Building Tomorrow's Society
Bâtir la Société de Demain

Fredericton, Canada

June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

AUTOMATIC CALIBRATION TOOL FOR 2D HYDRODYNAMICS MODELING

Hajjout, Nadia[1,2], Mahdi, Tew-fik[1,3],
[1] Département des génies Civil, Géologique et des Mines (CGM), École Polytechnique de Montréal, C.P. 6079, succursale Centre-Ville, Montréal, QC H3C 3A7, Canada
[2] nadia.hajjout@polymtl.ca
[3] tewfik.mahdi@polymtl.ca

Abstract: The roughness of a river and its floodplains, represented by Manning's coefficient is one of the major parameters that is unknown during river modeling. Thus, suggesting accurate Manning`s coefficients requires an extensive model calibration. Since manual fitting method can be very tedious, complex and time consuming, automatic calibration is well suited for complex river models. This paper presents an updated automatic calibration tool, O.P.P.S_V2, compatible with version 3 of the hydrodynamical software SRH-2D. O.P.P.S_V2 is completely autonomous and gives the best parameter values for which the difference between model-generated and measured observations is minimum. The calibration tool uses the software PEST, Parameter ESTimation, to fit roughness coefficients. For test and verification purposes, O.P.P.S_V2 is used to estimate Manning's coefficients for an experimental data set of a laboratory 2D flow. For comparison purposes, Manning's coefficients are estimated using both the direct step method and automatic calibration. The model responded well to the automatic calibration of Manning's roughness coefficient, computing a coefficient very similar to the one suggested by the theory.

Keywords: Manning's coefficients; Automatic calibration; River models; Parameter estimation; PEST; SRH-2D

1 Introduction

Multidimensional modeling produces better simulations for flood propagation. Indeed, 2D models gained in popularity in the engineer's community and are about to substitute to the prevailing 1D model. This popularity is mainly due to the additional precision that is offered by the bi-dimensional models. River modeling many uncertainties. Achieving a reliable model involves an accurate description of river characteristics. Roughness parameters can be affected by many factors (Te Chow 1959). Thus, the values of roughness are responsible of the main uncertainties encountered in river models.

Therefore, an appropriate value of Manning's roughness coefficients must be chosen carefully through the calibration process.

Manual calibration is not fit for the 2D models, which are far more complex than the 1D ones. Thus, it is recommended to use automatic calibration. Unfortunately, there is no method that could be generalized for all river models. This paper presents O.P.P.S_V2, a calibration tool, based on and valid for SRH-2D only. For validation purposes, a laboratory data set will be used. Also, Manning's coefficients from the direct step method will be compared to those by automatic calibration.

2 Models presentation

2.1 SRH-2D

SRH-2D (Sedimentation and River Hydraulics - Two-Dimensional),developed by USBR (Lai 2008), solves the 2D dynamic equations of Saint Venant (Eq. 1, 2 and 3) using the finite volume method.

$$[1]\ \frac{\partial h}{\partial t}+\frac{\partial hu}{\partial x}+\frac{\partial hv}{\partial y}=e$$

$$[2]\ \frac{\partial hu}{\partial t}+\frac{\partial huu}{\partial x}+\frac{\partial hvu}{\partial y}=\frac{\partial hT_{xx}}{\partial x}+\frac{\partial hT_{xy}}{\partial y}-gh\frac{\partial z}{\partial x}-\frac{\tau_{bx}}{\rho}$$

$$[3]\ \frac{\partial hv}{\partial t}+\frac{\partial huv}{\partial x}+\frac{\partial hvv}{\partial y}=\frac{\partial hT_{xy}}{\partial x}+\frac{\partial hT_{yy}}{\partial y}-gh\frac{\partial z}{\partial y}-\frac{\tau_{by}}{\rho}$$

The friction is determined using the Manning's equation (Eq. 4).

$$[4]\ \begin{pmatrix}\tau_{bx}\\ \tau_{by}\end{pmatrix}=\rho C_f\begin{pmatrix}u\\ v\end{pmatrix}\sqrt{u^2+v^2} \qquad C_f=\frac{gn^2}{h^{1/3}}$$

The turbulent stresses are computed by the Boussinesq equations (Eq. 5, 6 and 7):

$$[5]T_{xx}=2(\mu_0+\mu_t)\frac{\partial u}{\partial x}-\frac{2}{3}k$$

$$[6]T_{xy}=(\mu_0+\mu_t)\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)$$

$$[7]T_{yy}=2(\mu_0+\mu_t)\frac{\partial v}{\partial y}-\frac{2}{3}k$$

h is the water depth, u and v are the velocity components, e is a source term, T is the turbulent stress, τ is the shear stress, g is the gravitational acceleration, ρ is the mass density, μ_0 is the kinematic viscosity of water, μ_t is the turbulent eddy viscosity and k is the turbulent kinetic energy.

One major capability of SRH-2D is the use of a hybrid mesh (triangular and quadratic), which is the best in terms of efficiency and accuracy.

Furthermore, steady and unsteady flows can be simulated on SRH-2D, which uses a very robust and stable algorithm. SRH-2D support the use of the following turbulence models: Laminar, Constant, Parabolic and k-ε (k-epsilon).

The working environment and the visualization of the results are done using the SMS software (Surface-Water Modeling System(AQUAVEO 2016)) which has a graphical interface and allows the integration of several solvers like SRH-2D.

2.2 PEST

PEST (Parameter ESTimation), developed by Doherty(Doherty 1994), performs automatic calibration and sensitivity analysis of any model using input / output files in binary or ASCII format. It could be run with several types of models, and in various fields (hydraulic, hydrological ... etc.). The software offers a great flexibility in use, it adapts the calibration process to the needs of the model rather than adapting the model to the needs of the calibration process. The user designates the parameters to be adjusted, and the observed values before PEST carries out several simulations to achieve calibration.

Automatic calibration within PEST uses three types of files: template, instruction & control file. PEST takes control of the SRH-2D and starts by creating an image of the model's input file. This image is then iteratively modified, according to a series of instructions provided by the user, by varying the value of the identified calibration parameters. For every iteration, PEST runs the model and observes the results generated in the output file. At the end of the procedure, it provides the optimal combination of the calibrated parameters generating the smallest difference between the results obtained and the field observations (Doherty 2008).

2.3 O.P.P.S_V2

Developed by Deslauriers and Mahdi(Deslauriers and Mahdi 2018), O.P.P.S_V1 is an automatic tool used to calibrate any river model based on SRH-2D(Version 2). It has a user-friendly graphic interface. The program is autonomous and returns the results with the best parameter values for the simulation. The second version of the calibration tool, O.P.P.S_V2, is adapted to the version 3 of SRH-2D which uses three input files namely:"*.srhhydro","*.srhmat" and "*.srhgeom". The tool verifies the validity of the supplied data and creates the necessary files to run PEST. Thus, PEST template, instruction and control files are created automatically by O.P.P.S_V2. Therefore, the required files to run PEST are ready and O.P.P.S_V2 executes PEST using a script to launch automatically the program(AutoHotkey 2014). O.P.P.S_V2 executes the model, SRH-2D, until the objective function termination criteria is achieved, thus, when the model converges to a solution giving the smallest residual between the calculation results and the field data. The results can then be displayed with the O.P.PS_V2 tool (Figure 1).

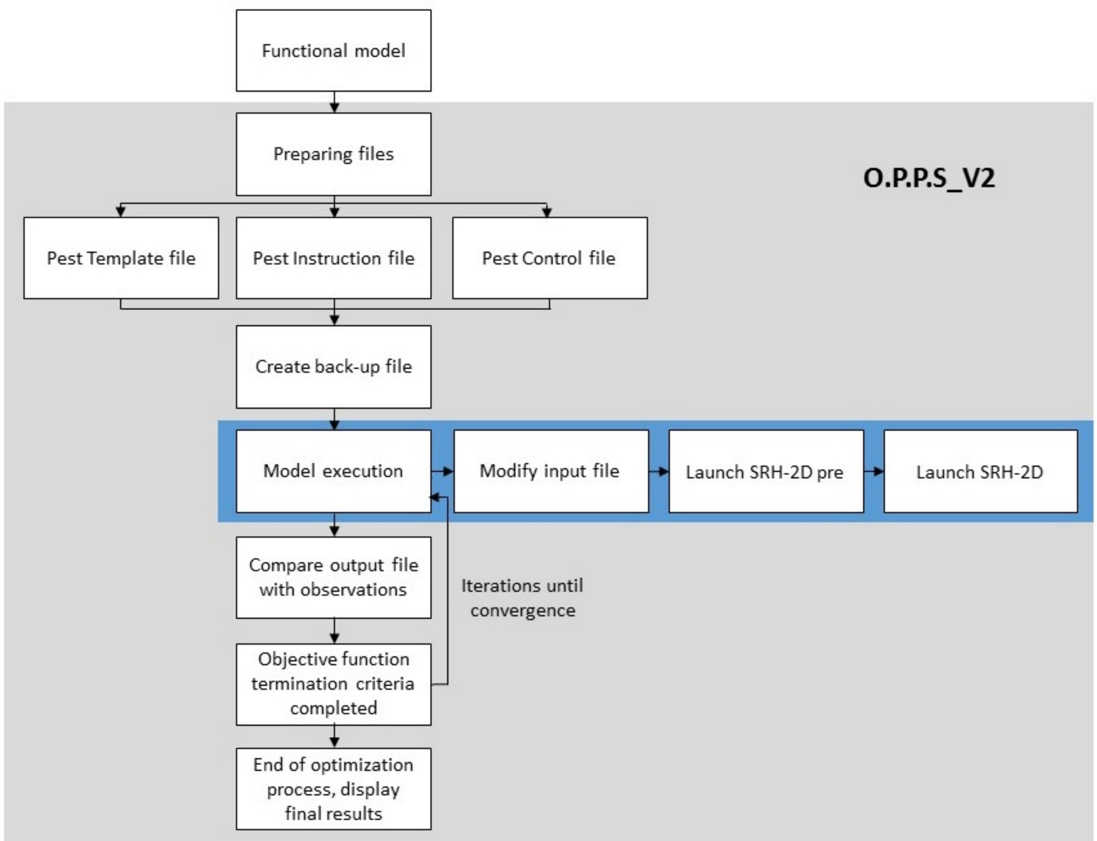

Figure 1: O.P.P.S_V2 execution structure

3 Application: Laboratory to the data set

An experiment is conducted in the hydraulic laboratory of *École Polytechnique de Montréal.* A rectangular horizontal channel with a wood bottom and glass walls is equipped to collect the necessary data. The rectangular flume has a total length of 6.70 m, but only a portion of 3.7m is gaged, a width of 0.762 m and a depth of 0.764 m. The water depth is determined using four sensors placed on a mobile bench (Figure 2). The used sensors are mic+340/DIU/TC (one sensor) with an operating range of 350-5000mm and mic+130/DIU/TC (three sensors) with an operating range of 200-2000mm, both types have an accuracy of 1% (Microsonic 2017).The flow is measured with a MAG 910E electromagnetic flowmeter (OmniInstruments 2015) with an accuracy of 1%.

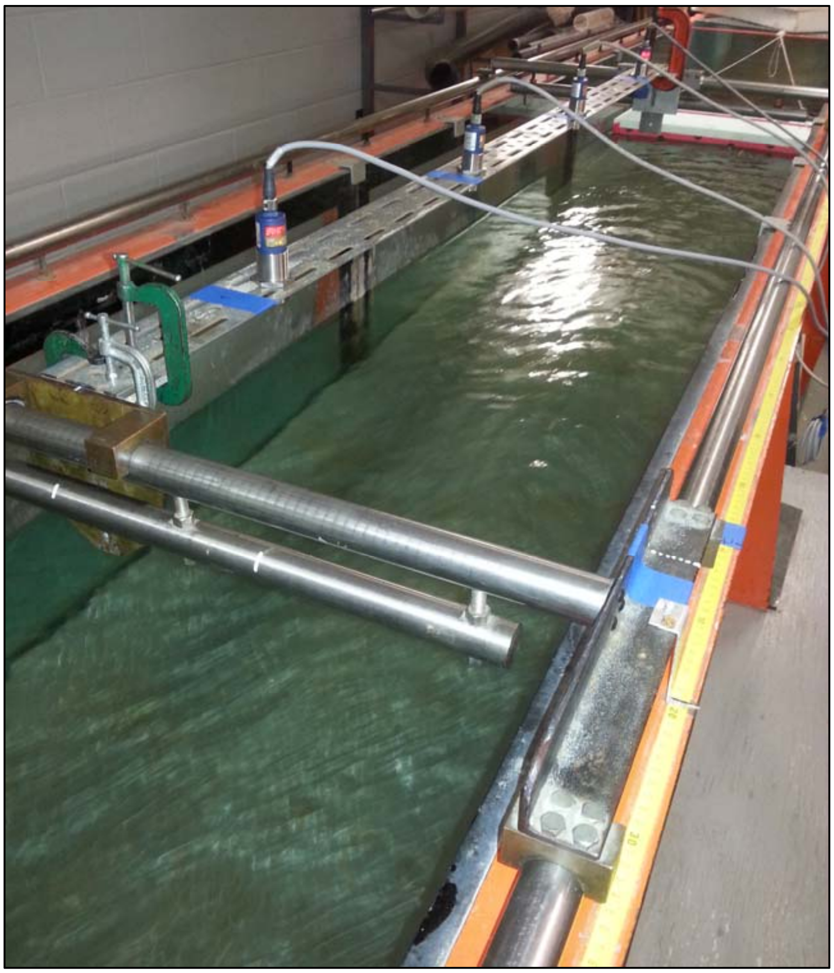

Figure 2: Experimental setup

The experiment starts once the flow is stabilized, to ensure a steady flow. A total of 120 points were surveyed during this experiment to retrieve the geometry of the channel and the water depths. Some of these data will serve as entries for the model. In fact, knowing the geometry of the channel, the inlet flow and the downstream depth the model can be set.

To determine Manning's coefficients, we use two methods. The first approach is one dimensional using the direct step method and the second approach consists of an automatic calibration.

3.1 1D calibration

Manning's coefficients, for unidimensional flow, are calculated using the direct step method calculating the energy slopes (Henderson 1996, Te Chow 1959) and using the central water line, to not involve the effects of the side walls of the channel on the flow. We select 10 points among the 22 points for the calculations. These points are the ones that best represent the water line (Figure 3). The Manning's coefficient obtained in this case is 0.024, which is higher than the Manning's coefficient suggested theoretically. In fact, for a channel with a wooden bed (0.012-0.018) and sidewalls of glass (0.009-0.013), the equivalent Manning's coefficient is in the range 0.011- 0.016(Te Chow 1959).

3.2 2D calibration

To conduct the automatic calibration, a simulation is run on SRH-2D to obtain all the required files for O.P.P.S_V2. Then among the 120 points surveyed 110 are used, we exclude the points near the boundary conditions. A first automatic calibration is run. The result is a Manning's coefficient of 0.017 (Table 1) that is slightly higher than what is expected theoretically (Section 3.1). For a more relevant result, we proceed to an analysis to choose the points to use for the automatic calibration by representing the water depth lines and removing the outliers, 48 points are selected (Figure 3).

Table 1: Obtained Manning's coefficients using O.P.P.S_V2

Observations	Estimated Manning
48	0.013
100	0.017

The Manning's coefficient found by automatic calibration is 0.013, which is consistent theoretically.

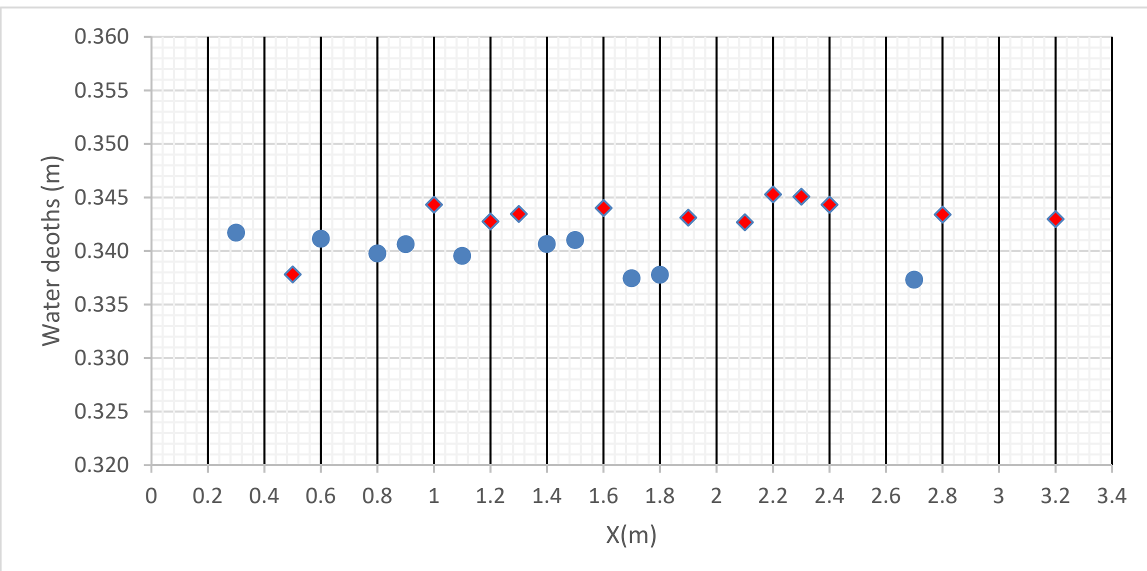

Figure 3: The selected points in the center line (blue) for the energy slope calculations

4 Conclusion

This paper presents the results of Manning's coefficients determination by two methods: calculating the energy slope (Direct step method) and automatic calibration, using an experimental dataset. The automatic calibration is done by an updated tool O.P.P.S_V2, which is based on SRH-2D version 3. The automatic calibration gives reasonable agreement between computed and observed water depths. The results of the unidimensional procedure using the direct step method, gives one Manning's coefficient higher. The differences are attributed to the 2D geometrical and turbulence effects for which the roughness coefficient stands as a calibration parameter.

References

AQUAVEO. 2016. "SMS 12.2 - The Complete Surface-water Solution.", accessed 1/18/2018. https://www.aquaveo.com/software/sms-surface-water-modeling-system-introduction.

AutoHotkey. 2014. https://autohotkey.com/.

Deslauriers, Simon, and Tew-Fik Mahdi. 2018. "Flood modelling improvement using automatic calibration of two dimensional river software SRH-2D." *Natural Hazards*. doi: 10.1007/s11069-017-3150-6.

Doherty, John. 1994. "PEST: a unique computer program for model-independent parameter optimisation." *Water Down Under 94: Groundwater/Surface Hydrology Common Interest Papers; Preprints of Papers*:551.

Doherty, John. 2008. PEST, Model Independent Parameter Estimation-User manual: Brisbane, Australia, Watermark Numerical Computing, accessed October 1, 2009.

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*.

Microsonic. 2017. "mic+340/DIU/TC." accessed 1/18/2018. https://www.microsonic.de/fr/capteurs-de-distance/cylindrique/micplus/capteurs-standard/capteurs-standard/micplus340diutc.htm.

OmniInstruments. 2015. "MAG 910 Electromagnetic Flowmeter." accessed 1/18/2018. http://www.omniinstruments.co.uk/flow-meters/electromagnetic-flow-meters-magnetic-flow-meters/mag910e-magnetic-flowmeter.html.

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