Modeling field-scale phosphorus transfer: model strengths and weaknesses, gaps in knowledge, and the role for scientists

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Arguably, the ultimate goal of applied research of phosphorus (P) transfer from agricultural fields to surface waters should be to develop and apply mathematical models. There are two primary reasons for this assertion: (1) models formalize our understanding of P transfer and force us to test that understanding and identify knowledge gaps; and (2) models allow us to quantify P transfer for environmental and management conditions when physical monitoring is not possible. An effective way to formalize understanding is through systematic model development from a perceptual model of our qualitative understanding of a system to a conceptual model of the mathematical equations to a procedural model of computer code. Two main approaches to modeling P transfer are empirical export models to calculate annual or seasonal loads or process-based models to simulate physical dynamics. Quantifying P transfer requires both a predictive capability of models and confidence that model algorithms function properly and represent the most current scientific information. Models must be structured in a way that allows for adequate validation with field monitoring data. Without validation, there is little confidence that the model can reasonably quantify P transfer. It is possible that the structure of a model, especially qualitative P transfer risk assessment tools, prevents its validation because its output is generated in a substantially different mathematical way from the how validation data are generated and processed. This may be different from a situation where a model does not validate because it is perceptually or conceptually incorrect or because of data uncertainty or limitations. Thus, it can be a challenge to understand why a model does not validate adequately, and thus to know when a model should be rejected because of poor perceptualization or conceptualization. Many commonly used, process-based P transfer models such as SWAT or ANSWERS often share the same algorithms and equations, many of which are empirically based. Many of these equations may be nearly 30 years old and could certainly be updated to better reflect current science. Furthermore, some models may be applied in situations for which their algorithms are not adequate. For example, a model like EPIC that was developed to estimate the impact of erosion on crop productivity may now be used to estimate P transfer from surface-applied animal manures or the degree of soil P stratification without appropriate changes to model formulation. While it is true that model development and validation is frequently limited by data availability, this may often be due less to our inability to generate adequate data and more to a disconnect between field scientists and model developers, whereby field scientists fail to communicate their perceptual understanding of P transfer and modelers fail to communicate where translation from perceptual to conceptual models is data limited. Ultimately, there may currently be too great an emphasis on, and thus unnecessary, data generation and too little emphasis on model development and application.