Determination of morphological input data for hydraulic 1-D models by using purposeful geodetic surveying

Détermination des données d'entrée morphologiques pour les modèles hydrauliques 1-D en utilisant des levés géodésiques ciblés

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RÉSUMÉ

Les modèles hydrauliques basés sur la physique sont devenus de plus en plus populaires en raison de leur haute résolution et de leur capacité à simuler l'évolution de la qualité de l'eau et des contraintes hydrauliques pour différents scénarios de structures d'ingénierie hydraulique sur les plans d'eau urbains. Ces modèles de haut niveau nécessitent néanmoins des données physiques éprouvées pour que les résultats fournis soient fiables. Par conséquent, la première difficulté de la modélisation est la collecte exhaustive des informations nécessaires. En particulier, la morphologie des canaux ouverts n'est pas bien documentée. La plupart du temps, les données fournies par les institutions publiques manque de précision et/ou ne sont pas très à jour. Si l'on se base sur des profils standards de substitution, cela peut entraîner des erreurs considérables pour les résultats hydrauliques (niveau, vitesse d'écoulement, contrainte de cisaillement) par conséquent, pour les états et processus des modèles de qualité (par exemple la surface mouillée, la ré-aération physique), cités en exemple dans cet article. Pour une modélisation fiable, sur les niveaux inférieurs, les conduits souterrains et les sections transversales des cours d'eau urbains, en particulier, devraient être définis avec suffisamment d'exactitude par une méthode pratique. Cet article présente un concept d'étude géodésique rentable et efficace permettant de déterminer les données structurelles manquantes. Ce concept combine la technologie de réception GPS cinématique en temps réel et la technologie de l'arpentage optique. Il est capable de produire toutes les données structurelles nécessaires pour le modèle hydraulique 1D sans trop de difficulté.

ABSTRACT

Physical based hydraulic models became more and more popular, because of their high resolution and ability to simulate the evolution of water quality and hydraulic stress for different scenarios of hydraulic-engineering structures at urban watercourses. Nevertheless, these high-level models need well-proofed physical data for reliable results. Therefor the first obstacle for modelling is the comprehensive collection of required information. Especially the morphology of open channels is not well documented. Data provided by public institutions are in most cases not precise and/or not up to date. The assumption of standard surrogate profiles can lead to enormous errors for hydraulic results (level, flow velocity, shear stress) and accordingly quality related model states and processes (e.g. wetted surface, physical re-aeration), as exemplarily shown in the paper. For reliable modelling, particularly, bottom levels, culverts and CS (cross-sections) of the urban watercourses should be defined sufficiently exact by a practical method. This paper presents a concept for a time (cost) effective geodetic survey to determine missing structural data. The concept combines real-time kinematic GPS with optical based surveying technology. It is capable to produce all necessary structural data for the 1D hydraulic model with reasonable effort.

KEYWORDS

Cross-section, GPS, MIKE11, modelling, stormwater

1 INTRODUCTION

A flat relief characterizes the North German Plain. In consequence of an anthropogenic influence over centuries, there are a lot of diverse, highly cross-linked water forms and uses. Caused by their small size, the hydraulic situation is very complex. The main target is the development of essential tools that provide an impression of the current state, forecasts and an assessment of structural measures. In the running research project, the following working packages are defined:

- The development of a coupled urban macro model (large-scale approach) which includes the catchment area, public sewer network and the system of watercourses to simulate the hydrological, hydraulic and material system behaviour
- Detailed measurement campaign at a characteristic subsystem for model calibration and clustered parametrisation of a reference model (small-scale approach)
- Transfer results and knowledge of the reference model into the macro model

The reference and the macro model will be constructed by coupling of sewer network model (MIKE URBAN by DHI) and a 1D streamflow model (MIKE 11 by DHI). Especially for realistic modelling of the natural watercourses, a precise knowledge of their morphology is mandatory.

2 METHODS

2.1 Key significance of cross-section in the model calculation

For a better understanding of the interaction between rainwater drainage and second order water bodies the one-dimensional model (MIKE 11 by DHI) was chosen to simulate flow, water level, water quality and sediment transport. It provides a fully dynamic solution based on the nonlinear 1-D Saint Venant equations.

Saint Venant Eq. according to the notation in MIKE 11 (1)

$$\frac{\partial Q}{\partial t} + \frac{\partial(\propto\frac{Q^2}{\boldsymbol{A}})}{\partial x} + g\boldsymbol{A}\frac{\partial \boldsymbol{h}}{\partial x} + \frac{gQ|Q|}{C^2A\boldsymbol{R}} = 0 \qquad (1)$$

where *Q* is the discharge (in m³/s), ***A*** is the flow area (in m²), *q* is the lateral inflow (in m³/s), ***h*** is the stage above sea level (in m), *C* is the Chezy resistance coefficient, ***R*** is the hydraulic radius (in m) *and* *α* is the momentum distribution coefficient.

The parameters A, R and h are essential key variables in the Saint Venant equation and are the outcome themselves of the definition of the specific cross-section. In contrast to other modelling tools (e.g. HEC-HMS), the editing of the cross sections also defines the bottom slope. This underlines the strong influence of the cross-sections according to streamflow and water level calculation. The shape of the cross-section has also effect on ecological structure and functioning. According to the equation (2) the bed shear stress is a function of hydraulic radius.The quantity of the water surface or riverbed are input parameters for the simulation of the dissolved oxygen or the adsorption of dissolved phosphorus to particles of river sediment.

Bed shear stress Eq. according to the notation in MIKE 11 (2)

$$\tau = \rho g\boldsymbol{R}\frac{V^2}{M^2\boldsymbol{R}^{4/3}} \qquad (2)$$

2.2 Cross-section determination for the reference model

The 1-D modelling program MIKE 11 (by DHI) needs geo-referenced cross-sections as input parameters. They are necessary to generate the longitudinal profile and the wetted area of the stream. The determination of the cross-sections is in the field of geodetic surveying. The objective is to use workable measurement procedures, which provides sufficiently precise coordinates.

Table 1: Comparison between surveying technology for small water streams

Method	Altitude Error	Advantage	Disadvantage	Geo-referenced
Total station	± 0,01m	From one position several cross-sections could be	Needs a long training period and relative high	NO

		determined	acquisition costs	
Manual measurement with levelling staff	± 0,05m	In contrast to the other methods, this method is inexpensive and is able to react fast	Time consuming and also error-prone	NO
RTK-GPS	± 0,015m	RTK-GPS makes flexible, fast and reliable surveying possible	Signal disturbance by foliage of bank vegetation	YES
Spirit levelling in combination with distance measurement	± 0,001m	Very precise measuring method	Have to change the position to determine several cross sections	NO

Generally, the RTK-GPS is the best choice for surveying of small streams. However, often one bank side is nearly complete forested. Under these conditions, no high reception quality is available for the RTK-GPS. In these cases, an intelligent combination of RTK-GPS and traditional observation (total station) results a good compromise between spatial resolution and time efficiency.

There are no official benchmarks in the range of the total station to reference the elevation and position of measured cross sections. Therefore, we have to set temporary, not official reference marks at each measuring place of the watercourse. These reference marks are designed to be set in concrete structures or on similar position stable constructions and geo-referenced by measurement with the RTK-GPS. The reference marks have to be position-stable along the period of investigation (3 years).

2.3 Cross-section determination for the macro model

The research area extends across the rural and urban regions of the city of Rostock and comprises water streams with a total length of more than 100 km. For the whole system, a terrestrial surveying is only feasible in a long term approach. Therefore, it is necessary to investigate a method, which blends existing data with information from remote measurement technique. The profile was elevated and provided by the water information system of the Agency for the Environment, Nature Conservation and Geology of Mecklenburg-Vorpommern. This trapezoidal rule profiles are not georeferenced. The missing position information was edited by using digital terrain model with a vertical resolution of two meters and orthophotos.

2.4 Comparison of the discharge capacity at a case study

For a case study, the hydraulic deviations between an exactly measured cross profile and a nearly similar, simplified profile, which was achieved by the GIS-based method, are compared. The channel's discharge capacity was calculated by using the Manning-Strickler approach, with a value of Manning's n (ressitstence number) of 0,03 and bottom slope of 0,001. In addition, several simulitions with the hydrodynomic modul of MIKE 11 (by DHI) verifys the result shown in Figure 2.

RESULTS AND DISCUSSION

The Figure 1 shows the detailed surveyed cross-section of the reference model in comparison to the generated cross-section from the macro model. In addition, in order to aid comparison, width and height of the cross-section were set to the similar value.

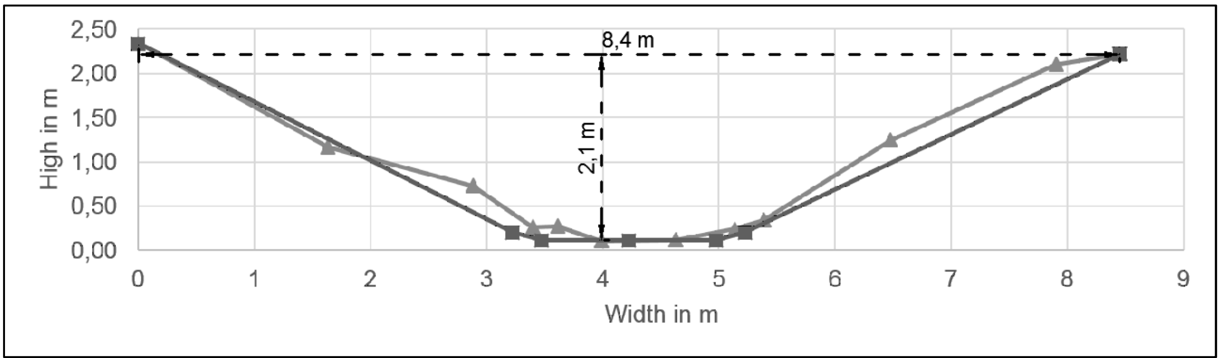

Figure 1. Generated and surveyed profile. Squares: generated CS; Triangles: surveyed CS

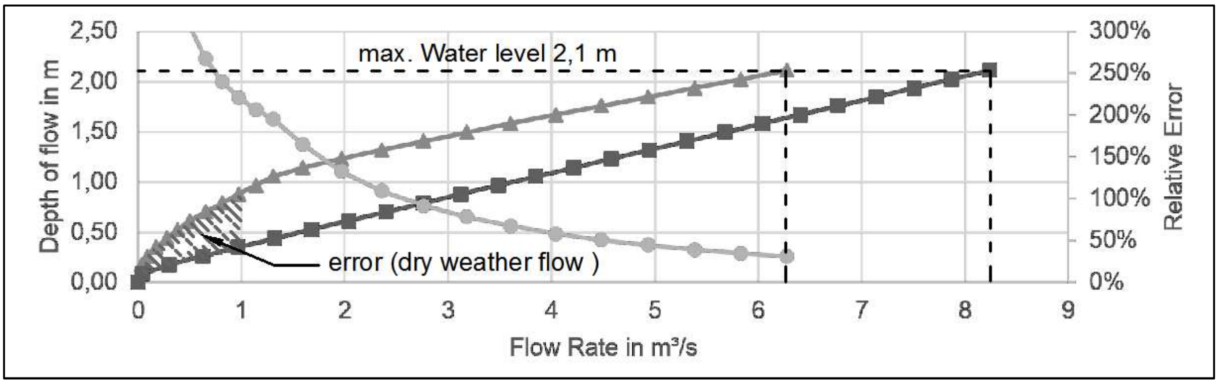

Figure 2. Comparison of discharge capacity of the generated and surveyed CS. Circle: relative error; Squares: generated CS; Triangles: surveyed CS

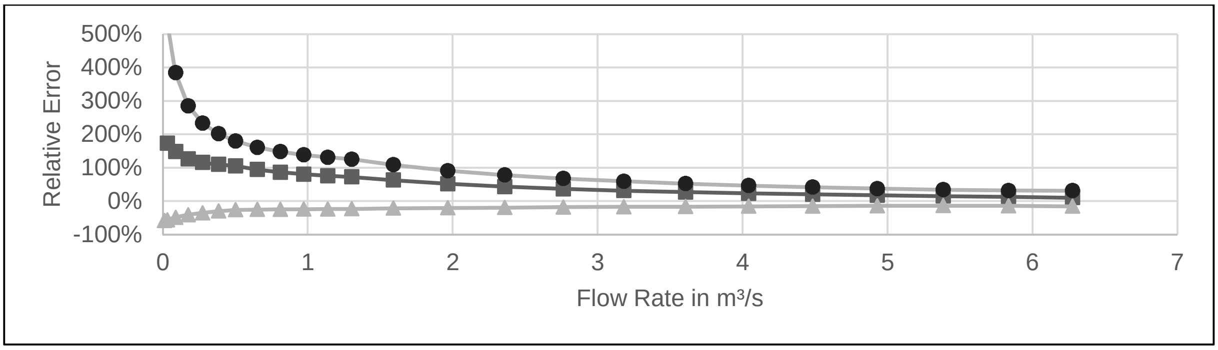

Figure 3. Comparison of potential sources of errors. Circle: hydraulic radius; Squares: wetted area; Triangles: wetted perimeter

The following issues can be highlighted:

- The hydraulic radius is the quotient of the wetted cross-sectional area and the wetted perimeter. The wetted area of the generated cross-section is overestimated while the wetted perimeter is underestimated. Simplified estimation of cross-sections lend to inexact hydraulic radii and in consiquence to rather strong deviations for discharge, flow depth and derived modelling results.
- It turned out that the maximum discharge capacity of the generated cross-section (macro model) according to the surveyed cross-section (reference model) is overestimated (30%). This has an considerable effect on the flood simulation. At full charge conditions (max water level is 2.11 m) the real discharge capacity is much lower (6,27 m³/s) instead of expected one (8,24 m³/s).
- Even more serious are the relatively large flow rate errors of 200-800% at dry weather flow conditions. There would be a danger of wrong calibration of rainfall runoff models where only water level informations are availible. In this cases a continues flow stream measurement system is essential.

CONCLUSION

At first glance it surprise, that very similar looking cross sections, have large differences in discharge capacity – especially at dry weather conditions. Therefore, high-resolution models are very sensitive to the accuracy of cross sections. This effect is particularly distinctive, when relatively small rivers are model- linked to large catchment areas. In further studies, we want to investigate the hydraulic performance of structured and renatured watercourses second order.

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