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NUMERICAL STUDY COMPARING ESTIMATED 1D and 2D MANNING'S COEFFICIENTS

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Abstract: Two numerical experiments were conducted, the first one involving a straight prismatic channel to simulate the one-dimensional flow and the second experiment uses a curved rectangular channel to emphasize the 2D flow characteristics. The flow in both cases is modeled by a 2D model, using given roughness parameters, Manning's coefficients. Afterwards, the results of both numerical experiments are used to recalculate Manning's coefficients, in each case study, by the direct step method (Slope energy) using the channel's centerline for the calculations. The aim of this paper is to compare the estimated Manning's coefficients, for a prismatic and rectangular channel, in the case where the flow is mainly one-dimensional and when the 2D effects are more obvious. In general, a good agreement is observed between the original Manning's coefficients and the estimated one in the straight configuration whereas the second configuration demonstrates a divergence between suggested and calculated Manning's coefficients.

Keywords: Flow; modeling; Manning's coefficient; SRH-2D; HEC-RAS_1D, Direct step method.

1 INTRODUCTION

Two-dimensional models have been gaining popularity lately and were found to perform well compared to their predecessors, especially when 2D and 3D flow effects are obvious, as in meandering channels or near some hydraulic structures (Tayefi et al. 2007). One of the main differences between 2D and 1D models is the definition of the roughness parameters, usually accounted for by Manning's coefficients (Morvan et al. 2008). In fact, for the same channel, obtaining the same results using one- / two-dimensional models, requires using smaller Manning's coefficients for the 2D model. For instance, values of the roughness coefficients in a one-dimensional model are used in meandering streams, to account for the effect of sinuosity, which would increase the value of the coefficient by 30% (Morvan et al. 2008, Te Chow 1959a), compared to a 2D model that already captures channel's geometry.

2 METHODOLOGY

This paper aims to state the differences between 1D and 2D models regarding the Manning's coefficients, using finite differences approach, namely the direct step method (Henderson 1996, Te Chow 1959b), to retrieve the corresponding 1D Manning's coefficients for both cases in the case of a straight prismatic channel and a curved prismatic channel. For this purpose, SRH-2D, Sedimentation and River Hydraulics - Two-Dimensional, is used. Developed by USBR (Lai 2008), the software solves the 2D dynamic equations of Saint Venant using finite volume method. Manning's coefficients are calculated using the following expression, that is derived from the slope energy equation (Eq.1):

$$[1]\ n = \frac{R_{Av}^{2/3}}{U_{av}} \sqrt{J_f - \frac{\Delta h}{\Delta \mathrm{x}}(1 - F_r^2)}$$

Where n is the Manning's coefficient; R_{av} is the average hydraulic radius (for successive depths); U_{av} is the average velocity; Δx is the spatial variation in the x-direction; Δh is water depth variation; F_r is Froude number.

Calculations are done within the centerline to not involve walls effects on the flow. Afterwards, the obtained Manning's coefficients are inputted into a widely used one-dimensional model (i.e. HEC-RAS_1D), to assess the model's response according to used roughness parameters. It would be interesting to use the 2D tool of HEC-RAS, since it solves the same numerical schemes as the 1D tool. However, since the tool is still under development, it's more suitable to use 2D models that are well established.

1.1 Straight rectangular channel

The first numerical experiment conducted, simulates a flow in a uniform straight rectangular channel with a bed slope of 0.001. The channel is subdivided in four regions (Sand, gravel, rock and earth materials), each having a different Manning's coefficient, ranging from 0.01 (Sand) to 0.04 (Rock) (Figure 1). The simulation was run with different boundary conditions, with four discharges upstream and their corresponding critical depth downstream, used data are listed in Table 1. Before setting up the critical depth as the exit boundary condition, a little test was performed, it involves using different water depths downstream for the same discharge to evaluate Manning's 1D coefficient response regarding this condition. The outcome of the experiments yields that a rising water depth condition (by 300 %), results in a Manning's coefficient rise (by 105%) as well. Considering the low percentage by which Manning's coefficient is increasing compared to water depths, the selected boundary condition for the rest of the study is critical depth.

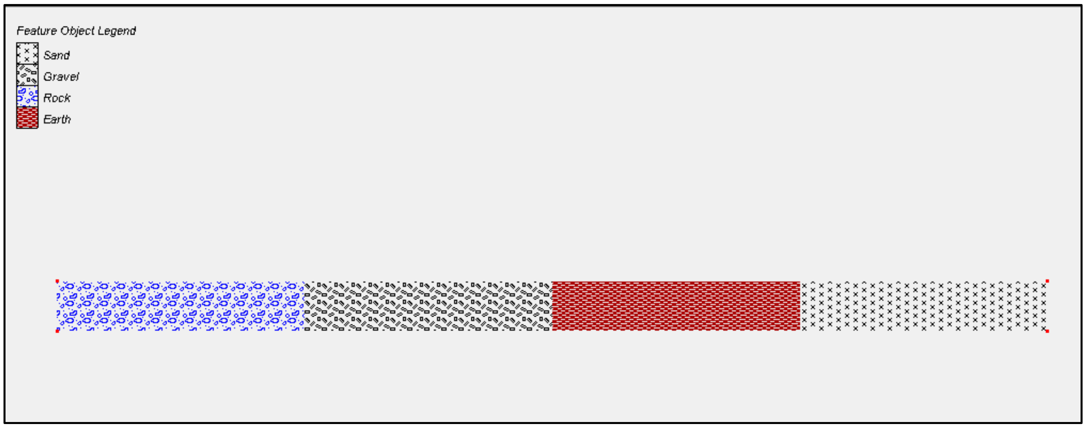

Figure 1: Materials used for each flow area in the case of a straight rectangular channel

Table 1: Boundary conditions for the straight rectangular channel

	Boundary Conditions	
	Inlet BC (m^3/s)	Outlet BC (m)
Case 1	3	0.33
Case 2	9	0.69
Case 3	18	1.097
Case 4	27	1.438

For each case, Manning's 1D coefficient are estimated, using slope energy method. This gives a set of Manning's coefficients for every region, which are nearly the same as the given Manning's 2D coefficients. The general tendency is that the average Manning's 1D coefficient (For a specific region) is either equal or slightly higher than the given 2D coefficient (Table 2).

Table 2: Average Manning's 1D coefficients for a straight reach, Q=18m3/s

	n_1D	n_2D
n_aver_Sand	0.012	0.01
n_aver_Earth	0.021	0.02
n_aver_Gravel	0.031	0.03
n_aver_Rock	0.040	0.04
Q 18	m3/s	

1.2 Curved rectangular channel

Similarly, to the straight channel case, the flow area is subdivided into four regions with Manning's coefficients (**Figure 2**) and boundary conditions (Table 1) remaining the same as for the previous case. Manning's 1D coefficients obtained are higher than the 2D ones. Furthermore, for a singular Manning's 2D value a range of Manning's 1D values is obtained. For instance, for the first 20 meters (Rock area) of the channel, resulting Manning's values range from 0.021 to 0.11. Average Manning's coefficient is calculated for each flow area and compared with the given 2D coefficients. The result yields higher 1D Manning's coefficients (e.g. Table 3 in the case of Q=18m^3/s), as predicted, since with the direct step the roughness parameter accounts for geometric and turbulence effects.

Table 3: Average Manning's 1D coefficients, Curved reach, Q=18m3/s

	n_1D	n_2D
n_aver_Sand	0.019	0.01
n_aver_Earth	0.023	0.02
n_aver_Gravel	0.031	0.03
n_aver_Rock	0.047	0.04
Q 18	m3/s	

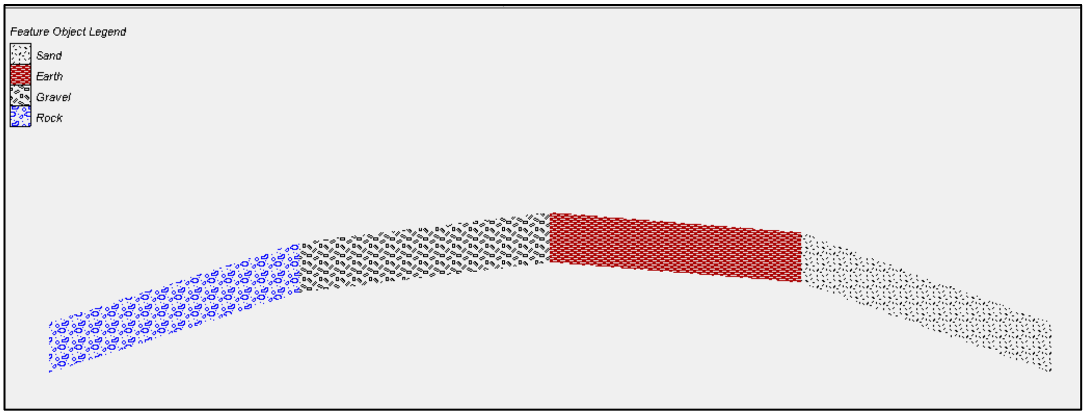

Figure 2: Materials used for each flow area in the case of a curved rectangular channel

1.3 1D vs 2D model

One-dimensional modelling is done using the 1D solver of HEC-RAS (HEC-RAS _1D), a 1D model widely used by hydraulicians, developed by the US Army Corps of Engineers (USACE). This software evaluates flowrates and water levels in all sections of a channel, for a given flow data (steady flow), or a given hydrograph (unsteady flow). The needed data to perform the calculations are listed in several categories: geometric data, Steady/Unsteady flow data, Sediment data, and Water quality. The geometrical data is essential to any HEC-RAS_1D analysis, the other entries depend on the user interests. 1D modelling with HEC-RAS_1D involves solving the Saint-Venant equations that are simplified according to the simulated model.

The previous simulations conducted in the two-dimensional model are done using HEC-RAS_1D. Two processes are considered while assigning the Manning's coefficients. First, the chosen Manning's 2D coefficients are used, and then the generated set of Manning's coefficients following the use of the slope energy method.

In the case of a straight rectangular channel, both methods suggest the same Manning's coefficient. Thus, the 1D and 2D model give nearly identical results. In fact, the root-mean-square error (RMSE) based on SRH-2D results, as the observed data, and HEC-RAS_1D results, using the generated set of 1D Manning's coefficients and the 2D given coefficients, gives approximately the same results for both approaches which is equal to 0.05. Furthermore, the correlation of both results with SRH-2D water profile is substantially the same, R^2=0.99, the results are plotted in **Erreur ! Source du renvoi introuvable.**.

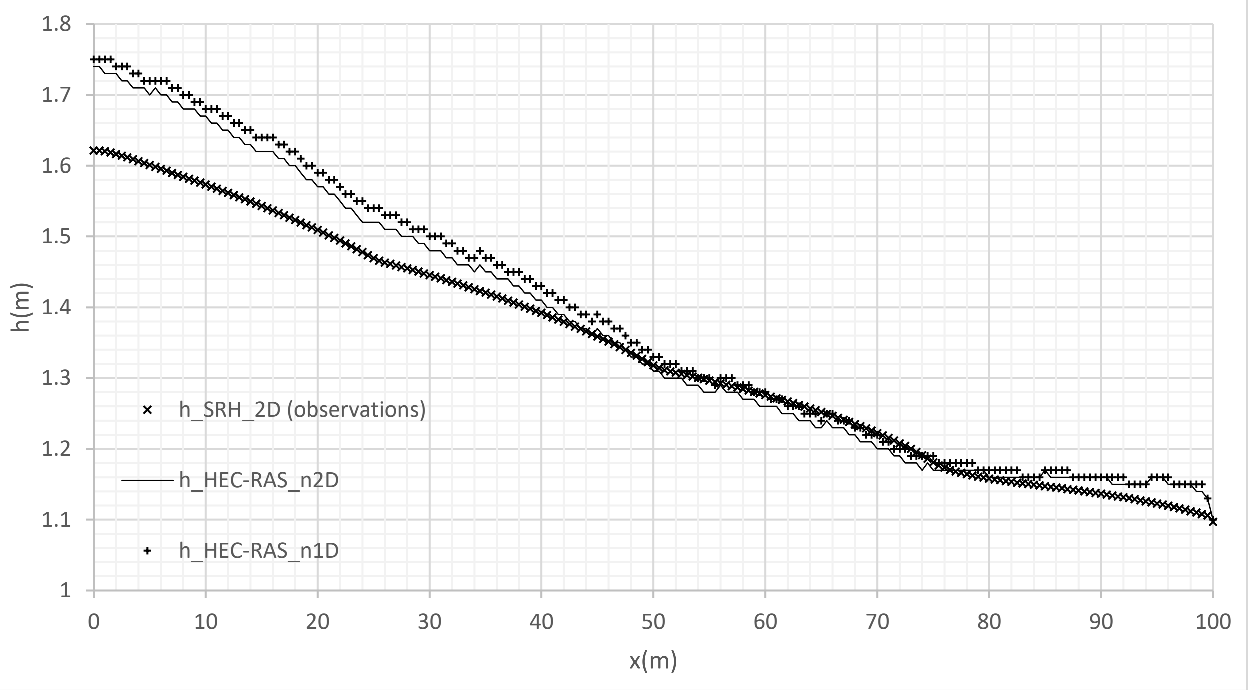

Figure 3:Comparison of waterlines obtained using HEC-RAS_1D (Manning's 1D and 2D) and SRH-2D, for a straight channel

For the curved rectangular channel, we found that the Manning’s coefficients (1D) set gives the smallest RMSE (n_1D_RMSE=0.069 and n_2D_RMSE=0.1), and a better correlation with SRH-2D water-profile (R^2=0.99 compared to 0.90 for n_2D). The obtained waterlines using the 1D and 2D model are shown in Figure 4.

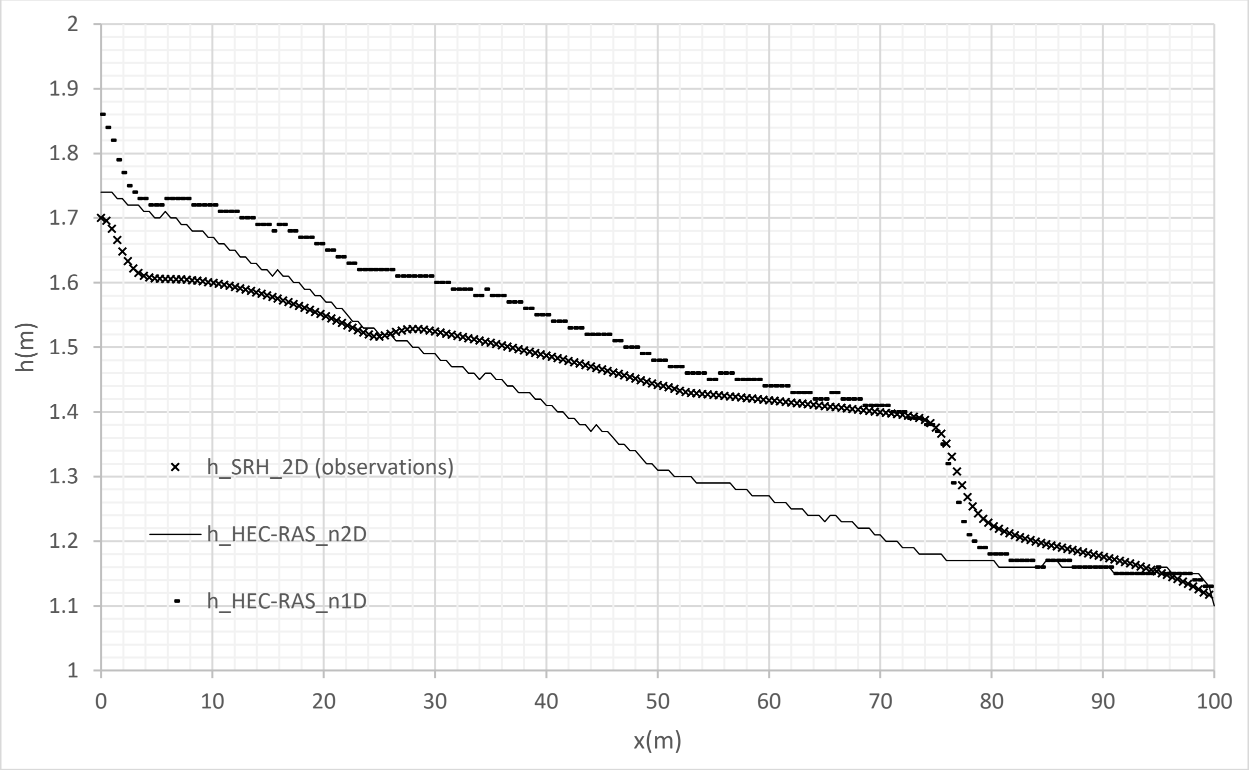

Figure 4: Comparison of waterlines obtained using HEC-RAS_1D (Manning's 1D and 2D) and SRH-2D, for a curved channel

3 DISCUSSION

In the case of the straight rectilinear channel, for any data set of water depths, the Manning's 1D and 2D coefficients are practically the same, which validates the statement of fluid mechanics that neglects the *"y"* velocity components, when the flow can be considered one-dimensional. When the two-dimensional effect is obvious, the 1D and 2D model's results diverge. Hence, using the set of Manning's coefficients generated by the energy slope method is what works best with HEC-RAS_1D and minimizes the residual differences. Comparison of the water profiles obtained with HEC-RAS_1D for both straight and curved channel yields that the same water profile is obtained when using the given 2D Manning's coefficients, suggesting that HEC-RAS_1D does not account for the channel's meandering.

However, for each Manning's 2D coefficient, a set of Manning's 1D coefficients can be generated using the direct step method. Indeed, the 1D Manning's coefficient is a calibration parameter, which stands for the effect of flowrate, water elevation, geometry, turbulence as well as other effects. This means that the roughness parameter definition deviates of its definition in a 2D model (Morvan et al. 2008), where the two-dimensional effects are captured by the numerical model and the turbulence is considered when solving the Saint Venant equations.

4 CONCLUSION

Since the estimation of the roughness parameter is a major difficulty in modelling, this paper investigated the differences between Manning's 1D and 2D coefficients, to raise the awareness of the hydraulic practitioners that will be switching from the 1D to the 2D models. Based on this numerical experiment, it appears clearly that 1D Manning's coefficient, for overbanks flow or in curved channels, becomes a calibration parameter that takes on several effects. Therefore, practitioners need advisement on the selection of the best Manning's coefficients for 2D models.

5 ACKNOWLEDGMENT

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6 REFERENCES

Henderson, Francis Martin. 1996. *Open channel flow*: Macmillan.

Lai, Yong G. 2008. "SRH-2D version 2: Theory and User's Manual." *Sedimentation and River Hydraulics–Two-Dimensional River Flow Modeling, US Department of Interior, Bureau of Reclamation, November*.

Morvan, Hervé, Donald Knight, Nigel Wright, Xiaonan Tang, and Amanda Crossley. 2008. "The concept of roughness in fluvial hydraulics and its formulation in 1D, 2D and 3D numerical simulation models." *Journal of Hydraulic Research* 46 (2):191-208.

Tayefi, V, SN Lane, RJ Hardy, and D %J Hydrological Processes: An International Journal Yu. 2007. "A comparison of one-and two-dimensional approaches to modelling flood inundation over complex upland floodplains." 21 (23):3190-3202.

Te Chow, Ven. 1959a. *Open channel hydraulics*: McGraw-Hill Book Company, Inc; New York.