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Reliability Enhancement of Predictive Computational Models in Hydroscience and Engineering

RELIABILITY ENHANCEMENT OF PREDICTIVE COMPUTATIONAL MODELS IN HYDROSCIENCE AND ENGINEERING

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More and more predictive computational models have been developed in support of engineering and management decisions for project design, planning and management in the field of hydroscience and engineering. It is of special importance for large scope and high cost projects with a long-lasting impact on the economy and the well-being of our society. Some of these projects require multi-disciplinary consideration, integration of models of different spatial and temporal scales, time- and cost-effectiveness, and satisfaction of multiple constraints. It has been experienced that it is ineffective to achieve such kind of decisions for these projects by traditional methods, such as analytic, physical modeling, and field studies, without the use of computational modeling. Therefore, computational modeling has been utilized to predict the outcomes of well-thought out alternative engineering designs and management plans from both short- and long-term points of view. The predicted outcomes are specifically useful in selecting the optimal decision(s). For these needs, the reliability of predictive computational models is of great importance.

Computational models for solving the real-world problems today are highly complex and sophisticated. There are numerous sources that could lead to serious concerns as to whether they are sufficiently reliable to predict the outcome of today's hydrosystems realistically under various conditions and in a complicated environment of the real world. This reliability issue has been studied by technical and/or task committees of several professional societies. Several validation, calibration, verification, and confirmation methodologies have been developed. This paper is to present some recent thoughts of the authors, who had been involved in the studies of ASCE-EWRI's Task Committee on Three-Dimensional Free Surface Flow Model Verification and Validation for more than 10 years. Task Committee proposed a three-step approach, which has been reported in a monograph entitled "Verification and Validation of 3-D Free Surface Flow Model" (Wang et. al, 2008) published by ASCE.

The proposed three steps are briefly outlined below. The purpose of the first step, Mathematical Verification is to insure that a computational model is free of unintentional errors or mistakes in the mathematical model's formulation, simplification, conversion into its corresponding numerical model; in the numerical solution techniques, domain descretization; in the computer program coding; and the order of convergence of the model results. This step is carried out by applying the model to simulate a flow-system with known analytical or manufactured solutions. If the model results are significantly different from those of known solutions, it must be due to the errors or mistakes in mathematics, numerical schemes, program coding, etc. of the model. Corrections are needed, before continuing the subsequent steps. On the other hand, if the agreements in both values and trends are established reasonably, and the test of

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convergence by refining the numerical grid is successful, the model is ready for the test of the next step.

The purpose of the second step-Physical Validation is to ascertain that the computational model's capability of representing the basic processes of a physical phenomenon, which it intends to simulate. Examples are boundary separations, vortex formation and shedding, wave propagation, mixing, etc. This step can be achieved by using the model to simulate the selected laboratory experiments and compare the results quantitatively to the sufficient amount of high quality data measured in the laboratory with less influence of un-controlled conditions. After passing the second step, the model is proven to be able to reproduce the key physical processes basic to the complex flow phenomenon, which it is developed for. One should have better confidence to apply this tool to the studies of the flow in the real world hydrosystems.

The third step is the Application Site Validation for assessing whether a computational model is capable to realistically predict the outcomes of flow system at a specific application site under the actual conditions. During this step, the model to be tested must first go through a site-specific calibration to insure that the key characteristics of the site have been included in the adjustable model parameters (or empirical coefficients). One is reminded that the calibration must be re-conducted when the model is to be applied to the same problem but at a different site. It is also very important that the data collected at the application site for calibration purpose has to be sufficient and of the highest quality possible.

The next question, which both the model developer and the prospective users would ask are obviously whether predicted reactions of a hydrosystem in the real world to external forcings are reliable, especially when some secondary forcings and/or complex characteristics may not be sufficiently considered in the mathematical equations of the model. To answer this question to the best of our ability, which is sometimes limited by the state of the knowledge in physics, mathematics, and numerical solution capabilities, one must apply additional empirical laws and functions collected in the vast scientific data in the field. Therefore, one needs to have sufficient amount of high quality field data to calibrate the empirical parameters imbedded in the empirical functions. This calibration process of the model is extremely important, because it is the only way to include the site specific characteristics into the model, so that the model prediction can be realistic. After the calibration, the model is ready to be validated for site specific applications, which can be carried out by comparing the model prediction with at least one set of field data taken at the application site, which must not have been used during the calibration. A reasonable level of agreement between the predicted results and measured field data and trend of variations spatially and temporally are considered as the validation of the model for field applications at this particular site. For different sites and at a substantial lapse of time even at the same site, a re-validation is highly recommended.

In view of the authors and their many colleagues, the model verification and validation procedure as proposed is far from being prefect. It is hoped that interested model developers and users would join the succeeding task committees of ASCE-EWRI to continue the advancement of the state of the art in the methodology for computational model verification and validation to enhance our confidence in reliability of predictive models in the future.

REFERENCES

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