Credibility and acceptability of mathematical models of environmental impacts of agriculture in The Netherlands

D. T. VAN DER MOLEN & P. C. M. BOERS
Institute for Inland Water Management and Waste Water Treatment (RIZA), PO Box 17, 8200 AA Lelystad, The Netherlands
e-mail: d.t.vdmolen@rizawrvs.minvenw.nl

Abstract A conceptual framework of credibility and acceptability is applied to a simple and a complex model to examine their usefulness in making decisions. The complex model was found to be not credible, i.e. not technically appropriate for its task, although a great deal of effort was put into its development. The condition of a relatively complete and thus large and complex model makes this finding almost unavoidable. Despite the low credibility, the acceptability of the complex model and its results is sufficient. The acceptability of the model is, however, not a guarantee that its results determine the outcomes of the decision making process. The simple model is credible for the variables included and for the area for which it was built. Its acceptability is limited as it is only applicable to a specific area and because the link with actual ecological effects is weak.

Key words agriculture; model acceptability; model credibility; nutrients; STONE

INTRODUCTION

Numerous papers on models start their introduction by stressing that models are nowadays indispensable tools to guide managers in making decisions. Are models really that important in decision making? We try to explore this subject by applying a framework for credibility and acceptability to models used in The Netherlands for determining agricultural impact with respect to nutrients in ground and surface waters.

Development and application of mathematical models usually follow the procedure of systems analysis. Model set up, parameter estimation, validation and application are well known key words in this procedure. Proper model building is summarized in credibility. On the other hand actors have to approve the model or its outcomes. This issue is referred to as acceptability. An extensive description of this framework based on credibility and acceptability is described by Van der Molen (1999). We applied this framework to two models. The first is a complex deterministic model with some empirical relationships, describing the fate of nutrients in the top layer of agricultural soils. The second model is also a mathematical model, although it is very simple, describing only phosphorus (P), and highly conceptual. Both models have been used to guide decision makers at a national scale in policy making for manure problems.

Below we briefly describe the models and provide an introduction to the framework of credibility and acceptability. The application of this framework to the models, with regard to their usage at a national scale, results in several findings.
DESCRIPTION OF THE TWO MODELS EXAMINED

In The Netherlands several initiatives have been taken to describe the fate of nutrients in agricultural soils at a regional or national scale. For policy making, however, the model ANIMO has been used most frequently (Berghuijs-Van Dijk et al., 1985; Boers, 1996). Recently the model has been adopted by several institutes (Boers et al., 1996), has been combined with other models, renamed (STONE) and has become the “standard” for decision making. STONE may be seen as (part of) a chain of models. Hydrological models describe the transport of water in the deep and shallow groundwater. A soil nutrient model describes the fate of nutrients in the shallow groundwater and results in output of nutrient flows to the different environmental compartments. Previously separated models describing nutrient uptake in crops have been incorporated in the soil model. Several inputs of the models mentioned originate from models as well; for example the atmospheric deposition to the agricultural soil. Other inputs are from national surveys (land use, soil characteristics, animal densities). Finally, the set up of scenarios is a task that is supported by several models; for example: land use in relation to manure application, the choice of meteorological conditions, and the calculation of initial conditions of soil variables. The model system generates nutrient fluxes to groundwater and surface water, but for descriptions of the ecological effects other models must be used. The model operates with time steps of days to decades with a spatial resolution determined mainly by that of the input.

In contrast with the complex model, a conceptual model for P saturation in sandy soils is examined. P saturation was defined as the ratio between total inorganic P and the binding capacity for P, based on the oxalate-extractable iron and aluminium content of soils (Schwertmann, 1964). Soils are considered to be saturated with P when more than 25% of the P adsorption capacity of the soil layer above the mean highest groundwater level is used (Van der Zee et al., 1990; Breeuwsma & Reijerink, 1992). This 25% saturation corresponds to 0.15 mg l⁻¹ total P in the water phase, equal to the Dutch quality standard for surface water. The model uses data on yearly average P surpluses, hydrology and soil chemistry.

CREDIBILITY AND ACCEPTABILITY OF MODELS

We follow Van der Molen (1999) in distinguishing model credibility from accept­ability. After the credibility of the model has been specified, the model may be either accepted or rejected. Credibility is the more technical appropriateness of the model and acceptability is the perception of the manager of its practical value. Systems analysis is mostly performed by modellers, but model results are used by managers. Managers have to judge if model results and the uncertainties are acceptable for use in decision making.

Young (1983) uses model credibility in a rigid way as “a property which depends upon success in all phases of the model-building procedure”. Rykiel (1996) defines credibility as “a sufficient degree of belief in the validity of the model to justify its use for research and decision making” and relates credibility to the amount of knowledge available, the purpose of the model and the consequences of any decision based on it. He considers credibility as a subjective qualitative judgment. We consider a model or a
Credibility and acceptability of mathematical models of environmental impacts of agriculture

Specific application of the model as credible if it went through the procedure of systems analysis and if the uncertainties involved in predictions have been considered. Credibility is thus characterized as sufficient insight in the precision of the different parts of the model and in the range in which the model can be applied quantitatively or qualitatively.

Model credibility and, specifically, validity for the relevant output variables may contribute to the acceptability of a model or its results. However, other considerations involved with acceptability may have a strategic, managerial or psycho-social background. For example, managers may have to offset rejection of model results against making a decision in another way or postponing the decision. Managers may decide that the model results are the best guess, irrespective of uncertainties or lack of significant discrimination between alternative courses of action. Furthermore, model results may be accepted because other actors approve of the results. Examples of managerial aspects affecting acceptability relate to constraints in time and money, e.g. deadlines such as the fixed time schedule of national policy cycles. A psycho-social aspect may be that managers tend to be “result-orientated” and may be more willing to accept model results leading to action compared with model results that do not ask for action. On the other hand, lack of public support may more likely lead to acceptance of model results that imply no action. Decisions of managers may be biased by (un)popular alternatives.

Many of the above-mentioned considerations affecting acceptability can be explained by the motivation to initiate a modelling project (Morgan & Henrion, 1990). The motivation may be substance-focused, i.e. aiming at increasing understanding or obtaining an answer to specifically formulated questions and alternatives. A position-focused motivation implies that only a subset of the results is used to provide arguments for one’s view or to justify an action (to be) taken. Contrary to these motivations, a process-focused motivation implies that results of a study are essentially irrelevant as long as they do not become inauspicious. The real motivation is to persuade others that things are under control, or just because it is prescribed by the law or other agreements. Finally, an analyst-focused motivation refers to professional recognition or simply enjoyment from a study.

A detailed checklist on credibility and acceptability is provided by Van der Molen (1999). Here we will globally apply this framework to the two types of models, distinguishing credibility and acceptability on the one hand and the complex model and the conceptual model on the other.

APPLICATION OF THE FRAMEWORK TO THE MODELS

Credibility of the complex model

During the first years of development of the model, there was extensive interaction with field and laboratory experiments. The model was not specifically developed for large-scale application, but was used for field application. At this stage the credibility was relatively high. When the modelling objective changed to large-scale application and assistance for decision making, no serious systems analysis was carried out. Initially the model focused on nitrogen (N) and organic matter. A description of P was
added later. The domain of application was extended without systematic examination of model structure and parameter values for other soils, crops, etc. Although the modellers worked in close cooperation with specialists, their contribution was limited by fixed choices in the model description. Parameter estimation was done by hand on a small data set. Parameterization was difficult because the model operates within the agricultural system, whereas most of the monitored data are of groundwater or surface water. There has not been an independent validation of model results. Uncertainties in the model outcomes have not been specified, although it was admitted that the outcomes had to be used in a comparative way (difference between several scenarios) rather than absolute, to decrease the effects of absolute errors. Credibility decreased significantly with the changed objectives of the model.

When the model was adopted by other institutes this low credibility was recognized. Several parts of the model (organic matter description, denitrification and crop uptake) were evaluated and adjusted, using the opinion of experts of several institutes. These systems analysis efforts improved the credibility of the model. However, the contribution of experimental data was limited due to the time schedule. Furthermore, with the introduction of consensus as a goal, integration with the scientific community was partly lost. A sensitivity and an uncertainty analysis were carried out (Groenenberg et al., 1995). The sensitivity analysis was carried out for five combinations of soil type, crop, groundwater table and level of manure application; uncertainty was explored for only one of these combinations. Only some of the model parameters were studied; the model structure and inputs were not analysed. The coefficient of variation of N and P losses to groundwater was 400% and 150%, respectively. The coefficient of variation of N and P fluxes to surface water was about 40%. Outcomes were highly dependent on the choice of the combination for the input.

**Credibility of the conceptual model**

This model was originally developed as a stationary model, describing the degree of P saturation of the soil. It is fed by annual P surpluses, as estimated from agricultural statistics. The P adsorption capacity is derived from soil chemical data, namely the oxalate-extractable Fe and Al. The relationships between degree of P saturation and the P concentration in the water phase surrounding soil particles, is based upon extensive laboratory research. Basically, the model produces GIS maps, showing the average P saturation in the soil. Transport routes from soil to surface water are not included and the model does not provide P losses to surface water. The domain of the model is limited and based upon well-published scientific work, resulting in a high credibility of the model.

**Acceptability of the complex model**

The motivation to develop the first version of the complex model was mainly substance-focused. Elements of an analyst-focused motivation were also present in its first few years. With the objective changing towards decision making, the motivation remained mainly substance-focused, although it may be argued that the motivation was
also partly position-focused. The model instrument was used to add arguments to stress the environmental problems related to the intensive agricultural practice. Finally, the process-focused orientation was also present. Policy documents appear every two to four years and in these documents statements about agricultural impact on the environment had to be made.

Acceptability of a model is extremely important when used in decision making. A decisive argument for choosing ANIMO as an instrument in decision making in the eighties was that developers and managers of the model belonged to an institute with experts in the field of agriculture. This was in spite of a lack of systems analysis expertise to conduct a proper model building and testing procedure. Developers and financiers did not pay much attention to this topic. In The Netherlands, the Institute for Inland Water Management and Waste Water Treatment, and the National Institute of Public Health and Environmental Protection, used different models to estimate agricultural impact on the environment at the beginning of the nineties. The first institute focused on surface waters, the second on groundwater. However, this situation was not favourable for the acceptability, even when outcomes were similar. Therefore, the joint further development and application of the model (STONE) was also initiated by acceptability. The development from ANIMO to STONE and the relationship with credibility and acceptability is illustrated in Fig. 1.

Acceptability of the conceptual model

In spite of the high degree of credibility of the model, the acceptability of the conceptual model appears to be limited. There are three major reasons for this. The
first is that the model was developed to operate for the sandy soils in the centre and the
south of The Netherlands only, so that it was not possible to draw any conclusions for
the other parts of the country. This was not accepted by most stakeholders. A second
reason was that the model does not describe the effects in, or the P loading to, the
surface waters. This appeared to be a major drawback when, according to calculations
with the model, most of the sandy soils were P saturated. It appeared to be impossible
to prioritize these areas based upon the effects in surface waters. Moreover, in later
studies the relationship between P saturation and actual P leaching to the surface
waters appeared to be weak. Finally, coupling with water quality models was not
possible due to the stationary character of the model.

DISCUSSION

Decision support systems generally consist of a chain of models. The determining role
of the weakest link in a chain is well known. Frequently, existing models are combined
but this is not a guarantee for balance in the complexity of the newly developed chain.
The first links in the chain are formed by the hydrological input, other inputs to the
model (manure application, crop, etc.) and initial conditions. Potentially, this
information contributes significantly to the overall uncertainty in the model results. For
example, P leaching is mainly determined by the hydrology and P content of the soil.
This P content is determined by previous manure application rates incorporated in the
initial conditions rather than the present manure application. These uncertainties
probably overrule uncertainties in the model structure and parameters, and may limit
the need for complexity of the soil nutrient model and following models. A
prerequisite for a chain of models is that the outcomes of the individual models can be
examined. In this way errors and bias may be traced and the effect on the overall
uncertainty may be estimated. The complex soil nutrient model results in diffuse
nutrient loads to surface- and groundwater on a field scale. However, these entities are
not measurable. A relatively “hard” observation is the nutrient load to small surface
waters from a drainage basin. An a priori inclusion of processes in these small water
bodies or, more generally, insights to the environmental effects in the systems analysis,
would probably have resulted in different choices with respect to the model structure
of the soil model.

Irrespective of the completeness of the systems analysis approach, “full credibility”
is not achievable for large models (Beck, 1981; Young, 1983; Van der Molen & Pinter,
1993; Oreskes et al., 1994) as:
- several combinations of parameter values will give similar results during parameter
  optimization,
- there are several subjective choices in optimizing model parameters,
- validity and uncertainty are highly dependent on the situations analysed,
- it is not possible to specify all sources of error.

The conceptual model describing P saturation in soils is a good example of the
right model for the specific question. The model should fit the problem, it should be
tailor-made. In general, during model development some generalization is aimed at,
which increases the complexity. Next, problems are frequently transferred to model
objectives with an existing instrument as a constraint. On the other hand, the turnover
time of questions tends to be faster than the development time of large models (Van der Molen, 1999). When the complex model became ready for use, nutrient leaching was not so much in the picture, but nutrient "losses" and "surpluses" (Boers, 1996; Van der Molen et al., 1998). Adaptation of the model to meet the new paradigms may in the end result in a cumbersome model. Not only the problems, but also solutions to a problem, may not fit into the model. For example, buffer strips or localized application of iron in the field (Boers, 1996) act on a scale smaller than fields, which is too small for the models examined here. More generally, models acting on a (near-)national scale will not be helpful to find tailor-made alternatives for specific regions, but in contrast will easily tend to generic, large-scale solutions. Furthermore, solutions extracted from model results only may induce other unwanted situations. For example, manure-injection into soil has adverse effects on biota living on the field. And in general, reductions of nutrient emissions may conflict with animal (and human) welfare (Van der Molen et al., 1998).

This may be seen as a plea for unpretentiousness and flexibility. One has to be very cautious using models that are unidentifiable and inflicted with large but unknown uncertainties. Furthermore, one has to be on the alert so as not to be dazzled by the scope of the model. With flexibility the model may adapt to meet situations not taken into account when the model was originally built. For complex models this kind of flexibility is, however, very difficult to achieve. With respect to this, the so-called export models (e.g. Heathwaite, 1995) may be an alternative, although their applicability in highly non-stationary conditions should be examined.

EPILOGUE

The complex model is accepted, although this is hardly justified by its credibility. The conceptual model is credible, but only applicable in a specific area and therefore not acceptable for application at a national scale.

Acceptability of a model is not a guarantee that the results are taken over unabridged in policy making. In policy making several more aspects are taken into account, of which economics and recently also international policy, such as the EC Nitrate Policy, are prominent. Adjusting agricultural practice to meet settled standards implies drastic changes in this industry and in the rural appearance of the country in general. The role of models has been that the issue is on the political agenda constantly. Maybe not even the model (results) itself but more the fact that so much people were involved with this matter, may have contributed to this. Therefore, instead of looking for further improvements to models, energy should be directed to watching over this commitment. This may be achieved by a dialogue about the results with scientists and stakeholders and an open mind to alternative approaches.

REFERENCES


