Predictive Capability Analysis of a new one-dimensional Hydraulic Model for Water Surface Level Simulation in PHABSIM

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ABSTRACT: Standard models of PHABSIM for water surface level simulation apply some of the classic one-dimensional hydraulic methods: MANSQ the Manning´s equation and WSP the "standard step". To analyze the predictive capability of the Weisbach-Darcy´s equation, we have developed the complementary algorithm WEISB, which is applicable to steady uniform flow. The presented formulation computes the Darcy´s friction factor by means of the Colebrook-White´s formula adapted to open channel flow. The simulations performed in eighteen representative transects of three basic types of habitat (rapids, runs and pools) of two typical fluvial reaches (high and low-gradient), reveals an aptitude of WEISB comparable to those of the current MANSQ and STGQ. Investigation lines are suggested to improve the potential of the algorithms of WEISB.

1 INTRODUCTION

The functional relationships between an index of relative suitability of the aquatic habitat (Payne 2003) and the discharge, developed in the Physical Habitat Simulation system PHABSIM (Bovee 1982), are based in some hydraulic predictions that combine with some specified suitability criteria.

The standard hydraulic simulation of PHABSIM uses statistical and one-dimensional hydraulic models (1D) in order to predict depths and velocities in each cell of the cross section, within a defined range of discharges (Q).

The quality of the water surface level (WSL) modeling determines the reliability of the cell predictions: directly in depths, and indirectly in adjusted velocities by the velocity adjustment factor. The three available models (Waddle, 2001) develop the initial approaches of the "Instream Flow Paper No. 5" (Bovee & Milhous 1978) to generate a rating curve with a steady flow: (1) STGQ as common statistical method, (2) MANSQ for an uniform régime, and (3) WSP for gradually varied conditions.

The STGQ model develops a least-squares bilogarithmic regression relating WSL to discharge, conceiving an effective depth determined by the stage of zero flow.

MANSQ applies the Manning´s equation to a cross section, accounting for the inherent variation of roughness with discharge by means of a variable water transport parameter (WTP); several options allow to configure the relationship between roughness and WTP (primitive IOC2), the type of hydraulic radius (IOC6) and the treatment of the ineffective flow area (IOC10).

The more rigorous approach of WSP applies the "standard step method for divided channels" (see Henderson 1966) to consecutive cross sections with a subcritical gradually varied flow, using the Roughness Modifier (RMOD) to model the changes in roughness with discharge.

In the report of Bovee & Milhous (1978), the acceptable range of simulation for STGQ and MANSQ was delimited, depending on the number of available pairs WSL-Q. The potential of WSP was analyzed in Milhous (1990), and some limitations were detected in Osborne et al. (1988). Bartz (1990) tested the current models on streams of three basic sizes in Colorado (small, medium, and large), and computed mean relative simulation errors smaller than 1%. As a reference, the absolute error of the predictions normally ranges from 3 mm to 6 mm (Waddle 2001).

The objective of this paper is to explore the potential of the well-known Weisbach-Darcy´s equation to simulate WSL by using the standard data in PHABSIM, as well as to compare its predictive capacity with those of the current models in different basic habitats.

2 METHODOLOGY

2.1 *Description of the "WEISB" model*

We have developed a complementary algorithm for 1D WSL simulation, that we have called "WEISB" (equation of WEISBach), applicable where the flow is steady, uniform and turbulent. It uses the empirical Weisbach´s formula with the Darcy´s friction coefficient (see Graf & Altinakar 1998, sect. 3.1) to compute the hydraulic resistance of a cross section due to skin friction. The wide-spread use of this formula in open channels has been highly recommended by the American Society of Civil Engineers (ASCE 1963):

$$U = \sqrt{\frac{8g}{f}}\sqrt{Rh \cdot S_0} \tag{1}$$

where *U* = mean channel velocity (m/s); *g* = gravity (m2/s); *f* = friction coefficient (dimensionless); *Rh* = hydraulic radius (m); and S_0 = slope (m/m). In Equation 1 is assumed that the hydraulic resistances of "Momentum" and "friction" are equivalent, which is valid under normal conditions (Yen 1992).

$$f = \frac{1}{4}\left[-\log\left(\frac{k}{12 \cdot Rh} + \frac{1.95}{Re^{0.9}}\right)\right]^{-2} \tag{2}$$

where *f* = friction coefficient; *k* = effective roughness (m); *Rh* = hydraulic radius (m); and *Re* = Reynolds number.

The calibration starts by deducing the observed effective roughness (k^{obs}) for all the available observed discharges (Q^{obs}). This is accomplished by solving a simplified overall expression of Equations 1 and 2 for a fully turbulent steady flow ($Re>10^6$), where the effect of the Reynolds number can be ignored (see White 1994, sect. 10.2):

$$k^{obs} = AT\left[\log Rh^{obs} - \frac{Q^{obs}}{5.66 \cdot Sm^{obs}\sqrt{g \cdot Rh^{obs} \cdot S_0}} + 1.08\right] \tag{3}$$

where the term AT is the antilogarithm (10^x), and the sub-index "obs" indicates they are observed values. Any reasonable value of the slope (S_0) can be used (e.g. 0.0025) to compute a fictitious though valid roughness. After that, we determine the variation of effective roughness with the discharge, for that two procedures have been designed: 1) a polynomial regression fit; and 2) an anchored adjustment with the discharge, similar to that of MANSQ (IOC2=0) but using the roughness instead of the water transport parameter (WTP).

The simulation begins estimating the simulated roughness (k^{sim}) for the simulation discharge (Q^{sim}) by means of one of the previous modes. This value is applied to an expression of the Equation 3 for the simulated variables (superscript "sim"),

$$Q^{sim} = 5.66\sqrt{g \cdot S_0}\, Sm^{sim}\sqrt{Rh^{sim}} \cdot \left(\log Rh^{sim} - \log k^{sim} + 1.08\right) \tag{4}$$

or to the general expression for turbulent flow, that includes the Reynolds number:

$$Q^{sim} = \sqrt{8 \cdot g \cdot Rh^{sim} \cdot S_0}\left[-2\log\left(\frac{k^{sim}}{12 \cdot Rh^{sim}} + \frac{1.95}{\left(Re^{sim}\right)^{0.9}}\right)\right] Sm \tag{5}$$

The simulated WSL (WSL^{sim}) is determined by sucessive approximations, that modify the hydraulic radius and the cross-sectional area, as well as the Reynolds number (Eq. 5).

2.2 *Data Processing*

WEISB has been tested in 18 representative cross sections of three basic habitats (riffles, runs and pools) in two basic fluvial reaches (low-gradient and high-gradient), with data of PHABSIM studies PHABSIM carried out in California and extracted to the computer file manteined by Thomas R Payne & Associates (TRPA, Arcata-CA). The high-gradient reach has been represented with data of the river "Yuba", in a wide area (45-65 m), with intermediate susbtrate (gravels and cobbles) and low gradient (< 1%). That of low-gradient with those of the river "South Fork American", a narrow reach (5-9 m), with bigh substrate (blocks and rocks) and pending discharge (>1%). In each one of the six representative transects we disposed of three observations WSL-Q, as well as their corresponding SZG.

The current models were executed with the package RHABSIM 2.2 (TRPA 2001), to calculate the simulated WSL during the observed flows. MANSQ has been applied with 12 configurations that combine: three calibration flows (L-Low, M-Medium and H-High), two types of roughness adjustment (IOC2: anchored in the flow or in the hydraulic radius) and one alternative of potential regression with the flow, two types of hydraulic radio (IOC6: normal or pondered), and two treatments of the ineffective area of flow (IOC10: hydraulic radius normal or modified). WEISB has been tested with 8 configurations that incorporate: a polynomial adjustment and three adjustments anchored with the flow, as well as the treatment of the ineffective area by means of a modification of the hydraulic radius or of the wet area.

The discrepancies between the simulated and the observed values of WSL in each transect were analyzed in terms of absolute and relative errors, as well as the typical deviations for each simulated level. Adding these errors hierarchically (level-section-habitat) we calculated the Mean Relative Error (MRE) and the Mean Absolute Error (MAE), ships between an Index for habitat suitability and the discharge.

5 CONCLUSION

The use of the Darcy-Weisbach formula in the algorithm 1D WEISB admits some predective techniques for a steady flow, uniform and turbulent, with unequal capacity, depending on the mode of friction coefficient calculation. When using the equation of Colebrook-White, the capacityd is comparable to those of MANSQ and STGQ, being more competitive in the riffles of the low-gradient reach, where the reduction of error is 32%.

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