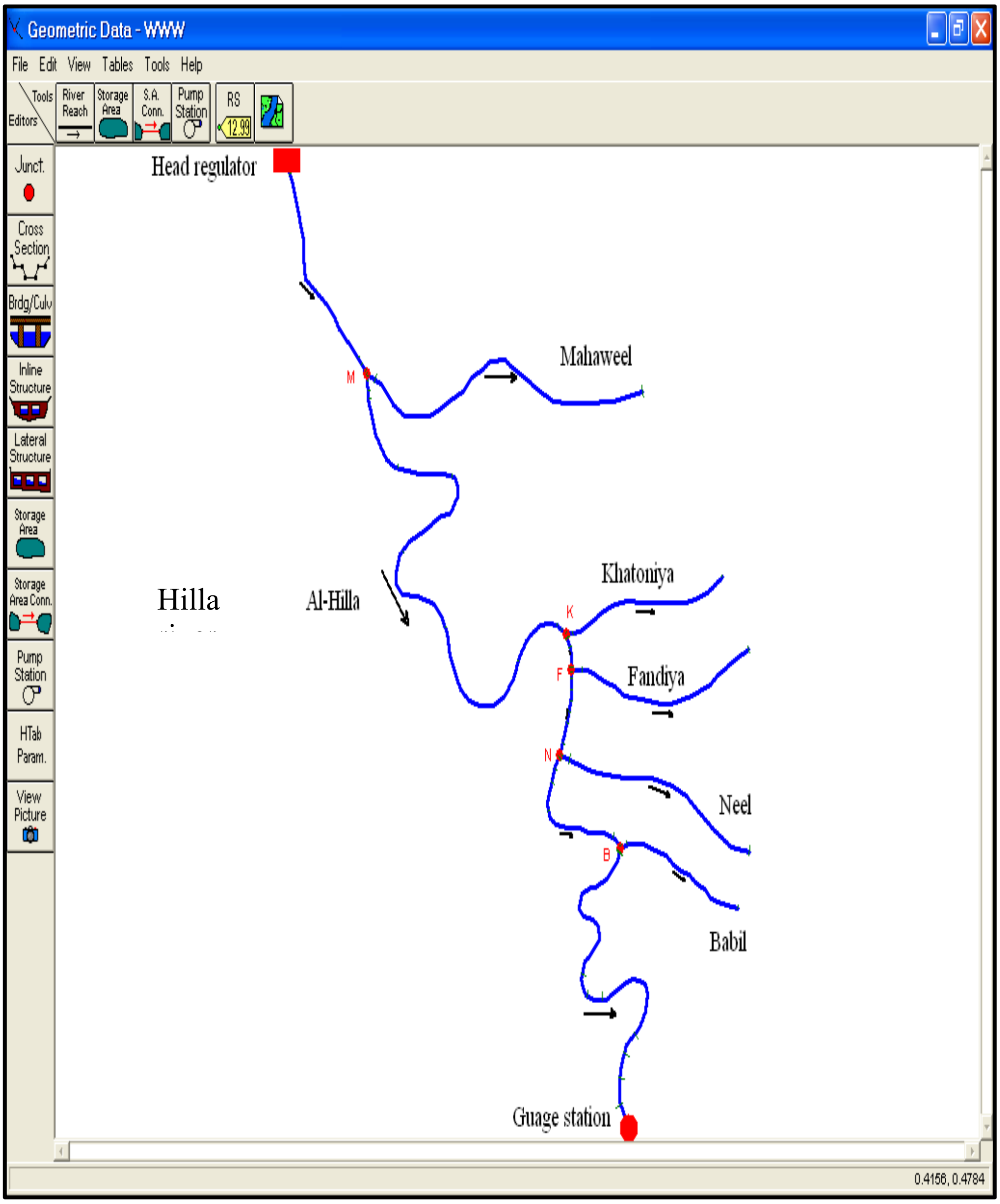

Figure 2: Schematic diagram of the Hilla system

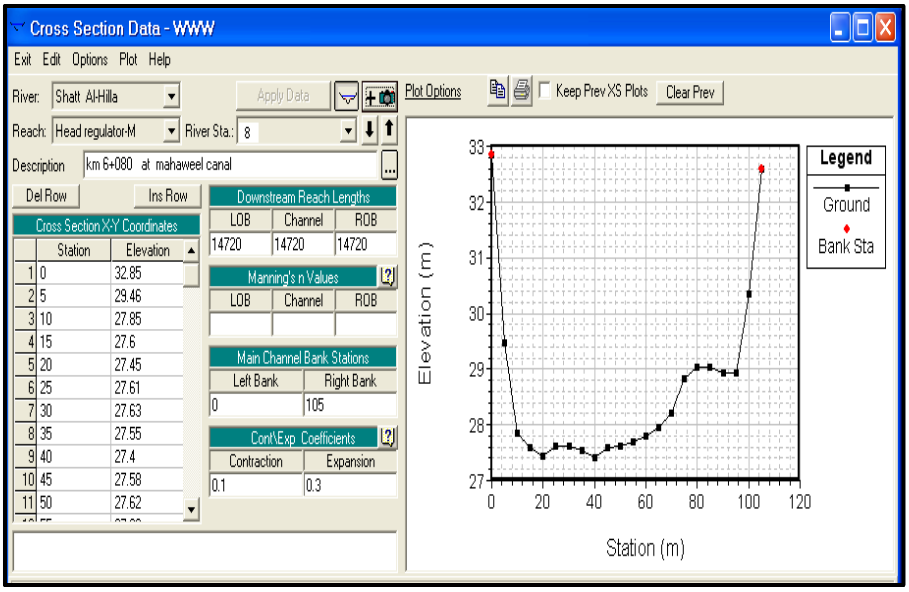

Figure 3: Cross-section data editor

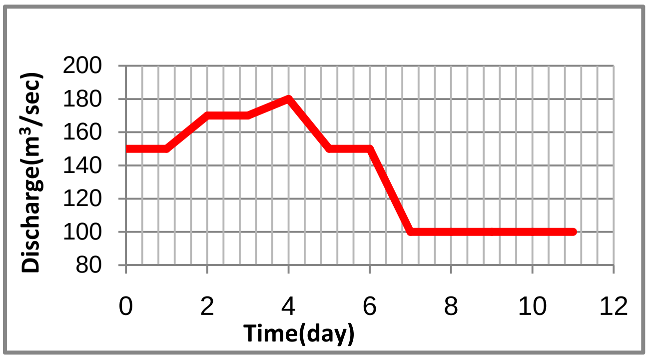

Figure 4: Observed discharge hydrograph at station (1)

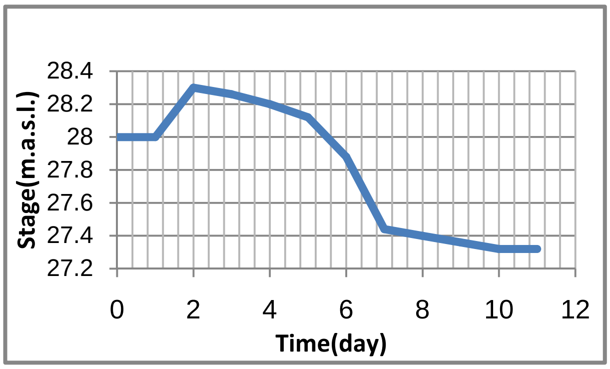

Figure 5: Observed stage hydrograph at station (50)

The initial conditions are the discharge (*Q*) and stage (*h*) along Hilla river at initial time computed using the computations of steady state flow using HEC-RAS model with decreasing discharge in Hilla river (due to diverting canals) as shown in Figs.(6) and (7).

In this unsteady flow simulation model, the assumed values of Manning's roughness coefficient (n) for Hilla river range between 0.025 and 0.03. Results of the model with these values of (n) and specified values of (θ=0.95) and (Δt=1 day) are compared with observed discharge and stage hydrographs measured at station (1) and station (50) as shown in Figs.(8), (9), (10) and (11). The weighting parameter (θ) is applied to the finite difference approximations when solving the unsteady flow equations. A practical limit is from (0.6) to (1). The default value of (θ) in HEC-RAS unsteady flow model is (0.95). The larger value of (θ) should be used to insure greater stability (HEC, 2009). Previous studies on unsteady flow simulation(direct routing) indicate that the value of weighting factor (θ) that gives a stable and accurate solution appears to be (0.95).

Fread et al. (1998) reported that by using larger time step (Δt) and (θ) approaching unity, the implicit finite difference equation becomes more stable. The same value (θ=0.95) was used by (Stubblefield, 1976; Al-Eoubaidy, 1999; HEC, 2009). The results of the unsteady flow HEC-RAS model show that the values of (n) in the range (0.025-0.03) give the closest agreement between the observed and computed hydrographs. Consequently, a good agreement is obtained with a value of (n=0.027) as shown in Figs. (12) and (13). Occasionally, the model may go unstable at the beginning of a simulation because of bad initial conditions. The flow measurements in rivers are subjected to many uncertainties and the hydrograph data generally contain measurement errors.

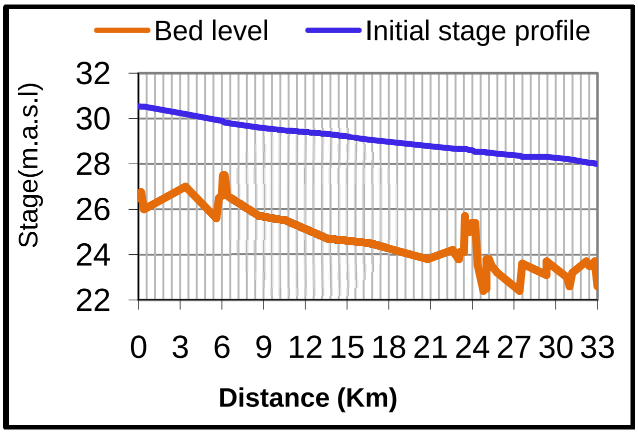

Figure 6: Initial stage

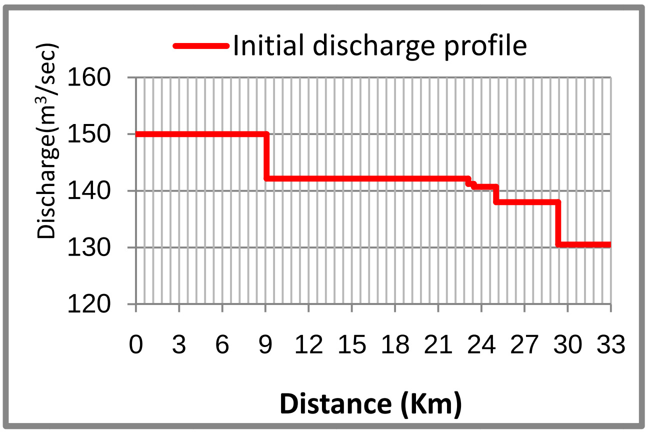

Figure 7: Initial discharge

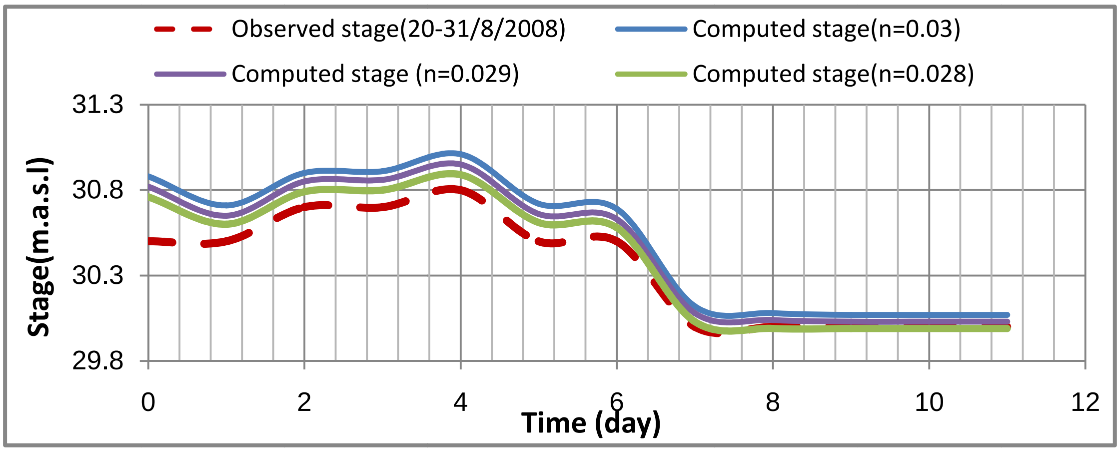

Figure 8: Computed and observed stage hydrographs at station no. (1) for different values of Manning's (n)

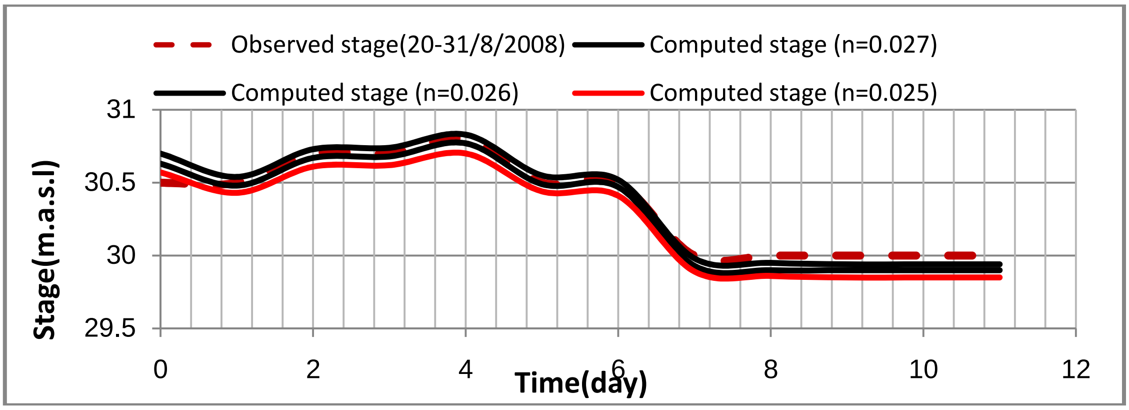

Figure 9: Computed and observed stage hydrographs at station no. (1) for different values of Manning's (n)

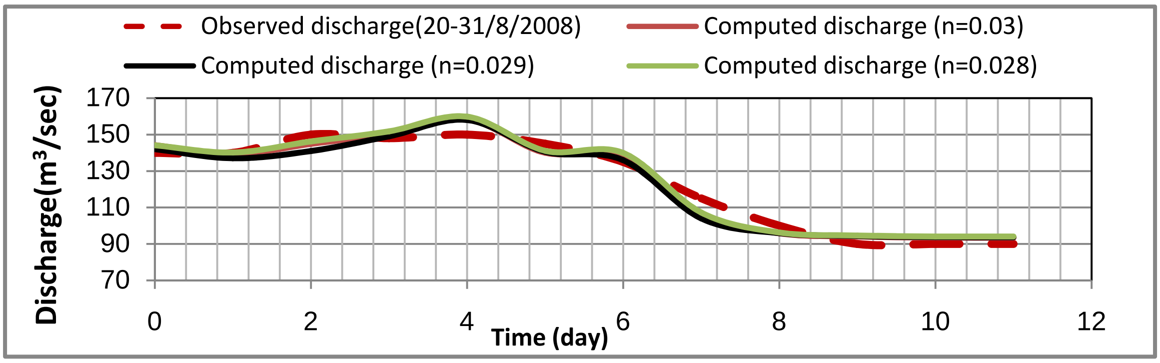

Figure 10: Computed and observed discharge hydrographs at station no. (50) for different values of Manning's (n)

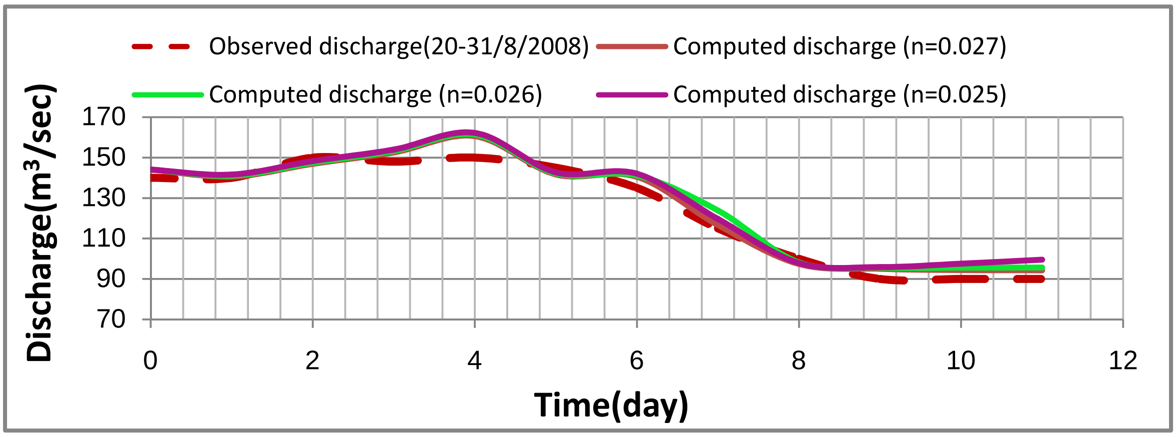

Figure 11: Computed and observed discharge hydrographs at station no. (50) for different values of Manning's (n)

Table 2. HEC-RAS schematization of Hilla river

	Reach	River station No.
Al-Hilla River	Head regulator-Mahaweel	1
		2
		3
		4
		5
		6
		7
		8
		9
		10
		11
		12
		13
	Mahaweel- Khatoniya	14
		15
		16
		17
		18
		19
		20
	Khatoniya- Fandiya	21
		22
		23
		24
	Fandiya- Neel	25
		26
		27
		28
		29
		30
		31
		32
		33
	Neel- Babil	34
		35
		36
		37
		38
		39
		40
	Babil-Guaging station	41
		42
		43
		44
		45
		46
		47
		48
		49
		50

A statistical test is used to compare the calculated results with the respective observed ones. The test is the root-mean-square (R.M.S.) test. Table (3) shows the statistical test of the calibration results; the root-mean-square (R.M.S.) values. These values are the results of the comparison between the observed and computed hydrographs: that of the stage at station no. (1) and of the discharge at station no.(50). As shown in Table (3), the values [Δt =24 hr; θ =0.95; n=0.027] provide the smallest (R.M.S.) value.

Table 3. Statistical test of the calibration results

<table>
<tr><th>Station no.</th><th>Δt (days)</th><th>θ</th><th>n</th><th>∑R.M.S. (Stage)</th><th>∑R.M.S. (Discharge)</th></tr>
<tr><td rowspan="6">1</td><td rowspan="6">1</td><td rowspan="6">0.95</td><td>0.025</td><td>0.1100</td><td rowspan="6">*</td></tr>
<tr><td>0.026</td><td>0.0738</td></tr>
<tr><td>0.027</td><td>0.0716</td></tr>
<tr><td>0.028</td><td>0.1014</td></tr>
<tr><td>0.029</td><td>0.1439</td></tr>
<tr><td>0.03</td><td>0.1907</td></tr>
<tr><td rowspan="6">50</td><td rowspan="6">1</td><td rowspan="6">0.95</td><td>0.025</td><td rowspan="6">**</td><td>6.274</td></tr>
<tr><td>0.026</td><td>5.802</td></tr>
<tr><td>0.027</td><td>4.770</td></tr>
<tr><td>0.028</td><td>5.079</td></tr>
<tr><td>0.029</td><td>5.511</td></tr>
<tr><td>0.03</td><td>4.851</td></tr>
</table>

* The discharge used as upstream boundary condition
** The stage used as downstream boundary condition

Table 4. Statistical test of the verification results of the observed and computed hydrographs[n=0.027; θ=0.95; Δt=24 hr]

Date	For stage hydrograph at station no.(1)	For discharge hydrograph at station no.(50)
	∑R.M.S.	∑R.M.S.
1-12 September 2008	0.086	7.84

Model verification, which is an essential test for any simulation model, is achieved by applying it to the second set of data from the period (1-12 September 2008) using the parameter (n=0.027) derived from the calibration runs. The verification process of the unsteady flow model has been achieved by making a comparison between the observed and computed hydrographs: that of the stage at [station no.(1)] and that of the discharge at [station no.(50)]. These locations have been chosen because there are no daily measurements at other locations on Hilla river that would suffice. Results of the verification process show that the (n) value of (0.027) reasonably produces hydrographs closer to the observed ones as shown in Figs.(12) and (13).

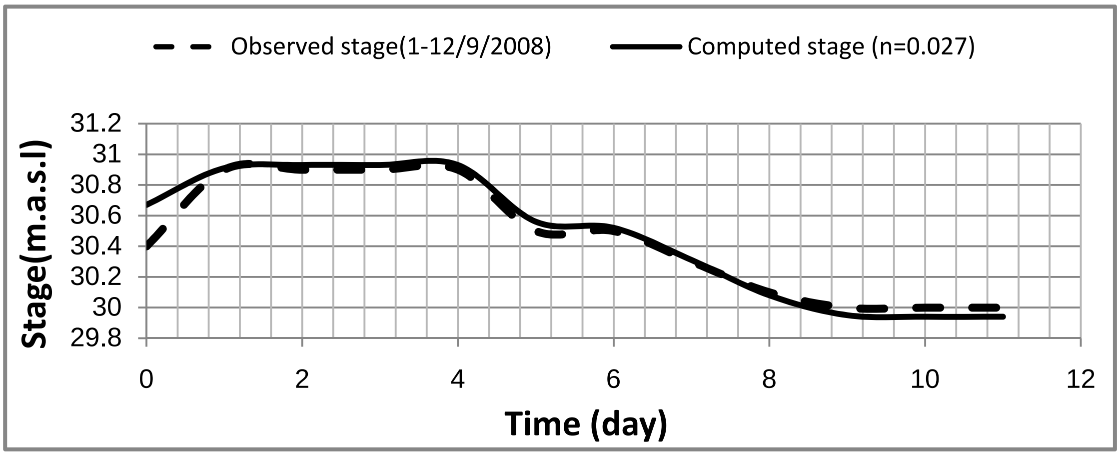

Figure 12: Computed and observed stage hydrographs at station no. (1) for the value of Manning's n=0.027

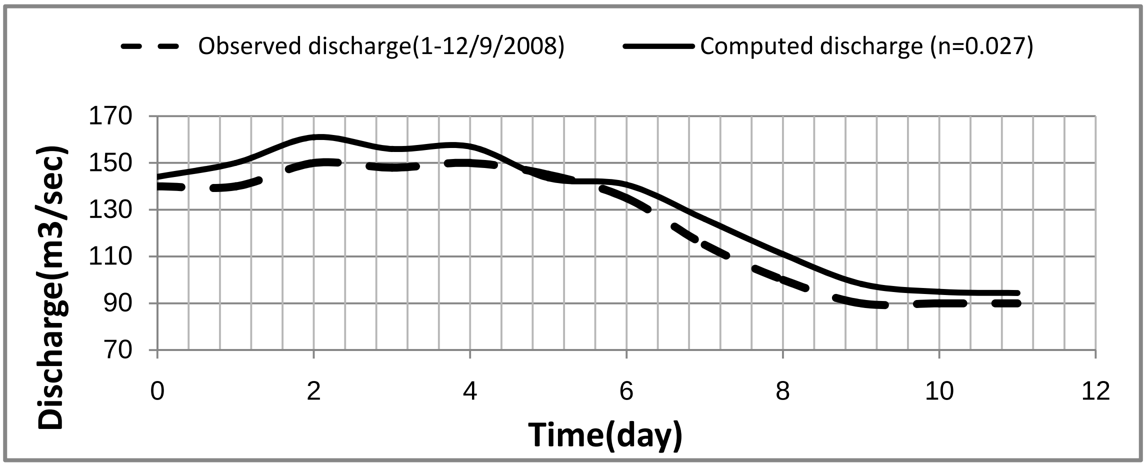

Figure 13: Computed and observed discharge hydrographs at station no. (50) for the value of Manning's n=0.027

Discharge and stage hydrograph results at station no. (1) and station no.(50) of Hilla river are as shown in Table (4). Analysis of results shows that the (n) value of (0.027) reasonably produces hydrographs closer to the observed ones and this indicates that the model is acceptable. This value of Manning's (n=0.027) is close to the value of (n=0.024) which has been used for Hilla river by Al-Masudi (2001) and to the value of (n=0.032) which has been used for Hilla river by Othman (2006).

CONCLUSIONS

Unsteady flow HEC-RAS model is developed for the upper reach of Hilla river to predict the value of Manning's (n) through calibration procedure. The appropriate value of Manning's (n) is (0.027), since it gives reasonable agreement between computed and observed hydrographs.

Notation

Q: discharge;
h: stage;
n: Manning's roughness coefficient;
θ :weighting factor;
Δt:time interval;
Δx:distance interval.

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