Geophysical Research Abstracts
Vol. 17, EGU2015-439, 2015
EGU General Assembly 2015

A model evaluation checklist for process-based environmental models

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Mechanistic catchment-scale phosphorus models appear to perform poorly where diffuse sources dominate. The reasons for this were investigated for one commonly-applied model, the INtegrated model of CAtchment Phosphorus (INCA-P). Model output was compared to 18 months of daily water quality monitoring data in a small agricultural catchment in Scotland, and model structure, key model processes and internal model responses were examined. Although the model broadly reproduced dissolved phosphorus dynamics, it struggled with particulates. The reasons for poor performance were explored, together with ways in which improvements could be made. The process of critiquing and assessing model performance was then generalised to provide a broadly-applicable model evaluation checklist, incorporating:

(1) Calibration challenges, relating to difficulties in thoroughly searching a high-dimensional parameter space and in selecting appropriate means of evaluating model performance. In this study, for example, model simplification was identified as a necessary improvement to reduce the number of parameters requiring calibration, whilst the traditionally-used Nash Sutcliffe model performance statistic was not able to discriminate between realistic and unrealistic model simulations, and alternative statistics were needed.
(2) Data limitations, relating to a lack of (or uncertainty in) input data, data to constrain model parameters, data for model calibration and testing, and data to test internal model processes. In this study, model reliability could be improved by addressing all four kinds of data limitation. For example, there was insufficient surface water monitoring data for model testing against an independent dataset to that used in calibration, whilst additional monitoring of groundwater and effluent phosphorus inputs would help distinguish between alternative plausible model parameterisations.
(3) Model structural inadequacies, whereby model structure may inadequately represent the conceptual model on which it is based. In this study, a number of model structural shortcomings were identified, such as a lack of dissolved phosphorus transport via infiltration excess overland flow, potential discrepancies in the particulate phosphorus simulation and a lack of spatial granularity.
(4) Conceptual challenges, as conceptual models on which predictive models are built are often outdated, having not kept up with new insights from monitoring and experiments. For example, soil solution dissolved phosphorus concentration in INCA-P is determined by the Freundlich adsorption isotherm, which could potentially be replaced using more recently-developed adsorption models that take additional soil properties into account.

This checklist could be used to assist in identifying why model performance may be poor or unreliable. By providing a model evaluation framework, it could help prioritise which areas should be targeted to improve model performance or model credibility, whether that be through using alternative calibration techniques and statistics, improved data collection, improving or simplifying the model structure or updating the model to better represent current understanding of catchment processes.