Uncertainty in complex three-dimensional sediment transport models: implications for management

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Introduction: Numerical simulation models for sediment transport are typically setup and applied to evaluate multi-scale or complex physical processes over interacting time scales. These models are calibrated by adjusting a number of independent parameters to obtain a match between field data and the simulated variables such as suspended sediment concentration (Oreskes et al. 1994). The results of such environmental modeling studies often provide the scientific basis for remediation decisions. In order more accurately translate model outcomes into management decisions, there is a need to better quantify model uncertainty. It is crucial that decision makers are aware of the limitations and uncertainties present in the reported results. This is especially the case for model scenarios investigating future conditions, which may be outside the model calibration time and space. Model uncertainty is a very broad term and is often used without referring to the nature or source of the uncertainty that is being dealt with. This presentation aims at examining the prognostic accuracy of a sediment transport model, by acknowledging the uncertainty in parameter space through equifinality and by testing the effect of equifinal parameter sets in scenarios for which the model was not calibrated.

Methods: The approach taken is based on the GLUE (Generalised Likelihood Uncertainty Estimation) methodology by Beven and Binley (1992), which is often applied in hydrological studies. The rationale for this method is that there are several combinations of parameter values (once the model has been calibrated) that can capture observations equally well, therefore being equifinal. Those not in favor of process based modeling approaches believe that equifinality reduces the applicability of models (e.g. Oreskes et al. 1994) and that these equifinal settings may hypothetically respond very differently outside the calibration space. This may occur when numerical models are used to predict the response of a river or estuary to e.g. deepening or different dredging strategies. Such measures may have such a large consequence that the equifinal parameter settings are no longer relevant. As three-dimensional sediment transport models are so computationally intensive, stochastic simulations are often not feasible and therefore the amount of simulations that can be carried out with these models is limited. Instead of a Monte Carlo simulation of parameter distributions, we generate multiple calibration sets through an iterative procedure which may be time-consuming but requires fewer simulations, and which ensures at the same time that the parameters are kept within a realistic range. This procedure consists of (1) a sensitivity analysis, (2) definition of multiple calibration sets based on the sensitivity analysis, and (3) fine-tuning of the multiple calibration sets.

Results: Results of analysis of equifinality in a modeling study of the Ems estuary, a heavily impacted estuary located on the Dutch-German border are presented. A 3D numerical model was developed (van Maren et al., 2015a) to explore measures to reduce the suspended sediment concentration (SSC) and thereby to improve the ecological status of the estuary. Different combinations of model input parameters leading to the same result (equifinality) may weaken the predictive capacity of the model. This is supported by the sensitivity of SSC over the tidal flats, for the different model settings. However, the predictive capacity of the model to simulate the effect of human interventions on the estuarine sediment dynamics was shown to not be significantly influenced by equifinality. Two future scenarios were tested with the model (offshore disposal of dredged sediment and restoration of the tidal channel depth) and were only marginally influenced by the model calibration settings. This strengthens the confidence in the numerical model predictions for this case: the modeled response to interventions seems only limitedly affected by numerical model settings.

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