6. STATE OF THE ART FOR HYDRODYNAMIC MODELLING

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6.1 Definition of the hydrodynamics domain

The domain of hydrodynamics is in fact underlining most of the simulation modelling activities. The hydrodynamic behaviour is one of the essential properties of the water. All the special cases like uniform flow, steady state flow or zero flow represent just the special states of the general hydrodynamic equations. The use of hydrodynamic simulation establishes the base for the simulation of advection dispersion phenomena, water quality processes and the sediment transport with potential morphological changes.

The simulation of hydrodynamics is used everywhere, where spatially and temporally changing flow of the water takes place. The hydrodynamic behaviour is then seen in water supply systems, sewer drainage systems, river systems (including lakes and reservoirs), estuaries and coastal waters. In this contribution, special attention will be put on hydrodynamics in water distribution systems, urban drainage systems, in open channel systems and in sediment transport.

6.1.1 Free surface hydrodynamics

Open channel hydrodynamics can be represented according to the objectives by 1, 2, 3D schematisation of the phenomena. It basically covers the description of transient flow, backwater effects, macro turbulence, flooding, flow over structures, looped systems, modeling in rivers, lakes and reservoirs, estuaries etc..

Hydrodynamic modelling in open channels then accommodates a wide range of different phenomena for which a variety of different codes, mathematical schematisation, procedure of model set-up and calibration, data requirements, detail of phenomena description, type of results and their presentation is used. From a modelling point of view it is possible to divide this range with respect to hydrological conditions, which should be modelled. In this case we can define mathematical models for low flow, normal flow and high flow conditions. This basic categorization should be further divided based on modelled process and required results like just hydrodynamics variables (water levels, discharges) or sediment transport. This second categorisation can also be divided for more detailed description, which in principle follows different requests for modelling results and modelling techniques. Different kind of wanted results also has different data requirements and has to be adopted according to the original modelling purposes.

6.1.2 Water supply and water distribution modelling

Water supply and water distribution hydrodynamics can be represented according to the objectives, again by 1, 2 or 3D schematisation of the phenomena. It basically covers the description of water hammer effects, pressure distribution, slow transient flow, looped systems and age of water.
Hydrodynamic modelling in water distribution and water supply systems is mainly focussing on the quasi steady state phenomena. However, in some cases the full hydrodynamics, including water hammer effects, is needed. The range of modelling varies from skeletal conceptual models to detailed models according to the project objectives. The calibration is either manual of automatic based on predefined procedures. The results from the modelling are also used for subsequent sediment transport or even for water quality simulation.

Typical problems for which QA are needed include:
- Reproduction of the same results on very complex system – numerical stabilisation
- Leakage detection – variation of pressures – wrong Q distribution
- Water quality calibration

6.1.3 Urban drainage modelling

Urban drainage hydrodynamics can be represented according to the objectives by 1 or 3D schematisation of the phenomena. It basically covers the description of transient flow, backwater effects, water storage, flow over structures, infiltration, looped systems.

Hydrodynamic modelling of urban drainage mainly focuses on modelling of sewer systems. However, due to the nature of the drainage on the urbanisation areas the simulation in open channels and on wastewater treatment plant is also carried out and sometimes integrated. The simulation covers dry weather conditions, inflow infiltration, hydraulic capacity surcharge, impact of combined sewer overflow on receiving water, residual contamination from waste water treatment plant, analysis of the sediment transport, chemical and biochemical processes in a sewer, etc. From a modelling viewpoint the urban drainage can be schematised according to the selected modelling concept and project objectives into a lumped conceptual model, a strategic planning model or a detailed design model. All these models differ in objectives, in a level of schematisation, expected results and of course data and time requirements.

Typical problems for which QA are needed include:
- Leakage and infiltration, changes of mass balance
- Reproducibility of dynamic results (losses pressurised flow, CSO behaviour)
- WQ reproducibility of results

6.1.4 Sediment transport

The sediment transport modelling is based on hydrodynamics modelling adding the modelling of the sediment properties, the transport in suspension and as bed load and the consequences on mobile bed formed by the alluvia, the sediments resting in beds and banks.

The modelling may be from 1D to 3D and aims at the study of the morphological evolution of streams (pipe systems, lakes, estuaries and coastal areas) with highly variable flow regime, irregular cross section and graded bed material. The modelling shall provide the means to analyze transient and long term river (and other water bodies) phenomena and shall be designed so that it can be used either with rigid boundary channels or with mobile boundary channels.

6.2 Needs for QA guidelines

The need for QA is clearly seen also in the domain of hydrodynamics. There is in addition one more fact to support the importance of QA for hydrodynamics. The simulation of hydrodynamics phenomena is often used for subsequent water quality or
sediment transport simulation. Recognising the effect of error accumulation it is crucial that the hydrodynamics part of the simulation model be as correct as possible.

The QA guidelines for hydrodynamic modelling are more or less known for professional modellers, but not widely published or standardised. In practice, it would be quite useful to have a general guideline describing in detail all possible purposes of hydrodynamic modelling tasks and outputs and their requirements for necessary input data, mathematical schematisation and proper model type selection, parameters for result processing and presentation, possible calibration techniques and so on. From practical experience it is however known that the modeller very often just use data that are available and that are quite often not sufficient for proper model calibration and verification. In such cases, guidelines should also define necessary minimum data requirements and may comprise description of the effects on the credibility of the modelling results of having poor data.

With respect to the sediment transport modelling it is important to note that the uncertainties arising from the use of sediment transport predictors and friction factor relationships are considered to be more important than the inaccuracies introduced by the numerical scheme (Belo, 1994). The most complex issue of sediment transport modelling for coarse sediment like sand is related to low flow simulations, where sediment grading and armouring occur. For fine grain size such as clay particles the description is complicated by cohesive forces that may depend on the interaction between physical, chemical and biological factors.

6.3 Discussion in scientific literature

A comprehensive search in the literature and on the Internet resulted in almost no references on the issue of QA in simulation modelling. Some sources of information were found only at WaPug web site in addition to those mentioned by HarmoniQuA site. However, it is expected, that internal QA standards have been developed by local consultants. This finding possibly indicates that this issue is not in fact appreciated to be fully openly discussed and followed in the simulation modelling community.

The International Association of Hydraulic Research (IAHR) has developed a description for the validation of the modelling software, IAHR (1994), including hydrodynamics as a domain. Ten hydraulics laboratories were involved, namely CEDEX, DHI, DELFT, HR Wallingford, LHF, LNH, LNEC, NHL, SOGREAH and VITUKI.

6.3.1 Key issues

Key topics to be included into the discussion on this issue are:

- Methods of calculation (FEM, FDM)
- Prediction within validation limits
- Role of model constants
- Governing equations
- Model instabilities
- Freedom in model building

From the modelling point of view, it can be said that the quality model validation is based on at least the following assumptions:

- Level of quality of the description of structural state of the system
- Level of quality of the description of initial and boundary conditions
- Level of quality of the description of system parameters (coefficients, constants)
However, there is still uncertainty in the process that is covered neither in the governing equations and in the boundary conditions nor in the method of calculation (FEM, FDM,...) causing troubles in predictions.

6.4 Existing guidelines

The Dutch GMP Handbook and the WaPug Code of Practice (see for details chapters 12 and 17) are important sources of information bringing in light the issue of QA for the hydrodynamic domain. GMP is more general in principle and does not provide too much detailed guidance for the hydrodynamic domain, but reference is made as to generic QA guidelines.

In the next paragraphs, the general guidelines from WAPUG „Code of practice for the hydraulic modelling of sewer systems“. The document is structured into a number of sections describing in a chronological manner the overall procedure related to model building and validation. The essential distinction is at the very beginning made among different types of models serving different project purposes. Then, several subsequent chapters are describing the particular way of model schematisation (including issues like additional storage, ancillaries modelling), flow survey evaluation, data gathering, etc. Special care is devoted to the validation of a simulation model including comprehensive performance criteria. According to this documentation, several levels of model validation are supposed to be passed as described in the following sections.

6.4.1 Historical flooding tests

The historical data verification has to be carried out, if the historical flooding reports are available for the modelled site. The historical data verification needs to be based on the existing information on recent historical flooding in the respective catchments. The model needs to be checked on reproducing similar surcharge consequences as was found in the operation failure files. The model has to be evaluated as verified on historical flooding once it reproduces the flooding at the same locations as in the reality without considering the duration of flood or water level height.

6.4.2 Model stability test

Three synthetic rainfall events need to be used for the routine stability test. For that case 1 in 50 years, 1 in 5 years and low intensity and long duration multi peak rain with the duration of 60 minutes can be used. The execution of the three model runs will be done using defined synthetic rainfall data. The overall mass balance will be checked at the outlet of the system together with graphs showing time series of outlet discharges and water levels. The mass balance has to vary within +10%. The mass balance at all ancillaries will be evaluated in the same way.

The overall stability of the model will be evaluated on a set of produced hydrographs and water level graphs. These graphs will be produced as follows:

- The graph has to be produced upstream of each ancillary.
- The set of graphs has to be produced for all main trunk sewers bigger than 1.5 meter in height.
- The graphs will be produced at every 10th manhole in a referred sewer. The graphs will be checked for instabilities or oscillations.

6.4.3 Flow survey verification tests

Routine model tests

The overall mass balance needs to be checked at the outlet of the system together with graphs showing time series of outlet discharges and water levels. The mass balance...
has to vary within +10%. The mass balance at all ancillaries has to be evaluated in the same manner as described above. The mass balance has to vary within ±10%.

**DWF verification tests**

Two dry weather days have to be selected from the flow survey records. The predicted and measured data will then be verified to meet the following criteria:

- The peak flow rate will vary by not more than ±10%
- Total volume of flow during the selected period will vary by not more than ±10%

**Storm verification tests**

The storm verification test has to be performed on three selected storm events defined during the evaluation of the flow survey. For each storm event the following criteria have to be met by comparing the predicted and measured data:

- The peak flow rate will vary by not more than ±25% - ±15%
- Total volume of flow will vary by not more than ±20% - ±10%
- The surcharge will vary by not more than ±0,5m - ±0,1m
- The general shape of the two hydrographs will be similar
- If there is a local flooding reported for the storm, the performance of the model has to fulfil the criteria for flooding tests

The experience shows that it is rarely if ever possible to fully comply with all verification criteria at every monitoring site. This may be for example because the flow survey data have intermittent errors caused by ragging or because rainfall variations have occurred which the installed gauges have not picked up so, that the spatial rainfall distribution over the large size catchments can not be fully taken into account.

The presented example shows the complexity of the problem of QA. Here just some QA procedures are defined for the validation of simulation model in urban drainage area. And even then, it is not an easy task to comply with all the performance criteria once the restricted project budget or natural conditions require finalisation of a monitoring campaign before good quality data are obtained.

**6.4.4 Discussion of existing guidelines**

Examples of performance criteria for sewer system validation were shown above. As an additional complication all these approaches related to the best fit between two curves depend on the selection of standard to be applied. Consequently, use of different standards may often result in large differences between results.

In IAHR (1994) the validation of computational modelling software was based on five main subjects, namely the physical system description, the model functionality (applications and processes), the conceptual model (assumptions and approximations, claims and substantiations), the algorithmic implementation (assumptions and approximations, claims and substantiations) and the software implementation (implementations techniques, claims and substantiations).

**6.5 Conclusions and recommendations with respect to the further HarmoniQuA work**

QA guidelines can be used to meet specific QA requirements in terms of clarification of the modelling process, recommendation for distinct modelling activities, templates or checklist suggestions, etc. However, it must be emphasised that there will still be some part of the modelling work that is based on modellers’ experience, intuition and creativity. These competences can be never replaced by any guideline, so many details
of the modelling work can not be covered by QA guidelines. The QA guidelines should serve at least the following general purposes:

- Standardisation of modelling procedures and data processing
- Definition of minimum data requirements for different type of modelling purposes
- Definition of minimal requirements and functionality of mathematical models for different modelling purposes (schematisation, used equations, ancillaries calculation, result presentation, modularity.)
- Procedure or methodology for model calibration and validation
- Estimation of result precision based on the above parameters

6.6 Acknowledgement

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6.7 References