Issues in Parameter Selection: Phytoplankton Settling Velocity

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(from Reckhow 1994)

Given the relative simplicity of all simulation models in comparison to the complexity of nature, it seems reasonable to question the legitimacy of any "mechanistic" mathematical description of surface water quality. Further, given data limitations and scientific knowledge limitations, it seems reasonable to question even the goal to strive for a model that need not be calibrated. The correctness of model structure, the knowledge of the model user, and the availability of experimental and observational evidence all influence parameter choice for mechanistic models. Unfortunately, too often knowledge and data are extremely limited, making choice of parameters and choice of important model processes guesswork to a distressingly large degree. The example presented below is not re-assuring with respect to the scientific support for the selection of model parameters.

One of the basic parameters in an aquatic ecosystem model is phytoplankton settling. An early example of its use is in the model proposed by Chen and Orlob (1972):

$$\frac{dVC_1}{dt} = QC_{in} + EA\frac{dC_1}{dt} - QC_1 + (\mu_1 - R_1 - s_1 - M_1)VC_1 - \mu_2 VC_2 F_{2,1} \qquad (1)$$

where:

V = *segment volume* (m^3)

C_1 = *phytoplankton concentration* (g/m^3)

Q = *flow volume* (m^3/t)

E = *diffusion coefficient* (m^2/t)

A = *segment surface/bottom area* (m^2)

μ_1 = *phytoplankton growth rate* (t^{-1})

R_1 = *phytoplankton respiration rate* (t^{-1})

s_1 = *phytoplankton settling rate* (t^{-1})

M_1 = *phytoplankton mortality rate* (t^{-1})

μ_2 = *zooplankton growth rate* (t^{-1})

C_2 = *zooplankton concentration* (g/m^3)

$F_{2,1}$ = *fractional feeding preference*

In Equation 1, settling is captured in the term:

$$\textit{phytoplankton settling (mass/ time)} = s_1 V C_1 \qquad (2)$$

Other examples of mathematical characterization of this process are similar; one common alternative approach is that phytoplankton settling is sometimes treated as a velocity term with an areal loss (see Chapra and Reckhow 1983, Chapter 14):

$$\textit{phytoplankton settling (mass / time)} = \upsilon_1 A C_1 \qquad (3)$$

where υ_1 is settling velocity (m/t) and *A* is area (m).

To understand some of the problems with the current approach for parameter determination in mechanistic surface water quality models, it is useful to examine this process further. For that purpose, "phytoplankton settling velocity" in Equation 3 provides a good example. Phytoplankton, or algae, are important in aquatic ecosystems, and thus one or more phytoplankton compartments are found in most mechanistic surface water quality models concerned with nutrient enrichment. Phytoplankton settling is one of the key mechanisms for removal of phytoplankton from the water column.

Stoke's law provides the starting point for the mathematical characterization of phytoplankton settling. Few models, however, employ Stoke's law; instead a simple constant settling velocity (in units of length/time) expression is commonly used. To apply a model with this settling velocity term, a modeler must either measure phytoplankton settling directly, or select a representative value from another study. Since field measurement of phytoplankton settling is a difficult task, use of literature-tabulated values is standard practice.

Probably the most thorough listing of suggested values for phytoplankton settling velocity is Bowie et al. (1985), which presents a two-page table of reported values, by algal type (see Table 1). Bowie et al. note that under quiescent conditions in the laboratory, phytoplankton settling is a function of algal cell radius, shape, density, and special cell features such as gas vacuoles and gelatinous sheaths. For natural water bodies, water turbulence can be quite important. In two- or three-dimensional models with hydrodynamic simulation, turbulence is accounted for in the model equations; in zero- or one-dimensional models, the effect of turbulence on phytoplankton settling must usually be incorporated into the choice of settling velocity.

That information is typically the extent of technical guidance employed by modelers when selecting this parameter using a reference like Table 1 from Bowie et al. The range of options in Table 1 is substantial, even within a single category (e.g., diatoms) for algal type. The algal cell size, shape, and other features mentioned in the previous paragraph can vary from species to species within a single type category, so this may be responsible for some of the variability in Table 1. However, even if the modeler who must choose a point estimate has data that identify dominant species in a water body at a particular time and location, dominance is apt to change with time and location. Further, models contain at most only a few distinct phytoplankton compartments, so a choice must still be made concerning species to be modeled and their characteristics.

Examination of the original references from which Table 1 was created does little to enlighten the parameter selection process. Most of the references in summarized Table 1 do not present observational studies on phytoplankton; rather, they are simulation model studies, and the value for phytoplankton settling velocity listed in Table 1 is the value chosen for the model. In some of the references checked, little or no basis was provided for the choice. When a rationale for choice was given, it was usually to adopt or adjust the few values presented in the literature from experimental studies, or to adopt a value from another modeling study. In one way or another, it appears that virtually all of the values presented in Table 1 have some dependency on the early experimental work of Smayda and Boleyn (1965) and other work by Smayda.

Unfortunately, evaluation studies of simulation models have provided little insight on good point estimates for this parameter. Observational data on surface water quality are almost always inadequate for testing functional relationships and assessing parameter choices. Typical observational data sets are noisy, with few measurements of each of only a few variables. In the case of phytoplankton settling velocity, observational data are apt to consist of phytoplankton cell densities at various dates, times, and areal locations, but probably not depths. Since phytoplankton are also removed from the water column through consumption by higher food chain organisms, the observational data do not permit separate identification of the removal mechanisms.

Given this situation, modelers have relied almost exclusively on the few experimental studies in the laboratory and their judgment concerning adjustments to these values. For one-dimensional models without explicit modeling of hydrodynamics, the chosen value may be as much as an order of magnitude higher than the laboratory values. Two- or three-dimensional models with hydrodynamics may incorporate the unadjusted laboratory value. After early modeling studies presented chosen values, these values were sometimes adopted in subsequent studies without comment (in effect, "default" values were identified). Thus, there is probably much less information in the columns of Table 1 than implied by the number of values reported.

In summary, the choices for phytoplankton settling velocity appear to be based on ad hoc adjustments to a few values measured under controlled conditions. There is virtually no field confirmation of choices made for parameters individually (as opposed to collectively). This situation is fairly typical of the state-of-the-art in surface water quality simulation modeling.

Table 1. *Phytoplankton settling velocities (Bowie et al. 1985).*[1]

Algal Type	Settling Velocity (m/day)	Algal Type	Settling Velocity (m/day)
Total Phytoplankton	0.05-0.5	Green Algae	0.05-0.19
	0.05-0.2		0.05-0.4
	0.02-0.05		0.02
	0.40		0.80
	0.03-0.05		0.1-0.25
	0.05		0.30
	0.2-0.25		0.08-0.18
	0.04-0.6		0.27-0.89
	0.01-4.0	Blue-Green Algae	0.05-0.15
	0.-2.0		0.00
	0.-30.		0.20
Diatoms	0.05-0.4		0.10
	0.1-0.2		0.08-0.2
	0.1-0.25		0.10-0.11
	0.03-0.05	Flagellates	0.50
	0.3-0.5		0.05
	2.50		0.09-0.2
	0.02-14.7		0.07-0.39
	0.08-17.1	Dinoflagellates	8.00
			2.8-6.0
		Chrysophytes	0.50
		Coccolithophores	0.25-13.6
			0.3-1.5

[1]See Bowie et al. (1985) for original references for reported settling velocities.

References

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